TECHNICAL REPORT

Potential Cost-effective GHG Reduction Opportunities at Selected Oil Production Facilities in Colombia

PREPARED FOR

Unidad de Disciplinas Especializadas
ECOPETROL-Instituto Colombiano del Petróleo
Bucaramanga, Colombia

Contact: Edgar Eduardo Yañez Angarita
Telephone: 57-7-6847202
E-mail: edgar.yanez@ecopetrol.com.co

PREPARED BY

Clearstone Engineering Ltd.
700, 900-6 Avenue S.W.
Calgary, Alberta, T2P 3K2
Canada

Contact: Dave Picard
Telephone: 1(403)215-2730
Facsimile: 1(403)266-8871
E-mail: dave.picard@clearstone.ca
Web site: www.clearstone.ca

March 31, 2013

DISCLAIMER

While reasonable effort has been made to ensure the accuracy, reliability and completeness of the information presented herein, this report is made available without any representation as to its use in any particular situation and on the strict understanding that each reader accepts full liability for the application of its contents, regardless of any fault or negligence of Clearstone Engineering Ltd.

EXECUTIVE SUMMARY

An emissions measurement and performance evaluation program was completed at the following facilities in Colombia:

- Acacias Oil Battery
- Castilla Oil Battery No. 2
- Chichimene Oil Battery
- Oil Well Sites
- Monterrey Oil Pump Station

The purpose of the study was to identify and quantify, in terms of magnitude and economic value, opportunities to reduce greenhouse gas (GHG) emissions and improve energy efficiencies. The field work for all but the Monterrey Oil Pump Station was conducted during the period of 31 October to 15 November 2012. The work at the Monterrey Oil pump Station was performed during the period of 6 to 9 February 2013.

The commodity prices used in this analysis have been assumed based on data provided by Ecopetrol. The applied prices are summarized in the table below. All prices presented in the report are expressed in US dollars (USD).

Table i: Applied commodity prices.

Commodity	Value	Units of Measure
Natural Gas	4.35	USD/GJ
Ethane	80.84	USD/m^3 (Liquid)
LPG	0.25	USD/L
NGL	566.08	USD/m^3 (Liquid)
Hydrogen	1.00	USD/kg
	0.09	USD/m^3
Electricity	0.08	USD/kW·h

The value of any potential marketable GHG credits was not considered but would have a positive impact on the practicability of each opportunity. A discount rate of 12% has been used in the economic evaluations.

The relative value of the different commodities on an equivalent-energy basis for the pricing indicated above is as follows:

Table ii: Relative commodity price index expressed on a gross energy basis (HHV).

Commodity	Value Relative to Processed Natural Gas
Natural Gas	1.0
Ethane	1.0
LPG	2.3

Table ii: Relative commodity price index expressed on a gross energy basis (HHV).	
Commodity	**Value Relative to Processed Natural Gas**
NGL	3.7
Hydrogen	1.6
Electricity	5.1

Throughout this report, emissions and potential emission reductions are reported in units of tonnes per annum, while process activity levels, natural gas losses and methane losses are all expressed in cubic metres per day. The volumetric flows are referenced at standard conditions of 101.325 kPa and 15ºC. The value of avoidable commodity losses and energy consumption are expressed on an annualized basis. All reported GHG emissions include contributions due to CH_4, CO_2 and N_2O emissions. The impact on emissions of selected criteria air pollutants is also considered, including volatile organic compounds (VOCs), SO_2, NO_x, CO, particulate matter [PM]).

All emissions calculations, economic-valuations and detailed analyses of measurement results were performed using Clearstone's web-based source-simulation and data-management application, CSimOnLine. This program features rigorous process simulation utilities, emission factor libraries, and calculations for detailed benchmarking of process systems and units. Moreover, it provides entry-time quality assurance checks of all input data as well as standardized reporting of the results. All cost estimates were prepared by a senior cost estimator and are Class 5 estimates (AACE RP No. 18R-97).

Measurement and Testing Program

The emissions measurement and performance testing work comprised:

- Source and process testing, data collection and engineering calculations to examine the practicability of reducing or recovering continuous flare gas flows at the Acacias Oil Battery and the Castilla Oil Battery No. 2. The testing included continuous flow measurements using an optical flow meter.
- Evaluation of solution gas emissions from the crude oil production tanks at the Castilla Oil Battery No. 2 and the Chichimene Oil Battery.
- Evaluation of evaporation losses from the diluted heavy oil sales storage tanks at Chichimene Oil Battery and Acacias Oil Battery.
- Evaluation of leakage from the vapour collection system at the Acacias Oil Battery.
- Evaluation of opportunities for energy efficiency improvements for the process heaters at the Chichimene Oil Battery.
- Evaluation of waste heat and vapour recovery opportunities at the Monterrey Oil Pump Station.
- Evaluation of casing gas recovery/utilization opportunities at the oil wells producing into the target oil batteries.

Emissions Reduction and Energy Efficiency Opportunities

Opportunities for gross savings of 49.8 million USD/y and emission reductions of 147.8 kt CO_2E/y were assessed. These results have not been extrapolated across all facilities; doing so would result in increased values. As depicted in Figures i to iii, the main cost-effective opportunity to reduce emissions and conserve energy at the visited oil production facilities is conserving the vent and flare gas at the heavy oil batteries.

The noteworthy leakage from the vapour collection system at the Acacias Oil Battery indicates a need to review the design practices for Ecopetrol's vapour collection systems.

The regular tuning of process heaters and engines is good practice; however, the tested units offered only marginal opportunities.

The installation of Organic Rankin Cycle (ORC) units to produce electric power from engine waste heat at the Monterrey Oil Pump Station offers a payback of only 4.6 to 5.0 years.

Implementation Cost

Preliminary capital costs have been assessed for identified opportunities to reduce energy consumption or emissions. Additional analysis of these opportunities may be appropriate after they have been confirmed and prioritized.

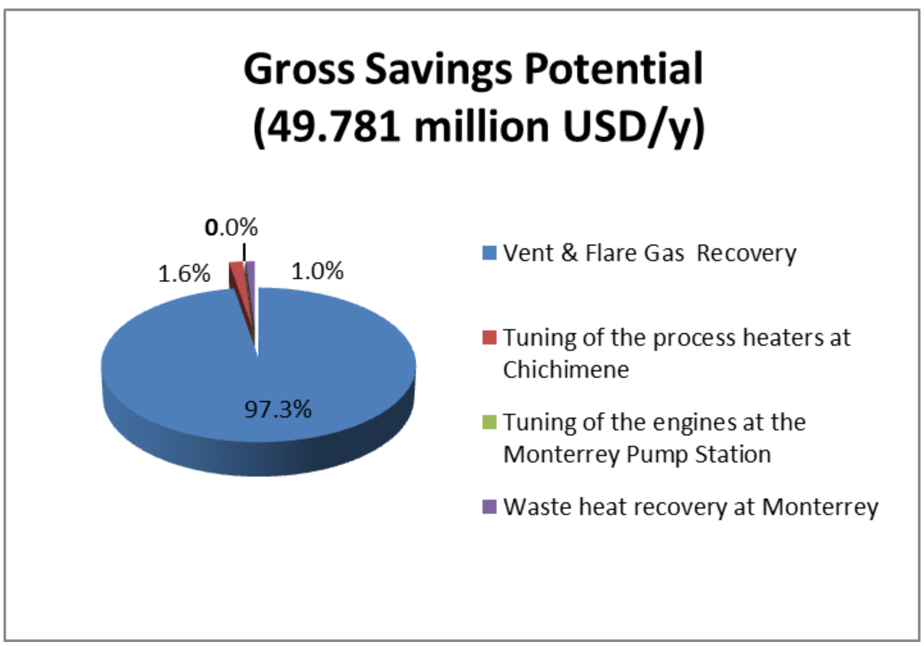

Figure i: A pie chart depicting the percentage contribution, by priamry source category, to the total gross savings potential of the assessed control opportunities relating to these sources.

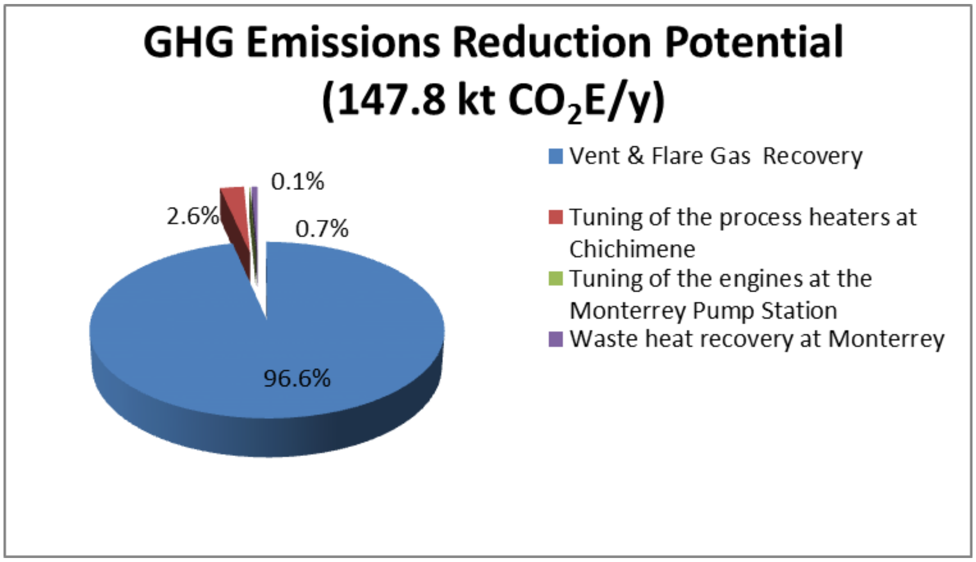

Figure ii: **A pie chart depicting the percentage contribution, by primary source category, to the total assessed GHG reduction potential for these sources.**

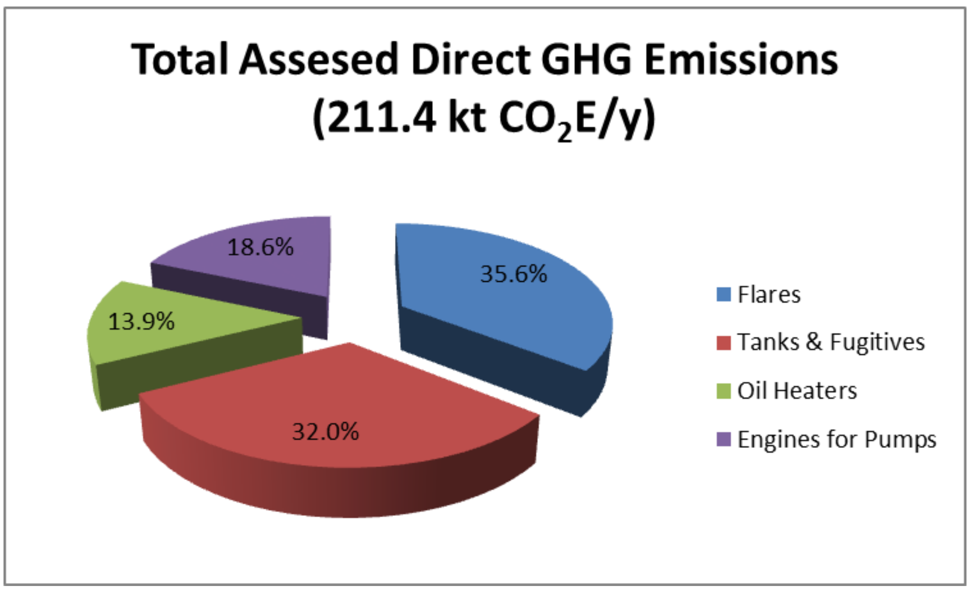

Figure iii: **A pie chart depicting the percentage contribution, by primarysource category, to the total uncontrolled direct GHG emissions from these sources.**

TABLE OF CONTENTS

DISCLAIMER .... **I**

EXECUTIVE SUMMARY .... **II**

TABLE OF CONTENTS .... **VI**

LIST OF TABLES .... **IX**

LIST OF FIGURES .... **X**

ACKNOWLEDGEMENTS .... **XI**

LIST OF ACRONYMS .... **XII**

1 INTRODUCTION **1**

2 FACILITY DESCRIPTION **3**

2.1 HEAVY OIL BATTERIES 3
2.2 HEAVY OIL WELLS 3
2.3 MONTERREY OIL PUMP STATION 3

3 PERFORMANCE EVALUATIONS **5**

3.1 SOLUTION GAS VENTING AND FLARING 5
3.2 PRODUCT EVAPORATION LOSSES 9
3.2.1 Diluted Heavy Oil *9*
3.2.2 Crude Oil *9*
3.3 FUGITIVE EQUIPMENT LEAKS 9
3.4 CASING GAS VENTING 9
3.5 PROCESS HEATERS 10
3.6 ENGINES 13

4 CONCLUSIONS AND RECOMMENDATIONS **17**

4.1 CONCLUSIONS 17
4.2 RECOMMENDATIONS 17

5 REFERENCES CITED **20**

NONE. **20**

APPENDIX A GLOSSARY **21**

APPENDIX B ECONOMIC EVALUATIONS METHODOLOGY **28**

B.1 BASIC VALUATIONS 28
B.2 AVOID PRODUCTION LOSSES OR FUEL CONSUMPTION 31
B.3 CAPITAL COSTS 32
B.4 CONSERVED OR DISPLACED ELECTRICITY 34
B.5 REMOVAL COSTS 34
B.6 SALVAGE VALUE 34
B.7 R&D COSTS 34
B.8 PROJECT LIFE 34
B.9 OPERATING COST 34
B.10 FINANCIAL DISCOUNT RATE 35
B.11 OTHER DISCOUNT RATES 35
B.12 INFLATION RATES 35
B.13 VALUE OF GHG REDUCTION 35

APPENDIX C FLARE SYSTEMS **36**

C.1 INTRODUCTION 36
C.2 BACKGROUND 36

C.3 PERFORMANCE EVALUATION METHODOLOGY 36
C.3.1 Flared Gas Flow Rate Determination 36
C.3.2 Purge Gas Flow Rate 41
C.3.3 Minimum Energy Content of Combined Flare Volume 43
C.3.4 Fuel Consumption Rate Reduction Options 43
C.3.5 Heating Value Requirement 45
C.3.6 Flare Efficiency 46
C.3.7 Wind Speed Correction 47
C.3.8 Steam Assisted Flare Analysis 47
C.3.9 Air Assisted Flare Analysis 50
C.4 CONTROL OPTIONS 52
C.4.1 Incinerators 52
C.4.2 Auto-Ignition System 53
C.4.3 Smokeless Flares 53
C.4.4 Management of Leaking Flare Valves 54
C.4.5 Flare Gas Recovery Systems 55
C.4.6 Recovery of Condensable Hydrocarbons from Flare Gas 56
C.5 REFERENCES 57
C.6 RESULTS 57

APPENDIX D STORAGE TANKS 58

D.1 INTRODUCTION 58
D.2 BACKGROUND 58
D.3 PERFORMANCE EVALUATION METHODOLOGY 58
D.3.1 Free-venting Storage Tanks Containing Stabilized or Weathered Hydrocarbon Liquids 59
D.3.2 Tanks Experiencing Flashing Losses 60
D.3.3 Tanks with Natural Gas Blanketing 61
D.4 CONTROL OPTIONS 62
D.5 REFERENCES 63
D.6 RESULTS 64

APPENDIX E FUGITIVE EQUIPMENT LEAKS 65

E.1 INTRODUCTION 65
E.2 BACKGROUND 65
E.3 EVALUATION METHODOLOGY 66
E.3.1 Leak Detection and Measurement 66
E.3.2 Leak Repair Economic Evaluation 68
E.3.3 Emission Control Guidelines 73
E.3.4 Fugitive Emission Control Options 74
E.4 REFERENCES 81
E.5 RESULTS 81

APPENDIX F HEATERS AND BOILERS 82

F.1 INTRODUCTION 82
F.2 BACKGROUND 82
F.2.1 Definitions 82
F.3 PERFORMANCE EVALUATION METHODOLOGY 84
F.3.1 Calculation of Fuel Consumption Rate of Crude Oil Heater 84
F.3.2 Fuel Costs and Fuel Cost Savings Results 85
F.3.3 Excess Emission and Emission Reduction Results 86
F.3.4 Fuel Gas Composition 86
F.3.5 Flue Gas Composition 86
F.3.6 Data Evaluation 86
F.4 ENERGY MANAGEMENT AND EMISSION CONTROL OPTIONS 87
F.4.1 Temperature Control 87
F.4.2 Flame Failure Detection 87
F.4.3 Air-to-Fuel Ratio Control 88

F.4.4 Preheating Combustion Air ... *89*
F.5 REFERENCES ... 89
F.6 RESULTS ... 89

APPENDIX G ENGINES ... 90

G.1 INTRODUCTION ... 90
G.2 BACKGROUND ... 90
G.2.1 Definitions ... *90*
G.3 PERFORMANCE EVALUATION METHODOLOGY ... 93
G.3.1 Avoidable Fuel Consumption ... *93*
G.3.2 Emissions and Emissions Reduction Potential ... *94*
G.3.3 Fuel Gas Composition ... *94*
G.3.4 Flue Gas Composition ... *94*
G.3.5 Data Evaluation ... *94*
G.4.1 Load Management ... *95*
G.4.2 Air-to-Fuel Ratio Controllers ... *95*
G.4.3 Waste Heat Recovery ... *96*
G.5 REFERENCES ... 97
G.6 RESULTS ... 97

APPENDIX H GAS ANALYSES ... 98

LIST OF TABLES

TABLE 1: CURRENT THROUGHPUTS OF THE SURVEYED OIL BATTERIES. 3
TABLE 2: COMMODITY LOSSES ASSOCIATED WITH CURRENT VENTING AND FLARING AT THE SELECTED OIL PRODUCTION FACILITIES IN COLOMBIA. 6
TABLE 3: ESTIMATED EMISSIONS FROM CURRENT VENTING AND FLARING AT THE SELECTED OIL PRODUCTION FACILITIES IN COLOMBIA. 6
TABLE 4: ECONOMIC ANALYSIS OF RECOVERING CONDENSABLE HYDROCARBON FROM THE WASTE GAS STREAMS AND USING THE RESIDUE GAS TO POWER THE PROCESS AND PRODUCE ELECTRICITY. 8
TABLE 5: TOTAL CURRENT FUEL CONSUMPTION BY THE PROCESS HEATERS AT THE CHICHIMENE OIL BATTERY...11
TABLE 6: POTENTIALLY AVOIDABLE INCREMENTAL FUEL CONSUMPTION FOR TUNING OPPORTUNITIES ON THE PROCESS HEATERS AT THE CHICHIMENE OIL BATTERY. 11
TABLE 7: ESTIMATED TOTAL CURRENT EMISSIONS DUE TO FUEL CONSUMPTION BY THE PROCESS HEATERS AT THE CHICHIMENE OIL BATTERY 11
TABLE 8: POTENTIALLY AVOIDABLE EMISSIONS DUE TO THE CURRENT TUNING OPPORTUNITIES ON THE PROCESS HEATERS AT THE CHICHIMENE OIL BATTERY. 12
TABLE 9: ECONOMIC ANALYSIS OF CONDUCTING REGULAR TUNING OF THE PROCESS HEATERS AT THE CHICHIMENE OIL BATTERY. 12
TABLE 10: TOTAL CURRENT FUEL CONSUMPTION BY THE NATURAL GAS-FUELLED PUMP ENGINES AT THE MONTERREY OIL PUMP STATION 13
TABLE 11: PORTION OF THE CURRENT FUEL CONSUMPTION BY THE NATURAL GAS-FUELLED PUMP ENGINES AT THE MONTERREY OIL PUMP STATION THAT COULD POTENTIALLY AVOIDABLE BY TUNING THE ENGINES..13
TABLE 12: ESTIMATED TOTAL CURRENT EMISSIONS FROM THE NATURAL GAS-FUELLED PUMP ENGINES AT THE MONTERREY OIL PUMP STATION 14
TABLE 13: POTENTIALLY AVOIDABLE EMISSIONS DUE TO THE CURRENT TUNING OPPORTUNITIES ON THE TESTED NATURAL GAS-FUELLED PUMP ENGINES AT THE MONTERREY OIL PUMP STATION 14
TABLE 14: DISPLACEMENT OF FUEL CONSUMPTION BY GENERATING ELECTRICITY FROM ENGINE WASTE HEAT AT THE MONTERREY OIL PUMP STATION 15
TABLE 15: ESTIMATED EMISSIONS ASSOCIATED WITH THE RECOVERABLE WASTE HEAT FROM THE NATURAL GAS FUELLED PUMP ENGINES AT THE MONTERREY OIL PUMP STATION. 15
TABLE 16: ECONOMIC ANALYSIS OF CONDUCTING ANNUAL TUNING OF THE PUMP ENGINES AT THE MONTERREY OIL PUMP STATION. 16
TABLE 17: ECONOMIC ANALYSIS OF INSTALLING ORGANIC RANKINE CYCLE (ORC) UNITS TO UTILIZE THE RECOVERABLE WASTE HEAT FROM THE PUMP ENGINES AT THE MONTERREY OIL PUMP STATION TO PRODUCE ELECTRIC POWER 16
TABLE 18: SUMMARY OF EVALUATED OPPORTUNITIES AND RECOMMENDED ACTIONS 18
TABLE 19: TYPICAL MINIMUM PURGE RATES TO AVOID UNSAFE AIR INFILTRATION 43
TABLE 20: AVERAGE FUEL GAS CONSUMPTION FOR ENERGY-EFFICIENT FLARE PILOTS[1]. 45
TABLE 21: SUMMARY OF REPAIR COSTS AND MEAN LIFE OF REPAIR FOR EQUIPMENT COMPONENTS IN NATURAL GAS AND NON-METHANE HYDROCARBON SERVICE. 70

LIST OF FIGURES

FIGURE 1: SCHEMATIC DIAGRAM DEPICTING A PAIR OF ULTRASONIC FLOW TRANSDUCERS WETTED TO THE FLOW IN A PIPE. 37
FIGURE 2: PHOTOGRAPH OF AN OPTICAL FLOW METER PROBE. 38
FIGURE 3: A PHOTOGRAPH OF ONE FLARE FLAME SHOWING THE RELATED DIMENSIONS FOR THE FLAME LENGTH APPROACH. 41
FIGURE 4: A PHOTOGRAPH OF A TYPICAL VAPOUR RECOVERY TOWER ELEVATED ABOVE THE STORAGE TANK...63
FIGURE 5: THE HI-FLOW SAMPLER BEING USED TO MEASURE A FLANGE LEAK RATE. 68
FIGURE 6: TYPICAL RECIPROCATING COMPRESSOR VENT AND PACKING SYSTEM. 76
FIGURE 7: TYPICAL CENTRIFUGAL COMPRESSOR DRY-GAS SEAL AND VENT SYSTEM. 80
FIGURE 8: PHOTOGRAPHS OF COMBUSTION TEST BEING CONDUCTED USING A PORTABLE COMBUSTION ANALYZER. 86

ACKNOWLEDGEMENTS

The assistance and cooperation of the following individuals is gratefully acknowledged:

- Edgar Eduardo Yañez Angarita (Ecopetrol)
- Staff at the visited Ecopetrol facilities.
- Michael Layer (Natural Resources Canada)

The financial and in-kind support of Environment Canada and Natural Resources Canada, and the kindness and help provided by all the staff at the surveyed facility are gratefully acknowledged.

LIST OF ACRONYMS

CAPP	-	Canadian Association of Petroleum Producers
GHG	-	Greenhouse Gas (CO_2, CH_4, N_2O, SF_6)
HHV	-	Higher Heating Value
LHV	-	Lower Heating Value
MJ	-	Megajoule
NAMA	-	Nationally Appropriate Mitigation Action
ng	-	Nanogram
NPV	-	Net Present Value
RISE	-	Research Institute of Safety and Environmental Technology
ROI	-	Return on Investment
THC	-	Total Hydrocarbons
USD	-	US Dollars

1 INTRODUCTION

This report presents the results of a study to identify and evaluate opportunities to reduce greenhouse gas (GHG) emissions and improve energy efficiencies at 3 heavy oil production facilities in Castilla oil field in Colombia, as well as at the oil wells that produce into these facilities. The specific opportunities considered at the targeted facilities included flare gas recovery, management of naphtha evaporation losses, optimization of process heaters, recovery of solution gas emissions from crude oil production tanks, and control of leakage from vapour collection systems. Additionally, engine tuning, waste heat recovery and vapour recovery options were evaluated at the Monterrey Oil Pump Station.

.

The completed study is in support of efforts to develop a nationally appropriate mitigation action (NAMA) plan to reduce GHG emissions in Colombia's oil and natural gas sector.

The key benefits of these opportunities include increased profits, improved overall energy efficiencies, conservation of a valuable non-renewable resource, reduced GHG emissions, reduced air pollution and both national and international recognition.

Some of the key reasons that significant cost-effective GHG reduction and energy efficiency improvement opportunities may exist are:

- Changes in operating conditions from initial design values.
- Capital constraints during initial design and construction of process systems resulting in inefficiencies.
- Progressive deterioration of equipment performance.
- Outdated designs that are based on previous low energy prices.
- Use of outdated technologies.
- Lack of quantitative data to build business cases for improvement opportunities.

The main advantages of conducting an independent integrated energy and emissions review are:

- Fresh views and insights coupled with knowledge and experience of the review team.
- Increased probability of identifying significant cost-effective emission reduction opportunities through a comprehensive facility examination.
- Potential synergies between disciplines for improved opportunity identification.
- Maximum utilization of the review team's expertise.
- Independent verification of the facility's performance.
- Transparent third-part determination of the emissions baseline and other data needed for the design of carbon credit projects.
- Opportunity for technology transfer to, and training of, facility staff.
- Access to specialized testing, measurement and analytical technologies that may not be readily available to the facility staff.

Additionally, the review provides the means to monitor performance over the long term by comparing performance against the baseline established at the time of the initial facility survey. This process, or benchmarking, can be applied at the facility level as well as at the individual process unit level. The following sections present a description of the surveyed facilities (Section

2), a summary and discussion of the key evaluation results (Section 3), conclusions and recommendations (Section 4), and references cited (Section 1). A glossary of key terminology is provided in Appendix A. Details of the methodology used to conduct economic evaluations are presented in Appendix B. The remaining appendices delineate the applied evaluation methodology and detailed calculation results for the primary source categories evaluated.

2 FACILITY DESCRIPTION

2.1 Heavy Oil Batteries

The targeted oil batteries were all heavy oil production facilities and were generally less than 4 years old. All three of these facilities blended the produced oil with purchased naphtha to meet sales pipeline viscosity specifications. Indications are that at least two of the sites were blending diluent (i.e., naphtha) with hot treated oil resulting in noteworthy evaporation losses of lighter hydrocarbon components from the sales tanks. All three sites were net sources of venting and flaring emissions.

The produced oil has an 18.9° API gravity and is stored with a BS & W value that is maintained between 0.20% and 0.40%.

Table 1: Current throughputs of the surveyed oil batteries.

Facility	Current Operating Conditions		
	Oil Production (bbl/d)	Water Production (bbl/d)	Naphtha Consumption (bbl/d)
Acacias Oil Battery	50,055	324,431	4816
Castilla Oil Battery No. 2	64,000	350,000	4,600
Chichimene Oil Battery	48,397	30,965	15,730

2.2 Heavy Oil Wells

Nine heavy oil wells were visited to allow measurement of the casing gas emissions. All of the wells featured submersible down-hole pumps and had the casing vent fully open. Aside from the wellhead, no other infrastructure was present at the well site.

2.3 Monterrey Oil Pump Station

The Monterrey Oil Pump Station features four phases of development:

- Monterrey I: this phase comprises 6 active pumps and 1 backup pump.
- Monterrey II: this phase comprises 2 active pumps and 1 backup pump.
- Monterrey III: this phase comprises 6 active pumps.
- Monterrey IV: this phase comprises 3 active pumps.

The pump drivers are all natural gas fuelled reciprocating engines ranging in size from 300 kW (400 hp) to 1030 kW (1380 hp). The required fuel gas is purchased from a local natural gas distribution system. Total fuel gas purchases, including fuel for onsite power generation, amounts to 2600 m^3/d.

The operating specification of the oil pipelines are as follows:

- API Gravity: 18.0 to 21.0˚
- BS&W: 0.800
- Viscosity: ≤300 cSt
- Salt: maximum of 20 lb/1000 bbl

3 PERFORMANCE EVALUATIONS

3.1 Solution Gas Venting and Flaring

Table 2 presents a summary of the commodity losses associated with the measured flaring and venting of solution gas at the visited heavy oil batteries. It also includes leakage measured from the vapour collection system at the Acacias Battery. Table 3 presents the estimated emissions from these sources. The detailed results and assessment methodology are presented in Appendixes C (Flares and Vents), D (Tanks).and E (Fugitive Equipment Leaks).

The market value of the listed commodities present in the flared and vented streams is approximately 51 million USD annually. Total GHG emission from this flaring and venting amounts to almost 143 kt/y of CO_2E.

The gas is being disposed of largely due to the lack of economic access to a gas gathering system and inadequate needs for use of the gas as fuel; however, the gas is rich in valuable LPG and NGL which could be used to supplement diluent requirements and the residue gas could be used to power the recovery process and produce supplemental electric power. An economic analysis of doing this is presented in

Table 4: Economic analysis of recovering condensable hydrocarbon from the waste gas streams and using the residue gas to power the process and produce electricity.

.

Table 2: Commodity losses associated with current venting and flaring at the selected oil production facilities in Colombia.

Source[3]	Value of Commodity Losses (USD/y)	Total Commodity Loss (m^3/h)	Residue Gas (10^3 m^3/d)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Acacias Flare #1	8,900,304	1,022.04	7.23	6.45	31.81	26.01	0.00
Acacias ATK-7301 (PVRV)	115,312	12.11	0.05	0.08	0.49	0.32	0.00
Acacias ATK-7302 (PVRV)	76,327	10.69	0.03	0.04	0.22	0.26	0.00
Acacias ATK-7305 (PVRV)	187,427	21.34	0.09	0.07	0.55	0.63	0.00
Acacias ATK-7306	4,553,721	325.31	0.57	1.26	11.43	16.65	0.00
Castilla Oil Battery No. 2 Tank ATK-7205B Vent	6,115,935	762.29	5.04	4.76	20.48	18.42	0.00
Castilla Oil Battery No. 2 Tank ATK-7204A Vent[1]	6,474,651	807.00	5.34	5.03	21.68	19.50	0.00
Chichimene Flare 1	5,276,662	583.81	6.71	2.40	6.64	20.32	0.00
Chichimene Flare 2	1,142,557	127.81	1.48	0.52	1.44	4.39	0.00
Chichimene Production Tanks	12,546,964	772.51	1.85	4.74	21.01	50.23	0.00
Chichimene Sales Oil (Diluted Heavy Oil) Tanks[2]	5,604,787	424.80	0.01	0.16	4.01	25.33	0.00
Total	50,994,647	4,869.71	28.40	25.51	119.76	182.06	0

1 Estimated based on process simulations.
1 Estimated based on rigorous process simulations.
2 Estimated based on the composition of the vapours vented from the tank during filling, and the working losses.
3 All other values presented in this table were measured.

Table 3: Estimated emissions from current venting and flaring at the selected oil production facilities in Colombia.

Source Name	CH_4 (t/y)	CO_2 (t/y)	N_2O (t/y)	CO_2E (t/y)	VOC (t/y)	CO (t/y)	NO_x (t/y)	SO_2 (t/y)	PM (t/y)
Acacias Flare #1	2.74	45,371.15	0.07	45,451.34	19.16	121.73	22.34	0.00	43.61
Acacias ATK-7301 (PVRV)	13.52	3.53	0.00	287.36	172.31	0.00	0.00	0.00	0.00
Acacias ATK-7302 (PVRV)	7.31	1.90	0.00	155.41	105.14	0.00	0.00	0.00	0.00
Acacias ATK-7305 (PVRV)	21.60	0.59	0.00	454.17	257.94	0.00	0.00	0.00	0.00
Acacias ATK-7306	142.02	8.43	0.00	2,990.93	6,171.19	0.00	0.00	0.00	0.00

Table 3: Estimated emissions from current venting and flaring at the selected oil production facilities in Colombia.									
Source Name	**CH_4 (t/y)**	**CO_2 (t/y)**	**N_2O (t/y)**	**CO_2E (t/y)**	**VOC (t/y)**	**CO (t/y)**	**NO_x (t/y)**	**SO_2 (t/y)**	**PM (t/y)**
Castilla Oil Battery No. 2 Tank ATK-7205B Vent	1,248.55	21.94	0.00	26,241.40	8,423.06	0.00	0.00	0.00	0.00
Castilla Oil Battery No. 2 Tank ATK-7204A Vent[1]	1,321.78	23.22	0.00	27,780.53	8,917.10	0.00	0.00	0.00	0.00
Chichimene Flare 1	33.25	23,890.78	0.04	24,601.01	9.10	64.90	11.91	0.00	23.25
Chichimene Flare 2	0.69	5,185.13	0.01	5,202.16	2.45	14.09	2.59	0.00	5.05
Chichimene Production Tanks	457.52	27.10	0.00	9,635.06	15,834.09	0.00	0.00	0.00	0.00
Chichimene Sales Oil (Diluted Heavy Oil) Tanks	2.81	12.43	0.00	71.51	6,701.50	0.00	0.00	0.00	0.00
Total	3,251.79	74,546.2	0.12	142,870.88	46,613.04	200.72	36.84	0	71.91

Table 4: Economic analysis of recovering condensable hydrocarbon from the waste gas streams and using the residue gas to power the process and produce electricity.								
Source Name	**Application Life Expectancy (y)**	**Capital Cost (USD)**	**Net Present Salvage Value (USD)**	**Net Operating Cost (USD/y)**	**Value of Conserved Energy (USD/y)**	**NPV (USD)**	**ROI (%)**	**Payback Period (y)**
Acacias Flare #1	20	6,240,000	0	0	8,455,289	56,039,773	135.00	0.7
Acacias ATK-7301 (PVRV)	20	57,600	0	0	109,546	749,292	190.18	0.5
Acacias ATK-7302 (PVRV)	20	48,000	0	0	72,510	486,095	151.06	0.7
Acacias ATK-7305 (PVRV)	20	57,600	0	0	178,056	1,253,918	309.12	0.3
Acacias ATK-7306	20	1,560,000	0	0	4,326,035	30,304,610	277.31	0.4
Castilla Oil Battery No. 2 Tank ATK-7205B Vent	20	3,657,600	0	0	5,810,138	39,138,578	158.85	0.6
Castilla Oil Battery No. 2 Tank ATK-7204A Vent[1]	20	3,873,600	0	0	6,150,918	41,432,691	158.79	0.6
Chichimene Flare 1	20	2,803,200	0	0	5,012,829	34,120,181	178.83	0.6
Chichimene Flare 2	20	614,400	0	0	1,085,429	7,380,628	176.66	0.6
Chichimene Production Tanks	20	3,710,400	0	0	11,919,616	84,086,831	321.25	0.3
Chichimene Sales Oil (Diluted Heavy Oil) Tanks	20	2,040,000	0	0	5,324,548	37,179,430	261.01	0.4
Total	20	24,662,400	0	0	48,444,914	332,172,027	196.43	0.5

1. NPV denotes net present value.
2. ROI denotes return on investment.

3.2 Product Evaporation Losses

3.2.1 Diluted Heavy Oil

Naphtha is used as a diluent to manage the viscosity of the produced heavy oil so that it can meet pipeline specifications. At two of the sites (Acacias and Chichimene), the heavy oil was diluted with naphtha while it was still hot and then was stored in free-venting fixed-roof sales storage tanks. Noteworthy amounts of emissions were detected from these sales oil tanks. These emissions are accounted for in Section 3.1; however, they could be reduced by either lowering the operating temperature of the crude oil treating system, or providing cooling of the treated heavy oil prior to being diluted with naphtha.

3.2.2 Crude Oil

The emissions from crude oil storage tanks at production facilities is addressed in Section 3.1.

There are crude oil storage tanks at the Monterrey Pump Station for temporary storage of treated crude discharged from the pipeline and station equipment during upsets and blowdown events (e.g., for inspection and maintenance purposes). Normally, there is little or no product in these tanks and the emissions are primarily due to breathing losses. The tank vents were scanned using a hydrocarbon vapour-imaging infrared (IR) camera and no emissions were detectable. Based on the lack of detectable emissions at the time of the site visit and given their limited utilization, these tanks do not offer a practicable vapour control opportunity. Copies of the IR video images are being provided separately from this report.

3.3 Fugitive Equipment Leaks

The inlet oil production tanks at Acacias were all connected to a vapour collection system that conducted the flash gas to the flare system. The pressure-vacuum valve on each of these tanks was passing appreciable amounts of vapour through the pressure relief port on the valves (seeTable 2). This would indicate an overpressure condition in the tanks due to under-sizing of the vapour collection system, and/or fouling of the vapour collection piping. This matter should be investigated more closely to resolve the cause of the over-pressuring. Possible explanations include: inadequate sizing of the vapour collection system, fouling of the vapour collection lines due to the use of carbon-steel piping for the vapour collection lines instead of corrosion resistant materials, malfunctioning of the pressure control system.

The total commodity losses associated with this leakage amounts to approximately 4.9 million USD/y and contributes 3.9 kt CO2E/y of GHG emissions (see Table 3). Additional information is provided in Appendix E.

3.4 Casing Gas Venting

Nine wells in the vicinity of the Chichimene Oil Battery were tested to determine the amount of casing gas they were venting. Only trace indications of emissions were present and the flows were too small to be measured. Consequently, the Chichimene oil field does not appear to offer any meaningful casing gas recovery opportunities. Better opportunities for casing gas recovery may exist in other oilfields in Colombia. An important consideration, where casing gas venting or flaring occurs, is the content of condensable hydrocarbons in the casing gas as this fraction is much more valuable than the CH_4 fraction and can greatly enhance the economics of managing these emissions, especially given the need for light hydrocarbon liquids for use as diluent in the heavy oil fields. Depending on the circumstances, it may be practicable to collect the gas and bring it to a central facility for processing. Otherwise, consideration may be given to the use of micro-condenser systems that can process the gas at the production facilities. Systems designed to economically process between 282 and 2,832 m^3/d are available.

3.5 Process Heaters

Combustion tests were performed on the two active process heaters at the Chichimene Oil Battery to identify potential tuning opportunities. Total current fuel consumption by these process heaters is summarized in Table 5. The amount by which this fuel consumption could be reduced by tuning the process heaters is given in Table 6. The estimated amount of emissions associated with the total fuel consumption is presented in Table 7 and the potential amount by which these emissions could be reduced by tuning the heaters is given in Table 8. An economic analysis of implementing a program to tune the heaters is presented in Table 9. The detailed results are presented in Appendix F.

The total value of the avoidable fuel consumption from the four heaters amounts to 0.94 million USD/y. Consequently, these heaters would benefit from a formal program for regular tuning. The primary tuning issue was high excess air values; although, Burner 2 on Heater 7473 had noteworthy amounts of unburned fuel in the exhaust. Tuning of the heaters to achieve optimum performance would reduce the emissions from the heaters by 4.6 kt CO_2E/y.

Table 5: Total current fuel consumption by the process heaters at the Chichimene Oil Battery.

Source	Value Fuel Consumption (USD/y)	Total Fuel Consumption (m^3/h)	Residue Gas (10^3 m^3/d)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Heater 7472 (Burner 1)	816,335	101.42	1.34	0.37	0.82	3.15	0.00
Heater 7472 (Burner 2)	816,335	101.42	1.34	0.37	0.82	3.15	0.00
Heater 7473 (Burner 1)	2,232,009	277.29	3.66	1.01	2.24	8.61	0.00
Heater 7473 (Burner 2)	2,232,009	277.29	3.66	1.01	2.24	8.61	0.00
Total	6,096,688	757.42	10.00	2.75	6.11	23.52	0.00

Table 6: Potentially avoidable incremental fuel consumption for tuning opportunities on the process heaters at the Chichimene Oil Battery.

Source	Value of Avoidable Fuel Consumption (USD/y)	Total Avoidable Fuel Consumption (m^3/h)	Residue Gas (10^3 m^3/d)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Heater 7472 (Burner 1)	213,670	26.55	0.35	0.10	0.21	0.82	0.00
Heater 7472 (Burner 2)	105,243	13.07	0.17	0.05	0.11	0.41	0.00
Heater 7473 (Burner 1)	347,507	43.17	0.57	0.16	0.35	1.34	0.00
Heater 7473 (Burner 2)	271,438	33.72	0.45	0.12	0.27	1.05	0.00
Total	937,858	116.51	1.54	0.42	0.94	3.62	0.00

Table 7: Estimated total current emissions due to fuel consumption by the process heaters at the Chichimene Oil Battery.

Source Name	CH_4 (t/y)	CO_2 (t/y)	N_2O (t/y)	CO_2E (t/y)	VOC (t/y)	CO (t/y)	NO_x (t/y)	SO_2 (t/y)	PM (t/y)
Heater 7472 (Burner 1)	19.42	3,776.88	0.06	4,202.95	52.39	53.93	0.71	0.00	0.05
Heater 7472 (Burner 2)	19.42	3,776.88	0.06	4,202.95	8.60	3,736.93	2.11	0.00	0.05
Heater 7473 (Burner 1)	7.05	10,326.68	0.16	10,524.43	19.02	0.67	2.83	0.00	0.14
Heater 7473 (Burner 2)	0.94	10,326.68	0.16	10,396.14	2.53	0.59	3.04	0.00	0.14
Total	46.83	28,207.12	0.44	29,326.49	82.54	3,792.13	8.71	0.00	0.39

Table 8: Potentially avoidable emissions due to the current tuning opportunities on the process heaters at the Chichimene Oil Battery.									
Source Name	**CH_4 (t/y)**	**CO_2 (t/y)**	**N_2O (t/y)**	**CO_2E (t/y)**	**VOC (t/y)**	**CO (t/y)**	**NO_x (t/y)**	**SO_2 (t/y)**	**PM (t/y)**
Heater 7472 (Burner 1)	5.08	988.57	0.02	1,100.10	13.71	14.12	0.19	0.00	0.01
Heater 7472 (Burner 2)	2.50	486.92	0.01	541.85	1.11	481.77	0.27	0.00	0.01
Heater 7473 (Burner 1)	1.14	1,673.42	0.03	1,705.47	3.08	0.11	0.46	0.00	0.02
Heater 7473 (Burner 2)	0.11	1,255.84	0.02	1,264.29	0.31	0.07	0.37	0.00	0.02
Total	8.84	4,404.76	0.07	4,611.70	18.21	496.07	1.29	0.00	0.06

Table 9: Economic analysis of conducting regular tuning of the process heaters at the Chichimene Oil Battery.								
Source Name	**Application Life Expectancy (y)**	**Capital Cost (USD)**	**Net Present Salvage Value (USD)**	**Net Operating Cost (USD/y)**	**Value of Conserved Energy (USD/y)**	**NPV (USD)**	**ROI (%)**	**Payback Period (y)**
Heater 7472 (Burner 1)	20	3,750	0	1,000	142,859	1,041,149	3782.90	0.0
Heater 7472 (Burner 2)	20	3,750	0	1,000	88,981	644,295	2346.15	0.0
Heater 7473 (Burner 1)	20	3,750	0	1,000	321,409	2,356,313	8544.25	0.0
Heater 7473 (Burner 2)	20	3,750	0	1,000	249,985	1,830,218	6639.60	0.0
Total	20	15,000	0	4,000	803,233	5,871,975	5328.22	0.0

1. NPV denotes net present value.
2. ROI denotes return on investment.

3.6 Engines

Combustion tests were performed on eight of the engines at the Monterrey Oil Pump Station to identify potential opportunities to reduce fuel consumption by tuning the engines. The total current fuel consumption by the engines is summarized in Table 10 and the potential amount by which the fuel consumption could be reduced through tuning the engines is given in Table 11. The total emissions by the engines is given in Table 12 and the emissions reduction potential from tuning the engines is given in Table 13. Additional details are provided in Appendix G. Half the engines tested showed some nominal opportunity for improvement, but overall, the engines were in reasonably good operating condition. By tuning the engines 14,122 USD/y in fuel savings could be realized, and the GHG emissions would be reduced by 0.159 kt/y of CO_2E.

Table 10: Total current fuel consumption by the natural gas-fuelled pump engines at the Monterrey Oil Pump Station

Source	Value of Displaced Fuel Consumption (USD/y)	Total Displaced Fuel Consumption (m^3/h)	Residue Gas (10^3 m^3/d)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Engine 001A	133,064	72.54	1.52	0.54	0.26	0.01	0.00
Engine 001C	133,064	72.54	1.52	0.54	0.26	0.01	0.00
Engine 4410	534,854	291.58	6.11	2.17	1.03	0.05	0.00
Engine 4420	534,854	291.58	6.11	2.17	1.03	0.05	0.00
Engine 4430	534,854	291.58	6.11	2.17	1.03	0.05	0.00
Engine 4440	534,854	291.58	6.11	2.17	1.03	0.05	0.00
Engine 4450	534,854	291.58	6.11	2.17	1.03	0.05	0.00
Engine 4460	534,854	291.58	6.11	2.17	1.03	0.05	0.00
Total	3,475,254	1,894.58	39.67	14.09	6.69	0.35	0.00

Table 11: Portion of the current fuel consumption by the natural gas-fuelled pump engines at the Monterrey Oil Pump Station that could potentially avoidable by tuning the engines.

Source	Value of Displaced Fuel Consumption (USD/y)	Total Displaced Fuel Consumption (m^3/h)	Residue Gas (10^3 m^3/d)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Engine 4420	5,012	2.73	0.06	0.02	0.01	0.00	0.00
Engine 4430	5,973	3.26	0.07	0.02	0.01	0.00	0.00
Engine 4440	865	0.47	0.01	0.00	0.00	0.00	0.00
Engine 4450	2,271	1.24	0.03	0.01	0.00	0.00	0.00
Total	14,122	7.70	0.16	0.06	0.03	0.00	0.00

Table 12: Estimated total current emissions from the natural gas-fuelled pump engines at the Monterrey Oil Pump Station.									
Source Name	**CH_4 (t/y)**	**CO_2 (t/y)**	**N_2O (t/y)**	**CO_2E (t/y)**	**VOC (t/y)**	**CO (t/y)**	**NO_x (t/y)**	**SO_2 (t/y)**	**PM (t/y)**
Engine 001A	2.71	1,396.63	0.16	1,502.02	0.35	41.29	0.45	0.00	0.11
Engine 001C	2.71	1,396.63	0.16	1,502.02	0.35	41.29	0.02	0.00	0.11
Engine 4410	10.89	5,613.78	0.63	6,037.43	1.40	165.95	33.75	0.00	0.45
Engine 4420	10.89	5,613.78	0.63	6,037.43	1.40	81.96	59.33	0.00	0.45
Engine 4430	10.89	5,613.78	0.63	6,037.43	1.40	81.96	59.33	0.00	0.45
Engine 4440	10.89	5,613.78	0.63	6,037.43	1.40	14.15	242.79	0.00	0.45
Engine 4450	10.89	5,613.78	0.63	6,037.43	1.40	37.14	162.59	0.00	0.45
Engine 4460	10.89	5,613.78	0.63	6,037.43	1.40	165.95	52.29	0.00	0.45
Total	70.74	36,475.91	4.09	39,228.61	9.08	629.69	610.55	0.00	2.92

Table 13: Potentially avoidable emissions due to the current tuning opportunities on the tested natural gas-fuelled pump engines at the Monterrey Oil Pump Station.									
Source Name	**CH_4 (t/y)**	**CO_2 (t/y)**	**N_2O (t/y)**	**CO_2E (t/y)**	**VOC (t/y)**	**CO (t/y)**	**NO_x (t/y)**	**SO_2 (t/y)**	**PM (t/y)**
Engine 4420	0.10	52.61	0.01	56.58	0.01	0.77	0.56	0.00	0.00
Engine 4430	0.12	62.69	0.01	67.42	0.02	0.92	0.66	0.00	0.01
Engine 4440	0.02	9.08	0.00	9.76	0.00	0.02	0.39	0.00	0.00
Engine 4450	0.05	23.84	0.00	25.64	0.01	0.16	0.69	0.00	0.00
Total	0.29	148.22	0.02	159.40	0.04	1.86	2.30	0.00	0.01

Opportunities for waste heat recovery from the engines to produce electric power using an Organic Rankine Cycle (ORC) process were investigated. The potential amount of indirect fuel consumption (i.e., fossil fuel consumption at the power plant) that would be displaced by generating electricity from the waste heat in the exhaust gases from each engine is summarized in Table 14. The indirect reduction in emissions that would occur is delineated in Table 15. Based on the assumed price of electricity and an ORC efficiency of 18% for producing electric power, installation of these units on the eight surveyed pump engines would reduce to energy costs by 0.52 million USD/y and reduce GHG emissions by 1.0 kt CO_2E/y.

Table 14: Displacement of fuel consumption by generating electricity from engine waste heat at the Monterrey Oil Pump Station							
Source	Value of Displaced Fuel Consumption (USD/y)	Total Displaced Fuel Consumption (m^3/h)	Residue Gas (10^3 m^3/d)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Engine 001A	16,651	9.08	0.19	0.07	0.03	0.00	0.00
Engine 001C	12,398	6.76	0.14	0.05	0.02	0.00	0.00
Engine 4410	134,189	73.15	1.53	0.54	0.26	0.01	0.00
Engine 4420	137,663	75.05	1.57	0.56	0.27	0.01	0.00
Engine 4430	136,157	74.23	1.55	0.55	0.26	0.01	0.00
Engine 4440	145,877	79.53	1.67	0.59	0.28	0.01	0.00
Engine 4450	142,388	77.62	1.63	0.58	0.27	0.01	0.00
Engine 4460	144,513	78.78	1.65	0.59	0.28	0.01	0.00
Total	869,836	474.20	9.93	3.53	1.68	0.09	0.00

Table 15: Estimated emissions associated with the recoverable waste heat from the natural gas fuelled pump engines at the Monterrey Oil Pump Station.									
Source Name	CH_4 (t/y)	CO_2 (t/y)	N_2O (t/y)	CO_2E (t/y)	VOC (t/y)	CO (t/y)	NO_x (t/y)	SO_2 (t/y)	PM (t/y)
Engine 001A	0.34	174.76	0.02	187.95	0.04	5.17	0.06	0.00	0.01
Engine 001C	0.25	130.13	0.01	139.95	0.03	3.85	0.00	0.00	0.01
Engine 4410	2.73	1,408.43	0.16	1,514.72	0.35	41.64	8.47	0.00	0.11
Engine 4420	2.80	1,444.90	0.16	1,553.94	0.36	21.09	15.27	0.00	0.12
Engine 4430	2.77	1,429.09	0.16	1,536.94	0.36	20.86	15.10	0.00	0.11
Engine 4440	2.97	1,531.11	0.17	1,646.66	0.38	3.86	66.22	0.00	0.12
Engine 4450	2.90	1,494.49	0.17	1,607.27	0.37	9.89	43.29	0.00	0.12
Engine 4460	2.94	1,516.80	0.17	1,631.26	0.38	44.84	14.13	0.00	0.12
Total	17.71	9,129.71	1.02	9,818.70	2.27	151.19	162.53	0.00	0.73

Table 16: Economic analysis of conducting annual tuning of the pump engines at the Monterrey Oil Pump Station.								
Source Name	**Application Life Expectancy (y)**	**Capital Cost (USD)**	**Net Present Salvage Value (USD)**	**Net Operating Cost (USD/y)**	**Value of Conserved Energy (USD/y)**	**NPV (USD)**	**ROI (%)**	**Payback Period (y)**
Engine 001A	20	0	0	2,000	0	-14,732	None	N/A
Engine 001C	20	0	0	2,000	0	-14,732	None	N/A
Engine 4410	20	0	0	2,000	0	-14,732	None	N/A
Engine 4420	20	0	0	2,000	$4,717	20,016	None	N/A
Engine 4430	20	0	0	2,000	$5,616	26,634	None	N/A
Engine 4440	20	0	0	2,000	$802	-8,822	None	N/A
Engine 4450	20	0	0	2,000	$2,134	988	None	N/A
Engine 4460	20	0	0	2,000	0	-14,732	None	N/A

1. NPV denotes net present value.
2. ROI denotes return on investment.

Table 17 presents an economic evaluation of installing ORC units on the eight pump engines. The payback period is in the range of 4.7 to 5.0 years for most of the units; however, the two smallest units only offer a payback of 40.4 to 54.1 years and therefore are not good candidates for this technology.

Table 17: Economic analysis of installing Organic Rankine Cycle (ORC) units to utilize the recoverable waste heat from the pump engines at the Monterrey Oil Pump Station to produce electric power.								
Source Name	**Application Life Expectancy (y)**	**Capital Cost (USD)**	**Net Present Salvage Value (USD)**	**Net Operating Cost (USD/y)**	**Value of Conserved Energy (USD/y)**	**NPV (USD)**	**ROI (%)**	**Payback Period (y)**
Engine 001A	20	416,990	0	0	10,319	-340,986	2.47	40.4
Engine 001C	20	416,990	0	0	7,701	-360,266	1.85	54.1
Engine 4410	20	416,990	0	0	83,205	195,876	19.95	5.0
Engine 4420	20	416,990	0	0	85,365	211,792	20.47	4.9
Engine 4430	20	416,990	0	0	84,428	204,889	20.25	4.9
Engine 4440	20	416,990	0	0	90,448	249,228	21.69	4.6
Engine 4450	20	416,990	0	0	88,300	233,404	21.18	4.7
Engine 4460	20	416,990	0	0	89,610	243,058	21.49	4.7

3. NPV denotes net present value.
4. ROI denotes return on investment.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The main cost-effective opportunities to reduce emissions and conserve energy at the visited oil production facilities are delineated in Table 18 and comprised the following:

- Conserving vent, flare and leakage gas at heavy oil batteries (48.444 million USD/y gross savings and 42.8 kt/y CO_2E GHG emissions reduction potential, with and estimated payback period of 0.5 years).

The regular tuning of process heaters and engines is good practice. The tuning of the heaters at Chichimene offers a good gross savings (0.803 million USD/y) and emissions reduction opportunity (3.9 kt CO_2E/y), with an estimated payback period of a month; mostly due to poor excess air levels.

The installation of ORC units to produce electric power from engine waste heat at the Monterrey Oil Pump Station offers a marginally attractive payback of less than 5 years for the larger units and is not practicable for the smaller units (0.521 million USD/y gross savings and 1.0 kt/y CO_2E GHG emissions reduction potential).

4.2 Recommendations

It is recommended that the recovery of natural gas liquids from the flare and vent gas streams at the heavy oil batteries be examined more closely. This would reduce purchases of naphtha and produce a clean-burning residue gas stream that could be used to fuel electric power generators.

Table 18: Summary of evaluated opportunities and recommended actions.						
Opportunity	**Potential Gross Savings (Million USD/y)**	**Potential GHG Reduction (kt/y)**	**Recommended Control Measures or Actions**	**Capital Costs (Million USD)**	**Payback Period (Years)**	**Comments**
Vent & Flare Gas Recovery at Acacias, Castilla and Chichimene Heavy Oil Batteries	48.444	142.8	Consider recovering condensable hydrocarbons from the gas for use as diluent and use the residue gas to generate electric power.	24.662	0.5	Needs to be further evaluated, and if viable, expanded to include all heavy oil batteries in the region.
Upgrading of the Vapour control system at the Acacias Heavy Oil Battery	4.686	3.7	Conduct an engineering review of the system to determine the root cause of the leakage problem. Then, if appropriate, review Ecopetrol's vapour control system design standards and practices to ensure these problems are not repeated at new facilities. Also, develop corrective measures to be applied at Acacias Heavy Oil Battery.	N/A	N/A	Needs to be further evaluated as part of any future vapour conservation scheme, or simply to reduce emissions of volatile organic compounds (VOCs).
Tuning of the process heaters at the Chichimene Heavy Oil Battery	0.803	3.9	Implement a formal program. tuning program	0.015	0.02	This should be considered for all production facilities that have process heaters and boilers.
Tuning of the engines at the Monterrey Pump Station	0.013	0.1	The engines where reasonably well tuned as is reflected in the small size of this opportunity.	N/A	N/A	This should be considered for all engines at production

Table 18: Summary of evaluated opportunities and recommended actions.						
Opportunity	**Potential Gross Savings (Million USD/y)**	**Potential GHG Reduction (kt/y)**	**Recommended Control Measures or Actions**	**Capital Costs (Million USD)**	**Payback Period (Years)**	**Comments**
			Nonetheless, there is still some opportunity for improvement. It is recommended that a regular monitoring program be implemented and that a risk-based approach to maintaining the engines be implemented.			and pipeline facilities.
Waste heat recovery at the Monterrey Pump Station	0.521	1.0	It is recommended that ORMAT waste-heat recovery units be considered for the engines that offer a 5-year or better payback period.	2.502 (excluding the engines with payback periods >5 years)	4.6 to 5.0	This should be considered at all sites where the waste heat is economical to recover and can either be used directly in the process or where it can be used generate electric power to reduce purchases from electric utility grid.

5 REFERENCES CITED

None.

APPENDIX A GLOSSARY

General Terminology

Air Toxics -	air pollutants that are either known or believed to have an adverse effect on human health. For many such compounds 15-minute, 1-hour and 8-hour occupational exposure limits have been established but acceptable limits for prolonged low-concentration exposure are uncertain.
Acid Precipitation -	acid precipitation (or acid rain) results from the atmospheric emission of SO_x and NO_x. Both types of pollutants are products of combustion. In the air, these substances react with atmospheric moisture to produce sulphuric (H_2SO_4) and nitric (HNO_3) acid, respectively. Eventually, these substances are carried to earth by precipitation (rain or snow). The precursors of acid rain may produce respiratory and other internal disease when inhaled in high concentrations. Also, acid rain has potentially serious indirect effects on human health. The two major concerns regarding indirect health effects are: (1) the leaching of toxic chemicals by acidified waters leading to contamination of drinking water supplies, and (2) the contamination of edible fish by toxic chemicals, principally mercury. Acid rain has also been known to damage aquatic ecosystems (National Research Council, 1981).
Choked Flow -	occurs where the local fluid velocity is equal to the speed of sound in that fluid at its flowing temperature and pressure. Under these conditions the fluid flow is too fast for decompression waves to travel upstream. Consequently, there is no longer any driving force for further increases in the flow rate and the flow is therefore choked.
Combustion Efficiency -	the extent to which all input combustible material has been completely oxidized (i.e., to produce H_2O, CO_2 and SO_2). Complete combustion is often approached but is never actually achieved. The main factors that contribute to incomplete combustion include thermodynamic, kinetic, mass transfer and heat transfer limitations. In fuel rich systems, oxygen deficiency is also a factor.
Criteria Air Pollutants -	pollutants for which ambient air quality objectives have been promulgated. These typically include SO_2, NO_x, PM,

and CO. Additionally, VOCs also may be a criteria air pollutant in some jurisdictions.

Destruction Efficiency - the extent to which a target substance present in the input combustibles has been destroyed (i.e., converted to intermediate, partially-oxidized and fully-oxidized products of combustion).

Fugitive Emissions - unintentional leaks from piping and associated equipment components (e.g., from seals, packings or gaskets, or leaks from underground pipelines [resulting from corrosion, faulty connection, etc.]). Fugitive sources tend to be continuous emitters and have low to moderate emission rates.

Global Warming Potential (GWP) - the amount of radiative forcing on the climate produced per unit mass of a specific greenhouse gas relative to that produced by CO_2. For example, CO_2 has a GWP of 1 while CH_4 and N_2O have GWPs of 21 and 310, respectively. These values include both direct and indirect effects.

Greenhouse Gases - these are substances that cause radiative forcing on the climate (i.e., contribute to global warming) when emitted into the atmosphere. Current focus is on those greenhouse gases increasing in atmospheric due to human activities, primarily CO_2, CH_4, CFCs and N_2O.

Continued global warming could be expected to result in a significant rise in the present sea level, altered precipitation patterns and changed frequencies of climatic extremes. The potential effects of these changes include altered distribution and seasonal availability of fresh water resources, reduced crop yields and forest productivity and increased potential for tropical cyclones.

Heat Rate - the amount of heat energy (based on the net or lower heating value of the fuel) which must be input to a combustion device to produce the rated power output. Heat rate is usually expressed in terms of net J/kW·h.

Kinetics and Thermodynamics - thermodynamic equilibrium defines the maximum extent to which a chemical reaction, such as combustion, may proceed (i.e., the point at which there is no further tendency for change).

Chemical kinetics determines the rate at which a chemically reacting system will approach the point of thermodynamic equilibrium.

Methane Content of Natural Gas - volume of methane contained in a unit volume of natural gas at 15°C 101.325 kPa.

Nitrogen Oxides (NO_x) - the total of all forms of oxidized nitrogen at a given measurement point. The primary form of NO_x emitted by combustion devices is NO_2; however, other forms may include NO, N_2O, NO_3, N_2O_4 and N_2O_5. Convention is to express total NO_x in terms of equivalent NO_2.

There are three mechanisms for the formation of NO_x in combustion processes: thermal fixation of nitrogen from the combustion air (thermal NO_x), oxidation of fuel-bound nitrogen compounds (chemical NO_x), and the formation of CN compounds in the flame zone which subsequently react to form NO (prompt NO_x). Thermal NO_x is the predominant form of NO_x produced from natural gas combustion. The conditions that govern the formation of thermal NO_x are the peak temperature, residence time at the peak temperature and the availability of oxygen while that temperature exists.

Fuel-bound nitrogen is an important source of NO_x where appreciable amounts of such fuels are used. The extent of conversion of fuel-bound nitrogen to NO is nearly independent of the parent fuel molecule, but is strongly dependent on the local combustion environment and on the initial amount of fuel-bound nitrogen.

Prompt NO_x is associated with the combustion of hydrocarbons. The maximum formation of prompt NO_x is reached on the fuel-rich side of stiochiometric, it remains high through a fuel-rich region, and then drops off sharply when the fuel-air ratio is about 1.4 times the value at stiochiometric.

NO_x controls can be classified into types: post combustion methods and combustion control techniques. Post combustion methods address NO_x emissions after formation while combustion control techniques prevent the formation of NO_x during the combustion process. Post combustion methods tend to be more expensive than combustion control techniques.

Post combustion control methods include selective non-catalytic reduction, and selective catalytic reduction.

Combustion control techniques depend on the type of combustion device and fuel. Nonetheless, they generally are designed to achieve lower combustion temperatures without significantly affecting combustion efficiency and power output, and to avoid/minimize the use of nitrogen containing fuels.

Particulate Matter (PM) - particulate matter is that portion of the flue gas which exists as a solid or liquid droplet when it leaves the stack and cools to ambient conditions. Carbonaceous particulate that forms from gas-phase processes is generally referred to as soot, and that developed from pyrolysis of liquid hydrocarbon fuels is referred to as coke or cenospheres.

The potential for particulate emissions is generally dependent on the composition of the fuel and the type of combustion device. Combustion of natural gas produces very small amounts of particulate emissions compared to other types of fuels. Nonetheless, the amount of particulate emissions will tend to increase with the molecular weight of the gas. Also, reciprocating engines produce the most particulate matter while heaters and boilers produce the least. Most of the particulate matter emitted by reciprocating engines is reportedly due to lubricating oil leakage past the piston rings.

Particulate emissions generally are classified as PM, $PM_{10,}$ $PM_{2.5}$ and PM_1 according to the maximum diameter of the material, namely, total PM, and PM with a diameter less than 10, 2.5 and 1 microns, respectively. PM_{10} and smaller particulate matter are of greatest concern because of their ability to bypass the body's natural filtering system.

Photochemical Oxidants - photochemical oxidants are a class of pollutants produced by the reaction of VOCs and NO_x in the presence of solar radiation which accumulate in the air near ground level. Ozone (O_3) is the principal oxidant produced; however, significant levels of peroxyacetyl nitrate (PAN) and nitrogen dioxide (NO_2) also occur.

Exposure to increased ozone concentrations can cause short-term impairment of the respiratory system and is suspected of playing a role in the long-term development of chronic lung disease.

Damage to vegetation caused by ozone is reported (Wilson et al., 1984) to be greater than that caused by commonly occurring air contaminants such as SO_2, NO_2, or acidic precipitation. Also, elevated ozone concentrations produce smog and cause deterioration and cracking of rubber products.

Pipeline Leak - fugitive emission through a small opening in the wall of the pipeline or from valves, fittings or connectors attached to that pipeline.

Power Output - for engines it is the net shaft power available after all losses and power take-offs (e.g., ignition-system power generators, cooling fans, turbo chargers and pumps for fuel, lubricating oil and liquid coolant) have been subtracted. For heaters and boilers it is the net heat transferred to a target process fluid or system.

Products of Incomplete Combustion - these are any compounds, excluding CO_2, H_2O, SO_2, HCl and HF, that contain C, H, S, Cl or F and occur in the flue gas stream. These compounds may result from thermodynamic, kinetic or transport limitations in the various combustion zones. All input combustibles are potential products of incomplete combustion. Intermediate substances formed by dissociation and recombination effects may also occur as products of incomplete combustion (CO is often the most abundant combustible formed).

Residual Flare Gas - the sum of the flare purge gas flow and any leakage into the flare header. This is the total gas flow rate that occurs in the header to an intermittent flare during the periods between flaring events.

Standard Reference Conditions - most equipment manufacturers reference flow, concentration and equipment performance data at ISO standard conditions of 15°C, 101.325 kPa, sea level and 0.0 percent relative humidity.

The following equation shows how to correct pollutant concentrations measured in the exhaust to 3 percent oxygen (15% excess air) for comparison and regulatory compliance purposes:

$$ppm\,(3\,\%) = \frac{21 - 3}{21 - O_2(actual)}\ x\ ppm\,(actual)$$

Subsonic Flow - flow where the local fluid velocity is less the speed of sound in that fluid at its flowing temperature and pressure.

Sulphur Oxides (SO_x) - usually almost all sulphur input to a combustion process as part of the fuel or waste materials being burned is converted to SO_x. Only a few percent of the available sulphur is emitted as sulphate particulate and other products of incomplete combustion. The produced SO_x is comprised mostly of SO_2 (typically 95 percent) with the rest being SO_3. For simplification purposes it is assumed throughout this document that all input sulphur is converted to SO_2.

Thermal Efficiency - the percentage or portion of input energy converted to useful work or heat output. For combustion equipment, typical convention is to express the input energy in terms of the net (lower) heating value of the fuel. This results in the following relation for thermal efficiency:

$$\eta = Thermal\ Efficiency = \frac{Useful\ Work/Heat\ Output}{Net\ Heat/Energy\ Input}\ x\ 100\%$$

Alternatively, thermal efficiency may be expressed in terms of energy losses as follows:

$$\eta = \left(1 - \frac{\Sigma Energy\ Losses}{Net\ Heat/Energy\ Input}\right) x\ 100\%$$

Losses in thermal efficiency occur due to the following potential factors:

- exit combustion heat losses (i.e, residual heat value in the exhaust gases),

- heat rejected through coolant and lube oil cooling systems (where applicable),
- heat losses from the surface of the combustion unit to the atmosphere (i.e., from the body and associated piping of a heater, boiler or engine),
- air infiltration,
- incomplete combustion, and
- mechanical losses (e.g., friction losses and energy needed to run cooling fans and lubricating-oil pumps).

Total Hydrocarbons - all compounds containing at least one hydrogen atom and one carbon atom.

Total Volatile Organic Compounds (TOC) - all VOCs plus all non-reactive organic compounds (i.e., methane, ethane, methylene chloride, methyl chloroform, many fluorocarbons, and certain classes of per fluorocarbons).

Vented Emissions - vented emissions are releases to the atmosphere by design or operational practice, and may occur on either a continuous or intermittent basis. The most common causes or sources of these emissions are pneumatic devices that use natural gas as the supply medium (e.g., compressor starter motors, chemical injection and odourization pumps, instrument control loops, valve actuators, and some types of glycol circulation pumps), equipment blowdowns and purging activities, and venting of still-column off-gas by glycol dehydrators.

Volatile Organic Compounds (VOC) - any compounds of carbon, excluding carbon monoxide, and carbon dioxide, which participate in atmospheric chemical reactions. This excludes methane, ethane, methylene chloride, methyl chloroform, many fluorocarbons, and certain classes of per fluorocarbons.

Waste Gas - any gas that leaks into the environment or is vented or flared.

APPENDIX B ECONOMIC EVALUATIONS METHODOLOGY

B.1 Basic Valuations

(1) Value of an energy stream (USD/y)

The value of an energy stream is assessed using the following relation:

$$V = (Q_{V_{CH4}} \cdot p_{CH4} + Q_{L_{LPG}} \cdot p_{LPG} + Q_{L_{NGL}} \cdot p_{NGL} + Q_{H2} \cdot p_{H2} + e \cdot p_e) \cdot g_c$$

Equation 1

Where,

V	=	value of a stream (USD/y)
p	=	commodity price (USD/unit of flow measure)
e	=	electric power consumption (kW·h)
g_c	=	constant of proportionality
	=	365 d/y

(2) Value of Certified Carbon Credits

$$V_{CCC} = VER_{CO2E} \cdot p_{CO2E} \cdot g_c$$

Equation 2

Where,

V_{CCC}	=	Value of certified carbon credits (USD/y)
VER_{CO2E}	=	Verified CO_2E emission reductions achieved (t CO_2E/y)

(3) Net Present Value (NPV)

$$NPV = -CC + SV_{RE} + \frac{SV_{CE}}{(1+i)^N} + \sum_{n=1}^{n=N} \frac{((V_{Losses} \cdot \eta - OC + OCS)}{(1+i)^n}$$

Equation 3

Where,

n = a variable indicating the number of years since the start of the project (y),

N = life expectancy of the project or life expectancy of the control technology, whichever is less (y).

i = discount rate (expressed as a fractional value).

V_{Losses} = value of avoidable product losses or energy consumption ($/y). For the purposes of these calculations, the value of the product losses is assumed to remain constant with time, but would actually tend to increase due to inflation and supply and demand considerations. Also, the costs of any required processing have not been considered in assessing the value of the product losses (these costs are assumed to be small).

η = Control efficiency of the considered control technology (dimensionless fractional value).

OC = Operating cost of the considered control technology ($). For the purposes of these calculations, the operating cost is assumed to remain constant; however, these would tend to increase with time due to inflation.

OCS = Operating and maintenance savings from discontinued use of the replaced System (USD/y)

CC = Capital cost of the considered control technology (USD).

SV_{RE} = Net salvage value of any equipment removed when the control technology is installed (USD).

SV_{CE} = Net salvage value of the control equipment at the end of the project life or at the end of the life of the control technology, whichever occurs first (USD).

Overall, the actual value of avoided hydrocarbon losses is very site-specific and depends on many factors. Some important considerations are listed below:

- Cost to find, develop, produce, treat/upgrade/process/refine, and deliver the sales product,
- Parts of the system where emission reductions are achieved; for instance, gas conserved before processing is less valuable than gas conserved after processing.
- Impact of emission reductions on specific energy consumption, equipment life, workplace safety, operability, reliability and deliverability.
- Supply and Demand Constraints (Conserved gas often becomes reserve production that is not sold until the reservoir and market conditions change to the point where demand exceeds supplied; this time lag reduces the present value of such gas.)
- Market prices and current contract requirements.
- Government taxes and royalties.

(4) Net Operating Costs

$$NOC = OC + OCS$$

Equation 4

Where,

NOC = net operating costs (USD/y)
OC = Operating cost of the considered control technology (USD). For the
purposes of these calculations, the operating cost is assumed to remain constant; however, these would tend to increase with time due to inflation.
OCS = Operating and maintenance savings from discontinued use of the replaced
System (USD/y)

(5) Net Present Salvage Value

$$NPSV = SV_{RE} + \frac{FSV_{CE}}{(1+i)^N}$$

Equation 5

Where,

NPSV = Net present salvage value (USD).
SV_{RE} = Net salvage value of any equipment removed when the control technology
is installed (USD).
SV_{CE} = Net salvage value of the control equipment at the end of the project life or
at the end of the life of the control technology, whichever occurs first (USD).
N = life expectancy of the project or life expectancy of the control technology,
whichever is less (y).

(6) Return on Investment (ROI)

$$ROI = \frac{(V_{Losses} \cdot \eta - OC + OCS)}{CC - SV_{RE}} \cdot 100\%$$

Equation 6

Where,

V_{Losses} = Value of avoidable product losses or energy consumption (USD/y).
η = Efficiency of the selected control measure in reducing product losses and avoidable fuel consumption (fractional dimensionless value).
OC = Operating cost of the considered control technology (USD).
CC = Capital cost of the considered control technology (USD).

(7) Payback Period

$$PP = \frac{CC - SV_{RE}}{V_{Losses} \cdot \eta - OC + OCS}$$

Equation 7

B.2 Avoid Production Losses or Fuel Consumption

Avoided product or commodity losses, reduced fuel requirements, and displacement of wellhead natural gas production through capture and production of waste gas streams is all classified as conserved product and is assessed an economic value. The value of the product depends on the type of product and where in the system it is conserved, the quality of the conserved product, and the applicable regulatory and contract incentives. Generally, the value of natural gas decreases in moving upstream due to increasing treating, processing and transport requirements. One exception to this occurs on some parts of the gas transmission system where existing contracts between producers and pipeline companies offer no incentive for transmission companies to conserve gas. Consequently, for these sections of pipeline, the gas effectively has no value.

Overall, the actual value of avoided hydrocarbon losses is very site-specific and depends on many factors. Some important considerations are listed below:

- Cost to find, develop, produce, treat/upgrade/process/refine, and deliver the sales product,
- Parts of the system where emission reductions are achieved; for instance, gas conserved before processing is less valuable than gas conserved after processing.
- Impact of emission reductions on specific energy consumption, equipment life, workplace safety, operability, reliability and deliverability.
- Supply and Demand Constraints (Conserved gas often becomes reserve production that is not sold until the reservoir and market conditions change to the point where demand exceeds supplied; this time lag reduces the present value of such gas.)

- Market prices and current contract requirements.
- Government taxes and royalties.

B.3 Capital Costs

Capital costs may include the following major expense categories:

- Public Consultation and Regulatory Approvals,
- Engineering, Procurement and Project-management Services,
- Equipment and Materials,
- Construction Services, and
- Installation of Utility Services (e.g., electric power, fuel gas, water, telecommunications, and roadways).

The applicability and relative contribution of each expense category to total costs depends on the type of control technology being implemented and the specific application.

In assessing the capital costs for each technology it is assumed, for simplicity, that the costs are incurred all in the first year. This may be true for low-capital-cost options but for more capital-intensive options the cost would normally be incurred in phases over several years to help minimize risks. In many applications the total capital cost of a control technology is substantially greater than the direct costs of the basic control devices. For example, the end control device (e.g., an incinerator) for a large-scale vapour collection application may represent less that 10 percent of the total capital cost for the total vapour collection and control system.

Many of the control options considered are add-on devices that have about the same installed cost no matter if it is a new or retrofit application. Where the differences are potentially significant, a weighted cost is used to reflect the anticipated mix of new and retrofit applications. Technologies which may only be feasible in new applications (for example, field upgrading) are priced in terms of the incremental cost relative to a conventional system and are assumed to have fewer potential applications. Where one control device may service a number of different sources at a site (such as a flare system), only a single unit is priced.

The level of specificity and rigor used to assess capital costs varied according to the control technology and the available information. The specific cost elements considered, either directly or indirectly, in each case included the following:

- **Labour** - Labour hours are directly related to the quantities of materials. The relative efficiency of labour depends on the availability of skilled craftsmen and the relative site conditions. Weather conditions may also be important if significant outside work is planned. Remote sites or areas with infrequent workloads may have problems maintaining a reasonable number and selection of qualified crafts people. If adequate numbers of skilled people are not available, training is an option if the project is large enough; or else craftsmen can be imported from other locations. Subsistence and travel pay usually is required when importing crafts people.

- **Excavation/Civil** - Soil conditions and the required depth of any underground systems may have a significant impact on costs. Compaction is also more difficult to achieve in certain situations and this increases the hours needed for backfill operations. Other matters to consider are the presence of rock, high water tables, poor soil conditions requiring removal, availability of import fill, site access for equipment, degree of hand excavation or backfill required, and constraints on pile driving due to close proximity of sensitive operating equipment and buried piping.

- **Concrete -** Foundation costs can be substantial. If piling is required, then the cost of the concrete for pile caps is less than for a spread footing type foundation but the combined cost of piling and pile caps is usually higher. The depth of foundation needed to avoid frost lines is also a factor that can increase the amount of concrete required. Designing for earthquake zones increases the size of the foundations, rebar and anchor bolts and can add 20 to 30 percent to concrete costs. Additionally, soil and environmental conditions which attack concrete may require special mixes of concrete costing more and special coating or treatment of rebar and anchor bolts. Pouring and curing of concrete may require expensive heating and hoarding if done during severe winter conditions.

- **Structural Steel** - Structural steel is required for aboveground piping systems, equipment bases, access platforms, stairs and handrails. Some structural work may be done at fabrication shops and then shipped to the site for reduced costs. Typical company specifications require all structural steel work to be sandblasted, primed and painted.

- **Winterization of Equipment and Piping** - Winterization requirements can drive up costs if heat tracing or additional shelters are required.

- **System Reliability, Operability, Maintainability and Safety** - The reliability, operability, maintainability and risks associated with each option should be clearly identified and considered in the evaluation process. Special safeguarding measures and instrumentation controls may often be required and can add substantially to the overall cost.

- **Spacing** - Facilities that are space-limited may not be able to accommodate combustion-based control equipment due to their spacing requirements (usually at least 25 m). In some such cases it may be possible to acquire additional lease space for a price.

- **Public Response/Perception -** Particular concerns are the potential for off-site noise, visible flames, and odours, especially where the facility may be observed from residential areas, or nearby high-traffic roadways or navigable waterways.

B.4 Conserved or Displaced Electricity

The amount of utility power avoided through conservation measures or displaced by power production from waste gas streams is assessed and assigned a value based on the commercial price for electricity.

Actual costs may include both a demand and an energy charge, and the applicable rates vary with the size and type of service application. Lower rates are available to large general-service customers.

B.5 Removal Costs

Removal costs are separate from installation costs and apply where a process unit must be removed and replaced by an alternative unit (e.g., removing gas operating pumps and replacing them with electric powered units).

B.6 Salvage Value

This is the value of the installed emission control equipment at the end of the project life, and of any equipment removed as part of a control measure (e.g., changing out oversized compressors for improved energy efficiency). It is assumed that each control device has essentially zero salvage value at the end of the analysis period. The decline in value is attributed to a combination of equipment depreciation, obsolescence and high salvage costs.

B.7 R&D Costs

Some emerging and embryonic control technologies may be assessed a research and development cost. For simplicity, it is assumed that these costs are all incurred in the first year; however, they would normally be incurred over a much longer period of time (e.g., 5 to 10 years).

B.8 Project Life

The life of a given control option is application dependent and tied directly to the remaining economic life of the associated wells or upstream facilities. Traditionally, new oil and gas developments have been assessed based on a 20-year life expectancy. As the industry ages, however, the quality of finds in the Western Canadian sedimentary basin is gradually declining leading to reduced life expectancies for new projects. As well, average remaining life of existing facilities is declining. In some parts of the industry, such as heavy oil and shallow gas production, the average economic lives of wells has always been relatively low. A typical heavy oil well may only have 2 to 4 years of economic life through application of primary production techniques and an additional 4 to 6 years with subsequent application of enhanced recovery techniques.

B.9 Operating Cost

The operating amount is the cost of energy consumption, labour, parts, consumables (e.g., filters, replacement parts, lube oil, etc.), environmental reporting, on-going management and supervision, lease payments, insurance premiums, and other associated expenses (e.g., vehicles, subsistence, etc.) that may be required. If a control option is simply to employ a more environmentally-friendly method of performing a required process function, only incremental operating costs are considered.

In most cases, a bottom-up approach has been used to estimate operating costs. The amount of energy consumption is calculated based on the average amount of work done in controlling the target emissions and the efficiency of the process. All other costs are assessed in varying degrees of detail depending on the available information and nature of the control option. Typically, these efforts included compilation of pricing data from technology vendors and service companies, discussions with individual technology users and estimates of application-specific material and labour requirements by expense categories.

B.10 Financial Discount Rate

The discount rate and opportunity cost of equity in the upstream petroleum industry is usually taken to be a value in the range of 6 to 12 percent, depending on the segment of the industry. Typically, the discount rate increases in moving upstream through the industry in accordance with increasing financial risks. Accordingly, differing values within this range are applied herein.

In comparison, a non-redeemable guaranteed interest certificate (GIC) currently yields a 3.900 to 4.450 percent rate of return for a 1-year term, and a 5.150 percent return for a 10-year GIC. The prime interest rate is presently 6.250 percent. Most oil and gas ventures are expected to yield better than bank interest to compensate for the added risk involved.

B.11 Other Discount Rates

In addition to the overall financial discount rate, further discount factors may be applied to the relevant cost and revenue accounts for each control option to account for the applicable taxes, tax shields and royalties.

B.12 Inflation Rates

An average inflation rate may be assumed for the time series.

B.13 Value of GHG Reduction

The value of a GHG emission reduction option is simply calculated as the equalized annual value divided by the average annual CO_2 reduction. For now, this is set to zero.

APPENDIX C FLARE SYSTEMS

C.1 Introduction

Flare and vent systems exist in essentially all segments of the oil and gas industry and are used for two basic types of waste gas disposal: intermittent and continuous. Intermittent applications may include the disposal of waste volumes from emergency pressure relief episodes, operator initiated or instrumented depressurization events (e.g., depressurization of process equipment for inspection or maintenance purposes, or depressurization of piping for tie-ins), plant or system upsets, well servicing and testing, pigging events, and routine blowdown of instruments, drip pots and scrubbers. Continuous applications may include disposal of associated gas and/or tank vapours at oil production facilities where gas conservation is uneconomical or until such economics can be evaluated, casing gas at heavy oil wells, process waste or byproduct streams that either have little or no value or are uneconomical to recover (e.g., vent gas from glycol dehydrators, acid gas from gas sweetening units, and sometimes stabilizer overheads), and vent gas from gas-operated devices where natural gas is used as the supply medium (e.g., instrument control loops, chemical injection pumps, samplers, etc.). Typically, waste gas volumes are flared if they pose an odour, health or safety concern, and otherwise are vented.

C.2 Background

The design of a flare must consider the maximum flow rate or release volume, the waste gas composition, temperature and pressure, heat release rates, the minimum required destruction efficiency, the impact of the emissions at ground level and at downwind receptors, and the potential for liquids to be contained or formed in the waste gas being sent to the flare.

Specific design features that affect flare performance include the discharge nozzle (or burner tip) design, the ignition system, the purge gas system and, if applicable, the enriching gas and assist gas systems. A review of the flare design and features is conducted to determine if there is a potential to reduce energy consumption, recovery the flare gas and emissions.

C.3 Performance Evaluation Methodology

C.3.1 Flared Gas Flow Rate Determination

When evaluating opportunities for reducing fuel consumption and flared volumes, actual site measurements are preferred for assessing the flare performance and for completing economic evaluations.

If existing flare gas flow meters are in place, then the available flow readings from these are used if they are of adequate quality. Otherwise, independent measurements or assessments are performed during the site survey.

C.3.1.1Installed Flow Meters

Flare meters are excellent diagnostic tools which can be used to identify excessive purge rates and/or leakage into the flare system that might otherwise go unnoticed, as well as quantify total intermittent and continuous flared volumes Pilot, purge, enriching and assist gas should be metered independently wherever possible.

Alberta ERCB recommends the use of flare meters at larger oil and natural gas batteries, pipeline facilities and gas processing plants where there are multiple connections to the flare system, even when the aforementioned average flaring rate is not exceeded (ERCB 2006). Similar requirements exist in many other jurisdictions. At a minimum, sufficient fittings should be installed to facilitate periodic checking of the residual flare rate if continuous flare metering is not required or deemed necessary. Flare streams are particularly challenging to meter because of the high variability in flow and composition.

Generally, flare meters should be gas-composition independent and exhibit accuracy over a high turndown range (i.e. 1:100 or better). Ultrasonic flow meters are the preferred choice in most permanent vent or flare applications involving wet and dirty gas, provided the liquid content does not exceed about 0.5 percent by volume. Ultrasonic flow meters offer excellent rangeability (2000:1), low uncertainties (±2 to 5 percent of value), do not require frequent calibration, are not composition dependent (i.e., corrections for the composition of the gas are not required) and they do not pose any significant flow restriction (i.e., the transducers are only wetted to the flow and are not extended into the flow as depicted in Figure 1). If greater amounts of liquids are anticipated then a liquids knockout system should be installed immediately upstream of the flow meter. Orifice and venturi meters may be considered instead of ultrasonic flow meters in applications involving stable wet or dirty flows; they can tolerate the presence of more liquids but have the disadvantages of greatly reduced rangeability (5:1) and the need for frequent calibrations, especially if the gas composition is variable. If properly maintained and calibrated, they provide uncertainties of ±2 to 4 percent of full scale readings.

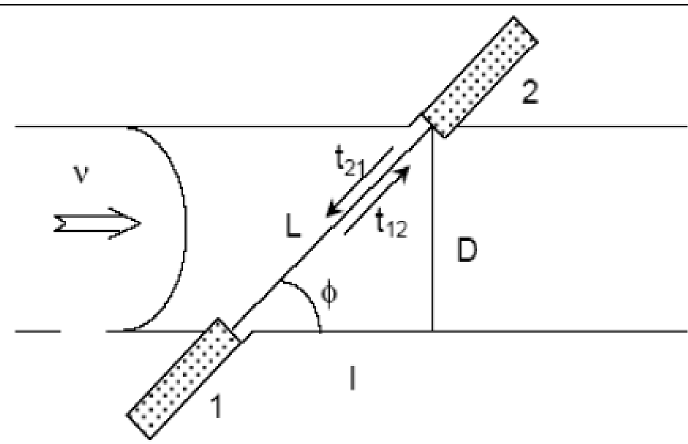

Figure 1: Schematic diagram depicting a pair of ultrasonic flow transducers wetted to the flow in a pipe.

Optical flow meters may also be considered. They are a more recent flare gas measurement technology and there is little published experience on the use of these flow meters. The optical flow meter measures flow velocity based on the transit time of naturally occurring particles in the flow stream over a short known path length. The rangeability of optical flow meters is 2000:1 and the uncertainty of the measurements is ±2.5 to 7 percent of value. The optical flow meter is reportedly suitable for moderately wet or dirty fluids. A particular advantage of the technology is that it comprises a single measurement probe that is easy to install (see Figure 2).

Figure 2: Photograph of an optical flow meter probe.

The use of thermal anemometers in flare gas flow measurement applications is generally not practical as they are highly composition dependent and are susceptible to fouling and cannot tolerate the presence of any liquids of condensation.

C.3.1.2 Independent Flow Measurements

If no flare metering is in place or the results available from those meters are of questionable accuracy, then the flare rate is measured using one of two basic techniques: a portable velocity probe or by conducting an inline tracer test. In either case, it is necessary that suitable ports be available; otherwise, the flaring rate is estimated using a flame-length technique (see the next section).

Most portable velocity probes can be inserted into the flare piping through a NPS ¾ full port valve. Typically, an optical flow meter manufactured by Photon Control. The instrument readings are continuously data logged at 1 Hz for sufficient time to characterize the flow variations. The velocity measurements are taken downstream of all tie-ins in a straight section of pipe. Where possible, the measurement point is selected to be 15 pipe-diameters downstream and 5 pipe-diameters upstream of any flow disturbances.

To conduct an inline tracer test it is necessary to have fittings on the flare line for injecting tracer gas and for withdrawing a sample. The injection point must be located somewhere on the flare line where there is flow and the sampling point needs to be sufficiently far downstream of the injection point and all tie-ins to allow for good mixing of the entire flare stream and the tracer gas. The basic approach involves injecting the tracer gas at a known rate and, based on the concentration of the tracer gas at the sample location, calculating the gas flow rate needed to produce the observed amount of tracer dilution. The selected tracer gas is a substance that is inert, easy to detect in low concentrations and not naturally occurring in the flare gas. Either SF_6 or N_2O is normally used. The tracer gas analyses are performed onsite using a micro-gas chromatograph or a cavity ringdown spectrometer, respectively.

C.3.1.3 Flow Estimation based on Flare Flame Length

If direct flow measurements cannot be performed then the flare rate is estimated using an empirical flame-length correlation derived by Gas Processors Suppliers Association (GPSA) from data provided in the flame-length versus heat-release-rate graphs presented in the American Petroleum Institute's (API's) Recommended Practice (RP) 521. The correlation applies to flare with simple tip designs and can be expected, where the gas composition is well known, to provide accuracies in the range of ±10 to 60% (i.e., based in the scatter in the available data). The better accuracies tend to occur at the higher flow rates. The correlation is applicable to turbulent diffusion flames for simple flare tip designs up to the point where flame lift-off from the flare tip starts to occur, and for greater flows, underestimates the actual flare rate.

The primary advantage of the method is that it is easy and safe to apply, and it provides a reasonable initial estimate of the flaring rate which makes it useful as a screening technique.

GPSA correlates the flame length L_f and the energy (equivalent) flare flow rate Q (W) of the flare gas stream using the following relation:

$$L_f = 2.14(Q \times 10^{-6})^{0.474}$$

Equation 8

The flame length is determined by photographing the flare tip (see Figure 3), and then scaling up the stack diameter D_p and flame length, L_p, dimensions measured from the photograph to match the actual stack diameter, D_f. This is done using the following relation:

$$L_f = \frac{L_p}{D_p} D_f$$

Equation 9

The flame from each flare is photographed using a Canon EOS 60D SLR digital camera equipped with a 200 mm zoom lens. Multiple images are taken of each flame to fully characterize the range of natural fluctuations in the flame size. The fluctuations in the flame length can be appreciable, even when the flow rate is constant. The flare rate correlates best with the average determined flame length.

The stack outside diameter is determined by back-calculation from the measured stack circumference and confirmed against standard pipe sizes.

The calorific value of the flare gas is determined based on typical gas analyses provided by the facility operators or based on flare gas samples collected and analyzed during the site survey.

With the flame length L_f known, the GPSA correlation is applied to back-calculate the flow rate of the flare gas.

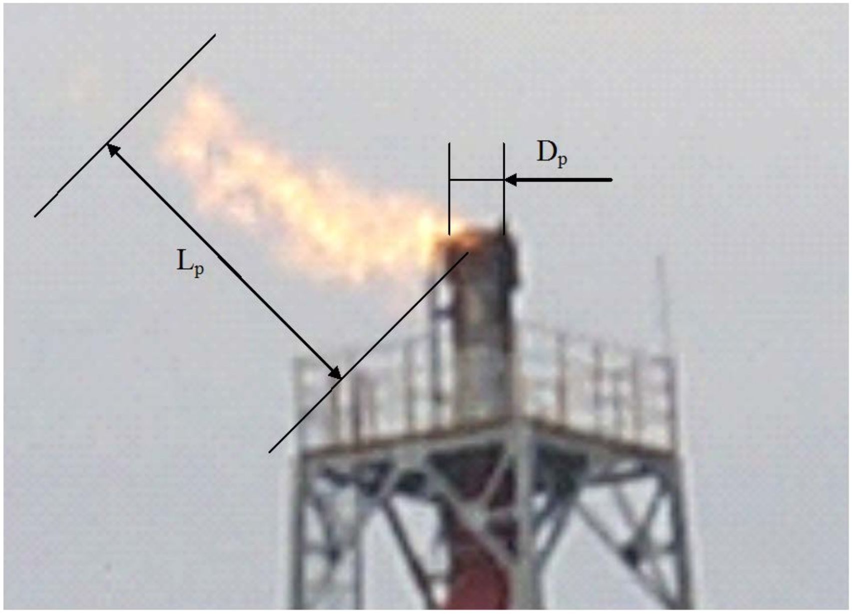

Figure 3: A photograph of one flare flame showing the related dimensions for the flame length approach.

C.3.2 Purge Gas Flow Rate

C.3.2.1Minimum Purge Rate based on BMP

For plain end flares, the purge gas required to avoid unsafe air infiltration can be estimated using the Husa purge model. (CAPP 2008) Equation 10 is an adaptation of the Husa purge model that can be used to estimate minimum purge gas requirements for flare systems:

$$Q = -\ln\left(\frac{O_2\%}{21}\right)\frac{KD^{3.46}}{Ls}[1 - 0.75(\frac{MW}{28.96})^{1.5}]$$

Equation 10

Where:

- Q is the purge gas consumption in m^3/h;
- K is 5.26×10^{-8} ;
- D is the internal diameter of the stack in mm;
- $O_2\%$ is the acceptable oxygen concentration at Ls in % (note: 6% is usually acceptable);

- *Ls* is the distance into the stack where the safe condition is met in m (note: the lesser of 7.62 m or 10 stack diameters is usually acceptable);
- *MW* is the molecular weight of the purge gas (19.5 is typical for raw natural gas).

Larger flares are often equipped with seals, which reduce the continuous purge rate required to avoid unsafe air infiltration into the stack. Purge reduction seals do not physically isolate the stack from the surrounding atmosphere. Instead, they utilize proprietary internals, either baffle-type or labyrinth-type, to reduce the ability for buoyant movement of air into the stack. Equation 11 can be used to estimate typical purge requirements for flare systems outfitted with baffle-type seals and Equation 12 can be used to estimate the typical purge gas consumption associated with labyrinth-type seals. Actual purge rates will depend on the seal design and should be obtained from the manufacturer. For baffle-type purge reduction tips (assuming an average purge velocity of 0.0122 m/s), the following relation may be applied to estimate purge gas requirements:

$$Q = 3.447 \times 10^{-5} D^2$$

Equation 11

Where:

- Q is the purge gas consumption in m^3/h;
- D is the internal diameter of the stack in mm;

For labyrinth-type purge reduction tips (assuming an average purge velocity of 0.0030 m/s), the following relations may be applied:

$$Q = 8.618 \times 10^{-6} D^2$$

Equation 12

Where:

- Q is the purge gas consumption in m^3/h;
- D is the internal diameter of the stack in mm;
  Assuming: the average required purge velocity for flares equipped with labyrinth-type purge reduction tips is 0.0030 m/s.

Table 19 presents typical minimum required purge gas rates for different sizes of flares equipped with different types of seals (CAPP 2008).

Table 19: Typical minimum purge rates to avoid unsafe air infiltration.			
Flare Diameter (NPS)[1]	Purge Gas Consumption Rate (m^3/h)		
	Plain End[2]	Baffle Type Seal	Labyrinth Type Seal
2	0.07	0.09	0.02
3	0.17	0.21	0.05
4	0.34	0.36	0.09
6	0.93	0.82	0.20
8	1.83	1.42	0.35
10	3.19	2.23	0.56
12	4.98	3.20	0.80
14	6.35	3.90	0.98
16	8.98	5.17	1.29
18	12.16	6.62	1.65
20	15.92	8.24	2.06
24	25.34	12.02	3.01
26	31.04	14.18	3.54
30	44.57	19.03	4.76
36	82.87	27.63	6.91
42	142.76	37.84	9.46
48	228.39	49.65	12.41
54	345.39	63.06	15.77
60	499.74	78.07	19.52

[1] Standard wall pipe

C.3.3 Minimum Energy Content of Combined Flare Volume

The minimum energy content of flared gas is an important performance consideration; the minimum requirements are typically specified by regulatory agencies.

ERCB (2006) Directive 060 requires the combined net heating value (i.e. lower heating value) of flared gases and make-up fuel to meet or exceed 20 MJ/m^3 except for existing flares with a history of stable operation and emergency flare systems in sour gas plants where the heating value may be as low as 12 MJ/m^3.

C.3.4 Fuel Consumption Rate Reduction Options

C.3.4.1Purge Gas Rate

Metered or estimated purge gas flow rates are compared to best management practice (BMP) values. The purge rate can be estimated from the flame length where residual flows include purge gas and leakage into the flare header, and do not include any contributions due to emergency or planned depressurization events.

The minimum required pure rate will depend on the type of seal used, stack diameter, properties of the purge gas and ambient and system conditions.

An opportunity may exist to reduce fuel consumed by continuously purged flare systems by installing purge reduction seals, using instrumentation to control purge rates, switching to an inert gas purge and/or reducing purge rates in response to leakage into the flare system. When evaluating purge gas reductions the purge rate required to maintain a safe stack condition (i.e. prevent air ingress) should be considered in conjunction with purge requirements to prevent burn back and provide adequate header sweep.

Purge reduction seals reduce the purge velocity required to avoid air infiltration into the flare stack and can lead to a significant reductions in the amount of purge gas consumption, especially on larger diameter stacks. These devices should be considered in most situations where flare systems are continuously purged.

The minimum purge rate required to avoid unsafe air ingress into the stack is not only a function of the stack diameter and purge gas composition, but is dependent on changes in ambient temperature, pressure, wind speed and temperature of products in the flare header. To compensate for the dynamic nature of these dependencies, continuous purge rates are often set above the minimum value required for the conditions under which the flare usually operates. An alternative to specifying an excessive purge rate is to use instrumentation to monitor critical parameters in the flare system (e.g. oxygen concentration, temperature, etc.) and automatically adjust the purge rate to maintain a safe stack condition. The reliability, regular calibration and preventive maintenance of instrumented purge gas control systems is critical to their success.

Leakage into the flare system can be difficult to identify and sometimes necessitates a plant shutdown to correct. During the time it takes to find and repair a leaking component, all or part of the losses can be mitigated by using the leak as a purge source and reducing the supply of purge gas up to the volume of the leak rate.

Some sources of leakage into a flare system are easy to detect because they are audible or cause condensation or ice formation on the outside of the leaking valve. However, many leakage sources are difficult to detect, even with thermal imaging cameras. A technology that has proven to be very effective in detecting leak flare gas valves is the VPAC, an acoustical leak detector manufactured by Mistras Group, which provides both leak detect and quantification capabilities. The amount of leakage is quantified by inputting the numeric acoustical reading from the VPAC into an empirical correlation along with information concerning the fluid, valve type and size and the pressure difference across the valve. This technology was originally developed in cooperation with BP and is most widely used at petroleum refineries, but it is also suitable for detecting leaking flare valves at upstream oil and natural gas facilities as well.

C.3.4.2Pilot Gas Rate

Many flares are outfitted with continuously burning gas pilots to ensure ignition of the flared gases or liquids. The number and type of pilots required depends on the flare size, stream composition and wind conditions. Typical pilot requirements and fuel consumption rates are summarized in Table 20. These rates assume an average pilot fuel consumption rate of 1.98 m^3/h/pilot which is reasonable for energy-efficient pilots fueled by sales-quality natural gas (U.S. EPA 2000); however, the actual consumption rate will depend on the burner design and fuel properties. The average fuel requirement of the pilot in Table 2 is multiplied by a safety factor of 2 to estimate the reasonable pilot fuel consumption rate for the flare.

Table 20: Average fuel gas consumption for energy-efficient flare pilots[1].

Flare Tip Diameter		Number of Pilot Burners	Average Pilot Gas Consumption	
Inches	Mm		m^3/h	m^3/d
1-10	25.4-254	1	1.98	47.52
12-24	304.8-609.6	2	3.96[1]	95.04[1]
30-60	762-1524	3	5.95	142.80
>60	>1524	4	7.93	190.32

1 Adapted from CAPP (2008). The value of average pilot gas consumption for 12 to 24 NPS flares is reported as 3.63 m^3/h in the original CAPP document. The correct value is 3.96 m^3/h based on the fuel consumption rate of 70 scf/h/pilot in the original source reference of USEPA (2000).

C.3.4.3Make-Up Gas Rate

Make-up fuel is sometimes required to raise the calorific value of flared waste gas to levels that will support stable and efficient combustion.

Equation 13 can be used to estimate minimum make-up gas requirements (CAPP 2008).

$$Q_m = Q_w \frac{LHV_r - LHV_w}{LHV_m - LHV_r}$$

Equation 13

Where:

- Q_m is the make-up fuel gas flow rate (m^3/h),
- Q_w is the waste gas flow rate (m^3/h),
- LHV_r is the required combined net heating value (i.e. 20 MJ/m^3),
- LHV_m is the lower heating value of the make-up gas (MJ/m^3),
- LHV_w is the net heating value of the waste gas (MJ/m^3).

The quantity of fuel gas used to raise the calorific value of waste gas streams can be reduced by using incinerators in place of flares or by installing instrumentation to automatically adjust the delivery of make-up gas.

C.3.5 Heating Value Requirement

According to ERCB (2006) Directive 060, the combined net or lower heating value of waste gas, including make-up fuel gas, directed to a flare must not be less than 20 MJ/m^3.

If the flare has a history of flame failure, odour complaints, and/or exceedances of the *Ambient Air Quality Objectives*, operators must operate with a combined flare gas heating value of not less than 20 MJ/m^3.

C.3.6 Flare Efficiency

For a typical flare, the efficiency improves as the exit velocity and heating value of the gas increase, and then decrease when soot formation (black smoke) and/or lift-off of the flame from the flare tip start to occur. A quantitative estimate of the flaring efficiency, where no flame lift-off is occurring, may be evaluated based on the following approach:

- Any aerosols that form in the flare gas between the flare knock-out drum and the flare tip is assumed to either pass through the flame zone unburned or to form soot. The amount of aerosol formation is estimated by determining the temperature of the flare knockout drum and assuming the gas at the flare tip is at ambient temperature. The formation of aerosols tends to reduce the heating value and exit velocity of the remaining gas phase since the aerosols are comprised mainly of the higher-molecular weight hydrocarbons.
- The combustion efficiency of the gas phase is assumed to be characterized by the flaring efficiency model published by Johnson *et al.* (1999). That model presents the flaring efficiency as a function of the stack diameter, exit velocity, flare gas heating value and the local wind speed, and was developed based on extensive wind tunnel tests on bench scale and full-scale flares.

The approach taken in Johnson's research project was to experimentally study scaled-down, generic pipe flares under well-controlled conditions to understand the performance of flares in general. To provide control over the wind, research was conducted in a closed-loop wind tunnel where the wind speed from a known direction could be set and the level of turbulence could be prescribed.

A methodology was developed to accurately determine the efficiencies of flares where the combustion products are predominantly gaseous. For a flare burning a mixture of hydrocarbon fuels, the efficiency is described by the "carbon conversion efficiency," which is the effectiveness of the flare in converting the carbon in the fuel to carbon in CO_2.

For a stream with a lower heating value (LHV < 30 MJ/m^3), the following relation applies:

$$(1-\eta)(LHV_{mass})^3 = 146.5\exp\{0.1745 \cdot U_\infty / [(gV_j)^{1/3}(d_0{}^{1/2})]\}$$

Equation 14

Where:

η	=	flare efficiency (dimensionless);
LHV	=	lower heating value of the flare gas (MJ/kg);
U_∞	=	wind speed (m/s);

g	=	gravitational constant (m/s^2);
V_j	=	flare gas exit velocity (m/s);
d_0	=	stack outside diameter (m).

Equation 14 presents the influence of crosswind speed, flare gas exit velocity, flare diameter, and fuel type to flare efficiency. Results show the crosswind has a strong effect on the destruction efficiency. At relatively low values of U_∞ the efficiencies are extremely high, but as U_∞ is increased the efficiency decreases dramatically. The destruction efficiency also depends on the mean fuel jet exit velocity (V_j). Higher velocity fuel jets are less sensitive to the effects of crosswind. The larger diameter flare stacks are more resistant to the effects of increased crosswind speed.

For a stream with greater a heating value (LHV > 30 MJ/m^3), Equation 14 overestimates the importance of energy density and gives unreasonably high efficiencies. The following correlation should be use in this case:

$$\begin{cases} \dfrac{U_\infty}{(gV_j)^{1/3} d_0^{1/2}} < 25 & 100 \cdot (1-\eta) = 0.12375 \cdot \exp\{0.16357 \cdot U_\infty / [(gV_j)^{1/3} (d_0{}^{1/2})]\} \\ \dfrac{U_\infty}{(gV_j)^{1/3} d_0^{1/2}} \geq 25 & 100 \cdot (1-\eta) = 14.75 \cdot \ln\{U_\infty / [(gV_j)^{1/3} (d_0{}^{1/2})]\} - 40.3695 \end{cases}$$

Equation 15

C.3.7 Wind Speed Correction

The flare destruction efficiency is calculated as a function of the wind speed at the stack top. To relate the wind speed back to wind speed at the standard monitoring height at meteorological monitoring stations, Equation 16 is used:

$$U_{\infty,Z} = U_{\infty,0} \left(\frac{H_Z}{H_0} \right)^n$$

Equation 16

Where:

U_∞	=	wind speed (m/s);
H	=	height (m);
Z	=	subscript representing stack top;
0	=	subscript representing meteorological monitoring station (the height is usually 10 m);
n	=	exponential constant (n = 0.3 is used for worst case scenario).

C.3.8 Steam Assisted Flare Analysis

The steam assisted flares are often used to promote smoke free operation. High pressure steam is injected into the combustion zone to promote better mixing and to promote complete combustion of the waste gas. The steam amount injected should be optimal to get the desired results. The steam requirement for an industrial flare ranges from 0.01 to 0.6 kg of steam per kg of flare gas (U.S. EPA 2000, 2012). The amount of steam used in the flare should be within this range to achieve high combustion efficiencies. Using excess steam leads to rapid reduction in combustion efficiency of the flare and also results in avoidable loss of steam and its energy. When the steam injection rate for the flare is known the losses associated with the excess steam requirement can be determined as follows:

$$S_{ex} = S_m - 0.6\, F_m \qquad \text{When } S_m \text{ is greater than } 0.6\, F_m$$

Equation 17

Where

S_{ex}	=	Excess steam being used (kg/h)
S_m	=	Measured steam injection rate (kg/h)
F_m	=	Mass Flow Rate of the Flare Gas (kg/h)

When the steam flow rate to the flare is not known or the measured steam mass flow rate is less than 1% of flare gas mass flow rate, the steam requirement for steam assisted flares is determined based on the following U.S. EPA (2000) recommendation:

$$S_{rq} = 0.4\, F_m \qquad \text{When } S_m \text{ is less than } 0.01\, F_m \text{ or } 0$$

Equation 18

Where

S_{rq}	=	Steam Requirement (kg/h)

The energy loss in excess steam is determined using the following equation:

$$E_{ex} = S_{ex}\,(H_{sb} - H_{wb})\, g_c$$

Equation 19

Where

E_{ex}	=	Energy loss in excess steam (kW)
H_{sb}	=	Enthalpy of steam used at the boiler pressure of the steam source (kJ/kg)
H_{wb}	=	Enthalpy of inlet water at the boiler inlet temperature and pressure Conditions (kJ/kg)
g_c	=	A constant of proportionality
	=	2.778×10^{-4} (h/s)

The enthalpy of steam at appropriate boiler pressure and water at boiler inlet temperature and pressure is determined using steam tables.

Similarly the steam energy requirement to provide the necessary steam flow for a steam assisted flare is determined using the following equation:

$$E_{rq} = (S_{rq} - S_m)(H_{sb} - H_{wb})\, g_c \qquad \text{When } S_m \text{ is less than } 0.01\, F_m \text{ or } 0$$

Equation 20

Where

E_{rq} = Energy requirement for extra steam to be provided to the flare (kW).

The fuel energy required for the generation of steam lost or extra steam requirement in a flare is computed as follows:

$$E_{engy\,loss} = \frac{E_{ex}}{\varphi_b} \,.\, 100$$

Equation 21

And

$$E_{engy\,req} = \frac{E_{rq}}{\varphi_b} \,.\, 100$$

Equation 22

Where

$E_{engy\,loss}$ = Fuel energy required for steam lost in the flare, (kW)

$E_{engy\,req}$ = Fuel energy required for extra steam requirement for the flare, (kW)

φ_b = Boiler efficiency (%)

= 80 % by default or the actual measured or estimated value when available.

The fuel energy value from Equation 21 or Equation 22 is used to estimate the value of the fuel saved or extra fuel required as follows:

$$V_{fuel} = E_{fuel} \,.\, C_{fuel} \,.\, g_c$$

Equation 23

Where

V_{fuel} = Value of fuel saved or cost of extra fuel required ($/y)above

E_{fuel} = Energy of fuel saved ($E_{engy\,loss}$) or extra fuel required ($E_{engy\,req}$) (kW)

C_{fuel}	=	Price of the fuel ($/GJ)
g_c	=	A constant of proportionality
	=	31.536 (GJ/kJ.s/y)

The emission rates for various combustion products and GHG are computed using the following equation:

$$ER_i = E_{fuel} \cdot EF_{i,b} \cdot g_c$$

Equation 24

Where

ER_i	=	Emission rate of substance 'i', (t/y)
$EF_{i,b}$	=	Emission factor for substance 'i' for the boiler, (ng/J)
g_c	=	A constant of proportionality
	=	3.1536×10^{-5} (t/ng.J/kJ.s/y)

The emission factors can be estimated either based on combustion analysis of the boiler or the default values of emission factors for industrial boilers provided in US EPA's AP-42 compilation of air pollutant emission factors.

C.3.9 Air Assisted Flare Analysis

Air assisted flares are being used in industry for smokeless operation of flares. Recently US EPA (2012) has published extensive measurement data on the combustion efficiency of air assisted flare operations. The results showed that the mass flow rate for air in air assisted flares should be less than 7 times the stoichiometric air mass flow rate required for the flare gas. The maximum air requirement for an air assisted flare is estimated using the following equation:

$$m_{a,max} = 7\, m_{a,stoich}$$

Equation 25

Where

$m_{a,max}$	=	maximum mass flow rate of air (kg/h).
$m_{a,stoich}$	=	Stoichiometric air requirement for flare gas combustion (kg/h).

The stoichiometric air requirement for flare gas is determined based on the composition of flare gas. Stoichiometric (or theoretical) combustion is a process which burns all the carbon (C) to CO_2, all hydrogen (H) to H_2O and all sulphur (S) to SO_2.

The excess air used in an air-assisted flare is determined using the following equation:

$$A_{ex} = A_m - m_{a,max}$$

Equation 26

Where

A_{ex}	=	Excess air being used (kg/h).
A_m	=	Measured air injection rate (kg/h).

The savings in energy consumption of blower or the energy requirement for the air blower for air assisted flare is determined as follows:

$$E_{sav} = \frac{A_{ex} \cdot g_c}{\beta_b \beta_m} . \Delta H_{ad}$$

Equation 27

Where

E_{sav}	=	Energy saving potential in air blower (kW)
β_b	=	Blower Efficiency (0.70 for typical blower).
β_m	=	Blower motor efficiency (0.9 for typical motor).
A_{ex}	=	Excess air flow rate (kg/h)
g_c	=	A proportionality constant
	=	2.778×10^{-4} (h/s).

And

$$\Delta H_{ad} = \frac{RT_a}{8.41}\left[\left(\frac{P_d}{P_a}\right)^{0.283} - 1\right]$$

Equation 28

Where

ΔH_{ad}	=	Adiabatic head generated by blower (kJ/kg).
R	=	Universal Gas Constant
	=	8.31451 (J/mol/K).
T_a	=	Ambient Temperature in absolute (°K).
P_d	=	Discharge Pressure in absolute for the blower (kPa).
P_a	=	Ambient Pressure in absolute (kPa).

Similarly the maximum power requirement for the blower is determined as follows:

$$E_{b,max} = \frac{m_{a,max} \cdot g_c}{\beta_b \beta_m} . \Delta H_{ad}$$

Equation 29

Where

$E_{b,max}$	=	Maximum energy requirement for air blower (kW).

C.4 Control Options

Where waste gas can support combustion, it is preferable to flare it than to vent it since this reduces greenhouse gas emissions as well as emissions of volatile organic compounds, air toxics and malodours. Where flares are used they need to be designed and operated to provide good destruction efficiencies, smokeless operation and to be fuel efficient.

There are various measures that may be considered for managing the fuel requirements of fares and for improving their destruction efficiencies. These options include switching to the use of incinerators, installing auto-ignition systems, optimizing purge gas consumption and providing assist gas to ensure smokeless combustion.

For intermittent flares, leakage of process gas into the flare header past the seats of pressure relieve valves and blowdown or drain valves can be a significant source of emissions and economic loss. Monitoring flare systems to detect excessive amounts of leakage and implementing a formal program to detect and repair individual leaks can offer attractive economic benefits. Flare gas recovery systems are an option for achieving nearly zero flaring except during process upsets.

For continuous flares, consideration should be given to conserving the gas by compressing it back into the process or a gas gathering system, utilizing the gas for onsite fuel needs or generate electric power (especially where it is possible to wheel the power across the electrical grid for use at other locations). Another option, for streams rich in condensable hydrocarbons, is to install a condenser system to recover the condensable fraction and use the residue gas to power the process and for onsite fuel or to produce electric power.

Further details on each of these opportunities is provided in the subsections below.

C.4.1 Incinerators

Incinerators are an alternative to flares that can be considered for disposing of steady continuous waste gas streams with low heating values. These devices maintain waste gases in the presence of oxygen at higher temperatures for longer residence times than flares. Destruction efficiencies are greater and gases with low calorific values can be more efficiently combusted. In many cases waste gas streams that do not meet the calorific requirements to maintain reliable and stable combustion in a flare can be disposed of using an incinerator without adding any fuel gas. Even in situations where incinerators do require fuel gas to treat a waste stream, the amount of fuel consumed is minimal compared to the make-up gas that would be required to sufficiently enrich the stream for disposal using a flare.

Although incinerators offer a number of benefits, they are not viable alternative to flares in all situations. Incinerators have lower turndown ratios (i.e., typically only 10:1) and higher capital cost than flares.

Instrumentation, including online calorimeters and flow meters, may be used to regulate the delivery of make-up gas to ensure calorific requirements of the combined stream are satisfied while minimizing the amount of fuel gas consumed. This may be particularly beneficial in situations where the composition and flow of the waste gas are variable.

C.4.2 Auto-Ignition System

The use of electronic ignition devices and/or energy efficient flare pilots can minimize the amount of fuel gas used to sustain flare pilots, while minimizing the potential for flame failure. Often operators will increase purge gas flows to reduce the likelihood of a flame failure which is much less energy efficient or cost effective than investing in a reliable auto-ignition system.

Electronic Ignition Devices- Electronic ignition devices that ensure continuous flare ignition by systematically producing high voltage electric sparks can often be used in place of gas operated pilots. Electric energy consumption is low and is typically supplied by solar recharged batteries.

Energy Efficient Pilots- In situations where pilots cannot be replaced by electronic ignition devices, the fuel efficiency of the gas pilot should be evaluated and consideration given to installing a better design. Efficiency of pilots can be maintained by ensuring that wind shielding and pilot nozzles are in good condition. Some vendors offer designs that consume as little as $0.57 m^3$/h/burner of fuel gas.

C.4.3 Smokeless Flares

Air and steam assisted systems are available that can be used to eliminate flare smoke formation and help improve flare efficiencies. These systems can be retrofit to existing flares but may require some modifications to the flare tip.

A rough order-of-magnitude cost for retrofitting a medium sized flare (e.g., 30 NPS) for smoke free operation is $150,000 to $300,000. This does not include installation.

The information needed to evaluate and design a system includes: stack diameter, stack height, flare rate, and flare gas composition. Air assist is preferable for smaller to medium sized applications and steam assist is normally used on larger flares; although, many facilities have converted from steam-assist to air-assist due to the lower operating costs and reduced emissions (i.e., direct and indirect).

An air-assist retrofit installation would include a blower, an air line to the top of the stack and a new flare tip and pilot assembly. The size of the air line would depend on the amount of air required to ensure smokeless operation. There are some basic rules of thumb regarding the mass of assist-air to waste-gas ratios. The existing structure would need to be checked to verify that it could support the additional weight. The size of the air line could be reduced by using higher-pressure air. This may require the use of air from the instrument air system or separate compressor, depending on pressure requirements. One vendor said they have used the derrick legs to transport assist air to the flare tip, assuming the legs are of tubular construction.

The air flow to the stack tip would be controlled by measuring the waste gas flow to the stack (e.g., by linking the blower controls into a flare gas flow meter output signal).

A two-stage flare may also be a good solution, assuming the smoking problems occur at lower relief rates. For example, a second line could be run up the existing stack, with a separate tip and pilot assembly. This option would only be applicable if the waste gas stream has sufficient pressure.

Typical vendors of smokeless flare systems include John Zinc, NAO Inc., Tornado Tech and Flare Industries.

C.4.4 Management of Leaking Flare Valves

It is reported that 5 to 10 percent of flare valves leak and 1 to 2 percent of those account for 70 percent of the leakage into flare headers. For flare systems that are sized for large relief events, significant amounts of leakage can easily go undetected (i.e., because the incremental flow is not visibly discernible and because the flow meters that are present are generally sized to only record much larger flows during relief or blowdown events).

The use of permanent monitoring systems or facilities should be considered to facilitate easy screening for excessive leakage into flare systems and where leakage occurs, this should leakage should be used to allow reduction of the flare purge gas requirements until the leaks can be isolated and repaired. Additionally, consideration should be given to implementing formal programs to detect and quantify individual flare valve leaks (for example, using a VPAC or similar technology).

Monitoring ports should be provided on all emergency vent and flare lines and blowdown systems to allow convenient periodic detection and quantification of residual flows in these systems where continuous flow meters are not provided or where such meters are only sized to quantify large flow rates (e.g., during relief or blowdown episodes).

Predictive maintenance techniques are preferable to reactive measures and should be considered for applications involving chronic or frequent leakers (e.g., compressor seal vents and leakage into vent and flare systems). This requires the implementation of continuous, frequent or early warning monitoring systems to provide advance notice of developing leaks and to facilitate pre-planning of repair or replacement activities.

Devices such as flow switches, flow meters, vapour sensors or transducers for other parameters that provide a good indication of leakage may be installed to allow continuous or frequent detection of leaks from component vent ports and in vent or flare systems.

An effective method of reducing fugitive emissions from pressure relief devices is to install a relief valve with a rupture disk immediately upstream of it, at each relief point. A pressure gauge or suitable telltale indicator is needed between the disk and the relief valve to indicate when the disk has failed (ASME, 1989). The rupture disk will shield the relief valve from corrosive process fluids during normal operation. If an overpressure condition occurs, replacement of the disk may be delayed until the next scheduled shutdown period. In the interim, protection against over-pressuring is provided by the relief valve. Sometimes a block valve is installed upstream of the relief system to facilitate early replacement or repair of the components. This use of an upstream block valve is allowed under most Boiler and Pressure Vessel Acts, provided the valve is normally car-sealed open.

The rupture disk should have a set pressure that is slightly higher than that of the relief valve to help avoid simmering problems.

An additional control method is to use resilient valve seats (elastomeric o-rings), as they have superior re-sealing characteristics.

These same strategies may be used to prevent leakage from pressure relief valves that release into closed-vent systems (for example, a flare system). In this case, leakage is difficult to detect and, as a result, may lead to a significant level of waste and cause unnecessary emissions from the combustion device.

The basic rupture disk assembly needed for use upstream of a pressure relief valve comprises a prebulged disk, disk holder, telltale indicator, and vent valve. Additionally, a spool piece may be required between the disk and the valve to provide adequate room for the disk to open during a rupture event. There are two basic types of rupture disks that may be used: forward acting and reverse acting. The forward acting disks are the least expensive and most commonly used type. The latter type is used in applications where significant vacuums or pressures may occur on the downstream side of the rupture disk. A forward acting disk would tend to break prematurely in these situations. A standard reason for using a reverse acting rupture disk is to allow the space between the disk and the pressure relief valve to be pressurized to test the set point of the valve in situ and to check for leaks.

For manual blowdown valves, one option to reduce leakage potential is to install as second valve to provide double shutoff protection.

C.4.5 Flare Gas Recovery Systems

While is preferable to control leakage into flare systems at the source, this may not always be practicable. Installing a flare gas recovery system can result in nearly 100 percent reduction of normal flaring, limiting flare operation to emergency releases and scheduled maintenance. Captured flare gas can then be reused as valuable fuel or feedstock.

Flare Gas Recovery systems perform the following processes:

- Isolating the flare header with a proprietary-design liquid seal or staging valve.
- Recovering the normally flared gases.
- Removing liquids.
- Compressing gases up to a defined pressure level.
- Cooling recovered gases (if required).
- Delivering the recovered gases into the facility, so they can be processed and re-used as fuel gas.

Typical flare gas recovery unit are sized for the following conditions:

- Flowrate Ranges: 0 to 11,100 m^3/h (0 to 10 MMSCFD).
- Pressure Ranges: 240 to 2070 kPa (35 to 300 psig)

Flare gas recovery systems may be used to recovery either continuous waste gas flows or residual flows to a flare or vent system and either put the recovery gas back into the facility inlet or, if the gas is sweet, put it into the fuel gas system. During a flaring event, the portion of the gas flow that is in excess of the capacity of the flare/vent gas recovery unit simply continues on to the flare/vent outlet. Given the challenge in trying to manage leakage into flare and vent headers and avoid facility shutdowns to repair such leaks, the economics for a flare gas recovery system can often be very attractive, especially at larger facilities.

C.4.6 Recovery of Condensable Hydrocarbons from Flare Gas

When a condensation approach is adopted to recover heavy hydrocarbon components, there are three different design technologies that may be considered: refrigeration, refrigerated lean oil absorption and Joule-Thomson expansion cooling.

Flare gas streams may contain both high-molecular-weight hydrocarbons, primarily propane, butane, pentane and heptane, as well as lighter components, methane and ethane. At petroleum refineries, the gas may also contain appreciable amounts of valuable hydrogen. When effectively processed, the higher-molecular-weight components of the flare gas can be separated from the lighter components to produce two valuable commodities: a hydrocarbon liquid product (composed of condensed natural gas liquids (NGL) and liquefied petroleum gas (LPG)) and a high-quality compressed residue gas available for conservation or use as fuel.

At production facilities, the producer can truck the recovered hydrocarbon liquids can be transported to marked by truck as a high vapour pressure product, dissolved in weathered crude oil and shipped by tank truck, or be injected into the crude oil pipeline (if one exists), which reduces evaporation losses, decreases the oil viscosity and thereby the specific pipeline energy requirements. The latter approach avoids the need for any onsite pressurized storage facilities for the produced hydrocarbon liquids. When processed downstream, the crude oil enriched with the condensate yields higher fractions of saleable liquid products such as ethane, propane, butane, isobutene and natural gasoline. In either case, these liquid fractions have a variety of different uses in the marketplace including enhancing oil recovery in oil wells, feedstock for oil refineries and petrochemical plants, and as sources of energy.

C.5 References

ERCB. 2006. Directive 060, Upstream Petroleum Industry Flaring, Incinerating, and Venting, Energy Resources Conservation Board, Alberta, Canada

CAPP. 2008. Fuel Gas Best management Practices, Efficient use of fuel gas in flaring operations, Canadian Association of Petroleum Producer

U.S. Environmental Protection Agency. 1998. *Compilation of Pollution Emission Factors, Vol.1, Station and Point Area Sources, AP-42(5th Edition)*. North Carolina. (http://www.epa.gov/ttn/chief/ap42/ch1/final/c01s04.pdf)

U.S. EPA. 2000. *EPA Air Pollution Control Cost Manual – Sixth Edition, Section 3.2 VOC Destruction Controls, Chapter 1 Flares* (EPA/542/B-02-001). United States Environmental Protection Agency. http://www.epa.gov/ttn/catc/dir1/cs3-2ch1.pdf

U.S. EPA. 2012. *EPA Parameters for properly designed and operated flares, Section 3.4.2* (EPA/542/B-02-001). United States Environmental Protection Agency. http://www.epa.gov/airtoxics/flare/2012flaretechreport.pdf

Johnson, M.R., Zastavniuk, O., Dale J.D., and Kostiuk, L.W. 1999. The Combustion Efficiency of Jet Diffusion Flames in Cross-flow. Paper presented at the Joint Meeting of the United States Sections – The Combustion Institute, Washington, D.C.

C.6 Results

The detailed flare analysis results are presented below:

Flare Index

Facility Name	Device Category	Tag Number	Name	Device Type	Service
Acacias Oil Battery	Flares		Flare	Flare Stack (Unassisted)	Emergency or Intermittent Waste Gas Disposal
Chichimene Station	Flares		Flare 1	Flare Stack (Unassisted)	Emergency or Intermittent Waste Gas Disposal
Chichimene Station	Flares	Flare 2-Chichimene	Flare 2	Flare Stack (Unassisted)	Emergency or Intermittent Waste Gas Disposal

Flare Simulation Information

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

General Simulation Data	
Activity Level[1]	1
Extrapolated Activity Level[1]	0
Ambient Temperature (^oC)	34.3
Ambient Pressure (kPa)	101.0
Average Wind Speed (m/s)	2.0
Met Station Height (m)	10.0
Stack Top Temperature (^oC)	N/A
Knockout Drum Temp (^oC)	N/A
Knockout Drum Pressure (kPag)	N/A

[1] Activity Level and Extrapolated Activity Level are used when extrapolating from the flare. The flare(s) not tested are assumed to have losses and emission of Extrapolated Activity Level/Activity Level times this flare.

Data Comments and Assumptions
N/A

Data Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	11-Sep-2013

Device	
Name	Flare
ID	N/A
On Site Location	N/A
Type	Flare Stack (Unassisted)
Service	Emergency or Intermittent Waste Gas Disposal
Manufacturer	N/A
Model	N/A
Model Year	N/A
Installation Date	N/A

Device Comments and Assumptions
Flare Stack

Applied Emission Factors		
Substance	**Value**	**Source**
CH_4 Emission Factor (ng/J)	47.09	User Entered
N_2O Emission Factor (ng/J)	0.10	US EPA AP-42
VOC Emission Factor (ng/J)	25.04	Calculated
CO Emission Factor (ng/J)	159.10	US EPA AP-42
PM Emission Factor (ng/J)	57.00	US EPA AP-42
NO_x Emission Factor (ng/J)	29.20	US EPA AP-42
HC Destruction Efficiency (%)	99.85	Calculated

Flare Stream and Stack Measurements

Property	Stream(s)
	Waste
Temperature (^oC)	40.8
Pressure (kPa gage)	17.5
Line Name	N/A
Cross Sectional Shape	Circular
Pipe Outside Diameter (mm)	273.1
Pipe Wall Thickness (mm)	6.35
Pipe Rectangular Length (mm)	N/A
Pipe Rectangular Width (mm)	N/A
Measurement Type	Optical Flow Meter
Reading Type	Velocity
Measurement Date	N/A
Velocity (m/s)	4.96633
Flow Rate (m^3/h)	---
Standard Flow Rate (std m^3/h)	---
Composition Name	Acacias Flare 1
Composition ID	33

Stack Details	
Flare End Seal Type	Unknown
Stack Outside Diameter (m)	0.58
Flare Wall Thickness (mm)	12.7
Flare Stack Height (m)	15.87
Auto-ignition	No
Pilot present	Yes
Knockout Drum Diameter (m)	N/A
Knockout Drum Length(m)	N/A

Waste Stream Composition Source Data

Anaylsis Adminstration Data	
Name	Acacias Flare 1
Description	N/A
Creation Date	3/5/2013
Sample Date	11/10/2012
Sample Type	Unknown
Substance Type	Flare Gas
Clearstone ID	33

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001523	0.001523	0.001554
Ethane	0.074018	0.074018	0.075491
Isobutane	0.102297	0.102297	0.104334
Isopentane	0.064775	0.064775	0.066064
Methane	0.294840	0.294840	0.300710
n-Butane	0.088864	0.088864	0.090633
n-Hexane	0.082006	0.082006	0.083638
Nitrogen	0.094413	0.094413	0.080594
n-Pentane	0.059141	0.059141	0.060319
Oxygen	0.004129	0.004129	0.000000
Propane	0.133994	0.133994	0.136662
Total	1.000000	1.000000	1.000000

Flare Fuel Composition Source Data

Anaylsis Adminstration Data	
Name	Propane
Description	Fuel gas (Flare). Assuming 0.8 propane and 0.2 ethane based on reported HHV (2373 BTU/scf)
Creation Date	6/14/2013
Sample Date	N/A
Sample Type	Computed
Substance Type	Fuel Gas
Clearstone ID	59

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Ethane	0.200000	0.200000	0.200000
Propane	0.800000	0.800000	0.800000
Total	1.000000	1.000000	1.000000

Flare Stack Simulation Results

Purge Gas	
Minimun flow (m^3/h)	0.0
Current Flow (m^3/h)	
Excess Flow (m^3/h)	0.0

Pilot Gas	
Minimun Flow (m^3/h)	7.9
Current Flow (m^3/h)	
Excess Flow(m^3/h)	0.0

Calculated Flare Stack Gas Composition	
Component Name	**Mole Fraction**
n-Butane	0.088864
n-Pentane	0.059141
n-Hexane	0.082006
Carbon dioxide	0.001523
Methane	0.294840
Ethane	0.074018
Propane	0.133994
Isobutane	0.102297
Nitrogen	0.094413
Oxygen	0.004129
Isopentane	0.064775
Total	1.000000

Flare Stack Gas	
Dew Temperature (^oC)	17.8
Optimal Conditions Dew Temperature (^oC)	17.8
Stack Liquid Formation Potential	No
Knockout Drum Liquid Formation	No
Calculated HC Distruction (%)	99.85%
Calcualted VOC Emision Factor (ng/J)	25.04
Calcualted Flare Gas Flow (m3/h)	1,022.0

Stack Hydrocarbon Destruction Efficiency Vs. Wind Speed

Wind Speed (m/s)	HC DE (%)
0.0	99.88
1.0	99.86
2.0	99.85
3.0	99.83
4.0	99.81
5.0	99.79
6.0	99.77
7.0	99.74
8.0	99.71
9.0	99.68
10.0	99.64
11.0	99.60
12.0	99.55
13.0	99.50
14.0	99.45
15.0	99.39
16.0	99.32
17.0	99.24
18.0	99.16
19.0	99.06
20.0	98.96

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Flare Gas Recovery	Pesimistic cost	95.00	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Flare Gas Recovery	Pesimistic cost	0	0	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Flare Gas Recovery	Pesimistic cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Flare		Emergency or Intermittent Waste Gas Disposal	8,900,304	1,022.0	7.23	6.45	31.81	26.01	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
2.7	45,371	0.07	45,451	19.2	121.7	22.3	0.0	43.6

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Flare Gas Recovery	95.00	6,240,000	0	0	8,455,289	56,039,773	135.50	0.74

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Flare Gas Recovery	2.61	43,103	0.07	43,179	18.20	115.64	21.22	0.00	41.43

Point Source Information

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Flare 1
ID	N/A
On Site Location	N/A
Category	Flares
Type	Stack (Unassisted)
Service	
Manufacturer	
Model	N/A
Model Year	N/A
Installation Date	N/A
	N/A

Data Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Device Comments and Assumptions
Flare Stack

General Simulation Data	
Operating Factor (%)[1]	100.00
Load Factor (%)[1]	100.00
Flow Adjustment (m^3/h)[1]	0.00
Adjustment Comment	NA
Activity Level[2]	1.0
Extrapolated Activity Level[2]	0.0
Ambient Temperature (^{o}C)	34.3
Ambient Pressure (kPa)	95.9

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.
[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

Data Comments and Assumptions
N/A

Applied Emission Factors		
Substance	**Value**	**Source**
CH_4 Emission Factor (ng/J)	81.97	User Entered
N_2O Emission Factor (ng/J)	0.10	US EPA AP-42
VOC Emission Factor (ng/J)	22.30	US EPA AP-42
CO Emission Factor (ng/J)	159.10	US EPA AP-42
PM Emission Factor (ng/J)	57.00	US EPA AP-42
NO_x Emission Factor (ng/J)	29.20	US EPA AP-42
HC Destruction Efficiency (%)	98.00	US EPA AP-42

Simulation Input Stream

Input Stream	
Temperature (^oC)	43.8
Pressure (kPa gage)	7.456
Line Name	N/A
Cross Sectional Shape	Circular
Pipe Outside Diameter (mm)	273.1
Pipe Wall Thickness (mm)	6.35
Pipe Rectangular Length (mm)	N/A
Pipe Rectangular Width (mm)	N/A
Measurement Type	Optical Flow Meter
Reading Type	Velocity
Measurement Date	Nov 13 2013 12:00AM
Velocity (m/s)	3.3
Flow Rate (m^3/h)	---
Standard Flow Rate (m^3/h)	---
Composition Name	2012-11-13 chimene flare1
Composition ID	18

Input Stream Composition Source Data

Anaylsis Adminstration Data	
Name	2012-11-13 chimene flare1
Description	N/A
Creation Date	1/8/2013
Sample Date	11/13/2012
Sample Type	Unknown
Substance Type	Tank Vapour
Clearstone ID	18

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001695	0.001695	0.001728
Ethane	0.048276	0.048276	0.049216
Isobutane	0.021130	0.021130	0.021542
Isopentane	0.111863	0.111863	0.114043
Methane	0.479072	0.479072	0.488407
n-Butane	0.047145	0.047145	0.048063
n-Hexane	0.067278	0.067278	0.068589
Nitrogen	0.059878	0.059878	0.045680
n-Pentane	0.108780	0.108780	0.110900
Oxygen	0.004043	0.004043	0.000000
Propane	0.050842	0.050842	0.051832
Total	1.000000	1.000000	1.000000

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Flare Gas Recovery	Vapor recovery System	95.00	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Flare Gas Recovery	Vapor recovery System	0	0	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Flare Gas Recovery	Vapor recovery System	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3$/d)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Flare 1		Emergency or Intermittent Waste Gas Disposal	5,276,662	583.8	6.71	2.40	6.64	20.32	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
33.2	23,891	0.04	24,601	9.1	64.9	11.9	0.0	23.3

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Flare Gas Recovery	95.00	2,803,200	0	0	5,012,829	34,120,181	178.83	0.56

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Flare Gas Recovery	31.58	22,696	0.04	23,371	8.64	61.65	11.32	0.00	22.09

Flare Simulation Information

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Data Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	11-Sep-2013

Device	
Name	Flare 2
ID	Flare 2-Chichimene
On Site Location	N/A
Type	Flare Stack (Unassisted)
Service	Emergency or Intermittent Waste Gas Disposal
Manufacturer	N/A
Model	N/A
Model Year	N/A
Installation Date	N/A

General Simulation Data	
Activity Level[1]	1
Extrapolated Activity Level[1]	0
Ambient Temperature (^oC)	34.3
Ambient Pressure (kPa)	95.9
Average Wind Speed (m/s)	2.0
Met Station Height (m)	10.0
Stack Top Temperature (^oC)	N/A
Knockout Drum Temp (^oC)	N/A
Knockout Drum Pressure (kPag)	N/A

[1] Activity Level and Extrapolated Activity Level are used when extrapolating from the flare. The flare(s) not tested are assumed to have losses and emission of Extrapolated Activity Level/Activity Level times this flare.

Device Comments and Assumptions
N/A

Applied Emission Factors		
Substance	**Value**	**Source**
CH_4 Emission Factor (ng/J)	82.95	User Entered
N_2O Emission Factor (ng/J)	0.10	US EPA AP-42
VOC Emission Factor (ng/J)	27.70	Calculated
CO Emission Factor (ng/J)	159.10	US EPA AP-42
PM Emission Factor (ng/J)	57.00	US EPA AP-42
NO_x Emission Factor (ng/J)	29.20	US EPA AP-42
HC Destruction Efficiency (%)	99.81	Calculated

Data Comments and Assumptions
N/A

Flare Stream and Stack Measurements

Property	Stream(s)
	Waste
Temperature (^oC)	46.7
Pressure (kPa gage)	0.383
Line Name	N/A
Cross Sectional Shape	Circular
Pipe Outside Diameter (mm)	168.3
Pipe Wall Thickness (mm)	7.1
Pipe Rectangular Length (mm)	N/A
Pipe Rectangular Width (mm)	N/A
Measurement Type	Optical Flow Meter
Reading Type	Velocity
Measurement Date	Nov 13 2012 12:00AM
Velocity (m/s)	2.22368
Flow Rate (m^3/h)	---
Standard Flow Rate (std m^3/h)	---
Composition Name	2012-11-13 chimene flare2
Composition ID	17

Stack Details	
Flare End Seal Type	Unknown
Stack Outside Diameter (m)	0.56
Flare Wall Thickness (mm)	12.0
Flare Stack Height (m)	15.85
Auto-ignition	No
Pilot present	Yes
Knockout Drum Diameter (m)	N/A
Knockout Drum Length(m)	N/A

Waste Stream Composition Source Data

Anaylsis Adminstration Data	
Name	2012-11-13 chimene flare2
Description	N/A
Creation Date	1/8/2013
Sample Date	11/13/2012
Sample Type	Unknown
Substance Type	Tank Vapour
Clearstone ID	17

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001715	0.001715	0.001745
Ethane	0.047963	0.047963	0.048798
Isobutane	0.020821	0.020821	0.021184
Isopentane	0.110086	0.110086	0.112002
Methane	0.480942	0.480942	0.489314
n-Butane	0.046677	0.046677	0.047490
n-Hexane	0.067218	0.067218	0.068388
Nitrogen	0.063606	0.063606	0.050987
n-Pentane	0.106857	0.106857	0.108718
Oxygen	0.003619	0.003619	0.000000
Propane	0.050495	0.050495	0.051374
Total	1.000000	1.000000	1.000000

Flare Fuel Composition Source Data

Anaylsis Adminstration Data	
Name	Propane
Description	Fuel gas (Flare). Assuming 0.8 propane and 0.2 ethane based on reported HHV (2373 BTU/scf)
Creation Date	6/14/2013
Sample Date	N/A
Sample Type	Computed
Substance Type	Fuel Gas
Clearstone ID	58

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Ethane	0.200000	0.200000	0.200000
Propane	0.800000	0.800000	0.800000
Total	1.000000	1.000000	1.000000

Flare Stack Simulation Results

Purge Gas	
Minimun flow (m^3/h)	3.5
Current Flow (m^3/h)	
Excess Flow (m^3/h)	0.0

Pilot Gas	
Minimun Flow (m^3/h)	7.9
Current Flow (m^3/h)	
Excess Flow(m^3/h)	0.0

Calculated Flare Stack Gas Composition	
Component Name	**Mole Fraction**
n-Butane	0.046677
n-Pentane	0.106857
n-Hexane	0.067218
Carbon dioxide	0.001715
Methane	0.480942
Ethane	0.047963
Propane	0.050495
Isobutane	0.020821
Nitrogen	0.063606
Oxygen	0.003619
Isopentane	0.110086
Total	1.000000

Flare Stack Gas	
Dew Temperature (^oC)	17.6
Optimal Conditions Dew Temperature (^oC)	17.6
Stack Liquid Formation Potential	No
Knockout Drum Liquid Formation	No
Calculated HC Distruction (%)	99.81%
Calcualted VOC Emision Factor (ng/J)	27.70
Calcualted Flare Gas Flow (m3/h)	127.8

Stack Hydrocarbon Destruction Efficiency Vs. Wind Speed

Wind Speed (m/s)	HC DE (%)
0.0	99.88
1.0	99.85
2.0	99.81
3.0	99.77
4.0	99.72
5.0	99.65
6.0	99.57
7.0	99.47
8.0	99.34
9.0	99.19
10.0	99.00
11.0	98.77
12.0	98.49
13.0	98.14
14.0	97.71
15.0	97.18
16.0	96.52
17.0	95.72
18.0	94.72
19.0	93.50
20.0	92.60

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Flare Gas Recovery	Pesimistic cost	95.00	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Flare Gas Recovery	Pesimistic cost	0	0	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Flare Gas Recovery	Pesimistic cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Flare 2	Flare 2-Chichimene	Emergency or Intermittent Waste Gas Disposal	1,142,557	127.8	1.48	0.52	1.44	4.39	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
0.7	5,185	0.01	5,202	2.5	14.1	2.6	0.0	5.0

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Flare Gas Recovery	95.00	614,400	0	0	1,085,429	7,380,628	176.66	0.57

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Flare Gas Recovery	0.65	4,926	0.01	4,942	2.33	13.39	2.46	0.00	4.80

APPENDIX D STORAGE TANKS

D.1 Introduction

The purpose of storage tanks at production facilities, natural gas processing plants and crude oil pipeline terminals is to provide temporary storage of the produced hydrocarbon liquids (i.e., oil or condensate) and water.

D.2 Background

Typical storage tanks operate at approximately atmospheric pressure and may include some vapor controls. Storage tanks include fixed-roof, internal floating-roof and external floating-roof designs. Tank selection and vapor controls are based on the type of fluid(s) or product(s) the tank will receive. Fluids are characterized by their Reid vapor pressure, operating temperature, composition and trace contaminants. Other considerations include the potential for dissolved gases to be contained in the fluid when it is transferred into the tank.

Atmospheric emissions from storage tanks comprise normal evaporation losses due to breathing and working effects, flashing losses when the received liquids have an initial vapor pressure close to or greater than local atmospheric pressure and potentially unintentional gas carry-through to the storage tanks. Flashing losses can be a major source of methane and VOC emissions at production facilities. Unintentional gas carry-through is less recognized, potentially significant and often an unaccounted for contributions to atmospheric emissions of methane from storage tanks which may be caused by the following:

- Leakage of process gas or volatile product past the seats of drain or blowdown valves into the product header leading to the tanks.
- Inefficient separation of gas and liquid phases upstream of the tanks allowing some gas carry-through (by entrainment) to the tanks. This usually occurs where inlet liquid production (e.g., produced water) has increased significantly over time resulting in a facility's inlet separators being undersized for current conditions.
- Piping changes resulting in the unintentional placement of high vapor pressure product in tanks not equipped with appropriate vapor controls.
- Displacement of large volumes of gas to storage tanks during pigging operations.
- The formation of a vortex at the drain on a vessel that is sending liquids to the storage tank(s).

D.3 Performance Evaluation Methodology

Where possible, emissions from storage tanks are quantified by direct measurement and compared to estimated values for the given conditions and activity levels. If the measured emissions are significantly greater than the predicted emissions, then this is used as an indication of possible unintentional gas carry-through to the storage tank.

Additionally, samples of the product vapor are collected and analysed to determine its composition. The vapour composition is important for determining the amount of methane emissions and for evaluating potential control options. The amount of condensable non-methane hydrocarbons in the vapors will add greatly to the value of these losses and improve the economics of potential control options.

The emissions from the tank are typically measured using a transit-time ultrasonic flow meter installed on a short flow cell, which is connected to the tank vent using flexible gas/vapour-tight ducting. This meter imposes essentially zero backpressure on the tank vent. The tank activity levels at the time of the measurement are determined using camp-on transit-time or Doppler flow meters to measure the flow of liquids into and out of the tank. As well, a micro-wave radar system is temporarily installed on the thief hatch to continuously measure the changes in liquid level. The readings from all of these sensors are continuously data logged and transmitted wirelessly to a base station for real-time trend analysis. The measurements are performed for sufficient time to characterize the observed variations in emission rates (e.g., for 1 hour or more).

In applications where the vent is too large to connect the flow cell, then point-in-time measurements are performed by conduct a velocity traverse across the tank vent using a micro-tip vane anemometer in accordance with US EPA Method 1A.

If there are multiple vents on a tank and not all of these can be directly accessed to perform an emissions measurement, then the gas exit velocity from the inaccessible openings is assumed to be the same as the exit velocity at the accessible openings, and the flows are determined based on these velocities and the sizes of the various openings. Dimensions of the opening are measured using tape measure, where they are accessible, or based on the tank design details or using photographic scaling techniques if they are not accessible. The measured flows are ultimately corrected to standard reference conditions. The vapor temperature is measured using a thermocouple and local barometric pressure is either measured using an electro barometer or referenced from readings available at the closest meteorological station.

The gas analyses are performed using a field-deployable optical gas chromatograph (GC) or a micro-GC fitted with a thermal conductivity detector and potentially, depending on the unit, a flame ionization detector for enhanced detection and speciation capabilities. Otherwise, the samples are sent to a local laboratory, site-specific analyses are provided by the site, estimates are developed based on rigorous process simulations, or a reasonable analogue is applied.

D.3.1 Free-venting Storage Tanks Containing Stabilized or Weathered Hydrocarbon Liquids

Emissions from tanks containing weathered or stabilized hydrocarbon liquids are estimated using the U.S. EPA's TANKS model, Version 4.09D. This model estimates emissions due to normal evaporation losses caused by breathing (or standing) and working effects.

The TANKS program is designed to estimate emissions of organic chemicals from storage tanks. The calculations are performed according to the empirical correlations and methodologies developed by the American Petroleum Institute and delineated in U.S. EPA's AP-42. After the user provides specific information concerning a storage tank and its liquid contents, the system produces a report which estimates the chemical emissions for the tank on an annual or partial year basis.

Breathing losses occur when the vapors are expelled from the tank due to changes in the pressure and temperature of the vapor (usually caused by changes in the weather). This type of loss is most important during long standing periods. Working losses occur when vapors from the tank are displaced by incoming liquids (i.e., filling losses) or wetted surfaces are exposed during lowering of the liquid level (i.e., emptying losses).

Equipment dimensions and operating data, as well as local meteorological data, are collected during the field survey. This information includes tank diameter, height, and working volume, tank roof type, tank colour, the set points on any pressure-vacuum safety valves, density and Reid vapor pressure of the weathered or stabilized hydrocarbon liquids stored in the tank, annual production rates, details on the liquid level changes during any emissions measurements performed on the tank, details on any vapor controls provided on the tank, local annual-average and monthly-average temperatures, annual-average wind speed and annual-average solar insulation factor, and local atmospheric pressure. If some meteorological data of the surveyed area are unknown, recommended data from cities in the US with similar climates are used for modeling purposes.

The Reid vapor pressure and the molecular weight of vapor and liquid are estimated based on Clearstone Engineering Ltd.'s crude oil property database.

D.3.2 Tanks Experiencing Flashing Losses

Flashing losses occur when the produced hydrocarbon liquid has a vapor pressure greater than local atmospheric pressure. The vapor that flashes from the product in going to a "stable" state is referred to as solution gas. The amount of solution gas emissions depends on the change in vapor pressures and is directly proportional to the amount of hydrocarbon liquid produced. Where flashing losses occur, they are usually the most dominant type of storage loss.

The amount of flashing losses is estimated based on a rigorous simulation of the process. The simulations are performed using Clearstone Engineering Ltd's proprietary process simulator and site-specific process operating data. These data include the basic process flow diagram, operating temperature and pressure of all process vessels that supply hydrocarbon liquids to the storage tanks, the temperature and Reid vapor pressure of the weathered liquid hydrocarbons stored in the tanks, and the total production rate of the final weathered hydrocarbon liquids and process sales gas.

D.3.3 Tanks with Natural Gas Blanketing

Tanks that are equipped with natural gas blanketing will feature pressure vacuum safety valves (PVSVs) and possibly a vapor collection system and end control device (e.g., a flare or vapor recovery compressor). During normal operations, the blanket gas will enter the tank when the liquid level or pressure in the tank decreases and will stop when the pressure in the tank vapor space reaches a certain set point value. If the pressure starts to rise (e.g., due to atmospheric temperature changes or rising liquid levels), the tank will vent a mixture of blanket gas and product vapors until the pressure drops to a predetermined set point.

If there is no vapor collection system, the vented gas will be discharged directly to the atmosphere through the PVSVs. If the tank is equipped with a vapor collection system then gas will vent into the vapor collection system and there should be no emissions from the PVSVs,.

During the site visit details of any natural gas blanketing system and vapor collection and control system are collected. This generally involves getting copies of the system design specifications and process and instrumentation diagram from the facility's data books, checking for signs of any emissions due to malfunctioning components, inadequate sizing of these systems or unintentional gas carry-through to the tanks. Typically, the tank is checked for any emissions from the roof top fittings, the amount of emissions is measured and the liquid level changes in the tank during the measurements are determined and used to correct the measurement results.

If there are emissions occurring, the objective is to determine if these are intentional and if the amount of emissions is normal based on the system design. If the emissions are unintentional or the emission rates are abnormal, then the potential causes of the emissions or excess emissions are determined. Problems to check for include the following:

- Improper set-points or operation of the blanket gas regulator. This can be determined by monitoring the pressure in the head space of the tank and determining when blanket gas regulator is opening and closing versus when it is suppose to be opening and closing.
- Fouling of the PVSVs causing them to stick open.
- Excessive backpressure on the tank due to fouling of the vapor collections system (e.g., due to liquid accumulation in low spots or build-up of scale) or restrictions imposed by the end control device (e.g., an undersized vapor recovery compressor).

Where the emissions from the tank are intentional, they will be equal to the amount of blanket gas consumption plus the amount of product evaporation losses. An approximate estimate of the amount of evaporation losses can be determined using US EPA's TANKS model; however, the model assumes the product is evaporating into air not blanket gas. So, the results will have to be adjusted to include the blanket gas contributions to the total.

D.4 Control Options

The primary options for controlling emissions from storage tanks are as follows:

- Minimize the volatility of the product being placed in the storage tank (e.g., optimize the operating temperature and pressure of any upstream separators and stabilizers, or installing a stabilizer if one does not already exist).
- Install floating roofs to minimize the exposed liquid surface area. Floating roofs typically provide a control efficiency of 90 percent of better and are limited to application involving products having a true vapor pressure less than 76 kPa at storage tank conditions. Floating roofos become very inefficient at greater vapor pressures and could become damaged and/or sink in the presence of excessive flashing losses.
- Tanks receiving products having a true vapor pressure greater than 76 kPa should be equipped with a vapor collection and treatment or recovery system. An alternative to installing a vapor collection system on each tank is to install a vapor recovery tower and simply capture the vapors from the tower rather than from each tank. Figure 4 shows a photograph of a typical vapor recovery tower designed by Hy-Bon Engineering Company, Inc. The tower is designed to let the oil depressurize to near atmospheric pressure while retaining sufficient hydrostatic head to allow the oil to flow by gravity to the tank farm. Thus, vapors need only be collected from the top of the vapor recovery tower than from each individual tank.

Figure 4: A photograph of a typical vapour recovery tower elevated above the storage tank.

D.5 References

CAPP. 2004. *A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H2S) Emissions by the Upstream Oil and Gas Industry, Volume 4, Methodology for CAC and H2S Emissions.* Canadian Association of Petroleum

Producers Publication No.: 2005-0014. Source: http://www.capp.ca/getdoc.aspx?DocId=86224&DT=NTV

U.S. EPA. 1995b. *Compilation of Air Pollutant Emission Factors. Volume I: Stationary Point and Area Sources.* NTIA. Springfield VA. Publication No. PB95-196028. Fifth Edition and Supplements.

D.6 Results

The detailed measurement and calculation results for the surveyed storage tanks are presented below:

Tank Index

Facility Name	Device Category	Tag Number	Name	Device Type	Service
Castilla Oil Battery No.2	Tanks	ATK-7204 A	ATK-7204 A	Fixed Roof	Primary Oil/Water Separation
Castilla Oil Battery No.2	Tanks	ATK-7205 B	ATK-7205 B	Fixed Roof	Primary Oil/Water Separation
Chichimene Station	Tanks		Production Tanks	Fixed Roof	Diluted Heavy Oil
Chichimene Station	Tanks		Sales Tanks Working Losses	Fixed Roof	Diluted Heavy Oil

Point Source Information

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Castilla Oil Battery No.2
Location	N/A
ID	Ecopetrol-Castilla2
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	ATK-7204 A
ID	ATK-7204 A
On Site Location	N/A
Category	Tanks
Type	
Service	
Manufacturer	
Model	N/A
Model Year	N/A
Installation Date	N/A

N/A

Data Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Mojgan Karimi
Prepared By	Ecopetrol
Report Generated	2013/09/11

Device Comments and Assumptions
Extrapolated based on the measured data from ATK-7205 B

General Simulation Data	
Operating Factor (%)[1]	100.00
Load Factor (%)[1]	100.00
Flow Adjustment (m^3/h)[1]	0.00
Adjustment Comment	NA
Activity Level[2]	1.0
Extrapolated Activity Level[2]	0.0
Ambient Temperature (°C)	25.0
Ambient Pressure (kPa)	101.0

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

Data Comments and Assumptions
N/A

Applied Emission Factors		
Substance	**Value**	**Source**
CH_4 Emission Factor (ng/J)	N/A	
N_2O Emission Factor (ng/J)	N/A	
VOC Emission Factor (ng/J)	N/A	
CO Emission Factor (ng/J)	N/A	
PM Emission Factor (ng/J)	N/A	
NO_x Emission Factor (ng/J)	N/A	
HC Destruction Efficiency (%)	N/A	

Simulation Input Stream

Input Stream	
Temperature (^{o}C)	25
Pressure (kPa gage)	101
Line Name	N/A
Cross Sectional Shape	Circular
Pipe Outside Diameter (mm)	N/A
Pipe Wall Thickness (mm)	N/A
Pipe Rectangular Length (mm)	N/A
Pipe Rectangular Width (mm)	N/A
Measurement Type	Transit-Time Ultrasonic Flow Meter
Reading Type	Flow Rate (Standard Conditions)
Measurement Date	N/A
Velocity (m/s)	---
Flow Rate (m^3/h)	---
Standard Flow Rate (m^3/h)	807.0
Composition Name	2012-11-13 Castilla 2 atk 7205b
Composition ID	11

Input Stream Composition Source Data

Anaylsis Adminstration Data	
Name	2012-11-13 Castilla 2 atk 7205b
Description	N/A
Creation Date	1/8/2013
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	11

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001765	0.001765	0.002130
Ethane	0.073181	0.073181	0.088332
Isobutane	0.082089	0.082089	0.099084
Isopentane	0.065423	0.065423	0.078968
Methane	0.275571	0.275571	0.332624
n-Butane	0.079017	0.079017	0.095376
n-Hexane	0.069298	0.069298	0.083645
Nitrogen	0.126038	0.126038	0.000000
n-Pentane	0.061946	0.061946	0.074771
Oxygen	0.045487	0.045487	0.000000
Propane	0.120185	0.120185	0.145068
Total	1.000000	1.000000	1.000000

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Vapour Recovery	Pesimistic cost	95.00	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Vapour Recovery	Pesimistic cost	0	0	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Vapour Recovery	Pesimistic cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
ATK-7204 A	ATK-7204 A	Primary Oil/Water Separation	6,474,651	807.0	5.34	5.03	21.68	19.50	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
1321.8	23	0.00	27,781	8917.1	0.0	0.0	0.0	0.0

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Vapour Recovery	95.00	3,873,600	0	0	6,150,918	41,432,691	158.79	0.63

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Vapour Recovery	1,255.69	22	0.00	26,392	8,471.25	0.00	0.00	0.00	0.00

Point Source Information

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Castilla Oil Battery No.2
Location	N/A
ID	Ecopetrol-Castilla2
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	ATK-7205 B
ID	ATK-7205 B
On Site Location	N/A
Category	Tanks
Type	
Service	
Manufacturer	
Model	N/A
Model Year	N/A
Installation Date	N/A

N/A

Data Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Mojgan Karimi
Prepared By	Ecopetrol
Report Generated	2013/09/11

Device Comments and Assumptions
Oil production tank

General Simulation Data	
Operating Factor (%)[1]	100.00
Load Factor (%)[1]	100.00
Flow Adjustment (m^3/h)[1]	0.00
Adjustment Comment	NA
Activity Level[2]	1.0
Extrapolated Activity Level[2]	0.0
Ambient Temperature (°C)	25.0
Ambient Pressure (kPa)	101.0

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

Data Comments and Assumptions
N/A

Applied Emission Factors		
Substance	**Value**	**Source**
CH_4 Emission Factor (ng/J)	N/A	
N_2O Emission Factor (ng/J)	N/A	
VOC Emission Factor (ng/J)	N/A	
CO Emission Factor (ng/J)	N/A	
PM Emission Factor (ng/J)	N/A	
NO_x Emission Factor (ng/J)	N/A	
HC Destruction Efficiency (%)	N/A	

Simulation Input Stream

Input Stream	
Temperature (^oC)	43.5
Pressure (kPa gage)	95.9
Line Name	N/A
Cross Sectional Shape	Circular
Pipe Outside Diameter (mm)	N/A
Pipe Wall Thickness (mm)	N/A
Pipe Rectangular Length (mm)	N/A
Pipe Rectangular Width (mm)	N/A
Measurement Type	Transit-Time Ultrasonic Flow Meter
Reading Type	Flow Rate (Standard Conditions)
Measurement Date	N/A
Velocity (m/s)	---
Flow Rate (m^3/h)	---
Standard Flow Rate (m^3/h)	762.3
Composition Name	2012-11-13 Castilla 2 atk 7205b
Composition ID	11

Input Stream Composition Source Data

Anaylsis Adminstration Data	
Name	2012-11-13 Castilla 2 atk 7205b
Description	N/A
Creation Date	1/8/2013
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	11

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001765	0.001765	0.002130
Ethane	0.073181	0.073181	0.088332
Isobutane	0.082089	0.082089	0.099084
Isopentane	0.065423	0.065423	0.078968
Methane	0.275571	0.275571	0.332624
n-Butane	0.079017	0.079017	0.095376
n-Hexane	0.069298	0.069298	0.083645
Nitrogen	0.126038	0.126038	0.000000
n-Pentane	0.061946	0.061946	0.074771
Oxygen	0.045487	0.045487	0.000000
Propane	0.120185	0.120185	0.145068
Total	1.000000	1.000000	1.000000

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Vapour Recovery	Pesimistic cost	95.00	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Vapour Recovery	Pesimistic cost	0	0	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Vapour Recovery	Pesimistic cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
ATK-7205 B	ATK-7205 B	Primary Oil/Water Separation	6,115,935	762.3	5.04	4.76	20.48	18.42	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
1248.5	22	0.00	26,241	8423.1	0.0	0.0	0.0	0.0

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Vapour Recovery	95.00	3,657,600	0	0	5,810,138	39,138,578	158.85	0.63

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Vapour Recovery	1,186.12	21	0.00	24,929	8,001.91	0.00	0.00	0.00	0.00

Point Source Information

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Sales Tanks Working Losses
ID	N/A
On Site Location	N/A
Category	Tanks
Type	
Service	
Manufacturer	
Model	N/A
Model Year	N/A
Installation Date	N/A

N/A

Data Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Mojgan Karimi
Prepared By	Ecopetrol
Report Generated	2013/09/11

Device Comments and Assumptions
Working Losses for both Sales Tanks.

General Simulation Data	
Operating Factor (%)[1]	100.00
Load Factor (%)[1]	100.00
Flow Adjustment (m^3/h)[1]	0.00
Adjustment Comment	N/A
Activity Level[2]	1.0
Extrapolated Activity Level[2]	0.0
Ambient Temperature (°C)	25.0
Ambient Pressure (kPa)	101.3

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

Data Comments and Assumptions
Working losses assuming that one tank is filling and one tank is emptying at all times.

Applied Emission Factors

Substance	Value	Source
CH_4 Emission Factor (ng/J)	N/A	
N_2O Emission Factor (ng/J)	N/A	
VOC Emission Factor (ng/J)	N/A	
CO Emission Factor (ng/J)	N/A	
PM Emission Factor (ng/J)	N/A	
NO_x Emission Factor (ng/J)	N/A	
HC Destruction Efficiency (%)	N/A	

Simulation Input Stream

Input Stream	
Temperature (^oC)	15
Pressure (kPa gage)	101.325
Line Name	N/A
Cross Sectional Shape	Circular
Pipe Outside Diameter (mm)	N/A
Pipe Wall Thickness (mm)	N/A
Pipe Rectangular Length (mm)	N/A
Pipe Rectangular Width (mm)	N/A
Measurement Type	Proration of Reported Unit Throughput
Reading Type	Flow Rate (Standard Conditions)
Measurement Date	N/A
Velocity (m/s)	---
Flow Rate (m^3/h)	---
Standard Flow Rate (m^3/h)	424.8
Composition Name	2012-11-13 chimene atk 7403a
Composition ID	14

Input Stream Composition Source Data

Anaylsis Adminstration Data	
Name	2012-11-13 chimene atk 7403a
Description	N/A
Creation Date	1/8/2013
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	14

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001795	0.001795	0.003023
Ethane	0.004319	0.004319	0.007274
Isobutane	0.017992	0.017992	0.030301
Isopentane	0.175530	0.175530	0.295618
Methane	0.001114	0.001114	0.001876
n-Butane	0.056153	0.056153	0.094570
n-Hexane	0.137190	0.137190	0.231048
Nitrogen	0.258625	0.258625	0.000000
n-Pentane	0.177466	0.177466	0.298879
Oxygen	0.147602	0.147602	0.000000
Propane	0.022213	0.022213	0.037409
Total	1.000000	1.000000	1.000000

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Vapour Recovery	Pesimistic cost	95.00	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Vapour Recovery	Pesimistic cost	0	0	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Vapour Recovery	Pesimistic cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas (10^3m^3/d)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Sales Tanks Working Losses		Diluted Heavy Oil	5,604,787	424.8	0.01	0.16	4.01	25.33	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
2.8	12	0.00	72	6701.5	0.0	0.0	0.0	0.0

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Vapour Recovery	95.00	2,040,000	0	0	5,324,548	37,179,430	261.01	0.38

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Vapour Recovery	2.67	12	0.00	68	6,366.42	0.00	0.00	0.00	0.00

Point Source Information

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Production Tanks
ID	N/A
On Site Location	N/A
Category	Tanks
Type	
Service	
Manufacturer	
Model	N/A
Model Year	N/A
Installation Date	N/A
	N/A

Data Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Mojgan Karimi
Prepared By	Ecopetrol
Report Generated	2013/09/11

Device Comments and Assumptions
Inlet Production tanks, Flashing losses.

General Simulation Data	
Operating Factor (%)[1]	100.00
Load Factor (%)[1]	100.00
Flow Adjustment (m^3/h)[1]	0.00
Adjustment Comment	N/A
Activity Level[2]	1.0
Extrapolated Activity Level[2]	0.0
Ambient Temperature (^{o}C)	25.0
Ambient Pressure (kPa)	101.3

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

Data Comments and Assumptions
Flashing Losses for Production tanks. Based of proration of measured flashing losses on one tank vs average site production.

Applied Emission Factors		
Substance	**Value**	**Source**
CH_4 Emission Factor (ng/J)	N/A	
N_2O Emission Factor (ng/J)	N/A	
VOC Emission Factor (ng/J)	N/A	
CO Emission Factor (ng/J)	N/A	
PM Emission Factor (ng/J)	N/A	
NO_x Emission Factor (ng/J)	N/A	
HC Destruction Efficiency (%)	N/A	

Simulation Input Stream

Input Stream	
Temperature (^oC)	15
Pressure (kPa gage)	101.325
Line Name	N/A
Cross Sectional Shape	Circular
Pipe Outside Diameter (mm)	N/A
Pipe Wall Thickness (mm)	N/A
Pipe Rectangular Length (mm)	N/A
Pipe Rectangular Width (mm)	N/A
Measurement Type	Extrapolated from Measured Value
Reading Type	Flow Rate (Standard Conditions)
Measurement Date	N/A
Velocity (m/s)	---
Flow Rate (m^3/h)	---
Standard Flow Rate (m^3/h)	772.5
Composition Name	2012-11-13 chimene atk 7401b Air Free
Composition ID	296

CLEARSTONE ENGINEERING

Input Stream Composition Source Data

Anaylsis Adminstration Data	
Name	2012-11-13 chimene atk 7401b Air Free
Description	Air free version of atk 0401b tank vapour for flashing loss calculation.
Creation Date	9/8/2013
Sample Date	11/13/2013
Sample Type	Computed
Substance Type	Tank Vapour
Clearstone ID	296

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.002151	0.002151	0.002151
Ethane	0.072020	0.072020	0.072020
Isobutane	0.057738	0.057737	0.057737
Isopentane	0.224662	0.224662	0.224662
Methane	0.099645	0.099645	0.099645
n-Butane	0.102687	0.102687	0.102687
n-Hexane	0.104504	0.104504	0.104504
n-Pentane	0.211825	0.211825	0.211825
Propane	0.124769	0.124769	0.124769
Total	1.000000	1.000000	1.000000

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Vapour Recovery	Pesimistic cost	95.00	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Vapour Recovery	Pesimistic cost	0	0	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Vapour Recovery	Pesimistic cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3$/d)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Production Tanks		Diluted Heavy Oil	12,546,964	772.5	1.85	4.74	21.01	50.23	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
457.5	27	0.00	9,635	15834.1	0.0	0.0	0.0	0.0

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Vapour Recovery	95.00	3,710,400	0	0	11,919,616	84,086,831	321.25	0.31

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Vapour Recovery	434.65	26	0.00	9,153	15,042.39	0.00	0.00	0.00	0.00

APPENDIX E FUGITIVE EQUIPMENT LEAKS

E.1 Introduction

Fugitive equipment leaks are the loss of process fluid to the environment past a seal, flanged, threaded or other mechanical connection, cover, valve seat, flaw or minor damage point. These are unintentional losses and may arise due to normal wear and tear, improper or incomplete assembly of components, inadequate material specification, manufacturing defects, damage during installation or use, corrosion, fouling and other operational effects (e.g., vibrations and thermal cycling). Some components, like mechanical seals, are designed to leak a small amount to provide some lubrication of, as well as heat and debris removal from the contact surfaces, but can leak excessively as the seal wears out.

E.2 Background

Emissions from fugitive equipment leaks are a major source of methane emissions at most natural gas facilities and reduce energy efficiency.

The potential for equipment leaks depends on a variety of factors including the type, style and quality of components, type of service (gas/vapour, light liquid or heavy liquid), age of component, frequency of use, maintenance history, process demands, process fluid characteristics (highly toxic or malodorous) and operating practices. Components in odourized or sour service tend to have much lower average fugitive emissions than those in non-odourized service. Components tend to have greater average emissions when subjected to frequent thermal cycling, vibrations or cryogenic service. Different types of components have different leak potentials and repair lives.

Most equipment components have some emissions; however, only a few percent of the potential sources at a site actually leak sufficiently at any time to be in need of repair or replacement. If the number of excessive leakers is less than 2 percent of the total number of potential leakers, the facility is generally considered to be well maintained and fugitive equipment leaks properly controlled.

Of those equipment components that are deemed to be leaking, typically, only a small percentage contribute most of the emissions (e.g., 5 to 10 percent of leakers may account for 80 to 90 percent of the emissions). Thus, the control of fugitive emissions is a matter of minimizing the potential for big leakers and providing early detection and repair of these when they occur. While a big leaker may occur in any application at any time it is in use or under pressure, efficient management of fugitive emissions is best achieved through the application of directed inspection and maintenance (DI&M) techniques. DI&M focuses inspection and correction efforts on the areas most likely to offer significant cost-effective control opportunities, with coarse or less frequent screening of other areas for additional opportunities. Big leakers often go unnoticed because they occur in elevated, crowded or noisy areas where they are not readily detected or the magnitude of the leak is not fully appreciated due to a lack of quantitative measurement results making it difficult to justify corrective action.

E.3 Evaluation Methodology

E.3.1 Leak Detection and Measurement

The methodology used to detect and measure fugitive equipment leaks at each surveyed site is delineated in the subsections below.

E.3.1.1 Leak Definition

An equipment component in natural gas service is deemed to be leaking when the emitted gas can be visualized using an infrared leak-imaging camera, produces a total hydrocarbon screening value of 10,000 ppm or more when screened using an organic vapour analyzer in accordance with U.S. EPA Method 21, or is detected by any other technique (e.g., audible, olfactory or visual).

E.3.1.2 Component Screening

All equipment components in natural gas service at the visited sites were screened for leaks. Components in light-liquid service generally were not screened since they do not contribute significantly to total hydrocarbon losses at oil and natural gas facilities due to their low average leak rates (U.S. EPA, 1995).

The types of components surveyed included flanged and threaded connections (i.e., connectors), valves, pressure-relief devices, open-ended lines, blowdown vents (i.e., during passive periods), instrument fittings, regulator and actuator diaphragms, engine and compressor crankcase vents and compressor seal vents. Typically, seal leaks are vented directly, or through integrated vent stacks, to atmosphere. In some cases they are connected to flare systems. In addition, they may be collected and recovered for use as fuel.

The leak detection (or screening) was primarily performed using a Flir leak-imaging infrared (IR) camera. Supplemental leak detection was provided in accordance with U.S. EPA Method 21 (1997) using portable hydrocarbon gas detectors (i.e. Bascom-Turner Gas Sentry CGI-201, CGI-211or GMI Gas Surveyor3).

All leak screening equipment was maintained in accordance with the manufacturer's specifications. In addition, calibration checks were performed on all gas sensors at the start of a survey or measurement campaign and daily functional and zero checks were performed.

E.3.1.3 Tagging Components

All identified leaking components were tagged and appropriate information regarding the location of these tags was recorded for easy repair follow-up, and the generation of an inventory list for reference by operations personnel. Where it was not practical or safe to tag a leaking component, only information on the location of the leak was recorded.

Leaking component tags, when used, were hung directly on the leaking component, or, if this was not practical, in close proximity, with appropriate location information included, so the actual leaking component could be easily located for repair. The tags are uniquely numbered, weather resistant, bright yellow for high visibility, and were securely hung using either plastic zip ties or corrosion resistant wire.

E.3.1.4 Leak-Rate Measurements

Leak-rate measurements were performed on all components that were accessible and safe to access. Otherwise, the amount of emissions was estimated using leaker emission factors applicable to the type of component.

The HiFlow Sampler was the primary method used to measure emission rates from leaking equipment components. This device has an accuracy of ±10 percent. Specific cases where the HiFlow Sampler was not used include any components leaking at rates above the upper limit of the unit (i.e., above about 14 m^3/h) and large diameter open-ended lines and vents. Where applicable, emissions from large diameter open-ended lines and vents were typically determined using a calibrated bagging technique or an appropriate flow-through measurement device (i.e., a precision rotary meter, diaphragm flow meter, or rotameter, depending on the flow rate) if total flow capture was safe and practicable to achieve, and the resulting backpressure on the vent system could be tolerated. Otherwise flows were determined by measuring the velocity profile across the vent line and the flow area at that point.

Flow velocities were measured using a pitot tube, hot-wire anemometer thermal dispersion anemometer or micro-tip vane anemometer. The traverse points were selected in general accordance with U.S. EPA Methods 1 and 1A, and any composition dependencies we accounted for.

When measuring flows from vents, a distinction was made between continuous and intermittent vent systems. Emissions from intermittent vents during inactive periods are defined as leakage. Emissions from continuous vent systems and intermittent vent systems during venting events are defined as venting emissions.

All measurement equipment was maintained in accordance with the manufacturer's recommendations.

Figure 5 shows the HiFlow sampler being used to measure a flange leak rate.

Figure 5: The Hi-FLow sampler being used to measure a flange leak rate.

E.3.2 Leak Repair Economic Evaluation

E.3.2.1 Natural Gas Price

The current market value of natural was provided by the operator and used to estimate the value of natural gas losses due to leakage. If no value was provided, then current values were obtained from the literature. The market value of natural gas is subject to large fluctuations, and operators' actual economic opportunities are dependent on current natural gas prices.

Overall, the actual value of avoided natural gas losses is very site-specific and depends on many factors including the following:

- Local market pricing.
- Impact of emission reductions on specific energy consumption, equipment life, workplace safety, and system operability, reliability and deliverability.
- Contract terms.
- Remoteness of the facility.
- Concentration of contaminants and non-methane hydrocarbons (NMHC) in the gas.
- Applicable taxes and tax shields.

E.3.2.2 Financial Discount Rate

The discount rate and opportunity cost of equity in the gas industry is arbitrarily taken to be six percent. Most oil and natural gas ventures are expected to yield better than bank interest to compensate for the risk involved.

E.3.2.3 Net Present Value (NPV)

The net present value of each target control option is the present value of benefits minus the present value of costs. The analysis period in each case is the expected life of the control measure (e.g., the average repair life or mean time between leak occurrences).

E.3.2.4 Payout Period

The payout period of each target control option is the number of periods (years) required to payout the net present value of the repair costs based on annual value of the gas saved.

E.3.2.5 Equalized Annual Value

The equalized annual value of each control option is the total value of the option (after capital and operating costs) expressed as an equivalent series of equal annual payments spread over the life of the project. Negative values indicate a net cost.

E.3.2.6 Value of GHG Reduction

The value of a GHG emission reduction option is calculated as the equalized annual value divided by the average annual CO_2-equivalent reduction.

E.3.2.7 Component Repair Costs and Mean Repair Life

The basic cost to repair or replace a leaking component was estimated based on the type and size of the component, typical billing rates quoted by the applicable types of service providers (e.g., compressor maintenance and repair companies, and valve repair and servicing companies) and the estimated amount of labour and materials required. Where possible, both direct and indirect contributions to these costs were considered. Direct contributions are the actual costs for parts, onsite labour, equipment, tools and disbursements, and are summarized in Table 21..

Indirect contributions are losses in revenues due to any associated shutdowns or process interruptions required outside of normally scheduled facility turnarounds, and the value of any gas that is vented or flared as part of the specified repair or replacement activity. Where indirect costs were significant, it was assumed that the work would be left until the next scheduled facility turnaround or shutdown. Otherwise, it was assume that the repairs are made within a short period of time following detection and evaluation of the leak.

It was assumed that a leak, once repaired, will remain repaired for some finite period of time, and then will reoccur. The mean time between failures is dependent on the type, style and quality of the component, the demands of the specific application, component activity levels (e.g., number of valve operations) and maintenance practices at the site. The estimated mean time between failures for each type of component is also provided in Table 21. These values are very crude estimates based on the experiences of Clearstone and limited feedback from the host facilities. The relatively low mean time between failures for connectors reflects wear and tear on these components from inspection and maintenance of associated equipment units. In a formal leak detection and repair program, information on mean times between failures is tracked on an ongoing basis and is used to identify problem service applications and to evaluate the potential need for changes to component specifications and maintenance practices.

Table 21: Summary of repair costs and mean life of repair for equipment components in natural gas and non-methane hydrocarbon service.

Source	Category	Size (inches)	Basic Repair Cost ($/source)	Mean Repair Life (years)
Compressor Seals	Reciprocating per seal	-	2 000	1
	Centrifugal	-	2 000	1
Compressor Valve Covers	All	-	200	1
Compressor Variable Volume Pocket Stem	All	-	400	1
Compressor Cylinder End	All	-	400	1
Flanges	All	0.5 - 0.75	25	2
		1 - 2.5	50	
		3 - 4	75	
		6 - 8	100	
		10 - 14	150	
		16 - 20	200	
		24 - 30	300	
		32	400	
Lube Oil Vent	-	-	4 000	1
Open-Ended Lines	All	0.5 - 0.75	60	2
		1 - 1.5	75	
		2	100	
		3	120	
		4	190	
		6	245	
		8	350	
		10	500	
		12	595	
		14	780	
		16	890	
		20	1 115	
		24	1 340	
		30	1 670	
Orifice Meters	All	-	150	1
Other Flowmeters	All	-	150	5
Pressure Relief Valves	Threaded	0.5 - 0.75	79	2
		1 – 2	84	
		2.5	95	
		3	107	
		4	135	
		6	203	
		8	270	
		10	338	
		12	405	

Table 21: Summary of repair costs and mean life of repair for equipment components in natural gas and non-methane hydrocarbon service.				
Source	**Category**	**Size (inches)**	**Basic Repair Cost ($/source)**	**Mean Repair Life (years)**
Pressure Relief Valves	Flanged	1	124	2
		1.5	130	
		2	135	
		2.5	146	
		3	180	
		4	214	
		6	253	
		8	290	
		10	363	
		12	435	
		16	580	
		20	725	
Pump Seal	All	-	500	1
Regulators	All	-	175	5
Threaded Connections	Pipe Thread	0.125 - 0.75	20	2
		1 - 2.5	30	
		3 - 4	50	
		6 - 8	100	
		10 - 14	200	
		16 - 20	300	
		24 - 30	400	
		32	500	
	Union	0.5 - 0.75	50	2
		1 - 2.5	100	
		3 - 6	150	
Tubing Connections	All	0.5 - 0.75	15	4
		1 - 2.5	25	
Valves	Ball	0.5 - 0.75	60	4
		1 - 1.5	75	
		2	100	
		3	120	
		4	190	
		6	245	
		8	350	
		10	500	
		12	595	
		14	780	
		16	891	
		20	1 114	

Table 21: Summary of repair costs and mean life of repair for equipment components in natural gas and non-methane hydrocarbon service.				
Source	**Category**	**Size (inches)**	**Basic Repair Cost ($/source)**	**Mean Repair Life (years)**
Valves	Butterfly	0.5 - 0.75	120	2
		1 - 1.5	150	
		2	200	
		3	240	
		4	380	
		6	490	
		8	700	
		10	1 000	
		12	1 190	
		14	1 560	
		16	1 783	
		20	2 229	
	Control (all types)	0.5 - 2	130	2
		3	141	
		4	177	
		6	282	
		8	353	
		10	459	
		12	560	
		14	653	
		16	747	
		20	933	
		24	1120	
	Gate	0.5 - 0.75	60	4
		1 - 1.5	75	
		2	100	
		3	120	
		4	190	
		6	245	
		8	350	
		10	500	
		12	595	
		14	780	
		16	920	
		20	1 000	
Valves	Globe	1 - 1.5	75	4
		2	100	
		3	120	
		4	190	
		6	245	
		8	350	
		10	500	
		12	600	
		16	800	
		20	1 000	
		24	1 200	
	Governor	All	200	4

Table 21: Summary of repair costs and mean life of repair for equipment components in natural gas and non-methane hydrocarbon service.				
Source	**Category**	**Size (inches)**	**Basic Repair Cost ($/source)**	**Mean Repair Life (years)**
	Injector (fuel gas)	All	200	4
	Needle	0.125 - 0.75	60	4
		1 - 1.5	75	
		2	100	
		2.5	125	
		3	150	
		4	200	
	Orbit	0.5 - 0.75	60	4
		1 - 1.5	75	
		2	100	
		3	120	
		4	190	
		6	245	
		8	350	
		10	500	
		12	595	
		14	780	
	Plug	0.5 - 0.75	60	4
		1 - 1.5	75	
		2	120	
		3	150	
		4	200	
		6	255	
		8	300	
		10	394	
		12	480	
		14	560	
		16	640	
		20	800	
		24	960	
		30	1 200	
Vents		1 - 4	2 000	1
		6 - 30	5 000	

E.3.3 Emission Control Guidelines

A best practice for the management of fugitive emissions at upstream oil and natural gas facilities has been published by CAPP (2007). CAPP's best management practice (BMP) is specific to fugitive equipment leaks, but also considers leakage directly to the atmosphere and unintentional gas carry-through to storage tanks.

Requirements for leak detection and repair programs at refineries and chemical plants typically mandate that the leak frequency should not exceed two percent for any group of components excluding pump and compressor seals (which may have a leak frequency benchmark of ten percent).

E.3.4 <u>Fugitive Emission Control Options</u>

E.3.4.1 Reciprocating Compressors

Packing is used on reciprocating compressors to control leakage around the piston rod on each cylinder. A schematic diagram of a conventional packing system is presented in Figure 6. Typically, the distance piece is either left open with the vent piping connected directly to the packing case, or the distance piece is closed and the vents may be connected to both the packing case and the distance piece. The packing and distance piece vents are commonly routed outside the building to the atmosphere if the process gas is sweet, but should be connected to an emission controlling vent system if the gas is sour. The latter approach provides continuous treatment of any emissions and allows for more convenient scheduling of any required maintenance to the packing system.

- **Vent Monitoring Systems -** It is good practice to install instrumentation on the vent lines to indicate excessive vent rates and the need for maintenance. A flow switch, sensitive rotameter, vapor sensor, orifice and pressure differential indicator providing flow indication, or a temperature element may be used depending on the application. <u>MUIS Controls Ltd.</u> and <u>Dwyer Instruments Inc.</u> provide a selection of suitable flow switches and flow meters.

- **Emission-Controlling Vent Systems -** Where emission-controlling vent systems are employed they should be designed to minimize the potential for either the flow of process gas through the distance piece into the compressor crank case, or air ingress to the vent system through the nose of the packing case or through the air breather on the crank case and past the wiper packing leading to the distance piece (depending on the location of the vent connections). Both conditions pose a potential explosion hazard. Additionally, the leakage of process gas into the crank case could possibly result in contamination of the lubricating oil or corrosion problems (especially if the process gas contains hydrogen sulphide).

  There are three basic types of emission-controlling vent systems that may be considered: low pressure vapour recovery units (e.g., for compressor fuel, incinerators, or flares). Vent gas capture may be achieved by using a small rotary vane or liquid ring vacuum pump or an ejector installed to maintain a vacuum on the vents and compress the vent gas for appropriate disposition. The gas can sometimes be used in the fuel gas system if it is compressed dry or it can be routed to a low-pressure flare. The pump is usually run on a continuous basis and at a constant speed. If there is no vent gas flow, the pump produces maximum vacuum on the vent lines. To reduce the risk of pulling air into the vent gas capture system and creating an explosive atmosphere in these situations, a natural gas purge controlled system using a vacuum regulator may be used to limit the maximum vacuum produced.

If there is not a continuous low-pressure flare system on site and recovery of the vent gas is not practical, a small natural draft incinerator unit or shrouded ground-level flare may be most suitable. A vacuum pump is not usually needed with these devices if piping distances are not too great since the natural draft of the selected combustion unit will provide a slight vacuum. The incinerator or flare may be equipped with an electronic ignition system to maintain the pilot. The pilot consumes a small amount of fuel gas. A solar panel and battery may be used to power the ignition system if there is no electricity available on site.

With compressors using lubricated packing, it is important to consider that the vented and drained fluids from the packing and distance piece will contain some oil. Small pressure vessels (drain pots) should be fitted on the vent and drain lines to capture these liquids. Appropriate design and operational practices must be followed to prevent gas release when these liquids are drained. If a closed process drain system is available which has a receiver vented to flare, this can be used. If a closed drain system is not available and it is a sweet application, the liquids may be injected into the flare header if the flare system is designed to accept non-volatile liquids. Fuel gas or an inert supply gas can be used to blow liquids up to the flare header and the oil eventually accumulates in the knock-out drum. Injecting sour lubricating oil into the flare system is not recommended, especially high viscosity "tallow" based oils used for cylinder/packing lubrication, as this oil will eventually plug up the system.

- **High Performance Packing Systems -** The effective life of packing systems can be increased by using more refined designs with tighter tolerances, smoother finishes, o-rings between packing cups and lapped cup surfaces. These changes must be coupled with improved rod surfaces and alignment and increased packing case maintenance to be effective.

- **Barrier Fluid Systems -** A barrier fluid system is an add-on control that is used in combination with an emission controlling vent system. Its purpose is to prevent leakage beyond the vent connections on the packing case or distance piece. This reduces or eliminates the need to maintain a constant vacuum on the vent system, and possibly the need to compress the vent gas. A barrier fluid system serves no useful purpose if the vents discharge directly to the atmosphere.

  Barrier fluid systems should include a means for monitoring barrier-fluid and vent flow, pressure, and temperature which can aid in predicting packing failures. If a greater-than-normal flow of barrier fluid is required to maintain barrier pressure or if excessive vent flow occurs, or there is a loss of pressure then a need for packing maintenance is indicated.

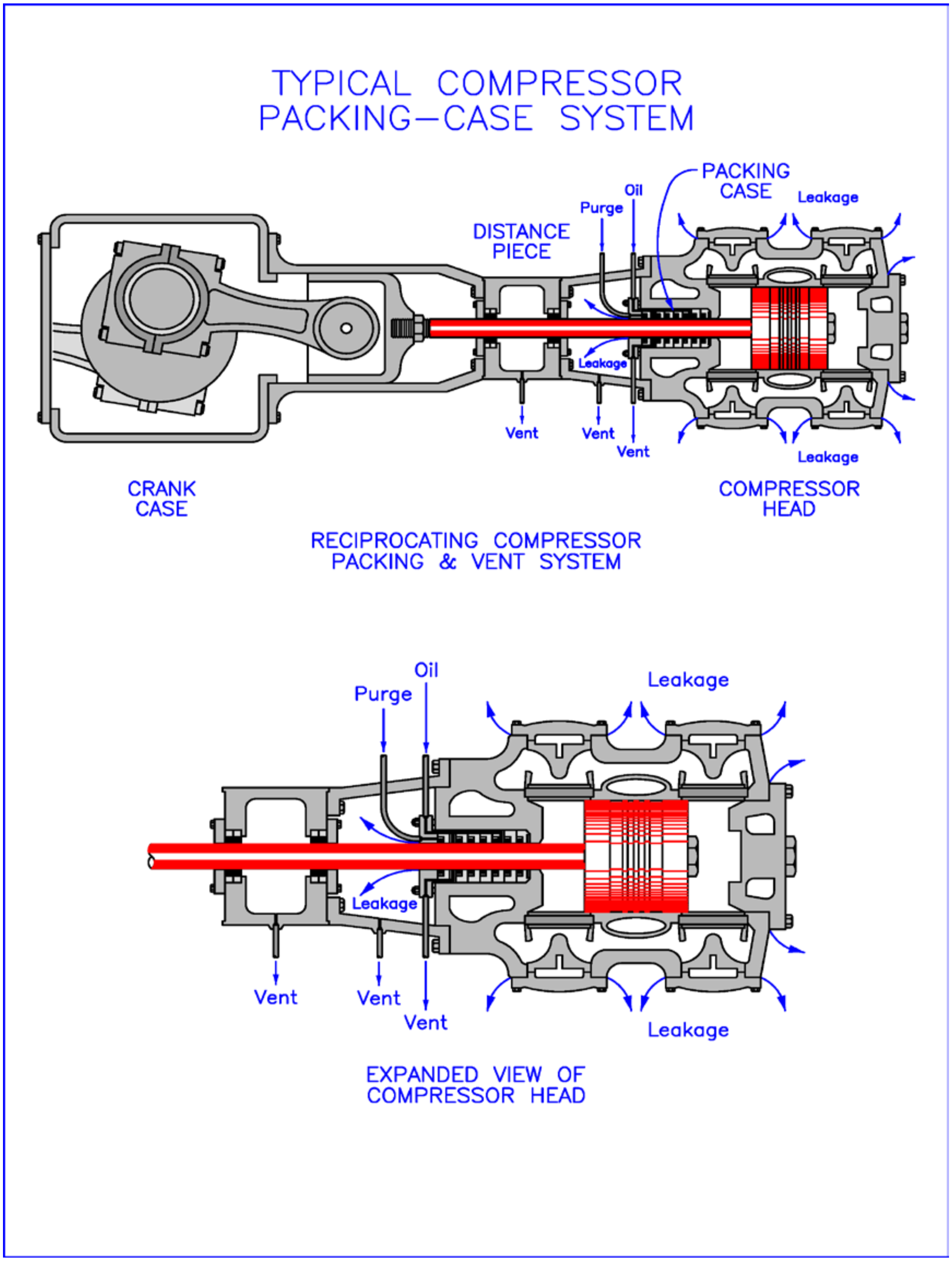

Figure 6: Typical reciprocating compressor vent and packing system.

The barrier is created by introducing a pressurized chamber between the vent connection and the nose of the packing mechanism or distance piece, and passing a continuous supply of an inert fluid (typically nitrogen, if it is available, or oil from the cylinder lubricator) through this void. The chamber is formed and sealed using side loaded packing rings. The pressure of the purge fluid is set so that any leakage that may occur will be from the barrier chamber (i.e., into the vent system and out the nose of the packing, partition or wiper case), rather than into it. Consequently, only inert purge fluid is leaked and not process gas.

A barrier fluid system may be easily retrofitted to any reciprocating compressor; although, some machining work will be required if there are no purge connections. API Specification 618 requires that a purge connection and side-loaded seal rings be provided at the following: (1) primary cylinder packing, (2) the wiper packing, and (3) at the partition packing where a two-compartment housing (distance piece) is used between the cylinder and the crank case.

- **Purge Gas Systems -** In sour applications, it is good practice to purge sweet natural gas through the packing case, intermediate section, and wiper section to prevent sour gas from entering the crank case. To do this a vacuum pump is installed on the "cylinder" distance piece, and purge gas is admitted to the "frame-side" distance piece.

- **Unit Shutdown Practices -** Leakage into unit blowdown systems can be a significant source of fugitive emissions from compressors. The amount of leakage is greatest when the compressor has been depressurized promoting leakage past the seats of the upstream and downstream unit isolation valves into the unit blowdown system. When the unit is left pressurized, leakage is only promoted past the seat of the unit blowdown valve. Thus, it is generally good practice to leave compressors pressurized when they are not running if this can be tolerated. For longer shutdowns, the compressor should be blown down.

- **Static Packing Systems -** If compressors are left pressurized when shut down, emissions from the compressor seals may be eliminated during those periods by installing a static packing system to affect a seal around the piston rod after the compressor is stopped. This helps contain the gas in the compressor cylinders and eliminates the need to maintain barrier-gas flow when the compressor is stopped. Leakage from cylinder gaskets and unloader glands can still occur. The emissions during operation are unaffected except that space taken up by the static packing may dictate that a less sophisticated running packing be used.

  A static packing system replaces some cups in the packing case (it is usually necessary to lap the case). It comprises a conformable seal made of relatively soft rubber or Teflon. The seal is brought into contact with the compressor rod by pressurized gas when the compressor is stopped. The amount of pressure required to actuate the seal is normally about half of the pressure in the cylinder; although, this may be greater. When the actuating pressure is lowered, the seal is released and the compressor may be restarted.

Static packing systems are not applicable to all compressors, (usually because of space and design limitations).

- **Valve Cap Leakage -** Leakage past the valve caps, as depicted in Figure 6, is only a problem with improperly specified O-Rings (i.e., due to explosive de-compression), or where lead or aluminum seals are used in lieu of O-Rings (such as EI, or IR compressors).

E.3.4.2 Centrifugal Compressors

Centrifugal compressors generally require shaft end seals between the compressor and bearing housings. Face contact oil lubricated mechanical seals or oil ring shaft seals are commonly used in hydrocarbon services. Dry gas shaft seals are frequently applied in many process and natural gas services and are the preferred choice for centrifugal compressors due to their lower leakage potential their impacts on improving energy efficiency (e.g., due to reduced friction losses and elimination of seal oil circulation pumps)..

There are several options for reducing atmospheric emissions from the seals on centrifugal compressors: emission controlling vent systems (degassing drum vent control) for mechanical contact and oil film seals, dry gas seals and pressurized motor drive compressors.

- **Emission-Controlling Vent Systems Used with Conventional Seals –** Face-contact seals use two sealing rings held in close contact by a spring mechanism balanced with fluid pressures from the process gas and seal oil. An oil ring seal uses a journal type ring which is sealed with pressurized and circulating oil. Both oil-lubricated face-contact and oil-film seals, often arranged in the double configuration, use oil at a pressure greater than the process gas pressure. They provide a positive seal from gas leakage along the shaft to the atmosphere; however, other emissions are associated with the system.

  Some oil leaks inward through the seal and is collected in drain traps before being returned to the reservoir. Gas from the traps should be routed to an emission-controlling vent system or back to the compressor suction. Any installations which vent the traps directly to atmosphere will have very high emissions and losses of process gas. The vent on lube-oil degassing drums should therefore be tied in to an emission-controlling vent gas system provided this does not impose excessive backpressure on the degassing drum and lube oil reservoir.

- **Dry Gas Seals -** Dry gas seals generally offer substantially reduced emissions compared to wet seal systems depending on the vent gas controls provided. Additionally, when properly applied, gas seals often yield both capital and operating cost savings over conventional oil lubricated seals. The capital savings are due to the simplification of the oil system by deletion of the seal oil part of the system. Operational savings can be realized in services where clean seal gas is available due to the longer running life of the essentially non-contacting seals.

Dry gas seals as depicted in Figure 7, operate without oil; however, lubricating oil is still required for the journal bearings. The dry gas seal has two precision machined sealing plates, usually one of silicon carbide or tungsten carbide and one of carbon. The seals are separated by clean, filtered seal gas which is used to create a pressure dam effect involving radial or spiral groves in one seal face. Due to very close running clearances, leakage rates are very low. Per-seal face-set leakage rates of about 0.5 kg/h can be expected, depending on the seal size and pressure differential.

The pressure differential across the seal must be maintained or the hydrodynamic forces will not separate the faces. Excessive vent back-pressure can therefore cause seal failure. To prevent loss of this pressure differential in applications involving single seals and low operating pressures, the outer seal vent is commonly routed to atmosphere at a safe location. The outer seal chamber is typically purged with nitrogen to prevent local discharge to atmosphere.

A tandem gas seal arrangement is available. The tandem arrangement provides protection in the event the inboard seal fails, and it is becoming the minimum standard for high pressure applications with flammable gases. The inter-seal vent can be routed to an appropriate emissions controlling vent system. Emissions are still typical at the outer seal vent.

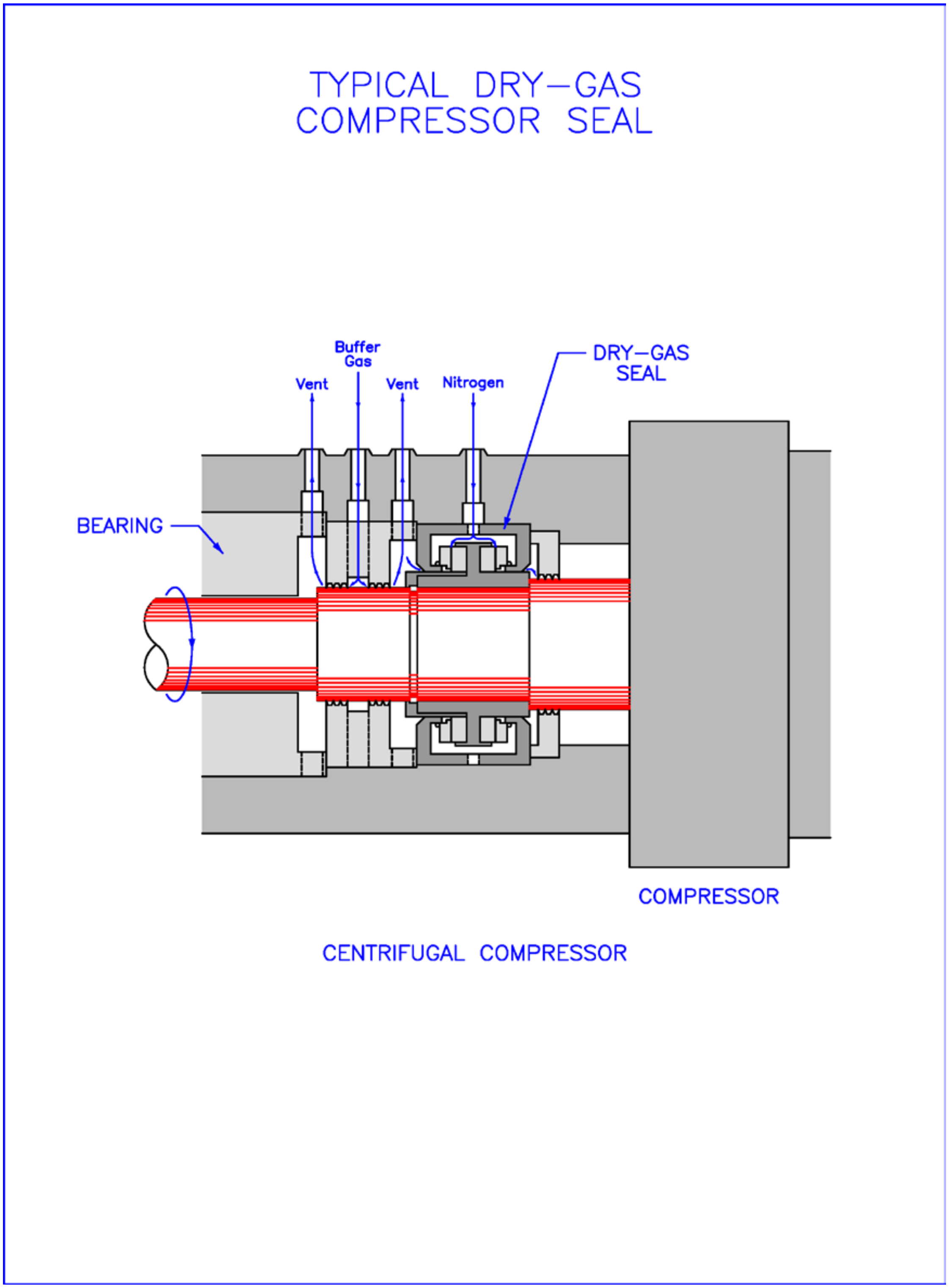

Figure 7: Typical centrifugal compressor dry-gas seal and vent system.

E.4 References

Canadian Association of Petroleum Producers. 2007. *Best Management Practice: Measurement of Fugitive Emissions at Upstream Oil and Gas Facilities*. CAPP Publication No.: 2007-0003, http://www.capp.ca/getdoc.aspx?DocId=116116&DT=PDF

U.S. EPA. 1995. Protocol for Equipment Leak Emission Estimates. NTIA, Springfield VA. Publication No. EPA-453/R-95-017 Section 2.

U.S. EPA. 2009, Methane to Markets Partnership. Oil and Natural Gas Industry. http://www.ontime.methanetomarkets.org/m2mtool/index.html

E.5 Results

The summary of estimated emissions from all identified leaking components, including compressor seal leaks, is presented in the following tables.

Fugitive Index

Facility Name	Device Category	Tag Number	Name	Device Type	Service
Acacias Oil Battery	Fugitive Equipment Leaks	ATK-7301	Tank 7301	Vapour Control System	Tank Vapour
Acacias Oil Battery	Fugitive Equipment Leaks	ATK-7302	Tank 7302	Vapour Control System	Tank Vapour
Acacias Oil Battery	Fugitive Equipment Leaks	ATK-7305	Tank 7305	Vapour Control System	Tank Vapour
Acacias Oil Battery	Fugitive Equipment Leaks	ATK-7306	Tank 7306	Vapour Control System	Tank Vapour

Point Source Information

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Tank 7301
ID	ATK-7301
On Site Location	Acacias
Category	Fugitive Equipment Leaks
Type	
Service	
Manufacturer	
Model	N/A
Model Year	N/A
Installation Date	N/A
	N/A

Data Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Device Comments and Assumptions
Surge Tank Vapor Control System Fugitive.

General Simulation Data	
Operating Factor (%)[1]	100.00
Load Factor (%)[1]	100.00
Flow Adjustment (m^3/h)[1]	0.00
Adjustment Comment	No comments
Activity Level[2]	1.0
Extrapolated Activity Level[2]	0.0
Ambient Temperature (^oC)	30.0
Ambient Pressure (kPa)	95.8

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

Data Comments and Assumptions
No comments

Applied Emission Factors		
Substance	**Value**	**Source**
CH_4 Emission Factor (ng/J)	N/A	
N_2O Emission Factor (ng/J)	N/A	
VOC Emission Factor (ng/J)	N/A	
CO Emission Factor (ng/J)	N/A	
PM Emission Factor (ng/J)	N/A	
NO_x Emission Factor (ng/J)	N/A	
HC Destruction Efficiency (%)	N/A	

Simulation Input Stream

Input Stream	
Temperature (^oC)	78.4
Pressure (kPa gage)	95.8
Line Name	N/A
Cross Sectional Shape	Circular
Pipe Outside Diameter (mm)	N/A
Pipe Wall Thickness (mm)	N/A
Pipe Rectangular Length (mm)	N/A
Pipe Rectangular Width (mm)	N/A
Measurement Type	Transit-Time Ultrasonic Flow Meter
Reading Type	Flow Rate (Standard Conditions)
Measurement Date	N/A
Velocity (m/s)	---
Flow Rate (m^3/h)	---
Standard Flow Rate (m^3/h)	12.1
Composition Name	2012-11-13 acacias atk 7301
Composition ID	8

Input Stream Composition Source Data

CLEARSTONE ENGINEERING

Anaylsis Adminstration Data	
Name	2012-11-13 acacias atk 7301
Description	N/A
Creation Date	1/8/2013
Sample Date	11/13/2012
Sample Type	Unknown
Substance Type	Tank Vapour
Clearstone ID	8

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.017885	0.017885	0.018783
Ethane	0.076065	0.076065	0.079882
Isobutane	0.140698	0.140698	0.147758
Isopentane	0.075394	0.075394	0.079178
Methane	0.187795	0.187795	0.197219
n-Butane	0.109457	0.109457	0.114950
n-Hexane	0.071530	0.071530	0.075119
Nitrogen	0.074623	0.074623	0.038800
n-Pentane	0.065562	0.065562	0.068852
Oxygen	0.010107	0.010107	0.000000
Propane	0.170885	0.170885	0.179460
Total	1.000000	1.000000	1.000000

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Vapour Recovery	Pesimistic cost	95.00	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Vapour Recovery	Pesimistic cost	0	0	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Vapour Recovery	Pesimistic cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3$/d)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Tank 7301	ATK-7301	Tank Vapour	115,312	12.1	0.05	0.08	0.49	0.32	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
13.5	4	0.00	287	172.3	0.0	0.0	0.0	0.0

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Vapour Recovery	95.00	57,600	0	0	109,546	749,292	190.18	0.53

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Vapour Recovery	12.84	3	0.00	273	163.69	0.00	0.00	0.00	0.00

Point Source Information

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Tank 7302
ID	ATK-7302
On Site Location	Acacias
Category	Fugitive Equipment Leaks
Type	
Service	
Manufacturer	
Model	N/A
Model Year	N/A
Installation Date	N/A
	N/A

Data Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Device Comments and Assumptions
Surge Tank

General Simulation Data	
Operating Factor (%)[1]	100.00
Load Factor (%)[1]	100.00
Flow Adjustment (m^3/h)[1]	0.00
Adjustment Comment	No comments
Activity Level[2]	1.0
Extrapolated Activity Level[2]	0.0
Ambient Temperature (^oC)	35.1
Ambient Pressure (kPa)	95.8

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

Data Comments and Assumptions
No comments

Applied Emission Factors		
Substance	**Value**	**Source**
CH_4 Emission Factor (ng/J)	N/A	
N_2O Emission Factor (ng/J)	N/A	
VOC Emission Factor (ng/J)	N/A	
CO Emission Factor (ng/J)	N/A	
PM Emission Factor (ng/J)	N/A	
NO_x Emission Factor (ng/J)	N/A	
HC Destruction Efficiency (%)	N/A	

Simulation Input Stream

Input Stream	
Temperature (^{o}C)	57
Pressure (kPa gage)	95.8
Line Name	N/A
Cross Sectional Shape	Circular
Pipe Outside Diameter (mm)	N/A
Pipe Wall Thickness (mm)	N/A
Pipe Rectangular Length (mm)	N/A
Pipe Rectangular Width (mm)	N/A
Measurement Type	Transit-Time Ultrasonic Flow Meter
Reading Type	Flow Rate (Standard Conditions)
Measurement Date	N/A
Velocity (m/s)	---
Flow Rate (m^3/h)	---
Standard Flow Rate (m^3/h)	10.7
Composition Name	2012-11-13 acacias atk 7302
Composition ID	7

CLEARSTONE ENGINEERING

Input Stream Composition Source Data

Anaylsis Adminstration Data	
Name	2012-11-13 acacias atk 7302
Description	N/A
Creation Date	1/8/2013
Sample Date	11/13/2012
Sample Type	Unknown
Substance Type	Tank Vapour
Clearstone ID	7

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.010895	0.010895	0.018792
Ethane	0.044852	0.044852	0.077363
Isobutane	0.052048	0.052048	0.089775
Isopentane	0.054899	0.054899	0.094694
Methane	0.115043	0.115043	0.198434
n-Butane	0.079085	0.079085	0.136411
n-Hexane	0.090036	0.090036	0.155300
Nitrogen	0.275947	0.275947	0.000000
n-Pentane	0.047837	0.047837	0.082513
Oxygen	0.144298	0.144298	0.000000
Propane	0.085060	0.085060	0.146717
Total	1.000000	1.000000	1.000000

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Vapour Recovery	Pesimistic cost	95.00	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Vapour Recovery	Pesimistic cost	0	0	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Vapour Recovery	Pesimistic cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Tank 7302	ATK-7302	Tank Vapour	76,327	10.7	0.03	0.04	0.22	0.26	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
7.3	2	0.00	155	105.1	0.0	0.0	0.0	0.0

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Vapour Recovery	95.00	48,000	0	0	72,510	486,095	151.06	0.66

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Vapour Recovery	6.94	2	0.00	148	99.88	0.00	0.00	0.00	0.00

Point Source Information

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Tank 7305
ID	ATK-7305
On Site Location	Acacias
Category	Fugitive Equipment Leaks
Type	
Service	
Manufacturer	
Model	N/A
Model Year	N/A
Installation Date	N/A
	N/A

Data Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Device Comments and Assumptions
Compensation Tank

General Simulation Data	
Operating Factor (%)[1]	100.00
Load Factor (%)[1]	100.00
Flow Adjustment (m^3/h)[1]	0.00
Adjustment Comment	No comments
Activity Level[2]	1.0
Extrapolated Activity Level[2]	0.0
Ambient Temperature (^{o}C)	32.3
Ambient Pressure (kPa)	95.8

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.

[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

Data Comments and Assumptions
No comments

Applied Emission Factors		
Substance	**Value**	**Source**
CH_4 Emission Factor (ng/J)	N/A	
N_2O Emission Factor (ng/J)	N/A	
VOC Emission Factor (ng/J)	N/A	
CO Emission Factor (ng/J)	N/A	
PM Emission Factor (ng/J)	N/A	
NO_x Emission Factor (ng/J)	N/A	
HC Destruction Efficiency (%)	N/A	

Simulation Input Stream

Input Stream	
Temperature (^oC)	35
Pressure (kPa gage)	95.8
Line Name	N/A
Cross Sectional Shape	Circular
Pipe Outside Diameter (mm)	N/A
Pipe Wall Thickness (mm)	N/A
Pipe Rectangular Length (mm)	N/A
Pipe Rectangular Width (mm)	N/A
Measurement Type	Transit-Time Ultrasonic Flow Meter
Reading Type	Flow Rate (Standard Conditions)
Measurement Date	N/A
Velocity (m/s)	---
Flow Rate (m^3/h)	---
Standard Flow Rate (m^3/h)	21.3
Composition Name	2012-11-10 acacias atk 7305
Composition ID	6

Input Stream Composition Source Data

Anaylsis Adminstration Data	
Name	2012-11-10 acacias atk 7305
Description	N/A
Creation Date	1/8/2013
Sample Date	11/10/2012
Sample Type	Unknown
Substance Type	Tank Vapour
Clearstone ID	6

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001697	0.001697	0.002364
Ethane	0.038917	0.038917	0.054222
Isobutane	0.075529	0.075529	0.105233
Isopentane	0.087576	0.087576	0.122018
Methane	0.170294	0.170294	0.237268
n-Butane	0.096855	0.096855	0.134946
n-Hexane	0.076975	0.076975	0.107248
Nitrogen	0.184935	0.184935	0.000000
n-Pentane	0.077116	0.077116	0.107445
Oxygen	0.097336	0.097336	0.000000
Propane	0.092770	0.092770	0.129256
Total	1.000000	1.000000	1.000000

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Vapour Recovery	Pesimistic cost	95.00	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Vapour Recovery	Pesimistic cost	0	0	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Vapour Recovery	Pesimistic cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Tank 7305	ATK-7305	Tank Vapour	187,427	21.3	0.09	0.07	0.55	0.63	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
21.6	1	0.00	454	257.9	0.0	0.0	0.0	0.0

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Vapour Recovery	95.00	57,600	0	0	178,056	1,253,918	309.12	0.32

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Vapour Recovery	20.52	1	0.00	431	245.04	0.00	0.00	0.00	0.00

Point Source Information

CLEARSTONE ENGINEERING

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Tank 7306
ID	ATK-7306
On Site Location	Acacias
Category	Fugitive Equipment Leaks
Type	
Service	
Manufacturer	
Model	N/A
Model Year	N/A
Installation Date	N/A
	N/A

Data Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Device Comments and Assumptions
Compensation Tank

General Simulation Data	
Operating Factor (%)[1]	100.00
Load Factor (%)[1]	100.00
Flow Adjustment (m^3/h)[1]	0.00
Adjustment Comment	No comments
Activity Level[2]	1.0
Extrapolated Activity Level[2]	0.0
Ambient Temperature (°C)	34.3
Ambient Pressure (kPa)	95.8

[1] Operating and Load Factors are multiplicative adjustments to the measured/reported flow rate applied during simulation, with 100% being no adjustment. Flow Adjustment is additional flow at standard conditions applied after all other corrections and adjustments.
[2] Activity Level and Extrapolated Activity Level are used when extrapolating from this Emission Point Source. The Unit(s)/Source(s) not tested are assumed to have losses and emissions of Extrapolated Activity Level/Activity Level times this Source.

Data Comments and Assumptions
No comments

Applied Emission Factors		
Substance	**Value**	**Source**
CH_4 Emission Factor (ng/J)	N/A	
N_2O Emission Factor (ng/J)	N/A	
VOC Emission Factor (ng/J)	N/A	
CO Emission Factor (ng/J)	N/A	
PM Emission Factor (ng/J)	N/A	
NO_x Emission Factor (ng/J)	N/A	
HC Destruction Efficiency (%)	N/A	

Simulation Input Stream

Input Stream	
Temperature (^{o}C)	54.7
Pressure (kPa gage)	95.8
Line Name	N/A
Cross Sectional Shape	Circular
Pipe Outside Diameter (mm)	203.2
Pipe Wall Thickness (mm)	N/A
Pipe Rectangular Length (mm)	N/A
Pipe Rectangular Width (mm)	N/A
Measurement Type	Transit-Time Ultrasonic Flow Meter
Reading Type	Flow Rate (Standard Conditions)
Measurement Date	N/A
Velocity (m/s)	---
Flow Rate (m^3/h)	---
Standard Flow Rate (m^3/h)	325.3
Composition Name	2012-11-10 acacias atk 7306
Composition ID	5

Input Stream Composition Source Data

Anaylsis Adminstration Data	
Name	2012-11-10 acacias atk 7306
Description	N/A
Creation Date	1/8/2013
Sample Date	11/10/2012
Sample Type	Unknown
Substance Type	Tank Vapour
Clearstone ID	5

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001590	0.001590	0.001720
Ethane	0.045251	0.045251	0.048939
Isobutane	0.114801	0.114801	0.124159
Isopentane	0.182940	0.182940	0.197852
Methane	0.073453	0.073453	0.079440
n-Butane	0.117824	0.117824	0.127428
n-Hexane	0.080592	0.080592	0.087161
Nitrogen	0.073240	0.073240	0.014940
n-Pentane	0.162471	0.162471	0.175714
Oxygen	0.015941	0.015941	0.000000
Propane	0.131896	0.131896	0.142647
Total	1.000000	1.000000	1.000000

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Vapour Recovery	Pesimistic cost	95.00	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Vapour Recovery	Pesimistic cost	0	0	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Vapour Recovery	Pesimistic cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Tank 7306	ATK-7306	Tank Vapour	4,553,721	325.3	0.57	1.26	11.43	16.65	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
142.0	8	0.00	2,991	6171.2	0.0	0.0	0.0	0.0

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Vapour Recovery	95.00	1,560,000	0	0	4,326,035	30,304,610	277.31	0.36

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Vapour Recovery	134.92	8	0.00	2,841	5,862.63	0.00	0.00	0.00	0.00

APPENDIX F HEATERS AND BOILERS

F.1 Introduction

The purpose of natural gas-fuelled heaters and boilers is to provide useful thermal work at the best possible energy conversion efficiency.

F.2 Background

Equipment design and operating data are collected during field surveys and input into a proprietary Clearstone software program to facilitate the calculation of the required parameters. The design and operating data includes equipment make, model, capacity, recommended settings, actual settings, and operating flow rates, temperatures, pressures and, where measured, fuel and exhaust (flue) gas composition. Measured fuel and exhaust gas compositions are used to determine the air-to-fuel and exhaust-to-fuel ratios.

A material balance is performed, on a mole basis, using the following stoichiometric relation:

$$Fuel + a \cdot Air \rightarrow b \cdot Flue + c \cdot H_2O$$

Equation 30

The mole balances used include nitrogen to determine *a*, carbon to determine *b* and hydrogen to determine *c*. These coefficients were used to determine the flow rates of the unknown streams from the known (measured) flow rates.

The information gap in the field measurement data are completed using either the manufacturer's data for the equipment or the typical default parameters provided by Clearstone software.

The stack gas heat loss is determined by Clearstone Software as the potential energy that can be recovered by cooling the stack gas from the measured stack gas temperature to 10°C above its dew point or 15°C whichever is greater. The rest of the heat content in flue gas is considered as unrecoverable losses. The economic value is assigned only to the recoverable energy.

For the purpose of combustion and thermal efficiency analyses, the stack gas temperature must be measured as close to the exhaust manifold of the combustion chamber as possible. In cases where the exhaust gases are used to preheat air or fuel, the stack gas temperature measurement should be performed after the heat exchanger.

F.2.1 Definitions

Combustion Efficiency and Energy Efficiency are assessed in the evaluation of process heaters and boilers.

F.2.1.1 Combustion Efficiency (CE)

Combustion efficiency is defined as the total enthalpy contained in the reactants minus the total enthalpy contained in the products divided by the energy content of the fuel. This may be written as follows:

$$\frac{\left(\dot{m}_{FUEL} \cdot h^{f}_{FUEL} + \dot{m}_{AIR} \cdot h^{f}_{AIR} - \dot{m}_{FLUE} \cdot h^{f}_{FLUE}\right)}{\dot{m}_{FUEL} \cdot LHV}$$

Equation 31

Where:

$\dot{m}$	is the molar flow rate of the stream (i.e., fuel, air, or flue gas) (kmole/h),
h^{f}	is the heat of formation of the stream (MJ/kmole), and
LHV	is the lower heating value of the fuel gas stream (MJ/kmole)

For heaters and boilers, expected combustion efficiencies are in the range of 99 to 99.99 percent.

F.2.1.2 Excess Air (EA)

Excess air is defined as the amount of supplied combustion air that is in excess of the stoichiometric amount required. Stoichiometric (or theoretical) combustion is a process which burns all the carbon (C) to CO_2, all hydrogen (H) to H_2O and all sulphur (S) to SO_2. Excess air is a function of the air-to-fuel ratio and, as a result, may be controlled with a mechanical or electronic link to the fuel gas flow control valve.

Typical excess air values vary on whether is a natural or forced draft design, the manufacturer and the model number. Typical values used in the evaluation of natural gas-fuelled heaters and boilers are based on the following criteria:

Heaters and Boilers	Excess air of 10 to 15 percent for natural draft and 5 to 10 percent for forced draft operations

F.2.1.3 Energy Efficiency (EF)

While combustion efficiency is useful in demonstrating how much of the energy in the fuel is converted to heat, it does not provide a complete description of how effectively the equipment is utilizing this energy.

Heat lost to exhaust is a function of combustion efficiency and the quantity of combustion air that is required for efficient operation. Useful work is whatever is left over after all losses have been accounted for. Since heat losses from the external surfaces of a heater or boiler are normally relatively small, the amount of heat lost up the stack is a good indication of whether or not the unit is being operated in an efficient manner.

A typical energy balance based on manufacturers' heat load data yields:

- Energy from Fuel 100 %
- Useful Work 70 to 85 %
- Radiation 2 to 5 %
- Exhaust 15 to 25 %

F.2.1.4 Recoverable Stack Heat

Stack heat losses are calculated using a simplified heat balance. The equation used is:

$$Fraction\ of\ \ Heat\ Lost = \frac{Stack\ Losses}{Heat\ Input}$$

Equation 32

where

Heat Input = Energy Content of Fuel + Sensible Heat in Fuel + Sensible Heat in Combustion Air

Stack Losses = Energy Content of the Exhaust Gas + Convective Stack Losses + Sensible Heat in the Exhaust Gas

F.3 Performance Evaluation Methodology

Combustion systems are analysed, using proprietary software, based on field operating data collected or measured. The results are compared to manufacturer's data or to equipment benchmark values as stated in the previous section.

The testing done on each unit involved analyzing the flue gas composition, measuring the flue gas temperature, obtaining the fuel gas composition, and where possible, measuring the flow rate of one or more of the following: fuel gas, combustion air and flue gas. Additionally, the make and model of each unit, and ambient temperature and barometric pressure at the site were recorded where available.

F.3.1 Calculation of Fuel Consumption Rate of Crude Oil Heater

Assuming the heater is solely used to provide heat for a crude oil heating process, the fuel consumption rate of the heater is estimate based on the amount of process heating that is required for that purpose.

After obtaining the inlet temperature, $T_{in,}$ and outlet temperature, T_{out}, of the crude oil, the fuel consumption rate of the heater is calculated as following:

$$Q \times HHV \times 10^{6} = mC_{p}(T_{out} - T_{in}) / eff$$

Equation 33

Where:

Q	→	fuel consumption rate (m^3/day);
HHV	→	the gross heating value of the fuel gas (MJ/m^3);
eff	→	the efficiency of the heater (assume 85%);
m	→	the crude oil mass production rate (kg/day);
C_p	→	the specific heat of the crude oil.

The crude oil specific heat (But/(lb)(^{o}F)) is calculated using the following equation [Perry & Chilton, 1973]:

$$C_{p} = \frac{0.388 + 0.00045t}{s}$$

Equation 34

Where:

t	→	the average temperature of the inlet and outlet (^{o}F);
s	→	the specific gravity of the crude oil.

A similar approach is applied for other heated fluids such as heat mediums and water.

F.3.2 Fuel Costs and Fuel Cost Savings Results

Fuel costs associated with the improper operation of combustion units are made up of two components:

- Any unburned fuel in the exhaust gas, and
- Incremental fuel associated with operating at excessive air-to-fuel ratios.

The value of unburned fuel is determined by calculating the heating value of the unburned or partially burned components of the exhaust gas, determining the fuel gas equivalent volume using the energy content of the natural gas used as fuel, and the assigned monetary value per unit of energy (typically in $/GJ).

The cost associated with operations using too much excess air is determined by comparing the measured air-to-fuel ratio with typical values specified by the equipment manufacturer or best management practice (BMP) values appropriate for the equipment being assessed. The cost is calculated by determining the amount of heat required to heat the excess air from ambient temperature to the exhaust stack temperature and applying the assigned monetary value of the energy.

The optimum air-to-fuel depends on the type of air supply (i.e., natural or forced draft), type of fuel, style of burner system and unit loading. Specific manufacturers' values are used wherever possible. In the absence of manufactures' data, average values for the types of units tested are used.

F.3.3 Excess Emission and Emission Reduction Results

Excessive emissions and potential emissions reductions are determined and expressed in terms of fuel gas (10^3 m^3/d), methane (tonnes CH_4/y) and total green house gases (GHG) (tonnes CO_2E/y). The Global Warming Potential of Methane is taken as 21 for purposes of calculation GHG emissions.

F.3.4 Fuel Gas Composition

Where possible, a fuel gas analysis is obtained from the facility operator. If wide fluctuations in fuel gas composition are typical for a facility, an analysis that is consistent with the equipment performance and flue gas measurements is required for use in all efficiency calculations. Where one is not available, a sample of the fuel is collected from the fuel gas line and sent to a suitable laboratory for analysis.

F.3.5 Flue Gas Composition

The flue gas analyses are conducted using a Testo 350 Portable Combustion Analyzer, or equivalent analyzer, equipped with detectors for O_2, CO, CO_2, NO_x, SO_2, and combustibles, and thermocouples for measuring ambient and stack-gas temperatures. A typical measurement is depicted in Figure 8. The flue gas is sampled either through a convenient sampling port on the exhaust stack or at the top of the stack. The flue gas temperature is measured close to the combustion chamber exit. All results are corrected to account for the actual fuel gas composition.

Figure 8: Photographs of combustion test being conducted using a portable combustion analyzer.

F.3.6 Data Evaluation

- Carbon Dioxide – Actual CO_2 emissions based on flue gas measured are compared to maximum possible CO_2 emissions based on fuel gas composition to determine combustion efficiency and potential loss of input energy due to incomplete combustion and the formation of CO. Actual emission values should not be compared to typical U.S. EPA AP-42 or CAPP values unless they are corrected for fuel gas composition.

- Carbon Monoxide – Measured CO emissions per unit of energy input, expressed as nanogram per Joule (ng/J), are compared to regulatory requirements, manufacturer's specifications or typical values provided by U.S. EPA AP-42 or CAPP for various types of combustion equipment. Significantly greater actual values may be caused by insufficient combustion air (e.g., due to fouling of the air intake or incorrect setting of the air intake dampers), faulty burners or poor mixing.
- Oxides of Nitrogen - Measured NO_x emissions per unit of energy input, expressed as ng/J, are compared to regulatory requirements, manufacturer's specifications or typical values provided by U.S. EPA AP-42 or CAPP for various types of combustion equipment. Significantly greater actual values may be caused by burner design causing high flame temperatures (heater/boiler), poor mixing or use of fuels containing high concentrations of organically bonded nitrogen.
- Methane (CH_4) - Measured CH_4 emissions per unit of energy input, expressed as ng/J, are compared to regulatory requirements, manufacturer's specifications or typical values provided by U.S. EPA AP-42 or CAPP for various types of combustion equipment. Significantly greater actual values may be caused by insufficient combustion air (e.g., due to fouling of the air intake or incorrect setting of the air intake dampers), faulty burners or poor mixing.

F.4 Energy Management and Emission Control Options

The opportunities for improving the performance of heaters and boilers address the losses associated with the combustion of fuel and the transfer of the energy from the flue gases to the material to be heated. Key improvement areas include:

- Temperature control.
- Flame failure detection.
- Air-to-fuel ratio control (typically, 5 to 25 percent potential savings).
- Preheating of combustion air or oxidant (typically 15 to 30 percent savings).

F.4.1 Temperature Control

Heaters and boilers that are operated using on/off control and experience frequent on/off cycling will experience inefficiencies due to poor combustion during the initial stages of burner firing, particularly for natural draft units. The implementation of modulating temperature control, or the adjustment of on/off setpoints to minimize on/off cycling is recommended in these situations.

F.4.2 Flame Failure Detection

Flame failure detection is a standard feature on large modern process heaters and boilers, but is absent on many of the smaller and medium sized units. In the absence of a flame failure detection system, if the burner pilot or flame is out when there is heat demand, the temperature control system will continue to supply gas to the burner which will then be exhausted up the flue stack unburned. In fact, the temperature control system will tend to maximize the supply rate of fuel to the burner in these cases. Often a thermocouple and automatic fuel shutoff valve can be installed to avoid this problem. This is particularly beneficial for unmanned field equipment and process units with multiple burner trains.

F.4.3 Air-to-Fuel Ratio Control

Ensuring the proper air-to-fuel ratio is maintained typically offers energy savings of 5 to 25 percent through improved combustion efficiencies and reduced stack losses. Stoichiometric combustion is not practical, since perfect mixing of the air and fuel would be needed to achieve complete fuel combustion. Without excess air, unburned hydrocarbons can enter the exhaust gas stream which can be both dangerous and environmentally harmful. Too much excess air is also undesirable since it carries away heat.

Caution should be used when reducing excess air. Although this is often an opportunity worth considering, it is important to maintain a certain amount of excess air. Excess air is essential to maintaining safe combustion. It is also used to carry heat to the material to be heated. As a result, operators should be careful to establish the proper amount of excess air according to the requirements of the burner and furnace. Important factors for setting the proper excess air include:

- Type of fuel used.
- Type of burner used.
- Process conditions.
- Process temperature.

Automatic air-to-fuel ratio control systems can be readily retrofit to natural draft systems. This requires the installation of an oxygen sensor in the flue gas stream, a forced-air supply system and a controller. Generally, the more practicable option is to manually check and adjust the air-to-fuel ratio on a regular basis. At a minimum, this should be done at the start of each season to adjust for changes in the air density. To facilitate regular tests to determine the air-to-fuel ratio, it is recommended that a ¼" diameter hole be drilled at a convenient location near the base of the vertical portion of the stack.

The air-to-fuel ratio on a natural draft furnace may be adjusted by either changing the damper position on the air intake (if applicable) or changing the setpoint on the fuel gas pressure regulator, or some combination thereof. If there is no adjustable damper on the air intake, consideration should be given to installing one.

The following is a brief checklist or potential problems to watch for in furnaces equipped with forced air systems:

- Combustion air leaks downstream of the air intake.

- Loose or worn linkages on forced air control systems (this could lead to poor control of the fuel air mixture over the range of operating conditions).
- Poor flame stability (this indicates improper fuel air control).
- Fouling of the air intake arrestor or screen (e.g., by bugs and airborne debris such as fine sand, dust, lant seeds and leaves).

The last two points also apply to natural draft furnaces.

F.4.4 Preheating Combustion Air

Recovering waste heat from the flue gas and using it to preheat the combustion air for the furnace can result in energy savings of 15 to 30 percent. If the unit is housed in a building and it is impracticable to install a waste heat recovery system, a simple approach which offers some savings is to draw all the combustion air from inside the building. This helps to recover some of the radiant heat losses from the body of the furnace and cool the building for the benefit of workers.

F.5 References

CAPP. 2003. *Calculating Greenhouse Gas Emissions*. Publication No. 2003-0003, Canadian Association of Petroleum Producers.

CETAC-West. 2008. *Efficient Use of Fuel Gas in Fired Heaters*. Fuel Gas Best Management Practices Module 6 of 17. CAPP Report, Calgary.

U.S. Environmental Protection Agency. 1998. *Compilation of Pollution Emission Factors, Vol.1, Station and Point Area Sources, AP-42(5th Edition)*. North Carolina. (http://www.epa.gov/ttn/chief/ap42/ch13/final/c13s05.pdf)

Perry & Chilton. 1973. Heat Generation and Transport: Liquid Petroleum Fuels. *Chemical Engineers' Handbook*. Fifth Edition, McGraw Hill, pp9-11.

F.6 Results

Results of calculations performed for the analysis of the process heaters and boilers at the surveyed facilities are presented below:

Heater and Boiler Index

Facility Name	Device Category	Tag Number	Name	Device Type	Service
Chichimene Station	Heaters and Boilers	AH7472 #1	Heater 7472 (burner 1)	Wall-fired (<=29 MW) Uncontrolled	Hot Oil Heater
Chichimene Station	Heaters and Boilers	AH7472 #1	Heater 7472 (burner 1)	Wall-fired (<=29 MW) Uncontrolled	Hot Oil Heater
Chichimene Station	Heaters and Boilers	AH7472 #1	Heater 7472 (burner 1)	Wall-fired (<=29 MW) Uncontrolled	Hot Oil Heater
Chichimene Station	Heaters and Boilers	AH7472 #2	Heater 7472 (burner 2)	Wall-fired (<=29 MW) Uncontrolled	Hot Oil Heater
Chichimene Station	Heaters and Boilers	AH7472 #2	Heater 7472 (burner 2)	Wall-fired (<=29 MW) Uncontrolled	Hot Oil Heater
Chichimene Station	Heaters and Boilers	AH7472 #2	Heater 7472 (burner 2)	Wall-fired (<=29 MW) Uncontrolled	Hot Oil Heater
Chichimene Station	Heaters and Boilers	AH7473 #1	Heater 7473 (burner 1)	Wall-fired (<=29 MW) Uncontrolled	Hot Oil Heater
Chichimene Station	Heaters and Boilers	AH7473 #1	Heater 7473 (burner 1)	Wall-fired (<=29 MW) Uncontrolled	Hot Oil Heater
Chichimene Station	Heaters and Boilers	AH7473 #1	Heater 7473 (burner 1)	Wall-fired (<=29 MW) Uncontrolled	Hot Oil Heater
Chichimene Station	Heaters and Boilers	AH7473 #2	Heater 7473 (burner 2)	Wall-fired (<=29 MW) Uncontrolled	Hot Oil Heater
Chichimene Station	Heaters and Boilers	AH7473 #2	Heater 7473 (burner 2)	Wall-fired (<=29 MW) Uncontrolled	Hot Oil Heater

Chichimene Station	Heaters and Boilers	AH7473 #2	Heater 7473 (burner 2)	Wall-fired (<=29 MW) Uncontrolled	Hot Oil Heater

Combustion Analysis
Report Summary

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Heater 7472 (burner 1)
ID	AH7472 #1
On Site Location	Chichimene
Category	Heaters and Boilers
Type	Wall-fired (<=29 MW) Uncontrolled
Service	Hot Oil Heater
Manufacturer	TECNITANQUES INGENIEROS
Model	0720 - 02
Model Year	N/A
Installation Date	N/A

Report Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Applied Emission Factors (ng/J)		
Substance	**Value**	**Source**
CH_4 Emission Factor	297.91	User Entered
N_2O Emission Factor	0.90	US EPA AP-42
VOC Emission Factor	803.61	User Entered
CO Emission Factor	827.25	User Entered
PM Emission Factor	0.80	US EPA AP-42
NO_x Emission Factor	10.95	User Entered

Device Comments and Assumptions
Oil Heater

Data Comments and Assumptions
N/A

Combustion Analysis Input

Gas Stream Conditions			
Stream	**Temperature (^oC)**	**Flow (m3/h @ STP)**	**Relative Humidity (%)**
Ambient Air	34.3		60.0
Fuel	34.3	101.4	0.0
Combustion Air	34.3	0.0	60.0
Flue Gas	328.9	0.0	N/A

General Simulation Data	
Analysis Method	Fuel Flow And Stack Gas
Flue Gas Type	Dry
Local Barometric Pressure (kPa)	95.8
Nominal Rated Power Output (kW)	0
Fuel Cost (USD/GJ)	3.66

Stack Gas Analysis	
Component	**Concentration (On A Dry Volume Basis)**
Oxygen (%)	14.10
Carbon Monoxide (ppm)	1,055.70
Total Combustible (ppm)	1,126.70
Unburnt Fuel (calculated) (ppm)	1,126.70
Nitric Oxide (ppm)	1.70
Nitrogen Dioxide (ppm)	7.40
Sulfur Dioxide (ppm)	0.00

Fuel Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001640	0.001640	0.001705
Ethane	0.040937	0.040937	0.042552
Isobutane	0.013576	0.013576	0.014112
Isopentane	0.092795	0.092795	0.096458
Methane	0.528976	0.528976	0.549854
n-Butane	0.033074	0.033074	0.034379
n-Hexane	0.060806	0.060806	0.063206
Nitrogen	0.092440	0.092440	0.064968
n-Pentane	0.093122	0.093122	0.096797
Oxygen	0.008031	0.008031	0.000000
Propane	0.034604	0.034604	0.035970
Total	**#VALUE!**	**1.000000**	**1.000000**

Combustion Analysis Output

Fuel Gas Characteristics	
Molecular Weight (kg/kmol)	35.8
Quality (inlet condition) (%)	1.0
Gross Heating Value (MJ/m^3)	73.4
Net Heating Value (MJ/m^3)	66.6
Theoretic Combustion Air Requirement (kmol/kmol)	19.2

Material Balance	
Stream	Flow Rate ($10^3 m^3/d$)
Fuel	2.43
Air	125.76
Stack Gas	129.80

Excess Air	
Type	Amount (%)
Actual	169.5
Recommended Lower Limit	5.0
Recommended Upper Limit	10.0

Energy Balance	
Type	Amount (kW)
Gross Input Energy	2,148.6
Net Input Energy	1,776.9

Avoidable Energy Consumption (Losses)		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
High Excess Air	18.4	327.4
Unburnt Fuel	7.7	137.6
Recoverable Heat in Flue Gas[1]	31.1	551.8

Unavoidable Energy Comsumption Losses		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unrecoverable Heat in Flue Gas[1]	16.8	298.0

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

Efficiencies	
Efficiency Type	Amount (%)
Apparent Thermal Efficiency	44.4
Carbon Combustion Efficiency	91.9

Stack Gas Characteristics	
Molecular Weight (kg/kmol)	28.27
Dew Temperature (°C)	42.9

Determined Flue Gas Emission Factors[2]	
Component	Amount (ng/J)
Carbon Monoxide	827.3
Carbon Dioxide	53,232.4
Methane	297.9
Ethane	43.2
Total VOC	803.6
Total Hydrocarbons	1,144.8
Nitric Oxide	1.4
Nitrogen Dioxide	9.5
Total Oxides of Nitrogen	11.0
Hydrogen Sulfide	0.0
Sulfur Dioxide	0.0
Carbon Disulfide	0.0
Carbonyl Sulfide	0.0
Total TRS	0.0

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The SO_2 emission factor is based on the concentration measured in the flue gas.

Dry Flue Gas Analysis	
Component	**Mole Fraction**
nitrogen	0.813574
oxygen	0.141000
carbon_dioxide	0.043235
carbon_monoxide	0.001056
methane	0.000664
n-pentane	0.000117
isopentane	0.000116
n-hexane	0.000076
ethane	0.000051
propane	0.000043
n-butane	0.000042
isobutane	0.000017
nitrogen_dioxide	0.000007
nitric_oxide	0.000002
Total	**#VALUE!**

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Tuning	4 per Year	17.50	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Tuning	4 per Year	0	1,000	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Tuning	4 per Year	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Heater 7472 (burner 1)	AH7472 #1	Hot Oil Heater	816,335	101.4	1.34	0.37	0.82	3.15	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
19.4	3,777	0.06	4,203	52.4	53.9	0.7	0.0	0.1

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Tuning	17.50	3,750	0	1,000	142,859	1,041,149	3782.90	0.03

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Tuning	3.40	661	0.01	736	9.17	9.44	0.12	0.00	0.01

Combustion Analysis Report Summary

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Heater 7472 (burner 2)
ID	AH7472 #2
On Site Location	Chichimene
Category	Heaters and Boilers
Type	Wall-fired (<=29 MW) Uncontrolled
Service	Hot Oil Heater
Manufacturer	TECNITANQUES INGENIEROS
Model	0720 - 02
Model Year	N/A
Installation Date	N/A

Report Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Applied Emission Factors (ng/J)		
Substance	**Value**	**Source**
CH_4 Emission Factor	297.91	User Entered
N_2O Emission Factor	0.90	US EPA AP-42
VOC Emission Factor	131.87	User Entered
CO Emission Factor	57,317	User Entered
PM Emission Factor	0.80	US EPA AP-42
NO_x Emission Factor	32.43	User Entered

Device Comments and Assumptions
Oil Heater

Data Comments and Assumptions
N/A

Combustion Analysis Input

Gas Stream Conditions			
Stream	**Temperature (^oC)**	**Flow (m3/h @ STP)**	**Relative Humidity (%)**
Ambient Air	34.3		60.0
Fuel	34.3	101.4	0.0
Combustion Air	34.3	0.0	60.0
Flue Gas	399.6	0.0	N/A

General Simulation Data	
Analysis Method	Fuel Flow And Stack Gas
Flue Gas Type	Dry
Local Barometric Pressure (kPa)	95.8
Nominal Rated Power Output (kW)	0
Fuel Cost (USD/GJ)	3.66

Stack Gas Analysis	
Component	**Concentration (On A Dry Volume Basis)**
Oxygen (%)	10.50
Carbon Monoxide (ppm)	59.70
Total Combustible (ppm)	266.70
Unburnt Fuel (calculated) (ppm)	266.70
Nitric Oxide (ppm)	4.30
Nitrogen Dioxide (ppm)	20.00
Sulfur Dioxide (ppm)	0.00

Fuel Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001640	0.001640	0.001705
Ethane	0.040937	0.040937	0.042552
Isobutane	0.013576	0.013576	0.014112
Isopentane	0.092795	0.092795	0.096458
Methane	0.528976	0.528976	0.549854
n-Butane	0.033074	0.033074	0.034379
n-Hexane	0.060806	0.060806	0.063206
Nitrogen	0.092440	0.092440	0.064968
n-Pentane	0.093122	0.093122	0.096797
Oxygen	0.008031	0.008031	0.000000
Propane	0.034604	0.034604	0.035970
Total	**1.000000**	**1.000000**	**1.000000**

Combustion Analysis Output

Fuel Gas Characteristics	
Molecular Weight (kg/kmol)	35.8
Quality (inlet condition) (%)	1.0
Gross Heating Value (MJ/m^3)	73.4
Net Heating Value (MJ/m^3)	66.6
Theoretic Combustion Air Requirement (kmol/kmol)	19.2

Material Balance	
Stream	Flow Rate ($10^3m^3/d$)
Fuel	2.43
Air	88.62
Stack Gas	92.68

Excess Air	
Type	Amount (%)
Actual	89.9
Recommended Lower Limit	5.0
Recommended Upper Limit	10.0

Energy Balance	
Type	Amount (kW)
Gross Input Energy	2,121.2
Net Input Energy	1,749.0

Avoidable Energy Consumption (Losses)		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
High Excess Air	11.7	205.1
Unburnt Fuel	1.2	20.4
Recoverable Heat in Flue Gas[1]	28.5	498.6

Unavoidable Energy Comsumption Losses		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unrecoverable Heat in Flue Gas[1]	15.8	276.4

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

Efficiencies	
Efficiency Type	Amount (%)
Apparent Thermal Efficiency	54.5
Carbon Combustion Efficiency	99.0

Stack Gas Characteristics	
Molecular Weight (kg/kmol)	28.17
Dew Temperature (°C)	47.9

Determined Flue Gas Emission Factors[2]	
Component	Amount (ng/J)
Carbon Monoxide	32.4
Carbon Dioxide	57,316.9
Methane	48.9
Ethane	7.1
Total VOC	131.9
Total Hydrocarbons	187.9
Nitric Oxide	2.5
Nitrogen Dioxide	17.8
Total Oxides of Nitrogen	20.3
Hydrogen Sulfide	0.0
Sulfur Dioxide	0.0
Carbon Disulfide	0.0
Carbonyl Sulfide	0.0
Total TRS	0.0

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The SO_2 emission factor is based on the concentration measured in the flue gas.

Dry Flue Gas Analysis	
Component	**Mole Fraction**
nitrogen	0.827502
oxygen	0.105000
carbon_dioxide	0.067148
methane	0.000157
carbon_monoxide	0.000060
n-pentane	0.000028
isopentane	0.000028
nitrogen_dioxide	0.000020
n-hexane	0.000018
ethane	0.000012
propane	0.000010
n-butane	0.000010
nitric_oxide	0.000004
isobutane	0.000004
Total	**1.000000**

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Tuning	4 per Year	10.90	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Tuning	4 per Year	0	1,000	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Tuning	4 per Year	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Heater 7472 (burner 2)	AH7472 #2	Hot Oil Heater	816,335	101.4	1.34	0.37	0.82	3.15	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
19.4	3,777	0.06	4,203	8.6	3736.9	2.1	0.0	0.1

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Tuning	10.90	3,750	0	1,000	88,981	644,295	2346.15	0.04

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Tuning	2.12	412	0.01	458	0.94	407.33	0.23	0.00	0.01

Combustion Analysis Report Summary

CLEARSTONE ENGINEERING

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Heater 7473 (burner 1)
ID	AH7473 #1
On Site Location	Chichimene
Category	Heaters and Boilers
Type	Wall-fired (<=29 MW) Uncontrolled
Service	Hot Oil Heater
Manufacturer	TECNITANQUES INGENIEROS
Model	0720 - 02
Model Year	N/A
Installation Date	N/A

Report Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Applied Emission Factors (ng/J)

Substance	Value	Source
CH_4 Emission Factor	39.54	User Entered
N_2O Emission Factor	0.90	US EPA AP-42
VOC Emission Factor	106.67	User Entered
CO Emission Factor	3.78	User Entered
PM Emission Factor	0.80	US EPA AP-42
NO_x Emission Factor	15.89	User Entered

Device Comments and Assumptions

Oil Heater

Data Comments and Assumptions

N/A

Combustion Analysis Input

Gas Stream Conditions			
Stream	**Temperature (°C)**	**Flow (m3/h @ STP)**	**Relative Humidity (%)**
Ambient Air	35.0		60.0
Fuel	35.0	277.3	0.0
Combustion Air	35.0	0.0	60.0
Flue Gas	238.2	0.0	N/A

General Simulation Data	
Analysis Method	Fuel Flow And Stack Gas
Flue Gas Type	Dry
Local Barometric Pressure (kPa)	95.8
Nominal Rated Power Output (kW)	0
Fuel Cost (USD/GJ)	3.66

Stack Gas Analysis	
Component	**Concentration (On A Dry Volume Basis)**
Oxygen (%)	14.50
Carbon Monoxide (ppm)	4.30
Total Combustible (ppm)	133.30
Unburnt Fuel (calculated) (ppm)	133.30
Nitric Oxide (ppm)	1.70
Nitrogen Dioxide (ppm)	9.90
Sulfur Dioxide (ppm)	0.00

Fuel Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001640	0.001640	0.001705
Ethane	0.040937	0.040937	0.042552
Isobutane	0.013576	0.013576	0.014112
Isopentane	0.092795	0.092795	0.096458
Methane	0.528976	0.528976	0.549854
n-Butane	0.033074	0.033074	0.034379
n-Hexane	0.060806	0.060806	0.063206
Nitrogen	0.092440	0.092440	0.064968
n-Pentane	0.093122	0.093122	0.096797
Oxygen	0.008031	0.008031	0.000000
Propane	0.034604	0.034604	0.035970
Total	**1.000000**	**1.000000**	**1.000000**

Combustion Analysis Output

Fuel Gas Characteristics	
Molecular Weight (kg/kmol)	35.8
Quality (inlet condition) (%)	1.0
Gross Heating Value (MJ/m^3)	73.4
Net Heating Value (MJ/m^3)	66.6
Theoretic Combustion Air Requirement (kmol/kmol)	19.2

Material Balance	
Stream	Flow Rate ($10^3 m^3/d$)
Fuel	6.66
Air	386.27
Stack Gas	397.38

Excess Air	
Type	Amount (%)
Actual	202.3
Recommended Lower Limit	5.0
Recommended Upper Limit	10.0

Energy Balance	
Type	Amount (kW)
Gross Input Energy	5,921.9
Net Input Energy	4,828.9

Avoidable Energy Consumption (Losses)		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
High Excess Air	15.3	738.6
Unburnt Fuel	0.9	43.9
Recoverable Heat in Flue Gas[1]	23.2	1121.0

Unavoidable Energy Comsumption Losses		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unrecoverable Heat in Flue Gas[1]	18.5	891.9

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

Efficiencies	
Efficiency Type	Amount (%)
Apparent Thermal Efficiency	57.4
Carbon Combustion Efficiency	99.2

Stack Gas Characteristics	
Molecular Weight (kg/kmol)	28.27
Dew Temperature (^oC)	42.4

Determined Flue Gas Emission Factors[2]	
Component	Amount (ng/J)
Carbon Monoxide	3.8
Carbon Dioxide	57,468.3
Methane	39.5
Ethane	5.7
Total VOC	106.7
Total Hydrocarbons	152.0
Nitric Oxide	1.6
Nitrogen Dioxide	14.3
Total Oxides of Nitrogen	15.9
Hydrogen Sulfide	0.0
Sulfur Dioxide	0.0
Carbon Disulfide	0.0
Carbonyl Sulfide	0.0
Total TRS	0.0

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The SO_2 emission factor is based on the concentration measured in the flue gas.

Dry Flue Gas Analysis	
Component	**Mole Fraction**
nitrogen	0.813252
oxygen	0.145000
carbon_dioxide	0.041598
methane	0.000079
n-pentane	0.000014
isopentane	0.000014
nitrogen_dioxide	0.000010
n-hexane	0.000009
ethane	0.000006
propane	0.000005
n-butane	0.000005
carbon_monoxide	0.000004
isobutane	0.000002
nitric_oxide	0.000002
Total	**1.000000**

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Tuning	4 per Year	14.40	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Tuning	4 per Year	0	1,000	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Tuning	4 per Year	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Heater 7473 (burner 1)	AH7473 #1	Hot Oil Heater	2,232,009	277.3	3.66	1.01	2.24	8.61	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
7.0	10,327	0.16	10,524	19.0	0.7	2.8	0.0	0.1

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Tuning	14.40	3,750	0	1,000	321,409	2,356,313	8544.25	0.01

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Tuning	1.01	1,487	0.02	1,516	2.74	0.10	0.41	0.00	0.02

Combustion Analysis
Report Summary

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Heater 7473 (burner 2)
ID	AH7473 #2
On Site Location	Chichimene
Category	Heaters and Boilers
Type	Wall-fired (<=29 MW) Uncontrolled
Service	Hot Oil Heater
Manufacturer	TECNITANQUES INGENIEROS
Model	0720 - 02
Model Year	N/A
Installation Date	N/A

Report Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Applied Emission Factors (ng/J)		
Substance	**Value**	**Source**
CH_4 Emission Factor	5.27	User Entered
N_2O Emission Factor	0.90	US EPA AP-42
VOC Emission Factor	14.22	User Entered
CO Emission Factor	3.31	User Entered
PM Emission Factor	0.80	US EPA AP-42
NO_x Emission Factor	17.08	User Entered

Device Comments and Assumptions
Oil Heater

Data Comments and Assumptions
N/A

Combustion Analysis Input

Gas Stream Conditions			
Stream	**Temperature (^oC)**	**Flow (m3/h @ STP)**	**Relative Humidity (%)**
Ambient Air	35.0		60.0
Fuel	35.0	277.3	0.0
Combustion Air	35.0	0.0	60.0
Flue Gas	316.5	0.0	N/A

General Simulation Data	
Analysis Method	Fuel Flow And Stack Gas
Flue Gas Type	Dry
Local Barometric Pressure (kPa)	95.8
Nominal Rated Power Output (kW)	50
Assumed Efficiency (%)	82
Assumed Loading (%)	100
Fuel Cost (USD/GJ)	3.66

Stack Gas Analysis	
Component	**Concentration (On A Dry Volume Basis)**
Oxygen (%)	11.80
Carbon Monoxide (ppm)	5.30
Total Combustible (ppm)	25.00
Unburnt Fuel (calculated) (ppm)	25.00
Nitric Oxide (ppm)	20.30
Nitrogen Dioxide (ppm)	3.40
Sulfur Dioxide (ppm)	0.80

Fuel Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001640	0.001640	0.001705
Ethane	0.040937	0.040937	0.042552
Isobutane	0.013576	0.013576	0.014112
Isopentane	0.092795	0.092795	0.096458
Methane	0.528976	0.528976	0.549854
n-Butane	0.033074	0.033074	0.034379
n-Hexane	0.060806	0.060806	0.063206
Nitrogen	0.092440	0.092440	0.064968
n-Pentane	0.093122	0.093122	0.096797
Oxygen	0.008031	0.008031	0.000000
Propane	0.034604	0.034604	0.035970
Total	**1.000000**	**1.000000**	**1.000000**

Combustion Analysis Output

Fuel Gas Characteristics	
Molecular Weight (kg/kmol)	35.8
Quality (inlet condition) (%)	1.0
Gross Heating Value (MJ/m^3)	73.4
Net Heating Value (MJ/m^3)	66.6
Theoretic Combustion Air Requirement (kmol/kmol)	19.2

Material Balance	
Stream	Flow Rate ($10^3m^3/d$)
Fuel	6.66
Air	277.80
Stack Gas	288.94

Excess Air	
Type	Amount (%)
Actual	117.4
Recommended Lower Limit	5.0
Recommended Upper Limit	10.0

Energy Balance	
Type	Amount (kW)
Gross Input Energy	5,837.5
Net Input Energy	4,788.4

Avoidable Energy Consumption (Losses)		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
High Excess Air	12.0	576.3
Unburnt Fuel	0.1	6.0
Recoverable Heat in Flue Gas[1]	24.3	1163.8

Unavoidable Energy Comsumption Losses		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unrecoverable Heat in Flue Gas[1]	16.7	800.6

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

Efficiencies	
Efficiency Type	Amount (%)
Apparent Thermal Efficiency	58.8
Carbon Combustion Efficiency	99.9

Stack Gas Characteristics	
Molecular Weight (kg/kmol)	28.19
Dew Temperature (°C)	46.5

Determined Flue Gas Emission Factors[2]	
Component	Amount (ng/J)
Carbon Monoxide	3.3
Carbon Dioxide	57,859.3
Methane	5.3
Ethane	0.8
Total VOC	14.2
Total Hydrocarbons	20.3
Nitric Oxide	13.6
Nitrogen Dioxide	3.5
Total Oxides of Nitrogen	17.1
Hydrogen Sulfide	0.0
Sulfur Dioxide	1.3
Carbon Disulfide	0.0
Carbonyl Sulfide	0.0
Total TRS	0.0

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The SO_2 emission factor is based on the concentration measured in the flue gas.

Dry Flue Gas Analysis	
Component	**Mole Fraction**
nitrogen	0.823044
oxygen	0.118000
carbon_dioxide	0.058902
nitric_oxide	0.000020
methane	0.000015
carbon_monoxide	0.000005
nitrogen_dioxide	0.000003
n-pentane	0.000003
isopentane	0.000003
n-hexane	0.000002
ethane	0.000001
propane	0.000001
n-butane	0.000001
isobutane	0.000000
Total	**1.000000**

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Tuning	4 per Year	11.20	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Tuning	4 per Year	0	1,000	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Tuning	4 per Year	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3$/d)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Heater 7473 (burner 2)	AH7473 #2	Hot Oil Heater	2,232,009	277.3	3.66	1.01	2.24	8.61	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
0.9	10,327	0.16	10,396	2.5	0.6	3.0	0.0	0.1

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Tuning	11.20	3,750	0	1,000	249,985	1,830,218	6639.60	0.02

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Tuning	0.11	1,157	0.02	1,164	0.28	0.07	0.34	0.00	0.02

APPENDIX G ENGINES

G.1 Introduction

The purpose of natural gas-fuelled engines is to provide useful mechanical work at the best possible energy conversion efficiency.

G.2 Background

The manufacturer's specifications and operating data for each active engine surveyed during the measurement campaign were input into a proprietary Clearstone software program to evaluate any departures from optimum potential performance. The manufacturer's specifications and compiled operating data include the engine type, make, model, maximum rated power output, performance curves, recommended settings, actual settings, and, where measured, fuel and exhaust (flue) gas composition and flows. The measured fuel and exhaust gas compositions are used to determine the air-to-fuel and exhaust-to-fuel ratios. The combustion air, fuel and flue gas flows were measured where possible. Otherwise, fuel consumption was determined based on the engine's efficiency and the amount of work it was performing.

A material balance was performed, on a mole basis, to solve the following stoichiometric relation and thereby determine the flow rates of the unknown streams from the known (measured) flow rates:

$$Fuel + a \cdot Air \rightarrow b \cdot Flue + c \cdot H_2O$$

Equation 35

A nitrogen balance was used to determine *a*, while b and c were determined using a carbon and hydrogen balance.

The potentially recoverable stack gas heat loss was determined, using proprietary Clearstone software, as the energy that can be recovered by cooling the stack gas from the measured stack gas temperature to 10°C above its dew point or to 15°C, whichever is greater. The remaining heat content of the flue gas was considered to be unrecoverable heat. Only the economic value of potentially recoverable heat loss was considered.

For the purpose of combustion and thermal efficiency analyses, the stack gas temperature must be measured as close to the exhaust manifold of the engine as possible, and, preferably, upstream of any catalytic converter. In cases where the exhaust gases are used to preheat air or fuel, the stack gas temperature measurement should be performed after the heat exchanger.

G.2.1 Definitions

Both combustion efficiency and energy efficiency are assessed in the evaluation of engines.

G.2.1.1 Combustion Efficiency (CE)

Combustion efficiency is defined as the total enthalpy contained in the reactants minus the total enthalpy contained in the products, divided by the energy content of the fuel. This may be expressed by the following relation:

$$\frac{\left(\dot{m}_{FUEL} \cdot h^f_{FUEL} + \dot{m}_{AIR} \cdot h^f_{AIR} - \dot{m}_{FLUE} \cdot h^f_{FLUE}\right)}{\dot{m}_{FUEL} \cdot LHV}$$

Equation 36

Where:

- $\dot{m}$ is the molar flow rate of the stream (i.e., fuel, air, or flue gas) (kmole/h),
- h^f is the heat of formation of the stream (MJ/kmole), and
- LHV is the lower heating value of the fuel gas stream (MJ/kmole)

For ideal operation, reciprocating engine combustion efficiencies calculated with this equation are expected to be in the range of 95 to 98 percent when the amount of combustion air supplied is close to the stoichiometric value. The combustion efficiency can be greater than 99 percent when increased excess air is supplied as is the case for low NO_x operations and for natural gas fuelled turbine engines.

G.2.1.2 Excess Air (EA)

Excess air is defined as the amount of supplied combustion air that is in excess of the stoichiometric amount required. Stoichiometric (or theoretical) combustion is a process which burns all the carbon (C) to CO_2, all hydrogen (H) to H_2O and all sulphur (S) to SO_2. Excess air is a function of the air-to-fuel ratio and is controlled by the manual adjustments of the carburetor or fuel injection system, or automatically by an air-to-fuel ratio controller.

Optimum excess air values vary by type of fuel, engine, manufacturer and model number. Typical values for natural gas-fuelled engines are listed below:

Reciprocating Engines – 2-stroke	Air/Fuel ratio of 40 to 52 percent
Reciprocating Engines – 4-stroke	0.5 to 2 percent O_2 in exhaust gas for normal and 6 to 7.8 percent O_2 in the exhaust gas for low NO_x
Gas Turbines	15 to 18 percent oxygen in the exhaust gas.

G.2.1.3 Energy Efficiency (EF)

While combustion efficiency is useful in demonstrating how much of the energy in the fuel is converted to heat, it does not provide a complete description of how effectively the equipment is utilizing this energy.

Reciprocating Engines: A typical energy balance based on one manufacturers' heat load data yields:

- Energy from Fuel 100 %
- Useful Work 30 to 35 %
- Jacket Water and Oil Cooler 15 to 40 %
- Radiation 3.5 to 7.5 %
- Turbocharger After Cooler 1 to 6 %
- Exhaust (or Stack Losses) 20 to 35 %

The heat loads for jacket water, oil cooler, turbocharger after-cooler and radiation are typically determined by design or safe operating conditions. The amount of heat lost via the exhaust is a function of the engine's combustion efficiency and the quantity of combustion air that is required for efficient operation. Useful work is whatever is left over after all losses have been accounted for. Since heat losses to the jacket water, oil cooler, turbo-charger after cooler and radiation from the engine body are typically fixed by design, the amount of heat lost via the exhaust is a good indication of whether or not the engine is being operating efficiently.

Gas Turbines: A typical energy balance based on one manufacturers' heat load data yields:

- Energy from Fuel 100 %
- Useful Work 30 to 40 %
- Radiation 2 to 5 %
- Exhaust (or Stack Losses) 55 to 68 %

G.2.1.4 Recoverable Stack Heat

Stack heat losses are calculated using the following simplified heat balance relation:

$$Fraction\ of\ Heat\ Lost = \frac{Stack\ Losses}{Heat\ Input}$$

Equation 37

where

$$\begin{aligned} Heat\ Input = {} & Energy\ Content\ of\ Fuel + Sensible\ Heat\ in\ Fuel \\ & + Sensible\ Heat\ in\ Combustion\ Air \end{aligned}$$

Equation 38

Stack Losses = Energy Content of the Exhaust Gas + Convective Stack Losses + Sensible Heat in the Exhaust Gas

Equation 39

G.3 Performance Evaluation Methodology

The performance of natural gas-fuelled engines was analysed, using Clearstone's proprietary combustion system software and field operating data collected or measured during the site survey. The results are compared to the manufacturer's performance curve or, in the absence of performance curves, to the typical benchmark values presented in Section F.2.

The testing done on each unit comprised analyzing the flue gas composition, measuring the flue gas temperature, obtaining the fuel gas composition, and where possible, measuring the flow rate of one or more of the following: fuel gas, combustion air and flue gas. Additionally, the make and model of each active engine, and ambient temperature and barometric pressure at the site were recorded where available.

G.3.1 Avoidable Fuel Consumption

The incremental fuel costs associated with the improper tuning or operation of an engine comprises two parts:

- Increased fuel consumption due to unburned fuel in the exhaust gas.
- Increased fuel consumption from operating at excessive air-to-fuel ratios.

For reciprocating engines, there may also be inefficiencies due to excessive leakage past the piston rings resulting in crankcase blow-by, and due to loss of compression caused by leaking cylinder valves. These losses can potentially be evaluated by comparing the actual power output of the engine, where this is possible to determine (e.g., based on the work being performed and estimated mechanical losses), to its performance curve.

The value of any unburned or partially burned fuel is determined based on the residual heating value of the exhaust gas, the incremental amount of fuel needed to make up for this energy loss, and the specific price of the fuel or input energy (typically in $/GJ).

The cost associated with operations using too much excess air is determined by comparing the measured air-to-fuel ratio with typical values specified by the engine manufacturer or best management practice (BMP) values appropriate for the engine type being assessed. The cost is calculated by determining the amount of heat required to heat the excess air from ambient temperature to the exhaust stack temperature and applying the assigned monetary value of the energy.

The optimum air-to-fuel ratio for reciprocating engines varies significantly with the make and model of the unit. The manufacturers' values are used wherever possible; otherwise, the average value determined for the types of engines tested is used.

G.3.2 Emissions and Emissions Reduction Potential

Excessive emissions and potential emissions reduction opportunities are determined and expressed in terms of fuel gas (10^3 m^3/d), methane (t CH_4/y) and total greenhouse gases (GHG) (t CO_2E/y). The global warming potential of methane is taken as 21 for purposes of calculation GHG emissions.

G.3.3 Fuel Gas Composition

The fuel gas was either sampled and analyzed (e.g., using a field gas chromatograph [GC] or by sending the sample to a suitable laboratory) or obtained from the facility operator. If wide fluctuations in fuel gas composition are typical for a facility, an analysis that is consistent with the engine performance and flue gas measurements is required for use in the efficiency calculations. Where a representative fuel gas analysis is not available, a sample of the fuel is collected from the fuel gas line and sent to a suitable laboratory for analysis.

Clearstone's field gas chromatographs comprise a selection of micro GC/FID/TCD and GC/TCD units as well as an optical spectrometer capable of analyzing for C_1 to C_{5+} hycrocarbons and CO_2.

G.3.4 Flue Gas Composition

The flue gas analyses were conducted using a Testo 350 Portable Combustion Analyzer, or equivalent analyzer, equipped with detectors for O_2, CO, CO_2, NO_x, SO_2, and combustibles, and thermocouples for measuring ambient and stack-gas temperatures. The flue gas was sampled either through a convenient sampling port on the exhaust stack or at the top of the stack. The flue gas temperature was measured immediately downstream of the turbo charger (if applicable) or at the exhaust manifold if it was a naturally aspirated unit. All results were corrected to account for the actual fuel gas composition.

G.3.5 Data Evaluation

- **Carbon Dioxide –** Actual CO_2 emissions determined from the flue gas analyses are compared to the maximum possible CO_2 emissions determined based on the carbon content of the fuel. These results should not be compared to typical U.S. EPA AP-42 or CAPP emission factor values unless the published emission factors are corrected to the carbon content of the fuel.
- **Carbon Monoxide –** Measured CO emissions per unit of energy input, expressed as nanogram per Joule (ng/J), are compared to regulatory requirements, manufacturer's specifications or typical values provided by U.S. EPA AP-42 or

CAPP for target type of engines. Significantly greater actual values may be caused by fuel quality problems, insufficient combustion air, improper engine tuning, a faulty ignition system, or poor mixing.

- **Oxides of Nitrogen** - Measured NO_x emissions per unit of energy input, expressed as ng/J, are compared to regulatory requirements, manufacturer's specifications or typical emission factor values provided by U.S. EPA AP-42 or CAPP for various types of engines. Significantly greater actual values may be caused by improper tuning, poor mixing or high concentrations of organically bound nitrogen in the fuel.
- **Methane (CH_4)** - Measured CH_4 emissions per unit of energy input, expressed as ng/J, are compared to the applicable regulatory requirements, manufacturer's specifications or typical values provided by U.S. EPA AP-42 or CAPP for various types of engines. Significantly greater actual values may be caused by fuel quality problems, insufficient combustion air, improper tuning, a faulty ignition system or poor mixing.

G.4 Energy Management and Emission Control Options

G.4.1 Load Management

Engines are typically designed to operate most efficiently when they are fully loaded. Where engines are significantly oversized for their application, consideration should be given to replacing the unit with a smaller, more appropriately sized engine. Where multiple units are operating in parallel, consideration should be given to limiting the number of units operating at one time to ensure optimum loading of the operating units. Depending on the situation, these measures can greatly reduce fuel consumption. Oversized engines tend to occur at older facilities where production rates have declined significantly and at newer sites the production potential was significantly overestimated during the design phase.

G.4.2 Air-to-Fuel Ratio Controllers

Engine operating conditions (e.g., engine speed and load, fuel gas quality, and ambient air conditions) change over time and this can have significant effects on the engine's performance and air-to-fuel ratio. Air-to-fuel ratio controllers are available which improve the performance of natural gas-fired, four-cycle, rich-burn and lean-burn reciprocating engines by optimizing and stabilizing the air-to-fuel ratio over a range of engine operating conditions.

Air-to-fuel ratio controllers use a closed-loop feedback system to automatically and continuously optimize the air-to-fuel mixture introduced to the engine based on various input parameters (potentially including fuel quality, engine load, flue gas O_2 levels and ambient conditions). This function provides the potential to improve engine fuel consumption and reduce engine emissions, particularly when noteworthy changes in engine load, fuel quality, or ambient conditions occur. Optimized and stabilized air-to-fuel ratios can improve engine performance, reduce lubrication oil degradation, and help minimize wear to major engine components.

Typically, the controller uses relationships between excess air in the combustion chamber, measured exhaust gas O_2 concentrations, and engine emissions to calculate optimum air-to-fuel ratios at various engine loads. More advanced systems monitor and account for changes in fuel quality.

The performance capabilities of air-to-fuel ratio controllers vary between vendors, and it is clear that not all engines respond favourably to the technology. For this reason, firm performance claims are difficult to obtain. Potential fuel savings of 18 to 24 percent are reported by the US EPA (2004).

Slipstream Technology - The manufacturer of one air-to-fuel controller, REM Technology Inc, has developed a patented enhancement to air-to-fuel ratio controllers called Slipstream technology. This technology allows waste natural gas streams at low or atmospheric pressure to be captured and used by the engine fuel system, thereby, reducing primary fuel consumption, treating waste natural gas streams that might otherwise be vented as methane, reducing overall emissions from the site and potentially increasing incremental production.

To incorporate the Slipstream technology, the engine must be equipped with a REMVue engine management system. Modifications to the carburetor, fuel gas system, wastegas and turbochargers are required to sustain reliable operation of the engine. The Slipstream system uses the REMVue monitoring and control features to allow engine management using commingled streams of the primary fuel source with the fugitive emission sources. The REMVue system can be installed on any style of natural gas fuelled reciprocating engine so the Slipstream technology is not limited to stoichiometric turbocharged engines.

The engine management system can adapt to varying fuel quality and sources. Potential sources of supplementary natural gas streams that the Slipstream system can reportedly accommodate include:

- Seal vents.
- Tank vents.
- Pneumatic controller vents.
- Process vent and flare systems.
- Dehydrator still column off gas (possibly).
- Natural gas plant recycle and residue gas and other internal sources.

G.4.3 Waste Heat Recovery

With typical thermal efficiencies of only 30 to 35 percent, gas-fired engines provide significant amounts of waste heat that may be beneficially recovered to effectively reduce the energy intensity of a facility. This heat could be used for a variety of useful purposes ranging from the production of utility heat to the generation of electric power. At larger facilities, electricity produced from waste heat recovery systems can be used to power electric compressors, other electric drive equipment, or sold to the electric power utility grid. This electricity is essentially emissions free as the waste heat already exists and supplemental firing is not needed. A good low-cost opportunity for waste heat recovery from engines exists at production and processing facilities that have both heat medium heaters and compressors. When the engines are running, waste heat captured from them can be used to offset the duty of the heat medium heater. This may be achieved by circulating the heat medium through the engine coolant system and installing a shell on the flue gas stack and circulating the heat medium through the annulus between the flue stack and the installed shell.

G.5 References

GPSA. 2004. Engineering data Book, Gas Processors Suppliers Association, Vol I, Section 13.

U.S. EPA. 2004. Automated Air/Fuel Ratio Controls, Pro Fact Sheet No. 111, Natural Gas EPA Pollution Preventer.

G.6 Results

Results of calculations performed for the analysis of natural gas-fuelled engines at the surveyed facility are presented below:

Engine Index

Facility Name	Device Category	Tag Number	Name	Device Type	Service
Monterrey Station	Reciprocating Engines	I-001A	Engine 001A	4-Stroke Rich-Burn (90-105% load)	Oil Pump Driver
Monterrey Station	Reciprocating Engines	I-001C	Engine 001C	4-Stroke Rich-Burn (90-105% load)	Oil Pump Driver
Monterrey Station	Reciprocating Engines	III-4410	Engine 4410	4-Stroke Rich-Burn (90-105% load)	Oil Pump Driver
Monterrey Station	Reciprocating Engines	III-4420	Engine 4420	4-Stroke Rich-Burn (90-105% load)	Oil Pump Driver
Monterrey Station	Reciprocating Engines	III-4420	Engine 4420	4-Stroke Rich-Burn (90-105% load)	Oil Pump Driver
Monterrey Station	Reciprocating Engines	III-4430	Engine 4430	4-Stroke Rich-Burn (90-105% load)	Oil Pump Driver
Monterrey Station	Reciprocating Engines	III-4430	Engine 4430	4-Stroke Rich-Burn (90-105% load)	Oil Pump Driver
Monterrey Station	Reciprocating Engines	III-4440	Engine 4440	4-Stroke Rich-Burn (90-105% load)	Oil Pump Driver
Monterrey Station	Reciprocating Engines	III-4440	Engine 4440	4-Stroke Rich-Burn (90-105% load)	Oil Pump Driver
Monterrey Station	Reciprocating Engines	III-4450	Engine 4450	4-Stroke Rich-Burn (90-105% load)	Oil Pump Driver
Monterrey Station	Reciprocating Engines	III-4450	Engine 4450	4-Stroke Rich-Burn (90-105% load)	Oil Pump Driver

Monterrey Station	Reciprocating Engines	III-4460	Engine 4460	4-Stroke Rich-Burn (90-105% load)	Oil Pump Driver

8

Combustion Analysis Report Summary

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	N/A
Name	Monterrey Station
Location	Monterrey-Casanare
ID	MonterreyStation
Category	Pump Station
Type	Oil
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Engine 001A
ID	I-001A
On Site Location	Monterrey (Yopal - Casanare)
Category	Reciprocating Engines
Type	4-Stroke Rich-Burn (90-105% load)
Service	Oil Pump Driver
Manufacturer	WAUKESHA
Model	F18GSI
Model Year	N/A
Installation Date	Sep 8 2009 12:00AM

Report Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Applied Emission Factors (ng/J)		
Substance	**Value**	**Source**
CH_4 Emission Factor	99.00	US EPA AP-42
N_2O Emission Factor	5.72	US EPA AP-42
VOC Emission Factor	12.70	US EPA AP-42
CO Emission Factor	1,509	US EPA AP-42
PM Emission Factor	4.09	US EPA AP-42
NO_x Emission Factor	16.50	User Entered

Device Comments and Assumptions
Internal Combustion Engine

Data Comments and Assumptions
N/A

Combustion Analysis Input

Gas Stream Conditions			
Stream	**Temperature (^oC)**	**Flow (m3/h @ STP)**	**Relative Humidity (%)**
Ambient Air	30.0		60.0
Fuel	30.0	72.5	0.0
Combustion Air	30.0	0.0	60.0
Flue Gas	327.2	0.0	N/A
Radiator Air (In)	30.0		0.0
Radiator Air (Out)	30.0		0.0

General Simulation Data	
Analysis Method	Fuel Flow And Stack Gas
Flue Gas Type	Dry
Local Barometric Pressure (kPa)	95.8
Nominal Rated Power Output (kW)	298
Assumed Efficiency (%)	31.69
Assumed Loading (%)	100
Fuel Cost (USD/GJ)	3.66

Stack Gas Analysis	
Component	**Concentration (On A Dry Volume Basis)**
Oxygen (%)	0.00
Carbon Monoxide (ppm)	0.00
Total Combustible (ppm)	0.00
Unburnt Fuel (calculated) (ppm)	0.00
Nitric Oxide (ppm)	57.30
Nitrogen Dioxide (ppm)	0.50
Sulfur Dioxide (ppm)	0.00

Fuel Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Ethane	0.082500	0.082500	0.087246
Isobutane	0.004680	0.004680	0.004949
Isopentane	0.000575	0.000575	0.000608
Methane	0.825081	0.825081	0.872547
n-Butane	0.004203	0.004203	0.004445
n-Heptane	0.000295	0.000295	0.000311
n-Hexane	0.000116	0.000116	0.000123
Nitrogen	0.042190	0.042190	0.000000
n-Pentane	0.000429	0.000429	0.000454
Oxygen	0.012210	0.012210	0.000000
Propane	0.027722	0.027722	0.029317
Total	**#VALUE!**	**1.000000**	**1.000000**

Combustion Analysis Output

Fuel Gas Characteristics	
Molecular Weight (kg/kmol)	18.6
Quality (inlet condition) (%)	1.0
Gross Heating Value (MJ/m^3)	43.1
Net Heating Value (MJ/m^3)	38.3
Theoretic Combustion Air Requirement (kmol/kmol)	11.1

Material Balance	
Stream	Flow Rate ($10^3 m^3/d$)
Fuel	1.74
Air	19.35
Stack Gas	21.24

Excess Air	
Type	Amount (%)
Actual	0.0
Recommended Lower Limit	2.0
Recommended Upper Limit	12.0

Energy Balance	
Type	Amount (kW)
Gross Input Energy	872.4
Net Input Energy	703.6

Avoidable Energy Consumption (Losses)		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Recoverable Heat in Flue Gas[1]	12.5	88.0

Unavoidable Energy Comsumption Losses		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unrecoverable Heat in Flue Gas[1]	15.6	109.8

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

Efficiencies	
Efficiency Type	Amount (%)
Apparent Thermal Efficiency	71.9
Carbon Combustion Efficiency	100.0

Stack Gas Characteristics	
Molecular Weight (kg/kmol)	27.53
Dew Temperature (^oC)	59.4

Determined Flue Gas Emission Factors[2]	
Component	Amount (ng/J)
Carbon Monoxide	0.0
Carbon Dioxide	51,045.1
Methane	0.0
Ethane	0.0
Total VOC	0.0
Total Hydrocarbons	0.0
Nitric Oxide	16.4
Nitrogen Dioxide	0.2
Total Oxides of Nitrogen	16.6
Hydrogen Sulfide	0.0
Sulfur Dioxide	0.0
Carbon Disulfide	0.0
Carbonyl Sulfide	0.0
Total TRS	0.0

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The SO_2 emission factor is based on the concentration measured in the flue gas.

Dry Flue Gas Analysis	
Component	**Mole Fraction**
nitrogen	0.878538
carbon_dioxide	0.121404
nitric_oxide	0.000057
nitrogen_dioxide	0.000001
oxygen	0.000000
Total	**#VALUE!**

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0.00	0.00	0.00	20	20	-128,982
Tuning	Once per year.	0.00	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0	0	0	0
Tuning	Once per year.	0	2,000	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tuning	Once per year.	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Engine 001A	I-001A	Oil Pump Driver	133,064	72.5	1.52	0.54	0.26	0.01	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
2.7	1,397	0.16	1,502	0.3	41.3	0.5	0.0	0.1

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Organic Rankin Cycle (ORC) Waste Heat	0.00	416,990	0	0	10,319	-340,986	2.47	40.41
Tuning	0.00	0	0	2,000	0	-14,732	NA	NA

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Organic Rankin Cycle (ORC) Waste Heat	0.00	20	0.00	20	0.00	0.00	0.00	0.00	0.00
Tuning	0.00	0	0.00	0	0.00	0.00	0.00	0.00	0.00

Capital Cost Details

Control Technology Type	Application description
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery

Cost Category	Cost Item Type	Item Description	Rate (USD/Unit)	Quantity (Unit)	Line Total (USD)
Construction	Crane Operation	(Crane 75 ton) Quantity in hours	450.00	10.0	4,500
	Electrical	(Electricians) Quantity in hours	60.00	140.0	8,400
	Freight	(Trucking) Quantity in hours	6,000.00	1.0	6,000
	Inspection and Quality Control	(Project Manager) Quantity in hours	120.00	100.0	12,000
	Instrumentation	(Instrument tech) Quantity in hours	60.00	40.0	2,400
	Labourers	(Insulation Removal) Quantity in hours	60.00	40.0	2,400
		(Labour) Quantity in hours	44.00	140.0	6,160
		(Scaffolding) Quantity in hours	80.00	60.0	4,800
	Mobilization and Demobilization	(Truck and Vans) Quantity in hours	25.00	300.0	7,500
		Garbage Removal	800.00	1.0	800
		Scrape Iron Removal	600.00	1.0	600
	Other Constuction Cost	(Custom Broker) Quantity in hours	1,000.00	1.0	1,000
		(Man lift) Quantity in hours	300.00	10.0	3,000
		(Painting) Quantity in hours	52.00	40.0	2,080
		(Zoom boom) Quantity in hours	480.00	5.0	2,400
		Contingency	34,462.00	1.0	34,462

		Porta Potties	550.00	1.0	550
	Pipefitting	(Pipe Fitters) Quantity in hours	58.00	140.0	8,120
	Shelter	(Office trailer) Quantity in hours	200.00	10.0	2,000
	Supervision (third party consultant)	(Commisioning) Quantity in hours	80.00	40.0	3,200
		(Foreman) Quantity in hours	70.00	80.0	5,600
		(Programming) Quantity in hours	130.00	20.0	2,600
		(Supervisor) Quantity in hours	90.00	100.0	9,000
	Welding	(Welder Helpers) Quantity in hours	44.00	140.0	6,160
		(Welder) Quantity in hour	110.00	140.0	15,400
Engineering and Drafting	Process	Engineering	37,908.20	1.0	37,908
Material	Control Panel	Techcable	10.00	300.0	3,000
	Instruments	Instrumentation	10,000.00	1.0	10,000
	Miscellaneous Material Cost	Cable tray	15.00	300.0	4,500
	Other Material Cost	Consumables	5,000.00	1.0	5,000
		ORC Skid Unit	173,000.00	1.0	173,000
		Synchronizing Gear	20,000.00	1.0	20,000
	Pipes and Fittings	Fittings	110.00	15.0	1,650
		Pipe	90.00	20.0	1,800
	Valves	Control Valves	4,500.00	2.0	9,000
				Total	416,990

Combustion Analysis Report Summary

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	N/A
Name	Monterrey Station
Location	Monterrey-Casanare
ID	MonterreyStation
Category	Pump Station
Type	Oil
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Engine 001C
ID	I-001C
On Site Location	Monterrey (Yopal - Casanare)
Category	Reciprocating Engines
Type	4-Stroke Rich-Burn (90-105% load)
Service	Oil Pump Driver
Manufacturer	WAUKESHA
Model	F18GSI
Model Year	N/A
Installation Date	Sep 8 2009 12:00AM

Report Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Applied Emission Factors (ng/J)		
Substance	**Value**	**Source**
CH_4 Emission Factor	99.00	US EPA AP-42
N_2O Emission Factor	5.72	US EPA AP-42
VOC Emission Factor	12.70	US EPA AP-42
CO Emission Factor	1,509	US EPA AP-42
PM Emission Factor	4.09	US EPA AP-42
NO_x Emission Factor	0.87	User Entered

Device Comments and Assumptions
Internal Combustion Engine

Data Comments and Assumptions
N/A

Combustion Analysis Input

Gas Stream Conditions			
Stream	Temperature (^oC)	Flow (m3/h @ STP)	Relative Humidity (%)
Ambient Air	35.0		60.0
Fuel	35.0	72.5	0.0
Combustion Air	35.0	0.0	60.0
Flue Gas	262.7	0.0	N/A
Radiator Air (In)	35.0		0.0
Radiator Air (Out)	35.0		0.0

General Simulation Data	
Analysis Method	Fuel Flow And Stack Gas
Flue Gas Type	Dry
Local Barometric Pressure (kPa)	95.8
Nominal Rated Power Output (kW)	298
Assumed Efficiency (%)	31.69
Assumed Loading (%)	100
Fuel Cost (USD/GJ)	3.66

Stack Gas Analysis	
Component	Concentration (On A Dry Volume Basis)
Oxygen (%)	0.00
Carbon Monoxide (ppm)	0.00
Total Combustible (ppm)	0.00
Unburnt Fuel (calculated) (ppm)	0.00
Nitric Oxide (ppm)	2.30
Nitrogen Dioxide (ppm)	0.50
Sulfur Dioxide (ppm)	119.50

Fuel Analysis Results			
Component Name	Mole Fraction		
	Entered	Normalized	Air Free
Ethane	0.082500	0.082500	0.087246
Isobutane	0.004680	0.004680	0.004949
Isopentane	0.000575	0.000575	0.000608
Methane	0.825081	0.825081	0.872547
n-Butane	0.004203	0.004203	0.004445
n-Heptane	0.000295	0.000295	0.000311
n-Hexane	0.000116	0.000116	0.000123
Nitrogen	0.042190	0.042190	0.000000
n-Pentane	0.000429	0.000429	0.000454
Oxygen	0.012210	0.012210	0.000000
Propane	0.027722	0.027722	0.029317
Total	**1.000000**	**1.000000**	**1.000000**

Combustion Analysis Output

Fuel Gas Characteristics	
Molecular Weight (kg/kmol)	18.6
Quality (inlet condition) (%)	1.0
Gross Heating Value (MJ/m^3)	43.1
Net Heating Value (MJ/m^3)	38.3
Theoretic Combustion Air Requirement (kmol/kmol)	11.2

Material Balance	
Stream	Flow Rate ($10^3m^3/d$)
Fuel	1.74
Air	19.52
Stack Gas	21.42

Excess Air	
Type	Amount (%)
Actual	0.0
Recommended Lower Limit	2.0
Recommended Upper Limit	13.0

Energy Balance	
Type	Amount (kW)
Gross Input Energy	878.0
Net Input Energy	705.4

Avoidable Energy Consumption (Losses)		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Recoverable Heat in Flue Gas[1]	9.3	65.7

Unavoidable Energy Comsumption Losses		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unrecoverable Heat in Flue Gas[1]	16.2	114.1

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

Efficiencies	
Efficiency Type	Amount (%)
Apparent Thermal Efficiency	74.5
Carbon Combustion Efficiency	100.0

Stack Gas Characteristics	
Molecular Weight (kg/kmol)	27.45
Dew Temperature (°C)	60.1

Determined Flue Gas Emission Factors[2]	
Component	Amount (ng/J)
Carbon Monoxide	0.0
Carbon Dioxide	51,045.1
Methane	0.0
Ethane	0.0
Total VOC	0.0
Total Hydrocarbons	0.0
Nitric Oxide	0.7
Nitrogen Dioxide	0.2
Total Oxides of Nitrogen	0.9
Hydrogen Sulfide	0.0
Sulfur Dioxide	92.5
Carbon Disulfide	0.0
Carbonyl Sulfide	0.0
Total TRS	0.0

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The SO_2 emission factor is based on the concentration measured in the flue gas.

Dry Flue Gas Analysis	
Component	**Mole Fraction**
nitrogen	0.878577
carbon_dioxide	0.121420
nitric_oxide	0.000002
nitrogen_dioxide	0.000001
oxygen	0.000000
Total	**1.000000**

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0.00	0.00	0.00	20	20	-96,264
Tuning	One per year.	0.00	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0	0	0	0
Tuning	One per year.	0	2,000	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tuning	One per year.	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Engine 001C	I-001C	Oil Pump Driver	133,064	72.5	1.52	0.54	0.26	0.01	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
2.7	1,397	0.16	1,502	0.3	41.3	0.0	0.0	0.1

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Organic Rankin Cycle (ORC) Waste Heat	0.00	416,990	0	0	7,701	-360,266	1.85	54.15
Tuning	0.00	0	0	2,000	0	-14,732	NA	NA

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Organic Rankin Cycle (ORC) Waste Heat	0.00	15	0.00	15	0.00	0.00	0.00	0.00	0.00
Tuning	0.00	0	0.00	0	0.00	0.00	0.00	0.00	0.00

Capital Cost Details

Control Technology Type	Application description
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery

Cost Category	Cost Item Type	Item Description	Rate (USD/Unit)	Quantity (Unit)	Line Total (USD)
Construction	Crane Operation	(Crane 75 ton) Quantity in hours	450.00	10.0	4,500
	Electrical	(Electricians) Quantity in hours	60.00	140.0	8,400
	Freight	(Trucking) Quantity in hours	6,000.00	1.0	6,000
	Inspection and Quality Control	(Project Manager) Quantity in hours	120.00	100.0	12,000
	Instrumentation	(Instrument tech) Quantity in hours	60.00	40.0	2,400
	Labourers	(Insulation Removal) Quantity in hours	60.00	40.0	2,400
		(Labour) Quantity in hours	44.00	140.0	6,160
		(Scaffolding) Quantity in hours	80.00	60.0	4,800
	Mobilization and Demobilization	(Truck and Vans) Quantity in hours	25.00	300.0	7,500
		Garbage Removal	800.00	1.0	800
		Scrape Iron Removal	600.00	1.0	600
	Other Constuction Cost	(Custom Broker) Quantity in hours	1,000.00	1.0	1,000
		(Man lift) Quantity in hours	300.00	10.0	3,000
		(Painting) Quantity in hours	52.00	40.0	2,080
		(Zoom boom) Quantity in hours	480.00	5.0	2,400
		Contingency	34,462.00	1.0	34,462

		Porta Potties	550.00	1.0	550
	Pipefitting	(Pipe Fitters) Quantity in hours	58.00	140.0	8,120
	Shelter	(Office trailer) Quantity in hours	200.00	10.0	2,000
	Supervision (third party consultant)	(Commisioning) Quantity in hours	80.00	40.0	3,200
		(Foreman) Quantity in hours	70.00	80.0	5,600
		(Programming) Quantity in hours	130.00	20.0	2,600
		(Supervisor) Quantity in hours	90.00	100.0	9,000
	Welding	(Welder Helpers) Quantity in hours	44.00	140.0	6,160
		(Welder) Quantity in hour	110.00	140.0	15,400
Engineering and Drafting	Process	Engineering	37,908.20	1.0	37,908
Material	Control Panel	Techcable	10.00	300.0	3,000
	Instruments	Instrumentation	10,000.00	1.0	10,000
	Miscellaneous Material Cost	Cable tray	15.00	300.0	4,500
	Other Material Cost	Consumables	5,000.00	1.0	5,000
		ORC Skid Unit	173,000.00	1.0	173,000
		Synchronizing Gear	20,000.00	1.0	20,000
	Pipes and Fittings	Fittings	110.00	15.0	1,650
		Pipe	90.00	20.0	1,800
	Valves	Control Valves	4,500.00	2.0	9,000
				Total	416,990

Combustion Analysis Report Summary

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	N/A
Name	Monterrey Station
Location	Monterrey-Casanare
ID	MonterreyStation
Category	Pump Station
Type	Oil
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Engine 4410
ID	III-4410
On Site Location	Monterrey (Yopal - Casanare)
Category	Reciprocating Engines
Type	4-Stroke Rich-Burn (90-105% load)
Service	Oil Pump Driver
Manufacturer	WAUKESHA
Model	L5794GSI
Model Year	N/A
Installation Date	Dec 9 2009 12:00AM

Report Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Applied Emission Factors (ng/J)		
Substance	**Value**	**Source**
CH_4 Emission Factor	99.00	US EPA AP-42
N_2O Emission Factor	5.72	US EPA AP-42
VOC Emission Factor	12.70	US EPA AP-42
CO Emission Factor	1,509	US EPA AP-42
PM Emission Factor	4.09	US EPA AP-42
NO_x Emission Factor	306.87	User Entered

Device Comments and Assumptions
Internal Combustion Engine

Data Comments and Assumptions
N/A

Combustion Analysis Input

Gas Stream Conditions			
Stream	**Temperature (^oC)**	**Flow (m3/h @ STP)**	**Relative Humidity (%)**
Ambient Air	30.0		60.0
Fuel	30.0	291.6	0.0
Combustion Air	30.0	0.0	60.0
Flue Gas	566.9	0.0	N/A
Radiator Air (In)	30.0		0.0
Radiator Air (Out)	30.0		0.0

General Simulation Data	
Analysis Method	Fuel Flow And Stack Gas
Flue Gas Type	Dry
Local Barometric Pressure (kPa)	95.8
Nominal Rated Power Output (kW)	1,029
Assumed Efficiency (%)	33.23
Assumed Loading (%)	100
Fuel Cost (USD/GJ)	3.66

Stack Gas Analysis	
Component	**Concentration (On A Dry Volume Basis)**
Oxygen (%)	0.00
Carbon Monoxide (ppm)	0.00
Total Combustible (ppm)	0.00
Unburnt Fuel (calculated) (ppm)	0.00
Nitric Oxide (ppm)	1,073.30
Nitrogen Dioxide (ppm)	2.60
Sulfur Dioxide (ppm)	0.00

Fuel Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Ethane	0.082500	0.082500	0.087246
Isobutane	0.004680	0.004680	0.004949
Isopentane	0.000575	0.000575	0.000608
Methane	0.825081	0.825081	0.872547
n-Butane	0.004203	0.004203	0.004445
n-Heptane	0.000295	0.000295	0.000311
n-Hexane	0.000116	0.000116	0.000123
Nitrogen	0.042190	0.042190	0.000000
n-Pentane	0.000429	0.000429	0.000454
Oxygen	0.012210	0.012210	0.000000
Propane	0.027722	0.027722	0.029317
Total	**1.000000**	**1.000000**	**1.000000**

Combustion Analysis Output

Fuel Gas Characteristics	
Molecular Weight (kg/kmol)	18.6
Quality (inlet condition) (%)	1.0
Gross Heating Value (MJ/m^3)	43.1
Net Heating Value (MJ/m^3)	38.3
Theoretic Combustion Air Requirement (kmol/kmol)	11.1

Material Balance	
Stream	Flow Rate ($10^3 m^3/d$)
Fuel	7.00
Air	77.93
Stack Gas	85.56

Excess Air	
Type	Amount (%)
Actual	0.2
Recommended Lower Limit	2.0
Recommended Upper Limit	12.0

Energy Balance	
Type	Amount (kW)
Gross Input Energy	3,506.9
Net Input Energy	2,828.2

Avoidable Energy Consumption (Losses)		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Recoverable Heat in Flue Gas[1]	25.1	709.6

Unavoidable Energy Comsumption Losses		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unrecoverable Heat in Flue Gas[1]	15.6	441.3

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

Efficiencies	
Efficiency Type	Amount (%)
Apparent Thermal Efficiency	59.3
Carbon Combustion Efficiency	100.0

Stack Gas Characteristics	
Molecular Weight (kg/kmol)	27.53
Dew Temperature (^oC)	59.4

Determined Flue Gas Emission Factors[2]	
Component	Amount (ng/J)
Carbon Monoxide	0.0
Carbon Dioxide	51,045.1
Methane	0.0
Ethane	0.0
Total VOC	0.0
Total Hydrocarbons	0.0
Nitric Oxide	308.4
Nitrogen Dioxide	1.1
Total Oxides of Nitrogen	309.6
Hydrogen Sulfide	0.0
Sulfur Dioxide	0.0
Carbon Disulfide	0.0
Carbonyl Sulfide	0.0
Total TRS	0.0

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The SO_2 emission factor is based on the concentration measured in the flue gas.

Dry Flue Gas Analysis	
Component	**Mole Fraction**
nitrogen	0.877815
carbon_dioxide	0.121109
nitric_oxide	0.001073
nitrogen_dioxide	0.000003
oxygen	0.000000
Total	**1.000000**

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0.00	0.00	0.00	20	20	-1,040,057
Tuning	Once per year.	0.00	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0	0	0	0
Tuning	Once per year.	0	2,000	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tuning	Once per year.	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas (10^3m^3/d)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Engine 4410	III-4410	Oil Pump Driver	534,854	291.6	6.11	2.17	1.03	0.05	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
10.9	5,614	0.63	6,037	1.4	166.0	33.7	0.0	0.4

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Organic Rankin Cycle (ORC) Waste Heat	0.00	416,990	0	0	83,205	195,876	19.95	5.01
Tuning	0.00	0	0	2,000	0	-14,732	NA	NA

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Organic Rankin Cycle (ORC) Waste Heat	0.00	163	0.00	164	0.00	0.00	0.00	0.00	0.00
Tuning	0.00	0	0.00	0	0.00	0.00	0.00	0.00	0.00

Capital Cost Details

Control Technology Type	Application description
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery

Cost Category	Cost Item Type	Item Description	Rate (USD/Unit)	Quantity (Unit)	Line Total (USD)
Construction	Crane Operation	(Crane 75 ton) Quantity in hours	450.00	10.0	4,500
	Electrical	(Electricians) Quantity in hours	60.00	140.0	8,400
	Freight	(Trucking) Quantity in hours	6,000.00	1.0	6,000
	Inspection and Quality Control	(Project Manager) Quantity in hours	120.00	100.0	12,000
	Instrumentation	(Instrument tech) Quantity in hours	60.00	40.0	2,400
	Labourers	(Insulation Removal) Quantity in hours	60.00	40.0	2,400
		(Labour) Quantity in hours	44.00	140.0	6,160
		(Scaffolding) Quantity in hours	80.00	60.0	4,800
	Mobilization and Demobilization	(Truck and Vans) Quantity in hours	25.00	300.0	7,500
		Garbage Removal	800.00	1.0	800
		Scrape Iron Removal	600.00	1.0	600
	Other Constuction Cost	(Custom Broker) Quantity in hours	1,000.00	1.0	1,000
		(Man lift) Quantity in hours	300.00	10.0	3,000
		(Painting) Quantity in hours	52.00	40.0	2,080
		(Zoom boom) Quantity in hours	480.00	5.0	2,400
		Contingency	34,462.00	1.0	34,462

		Porta Potties	550.00	1.0	550
	Pipefitting	(Pipe Fitters) Quantity in hours	58.00	140.0	8,120
	Shelter	(Office trailer) Quantity in hours	200.00	10.0	2,000
	Supervision (third party consultant)	(Commisioning) Quantity in hours	80.00	40.0	3,200
		(Foreman) Quantity in hours	70.00	80.0	5,600
		(Programming) Quantity in hours	130.00	20.0	2,600
		(Supervisor) Quantity in hours	90.00	100.0	9,000
	Welding	(Welder Helpers) Quantity in hours	44.00	140.0	6,160
		(Welder) Quantity in hour	110.00	140.0	15,400
Engineering and Drafting	Process	Engineering	37,908.20	1.0	37,908
Material	Control Panel	Techcable	10.00	300.0	3,000
	Instruments	Instrumentation	10,000.00	1.0	10,000
	Miscellaneous Material Cost	Cable tray	15.00	300.0	4,500
	Other Material Cost	Consumables	5,000.00	1.0	5,000
		ORC Skid Unit	173,000.00	1.0	173,000
		Synchronizing Gear	20,000.00	1.0	20,000
	Pipes and Fittings	Fittings	110.00	15.0	1,650
		Pipe	90.00	20.0	1,800
	Valves	Control Valves	4,500.00	2.0	9,000

Total	416,990

Combustion Analysis
Report Summary

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	N/A
Name	Monterrey Station
Location	Monterrey-Casanare
ID	MonterreyStation
Category	Pump Station
Type	Oil
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Engine 4420
ID	III-4420
On Site Location	Monterrey (Yopal - Casanare)
Category	Reciprocating Engines
Type	4-Stroke Rich-Burn (90-105% load)
Service	Oil Pump Driver
Manufacturer	WAUKESHA
Model	L5794GSI
Model Year	N/A
Installation Date	Dec 9 2009 12:00AM

Report Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Applied Emission Factors (ng/J)		
Substance	**Value**	**Source**
CH_4 Emission Factor	99.00	US EPA AP-42
N_2O Emission Factor	5.72	US EPA AP-42
VOC Emission Factor	12.70	US EPA AP-42
CO Emission Factor	745.23	User Entered
PM Emission Factor	4.09	US EPA AP-42
NO_x Emission Factor	539.46	User Entered

Device Comments and Assumptions
Internal Combustion Engine

Data Comments and Assumptions
N/A

Combustion Analysis Input

Gas Stream Conditions			
Stream	**Temperature (^oC)**	**Flow (m3/h @ STP)**	**Relative Humidity (%)**
Ambient Air	30.0		60.0
Fuel	30.0	291.6	0.0
Combustion Air	30.0	0.0	60.0
Flue Gas	575.4	0.0	N/A
Radiator Air (In)	30.0		0.0
Radiator Air (Out)	30.0		0.0

General Simulation Data	
Analysis Method	Fuel Flow And Stack Gas
Flue Gas Type	Dry
Local Barometric Pressure (kPa)	95.8
Nominal Rated Power Output (kW)	1,029
Assumed Efficiency (%)	33.23
Assumed Loading (%)	100
Fuel Cost (USD/GJ)	3.66

Stack Gas Analysis	
Component	**Concentration (On A Dry Volume Basis)**
Oxygen (%)	0.30
Carbon Monoxide (ppm)	2,771.70
Total Combustible (ppm)	0.00
Unburnt Fuel (calculated) (ppm)	0.00
Nitric Oxide (ppm)	1,852.70
Nitrogen Dioxide (ppm)	13.20
Sulfur Dioxide (ppm)	0.00

Fuel Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Ethane	0.082500	0.082500	0.087246
Isobutane	0.004680	0.004680	0.004949
Isopentane	0.000575	0.000575	0.000608
Methane	0.825081	0.825081	0.872547
n-Butane	0.004203	0.004203	0.004445
n-Heptane	0.000295	0.000295	0.000311
n-Hexane	0.000116	0.000116	0.000123
Nitrogen	0.042190	0.042190	0.000000
n-Pentane	0.000429	0.000429	0.000454
Oxygen	0.012210	0.012210	0.000000
Propane	0.027722	0.027722	0.029317
Total	**1.000000**	**1.000000**	**1.000000**

Combustion Analysis Output

Fuel Gas Characteristics	
Molecular Weight (kg/kmol)	18.6
Quality (inlet condition) (%)	1.0
Gross Heating Value (MJ/m^3)	43.1
Net Heating Value (MJ/m^3)	38.3
Theoretic Combustion Air Requirement (kmol/kmol)	11.1

Material Balance	
Stream	Flow Rate ($10^3m^3/d$)
Fuel	7.00
Air	78.61
Stack Gas	86.34

Excess Air	
Type	Amount (%)
Actual	1.1
Recommended Lower Limit	2.0
Recommended Upper Limit	12.0

Energy Balance	
Type	Amount (kW)
Gross Input Energy	3,507.3
Net Input Energy	2,828.5

Avoidable Energy Consumption (Losses)		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unburnt Fuel	0.9	26.5
Recoverable Heat in Flue Gas[1]	25.7	728.0

Unavoidable Energy Comsumption Losses		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unrecoverable Heat in Flue Gas[1]	15.6	441.8

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

Efficiencies	
Efficiency Type	Amount (%)
Apparent Thermal Efficiency	57.7
Carbon Combustion Efficiency	97.7

Stack Gas Characteristics	
Molecular Weight (kg/kmol)	27.51
Dew Temperature (°C)	59.2

Determined Flue Gas Emission Factors[2]	
Component	Amount (ng/J)
Carbon Monoxide	751.8
Carbon Dioxide	49,863.9
Methane	0.0
Ethane	0.0
Total VOC	0.0
Total Hydrocarbons	0.0
Nitric Oxide	538.3
Nitrogen Dioxide	5.9
Total Oxides of Nitrogen	544.2
Hydrogen Sulfide	0.0
Sulfur Dioxide	0.0
Carbon Disulfide	0.0
Carbonyl Sulfide	0.0
Total TRS	0.0

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The SO_2 emission factor is based on the concentration measured in the flue gas.

Dry Flue Gas Analysis	
Component	**Mole Fraction**
nitrogen	0.875357
carbon_dioxide	0.117005
oxygen	0.003000
carbon_monoxide	0.002772
nitric_oxide	0.001853
nitrogen_dioxide	0.000013
Total	**1.000000**

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0.00	0.00	0.00	20	20	-1,067,066
Tuning	Once per year.	0.88	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0	0	0	0
Tuning	Once per year.	0	2,000	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tuning	Once per year.	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Engine 4420	III-4420	Oil Pump Driver	534,854	291.6	6.11	2.17	1.03	0.05	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
10.9	5,614	0.63	6,037	1.4	82.0	59.3	0.0	0.4

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Organic Rankin Cycle (ORC) Waste Heat	0.00	416,990	0	0	85,365	211,792	20.47	4.88
Tuning	0.88	0	0	2,000	4,717	20,016	NA	0.00

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Organic Rankin Cycle (ORC) Waste Heat	0.00	168	0.00	168	0.00	0.00	0.00	0.00	0.00
Tuning	0.10	50	0.01	53	0.01	0.72	0.52	0.00	0.00

Capital Cost Details

Control Technology Type	Application description
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery

Cost Category	Cost Item Type	Item Description	Rate (USD/Unit)	Quantity (Unit)	Line Total (USD)
Construction	Crane Operation	(Crane 75 ton) Quantity in hours	450.00	10.0	4,500
	Electrical	(Electricians) Quantity in hours	60.00	140.0	8,400
	Freight	(Trucking) Quantity in hours	6,000.00	1.0	6,000
	Inspection and Quality Control	(Project Manager) Quantity in hours	120.00	100.0	12,000
	Instrumentation	(Instrument tech) Quantity in hours	60.00	40.0	2,400
	Labourers	(Insulation Removal) Quantity in hours	60.00	40.0	2,400
		(Labour) Quantity in hours	44.00	140.0	6,160
		(Scaffolding) Quantity in hours	80.00	60.0	4,800
	Mobilization and Demobilization	(Truck and Vans) Quantity in hours	25.00	300.0	7,500
		Garbage Removal	800.00	1.0	800
		Scrape Iron Removal	600.00	1.0	600
	Other Constuction Cost	(Custom Broker) Quantity in hours	1,000.00	1.0	1,000
		(Man lift) Quantity in hours	300.00	10.0	3,000
		(Painting) Quantity in hours	52.00	40.0	2,080
		(Zoom boom) Quantity in hours	480.00	5.0	2,400
		Contingency	34,462.00	1.0	34,462

		Porta Potties	550.00	1.0	550
	Pipefitting	(Pipe Fitters) Quantity in hours	58.00	140.0	8,120
	Shelter	(Office trailer) Quantity in hours	200.00	10.0	2,000
	Supervision (third party consultant)	(Commisioning) Quantity in hours	80.00	40.0	3,200
		(Foreman) Quantity in hours	70.00	80.0	5,600
		(Programming) Quantity in hours	130.00	20.0	2,600
		(Supervisor) Quantity in hours	90.00	100.0	9,000
	Welding	(Welder Helpers) Quantity in hours	44.00	140.0	6,160
		(Welder) Quantity in hour	110.00	140.0	15,400
Engineering and Drafting	Process	Engineering	37,908.20	1.0	37,908
Material	Control Panel	Techcable	10.00	300.0	3,000
	Instruments	Instrumentation	10,000.00	1.0	10,000
	Miscellaneous Material Cost	Cable tray	15.00	300.0	4,500
	Other Material Cost	Consumables	5,000.00	1.0	5,000
		ORC Skid Unit	173,000.00	1.0	173,000
		Synchronizing Gear	20,000.00	1.0	20,000
	Pipes and Fittings	Fittings	110.00	15.0	1,650
		Pipe	90.00	20.0	1,800
	Valves	Control Valves	4,500.00	2.0	9,000
				Total	416,990

Combustion Analysis
Report Summary

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	N/A
Name	Monterrey Station
Location	Monterrey-Casanare
ID	MonterreyStation
Category	Pump Station
Type	Oil
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Engine 4430
ID	III-4430
On Site Location	Monterrey (Yopal - Casanare)
Category	Reciprocating Engines
Type	4-Stroke Rich-Burn (90-105% load)
Service	Oil Pump Driver
Manufacturer	WAUKESHA
Model	L5794GSI
Model Year	N/A
Installation Date	Dec 9 2009 12:00AM

Report Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Applied Emission Factors (ng/J)		
Substance	**Value**	**Source**
CH_4 Emission Factor	99.00	US EPA AP-42
N_2O Emission Factor	5.72	US EPA AP-42
VOC Emission Factor	12.70	US EPA AP-42
CO Emission Factor	745.23	User Entered
PM Emission Factor	4.09	US EPA AP-42
NO_x Emission Factor	539.46	User Entered

Device Comments and Assumptions
Internal Combustion Engine

Data Comments and Assumptions
N/A

Combustion Analysis Input

Gas Stream Conditions			
Stream	**Temperature (^oC)**	**Flow (m3/h @ STP)**	**Relative Humidity (%)**
Ambient Air	30.0		60.0
Fuel	30.0	291.6	0.0
Combustion Air	30.0	0.0	60.0
Flue Gas	573.8	0.0	N/A
Radiator Air (In)	30.0		0.0
Radiator Air (Out)	30.0		0.0

General Simulation Data	
Analysis Method	Fuel Flow And Stack Gas
Flue Gas Type	Dry
Local Barometric Pressure (kPa)	95.8
Nominal Rated Power Output (kW)	1,029
Assumed Efficiency (%)	33.23
Assumed Loading (%)	100
Fuel Cost (USD/GJ)	3.66

Stack Gas Analysis	
Component	**Concentration (On A Dry Volume Basis)**
Oxygen (%)	0.00
Carbon Monoxide (ppm)	3,333.70
Total Combustible (ppm)	0.00
Unburnt Fuel (calculated) (ppm)	0.00
Nitric Oxide (ppm)	4,364.30
Nitrogen Dioxide (ppm)	20.50
Sulfur Dioxide (ppm)	0.00

Fuel Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Ethane	0.082500	0.082500	0.087246
Isobutane	0.004680	0.004680	0.004949
Isopentane	0.000575	0.000575	0.000608
Methane	0.825081	0.825081	0.872547
n-Butane	0.004203	0.004203	0.004445
n-Heptane	0.000295	0.000295	0.000311
n-Hexane	0.000116	0.000116	0.000123
Nitrogen	0.042190	0.042190	0.000000
n-Pentane	0.000429	0.000429	0.000454
Oxygen	0.012210	0.012210	0.000000
Propane	0.027722	0.027722	0.029317
Total	**1.000000**	**1.000000**	**1.000000**

Combustion Analysis Output

Fuel Gas Characteristics	
Molecular Weight (kg/kmol)	18.6
Quality (inlet condition) (%)	1.0
Gross Heating Value (MJ/m^3)	43.1
Net Heating Value (MJ/m^3)	38.3
Theoretic Combustion Air Requirement (kmol/kmol)	11.1

Material Balance	
Stream	Flow Rate ($10^3 m^3/d$)
Fuel	7.00
Air	77.93
Stack Gas	85.68

Excess Air	
Type	Amount (%)
Actual	0.2
Recommended Lower Limit	2.0
Recommended Upper Limit	12.0

Energy Balance	
Type	Amount (kW)
Gross Input Energy	3,506.9
Net Input Energy	2,828.3

Avoidable Energy Consumption (Losses)		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unburnt Fuel	1.1	31.6
Recoverable Heat in Flue Gas[1]	25.5	720.0

Unavoidable Energy Comsumption Losses		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unrecoverable Heat in Flue Gas[1]	15.6	441.3

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

Efficiencies	
Efficiency Type	Amount (%)
Apparent Thermal Efficiency	57.8
Carbon Combustion Efficiency	97.2

Stack Gas Characteristics	
Molecular Weight (kg/kmol)	27.50
Dew Temperature (°C)	59.4

Determined Flue Gas Emission Factors[2]	
Component	Amount (ng/J)
Carbon Monoxide	895.7
Carbon Dioxide	49,637.7
Methane	0.0
Ethane	0.0
Total VOC	0.0
Total Hydrocarbons	0.0
Nitric Oxide	1,256.2
Nitrogen Dioxide	9.0
Total Oxides of Nitrogen	1,265.3
Hydrogen Sulfide	0.0
Sulfur Dioxide	0.0
Carbon Disulfide	0.0
Carbonyl Sulfide	0.0
Total TRS	0.0

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The SO_2 emission factor is based on the concentration measured in the flue gas.

Dry Flue Gas Analysis	
Component	**Mole Fraction**
nitrogen	0.874705
carbon_dioxide	0.117576
nitric_oxide	0.004364
carbon_monoxide	0.003334
nitrogen_dioxide	0.000021
oxygen	0.000000
Total	**1.000000**

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0.00	0.00	0.00	20	20	-1,055,352
Tuning	Once per year.	1.05	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0	0	0	0
Tuning	Once per year.	0	2,000	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tuning	Once per year.	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Engine 4430	III-4430	Oil Pump Driver	534,854	291.6	6.11	2.17	1.03	0.05	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
10.9	5,614	0.63	6,037	1.4	82.0	59.3	0.0	0.4

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Organic Rankin Cycle (ORC) Waste Heat	0.00	416,990	0	0	84,428	204,889	20.25	4.94
Tuning	1.05	0	0	2,000	5,616	26,634	NA	0.00

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Organic Rankin Cycle (ORC) Waste Heat	0.00	166	0.00	166	0.00	0.00	0.00	0.00	0.00
Tuning	0.11	59	0.01	63	0.01	0.86	0.62	0.00	0.00

Capital Cost Details

Control Technology Type	Application description
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery

Cost Category	Cost Item Type	Item Description	Rate (USD/Unit)	Quantity (Unit)	Line Total (USD)
Construction	Crane Operation	(Crane 75 ton) Quantity in hours	450.00	10.0	4,500
	Electrical	(Electricians) Quantity in hours	60.00	140.0	8,400
	Freight	(Trucking) Quantity in hours	6,000.00	1.0	6,000
	Inspection and Quality Control	(Project Manager) Quantity in hours	120.00	100.0	12,000
	Instrumentation	(Instrument tech) Quantity in hours	60.00	40.0	2,400
	Labourers	(Insulation Removal) Quantity in hours	60.00	40.0	2,400
		(Labour) Quantity in hours	44.00	140.0	6,160
		(Scaffolding) Quantity in hours	80.00	60.0	4,800
	Mobilization and Demobilization	(Truck and Vans) Quantity in hours	25.00	300.0	7,500
		Garbage Removal	800.00	1.0	800
		Scrape Iron Removal	600.00	1.0	600
	Other Constuction Cost	(Custom Broker) Quantity in hours	1,000.00	1.0	1,000
		(Man lift) Quantity in hours	300.00	10.0	3,000
		(Painting) Quantity in hours	52.00	40.0	2,080
		(Zoom boom) Quantity in hours	480.00	5.0	2,400
		Contingency	34,462.00	1.0	34,462

		Porta Potties	550.00	1.0	550
	Pipefitting	(Pipe Fitters) Quantity in hours	58.00	140.0	8,120
	Shelter	(Office trailer) Quantity in hours	200.00	10.0	2,000
	Supervision (third party consultant)	(Commisioning) Quantity in hours	80.00	40.0	3,200
		(Foreman) Quantity in hours	70.00	80.0	5,600
		(Programming) Quantity in hours	130.00	20.0	2,600
		(Supervisor) Quantity in hours	90.00	100.0	9,000
	Welding	(Welder Helpers) Quantity in hours	44.00	140.0	6,160
		(Welder) Quantity in hour	110.00	140.0	15,400
Engineering and Drafting	Process	Engineering	37,908.20	1.0	37,908
Material	Control Panel	Techcable	10.00	300.0	3,000
	Instruments	Instrumentation	10,000.00	1.0	10,000
	Miscellaneous Material Cost	Cable tray	15.00	300.0	4,500
	Other Material Cost	Consumables	5,000.00	1.0	5,000
		ORC Skid Unit	173,000.00	1.0	173,000
		Synchronizing Gear	20,000.00	1.0	20,000
	Pipes and Fittings	Fittings	110.00	15.0	1,650
		Pipe	90.00	20.0	1,800
	Valves	Control Valves	4,500.00	2.0	9,000
				Total	416,990

Combustion Analysis Report Summary

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	N/A
Name	Monterrey Station
Location	Monterrey-Casanare
ID	MonterreyStation
Category	Pump Station
Type	Oil
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Engine 4440
ID	III-4440
On Site Location	Monterrey (Yopal - Casanare)
Category	Reciprocating Engines
Type	4-Stroke Rich-Burn (90-105% load)
Service	Oil Pump Driver
Manufacturer	WAUKESHA
Model	L5794GSI
Model Year	N/A
Installation Date	Dec 9 2009 12:00AM

Report Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Applied Emission Factors (ng/J)		
Substance	**Value**	**Source**
CH_4 Emission Factor	99.00	US EPA AP-42
N_2O Emission Factor	5.72	US EPA AP-42
VOC Emission Factor	12.70	US EPA AP-42
CO Emission Factor	128.63	User Entered
PM Emission Factor	4.09	US EPA AP-42
NO_x Emission Factor	2,208	User Entered

Device Comments and Assumptions
Internal Combustion Engine

Data Comments and Assumptions
N/A

Combustion Analysis Input

Gas Stream Conditions			
Stream	Temperature (^oC)	Flow (m3/h @ STP)	Relative Humidity (%)
Ambient Air	30.0		60.0
Fuel	30.0	291.6	0.0
Combustion Air	30.0	0.0	60.0
Flue Gas	588.4	0.0	N/A
Radiator Air (In)	30.0		0.0
Radiator Air (Out)	30.0		0.0

General Simulation Data	
Analysis Method	Fuel Flow And Stack Gas
Flue Gas Type	Dry
Local Barometric Pressure (kPa)	95.8
Nominal Rated Power Output (kW)	1,029
Assumed Efficiency (%)	33.23
Assumed Loading (%)	100
Fuel Cost (USD/GJ)	3.66

Stack Gas Analysis	
Component	Concentration (On A Dry Volume Basis)
Oxygen (%)	0.70
Carbon Monoxide (ppm)	460.70
Total Combustible (ppm)	0.00
Unburnt Fuel (calculated) (ppm)	0.00
Nitric Oxide (ppm)	7,306.30
Nitrogen Dioxide (ppm)	48.50
Sulfur Dioxide (ppm)	389.30

Fuel Analysis Results			
Component Name	Mole Fraction		
	Entered	Normalized	Air Free
Ethane	0.082500	0.082500	0.087246
Isobutane	0.004680	0.004680	0.004949
Isopentane	0.000575	0.000575	0.000608
Methane	0.825081	0.825081	0.872547
n-Butane	0.004203	0.004203	0.004445
n-Heptane	0.000295	0.000295	0.000311
n-Hexane	0.000116	0.000116	0.000123
Nitrogen	0.042190	0.042190	0.000000
n-Pentane	0.000429	0.000429	0.000454
Oxygen	0.012210	0.012210	0.000000
Propane	0.027722	0.027722	0.029317
Total	**1.000000**	**1.000000**	**1.000000**

Combustion Analysis Output

Fuel Gas Characteristics	
Molecular Weight (kg/kmol)	18.6
Quality (inlet condition) (%)	1.0
Gross Heating Value (MJ/m^3)	43.1
Net Heating Value (MJ/m^3)	38.3
Theoretic Combustion Air Requirement (kmol/kmol)	11.1

Material Balance	
Stream	Flow Rate ($10^3 m^3/d$)
Fuel	7.00
Air	81.42
Stack Gas	89.07

Excess Air	
Type	Amount (%)
Actual	4.7
Recommended Lower Limit	2.0
Recommended Upper Limit	12.0

Energy Balance	
Type	Amount (kW)
Gross Input Energy	3,508.7
Net Input Energy	2,829.1

Avoidable Energy Consumption (Losses)		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unburnt Fuel	0.2	4.6
Recoverable Heat in Flue Gas[1]	27.3	771.6

Unavoidable Energy Comsumption Losses		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unrecoverable Heat in Flue Gas[1]	15.7	444.0

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

Efficiencies	
Efficiency Type	Amount (%)
Apparent Thermal Efficiency	56.9
Carbon Combustion Efficiency	99.6

Stack Gas Characteristics	
Molecular Weight (kg/kmol)	27.57
Dew Temperature (°C)	58.7

Determined Flue Gas Emission Factors[2]	
Component	Amount (ng/J)
Carbon Monoxide	129.8
Carbon Dioxide	50,841.2
Methane	0.0
Ethane	0.0
Total VOC	0.0
Total Hydrocarbons	0.0
Nitric Oxide	2,204.6
Nitrogen Dioxide	22.4
Total Oxides of Nitrogen	2,227.0
Hydrogen Sulfide	0.0
Sulfur Dioxide	311.8
Carbon Disulfide	0.0
Carbonyl Sulfide	0.0
Total TRS	0.0

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The SO_2 emission factor is based on the concentration measured in the flue gas.

Dry Flue Gas Analysis	
Component	**Mole Fraction**
nitrogen	0.870304
carbon_dioxide	0.114881
nitric_oxide	0.007306
oxygen	0.007000
carbon_monoxide	0.000461
nitrogen_dioxide	0.000049
Total	**1.000000**

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0.00	0.00	0.00	20	20	-1,130,597
Tuning	Once per year.	0.15	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0	0	0	0
Tuning	Once per year.	0	2,000	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tuning	Once per year.	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3$/d)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Engine 4440	III-4440	Oil Pump Driver	534,854	291.6	6.11	2.17	1.03	0.05	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
10.9	5,614	0.63	6,037	1.4	14.1	242.8	0.0	0.4

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Organic Rankin Cycle (ORC) Waste Heat	0.00	416,990	0	0	90,448	249,228	21.69	4.61
Tuning	0.15	0	0	2,000	802	-8,822	NA	NA

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Organic Rankin Cycle (ORC) Waste Heat	0.00	178	0.00	178	0.00	0.00	0.00	0.00	0.00
Tuning	0.02	8	0.00	9	0.00	0.02	0.36	0.00	0.00

Capital Cost Details

Control Technology Type	Application description
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery

Cost Category	Cost Item Type	Item Description	Rate (USD/Unit)	Quantity (Unit)	Line Total (USD)
Construction	Crane Operation	(Crane 75 ton) Quantity in hours	450.00	10.0	4,500
	Electrical	(Electricians) Quantity in hours	60.00	140.0	8,400
	Freight	(Trucking) Quantity in hours	6,000.00	1.0	6,000
	Inspection and Quality Control	(Project Manager) Quantity in hours	120.00	100.0	12,000
	Instrumentation	(Instrument tech) Quantity in hours	60.00	40.0	2,400
	Labourers	(Insulation Removal) Quantity in hours	60.00	40.0	2,400
		(Labour) Quantity in hours	44.00	140.0	6,160
		(Scaffolding) Quantity in hours	80.00	60.0	4,800
	Mobilization and Demobilization	(Truck and Vans) Quantity in hours	25.00	300.0	7,500
		Garbage Removal	800.00	1.0	800
		Scrape Iron Removal	600.00	1.0	600
	Other Constuction Cost	(Custom Broker) Quantity in hours	1,000.00	1.0	1,000
		(Man lift) Quantity in hours	300.00	10.0	3,000
		(Painting) Quantity in hours	52.00	40.0	2,080
		(Zoom boom) Quantity in hours	480.00	5.0	2,400
		Contingency	34,462.00	1.0	34,462

		Porta Potties	550.00	1.0	550
	Pipefitting	(Pipe Fitters) Quantity in hours	58.00	140.0	8,120
	Shelter	(Office trailer) Quantity in hours	200.00	10.0	2,000
	Supervision (third party consultant)	(Commisioning) Quantity in hours	80.00	40.0	3,200
		(Foreman) Quantity in hours	70.00	80.0	5,600
		(Programming) Quantity in hours	130.00	20.0	2,600
		(Supervisor) Quantity in hours	90.00	100.0	9,000
	Welding	(Welder Helpers) Quantity in hours	44.00	140.0	6,160
		(Welder) Quantity in hour	110.00	140.0	15,400
Engineering and Drafting	Process	Engineering	37,908.20	1.0	37,908
Material	Control Panel	Techcable	10.00	300.0	3,000
	Instruments	Instrumentation	10,000.00	1.0	10,000
	Miscellaneous Material Cost	Cable tray	15.00	300.0	4,500
	Other Material Cost	Consumables	5,000.00	1.0	5,000
		ORC Skid Unit	173,000.00	1.0	173,000
		Synchronizing Gear	20,000.00	1.0	20,000
	Pipes and Fittings	Fittings	110.00	15.0	1,650
		Pipe	90.00	20.0	1,800
	Valves	Control Valves	4,500.00	2.0	9,000
				Total	416,990

Combustion Analysis Report Summary

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	N/A
Name	Monterrey Station
Location	Monterrey-Casanare
ID	MonterreyStation
Category	Pump Station
Type	Oil
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Engine 4450
ID	III-4450
On Site Location	Monterrey (Yopal - Casanare)
Category	Reciprocating Engines
Type	4-Stroke Rich-Burn (90-105% load)
Service	Oil Pump Driver
Manufacturer	WAUKESHA
Model	L5794GSI
Model Year	N/A
Installation Date	Dec 9 2009 12:00AM

Report Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Applied Emission Factors (ng/J)		
Substance	**Value**	**Source**
CH_4 Emission Factor	99.00	US EPA AP-42
N_2O Emission Factor	5.72	US EPA AP-42
VOC Emission Factor	12.70	US EPA AP-42
CO Emission Factor	337.73	User Entered
PM Emission Factor	4.09	US EPA AP-42
NO_x Emission Factor	1,478	User Entered

Device Comments and Assumptions
Internal Combustion Engine

Data Comments and Assumptions
N/A

Combustion Analysis Input

Gas Stream Conditions			
Stream	**Temperature (^oC)**	**Flow (m3/h @ STP)**	**Relative Humidity (%)**
Ambient Air	30.0		60.0
Fuel	30.0	291.6	0.0
Combustion Air	30.0	0.0	60.0
Flue Gas	585.3	0.0	N/A
Radiator Air (In)	30.0		0.0
Radiator Air (Out)	30.0		0.0

General Simulation Data	
Analysis Method	Fuel Flow And Stack Gas
Flue Gas Type	Dry
Local Barometric Pressure (kPa)	95.8
Nominal Rated Power Output (kW)	1,029
Assumed Efficiency (%)	33.23
Assumed Loading (%)	100
Fuel Cost (USD/GJ)	3.66

Stack Gas Analysis	
Component	**Concentration (On A Dry Volume Basis)**
Oxygen (%)	0.40
Carbon Monoxide (ppm)	1,236.70
Total Combustible (ppm)	0.00
Unburnt Fuel (calculated) (ppm)	0.00
Nitric Oxide (ppm)	5,000.00
Nitrogen Dioxide (ppm)	35.00
Sulfur Dioxide (ppm)	144.00

Fuel Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Ethane	0.082500	0.082500	0.087246
Isobutane	0.004680	0.004680	0.004949
Isopentane	0.000575	0.000575	0.000608
Methane	0.825081	0.825081	0.872547
n-Butane	0.004203	0.004203	0.004445
n-Heptane	0.000295	0.000295	0.000311
n-Hexane	0.000116	0.000116	0.000123
Nitrogen	0.042190	0.042190	0.000000
n-Pentane	0.000429	0.000429	0.000454
Oxygen	0.012210	0.012210	0.000000
Propane	0.027722	0.027722	0.029317
Total	**1.000000**	**1.000000**	**1.000000**

Combustion Analysis Output

Fuel Gas Characteristics	
Molecular Weight (kg/kmol)	18.6
Quality (inlet condition) (%)	1.0
Gross Heating Value (MJ/m^3)	43.1
Net Heating Value (MJ/m^3)	38.3
Theoretic Combustion Air Requirement (kmol/kmol)	11.1

Material Balance	
Stream	Flow Rate ($10^3 m^3/d$)
Fuel	7.00
Air	79.78
Stack Gas	87.45

Excess Air	
Type	Amount (%)
Actual	2.6
Recommended Lower Limit	2.0
Recommended Upper Limit	12.0

Energy Balance	
Type	Amount (kW)
Gross Input Energy	3,507.8
Net Input Energy	2,828.7

Avoidable Energy Consumption (Losses)		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unburnt Fuel	0.4	12.0
Recoverable Heat in Flue Gas[1]	26.6	753.0

Unavoidable Energy Comsumption Losses		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unrecoverable Heat in Flue Gas[1]	15.7	442.7

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

Efficiencies	
Efficiency Type	Amount (%)
Apparent Thermal Efficiency	57.3
Carbon Combustion Efficiency	99.0

Stack Gas Characteristics	
Molecular Weight (kg/kmol)	27.54
Dew Temperature (°C)	59.0

Determined Flue Gas Emission Factors[2]	
Component	Amount (ng/J)
Carbon Monoxide	340.7
Carbon Dioxide	50,509.8
Methane	0.0
Ethane	0.0
Total VOC	0.0
Total Hydrocarbons	0.0
Nitric Oxide	1,475.6
Nitrogen Dioxide	15.8
Total Oxides of Nitrogen	1,491.4
Hydrogen Sulfide	0.0
Sulfur Dioxide	113.2
Carbon Disulfide	0.0
Carbonyl Sulfide	0.0
Total TRS	0.0

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The SO_2 emission factor is based on the concentration measured in the flue gas.

Dry Flue Gas Analysis	
Component	**Mole Fraction**
nitrogen	0.873038
carbon_dioxide	0.116690
nitric_oxide	0.005000
oxygen	0.004000
carbon_monoxide	0.001237
nitrogen_dioxide	0.000035
Total	**1.000000**

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0.00	0.00	0.00	20	20	-1,103,744
Tuning	Once per year.	0.40	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0	0	0	0
Tuning	Once per year.	0	2,000	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tuning	Once per year.	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Engine 4450	III-4450	Oil Pump Driver	534,854	291.6	6.11	2.17	1.03	0.05	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
10.9	5,614	0.63	6,037	1.4	37.1	162.6	0.0	0.4

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Tuning	0.40	0	0	2,000	2,134	988	NA	0.00
Organic Rankin Cycle (ORC) Waste Heat	0.00	416,990	0	0	88,300	233,404	21.18	4.72

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Tuning	0.04	22	0.00	24	0.01	0.15	0.65	0.00	0.00
Organic Rankin Cycle (ORC) Waste Heat	0.00	173	0.00	174	0.00	0.00	0.00	0.00	0.00

Capital Cost Details

Control Technology Type	Application description
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery

Cost Category	Cost Item Type	Item Description	Rate (USD/Unit)	Quantity (Unit)	Line Total (USD)
Construction	Crane Operation	(Crane 75 ton) Quantity in hours	450.00	10.0	4,500
	Electrical	(Electricians) Quantity in hours	60.00	140.0	8,400
	Freight	(Trucking) Quantity in hours	6,000.00	1.0	6,000
	Inspection and Quality Control	(Project Manager) Quantity in hours	120.00	100.0	12,000
	Instrumentation	(Instrument tech) Quantity in hours	60.00	40.0	2,400
	Labourers	(Insulation Removal) Quantity in hours	60.00	40.0	2,400
		(Labour) Quantity in hours	44.00	140.0	6,160
		(Scaffolding) Quantity in hours	80.00	60.0	4,800
	Mobilization and Demobilization	(Truck and Vans) Quantity in hours	25.00	300.0	7,500
		Garbage Removal	800.00	1.0	800
		Scrape Iron Removal	600.00	1.0	600
	Other Constuction Cost	(Custom Broker) Quantity in hours	1,000.00	1.0	1,000
		(Man lift) Quantity in hours	300.00	10.0	3,000
		(Painting) Quantity in hours	52.00	40.0	2,080
		(Zoom boom) Quantity in hours	480.00	5.0	2,400
		Contingency	34,462.00	1.0	34,462

		Porta Potties	550.00	1.0	550
	Pipefitting	(Pipe Fitters) Quantity in hours	58.00	140.0	8,120
	Shelter	(Office trailer) Quantity in hours	200.00	10.0	2,000
	Supervision (third party consultant)	(Commisioning) Quantity in hours	80.00	40.0	3,200
		(Foreman) Quantity in hours	70.00	80.0	5,600
		(Programming) Quantity in hours	130.00	20.0	2,600
		(Supervisor) Quantity in hours	90.00	100.0	9,000
	Welding	(Welder Helpers) Quantity in hours	44.00	140.0	6,160
		(Welder) Quantity in hour	110.00	140.0	15,400
Engineering and Drafting	Process	Engineering	37,908.20	1.0	37,908
Material	Control Panel	Techcable	10.00	300.0	3,000
	Instruments	Instrumentation	10,000.00	1.0	10,000
	Miscellaneous Material Cost	Cable tray	15.00	300.0	4,500
	Other Material Cost	Consumables	5,000.00	1.0	5,000
		ORC Skid Unit	173,000.00	1.0	173,000
		Synchronizing Gear	20,000.00	1.0	20,000
	Pipes and Fittings	Fittings	110.00	15.0	1,650
		Pipe	90.00	20.0	1,800
	Valves	Control Valves	4,500.00	2.0	9,000
				Total	416,990

Combustion Analysis
Report Summary

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	N/A
Name	Monterrey Station
Location	Monterrey-Casanare
ID	MonterreyStation
Category	Pump Station
Type	Oil
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Device	
Name	Engine 4460
ID	III-4460
On Site Location	Monterrey (Yopal - Casanare)
Category	Reciprocating Engines
Type	4-Stroke Rich-Burn (90-105% load)
Service	Oil Pump Driver
Manufacturer	WAUKESHA
Model	L5794GSI
Model Year	N/A
Installation Date	Dec 9 2010 12:00AM

Report Administration Details	
Period Start	2013/06/07
Period End	2013/06/07
Data Contact	Alfonso Garcia
Prepared By	Ecopetrol
Report Generated	2013/09/11

Applied Emission Factors (ng/J)		
Substance	**Value**	**Source**
CH_4 Emission Factor	99.00	US EPA AP-42
N_2O Emission Factor	5.72	US EPA AP-42
VOC Emission Factor	12.70	US EPA AP-42
CO Emission Factor	1,509	US EPA AP-42
PM Emission Factor	4.09	US EPA AP-42
NO_x Emission Factor	475.51	User Entered

Device Comments and Assumptions
Internal Combustion Engine

Data Comments and Assumptions
N/A

Combustion Analysis Input

Gas Stream Conditions			
Stream	**Temperature (^oC)**	**Flow (m3/h @ STP)**	**Relative Humidity (%)**
Ambient Air	30.0		60.0
Fuel	30.0	291.6	0.0
Combustion Air	30.0	0.0	60.0
Flue Gas	601.8	0.0	N/A
Radiator Air (In)	30.0		0.0
Radiator Air (Out)	30.0		0.0

General Simulation Data	
Analysis Method	Fuel Flow And Stack Gas
Flue Gas Type	Dry
Local Barometric Pressure (kPa)	95.8
Nominal Rated Power Output (kW)	1,029
Assumed Efficiency (%)	33.23
Assumed Loading (%)	100
Fuel Cost (USD/GJ)	3.66

Stack Gas Analysis	
Component	**Concentration (On A Dry Volume Basis)**
Oxygen (%)	0.00
Carbon Monoxide (ppm)	0.00
Total Combustible (ppm)	0.00
Unburnt Fuel (calculated) (ppm)	0.00
Nitric Oxide (ppm)	1,666.30
Nitrogen Dioxide (ppm)	0.40
Sulfur Dioxide (ppm)	0.00

Fuel Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Ethane	0.082500	0.082500	0.087246
Isobutane	0.004680	0.004680	0.004949
Isopentane	0.000575	0.000575	0.000608
Methane	0.825081	0.825081	0.872547
n-Butane	0.004203	0.004203	0.004445
n-Heptane	0.000295	0.000295	0.000311
n-Hexane	0.000116	0.000116	0.000123
Nitrogen	0.042190	0.042190	0.000000
n-Pentane	0.000429	0.000429	0.000454
Oxygen	0.012210	0.012210	0.000000
Propane	0.027722	0.027722	0.029317
Total	**1.000000**	**1.000000**	**1.000000**

Combustion Analysis Output

Fuel Gas Characteristics	
Molecular Weight (kg/kmol)	18.6
Quality (inlet condition) (%)	1.0
Gross Heating Value (MJ/m^3)	43.1
Net Heating Value (MJ/m^3)	38.3
Theoretic Combustion Air Requirement (kmol/kmol)	11.1

Material Balance	
Stream	Flow Rate ($10^3 m^3/d$)
Fuel	7.00
Air	78.03
Stack Gas	85.66

Excess Air	
Type	Amount (%)
Actual	0.4
Recommended Lower Limit	2.0
Recommended Upper Limit	12.0

Energy Balance	
Type	Amount (kW)
Gross Input Energy	3,506.9
Net Input Energy	2,828.3

Avoidable Energy Consumption (Losses)		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Recoverable Heat in Flue Gas[1]	27.0	764.2

Unavoidable Energy Comsumption Losses		
Loss Type	Net Input Energy (%)	Loss Rate (kW)
Unrecoverable Heat in Flue Gas[1]	15.6	441.4

[1] The amount of potential recoverable heat was estimated by cooling the flue gas to 10 °C above its dew point and no less that the temperature of 15 °C. The unrecoverable portion is the energy still left in the flue gas at that temperature.

Efficiencies	
Efficiency Type	Amount (%)
Apparent Thermal Efficiency	57.4
Carbon Combustion Efficiency	100.0

Stack Gas Characteristics	
Molecular Weight (kg/kmol)	27.54
Dew Temperature (^oC)	59.4

Determined Flue Gas Emission Factors[2]	
Component	Amount (ng/J)
Carbon Monoxide	0.0
Carbon Dioxide	51,045.1
Methane	0.0
Ethane	0.0
Total VOC	0.0
Total Hydrocarbons	0.0
Nitric Oxide	479.5
Nitrogen Dioxide	0.2
Total Oxides of Nitrogen	479.7
Hydrogen Sulfide	0.0
Sulfur Dioxide	0.0
Carbon Disulfide	0.0
Carbonyl Sulfide	0.0
Total TRS	0.0

[2] Based on the gross heating value of the fuel at 15 ˚C and 101.325 kPa. The SO_2 emission factor is based on the concentration measured in the flue gas.

Dry Flue Gas Analysis	
Component	**Mole Fraction**
nitrogen	0.877394
carbon_dioxide	0.120939
nitric_oxide	0.001666
nitrogen_dioxide	0.000000
oxygen	0.000000
Total	**1.000000**

Control Technology Input

Control Technology Type	Application Description	Reduction Efficiencies (%)			Current System Life (y)	Control Technology Life (y)	Electric Power Requirements (kWh/y)
		Energy	Hydro-carbon	Sulphur			
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0.00	0.00	0.00	20	20	-1,120,127
Tuning	Once per year.	0.00	0.00	0.00	20	20	0

Control Technology Type	Application Description	Year-0 Equip. Removal Salvage Value (USD)	Operating Costs (USD)	Operating Costs Avoided (USD)	Technology EOL Salvage Value (USD)
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	0	0	0	0
Tuning	Once per year.	0	2,000	0	0

Control Technology Type	Application Description	Applied Emission Factors[1] (ng/J)						Hydrocarbon Destruction Efficiency (%)
		CH_4	N_2O	VOC	CO	PM	NO_x	
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tuning	Once per year.	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] Emission Factors used in simulation if the Control Technology consumes fuel as part of its operation.

Simulation Results

Source Name	Source Tag No.	Service Type	Value of Fuel/Loss Stream (USD/y)	Total Product Loss Flow (m^3/h)	Total Product Losses				
					Residue Gas ($10^3 m^3/d$)	Ethane (m^3/d liq)	LPG (m^3/d liq)	NGL (m^3/d)	Hydrogen (m^3/d)
Engine 4460	III-4460	Oil Pump Driver	534,854	291.6	6.11	2.17	1.03	0.05	0.00

Total (Direct and Indirect) Emissions (t/y)								
CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
10.9	5,614	0.63	6,037	1.4	166.0	52.3	0.0	0.4

Potential Control Options

Control Technology Type	Energy Recovery Efficiency (%)	Capital Cost (USD)	Net Present Salvage Value (USD)	Net Operating Cost (USD/y)	Value of Conserved Energy (USD/y)	NPV (USD)	ROI (%)	Payback Period (y)
Organic Rankin Cycle (ORC) Waste Heat	0.00	416,990	0	0	89,610	243,058	21.49	4.65
Tuning	0.00	0	0	2,000	0	-14,732	NA	NA

Control Technology Type	Estimated Emission Reduction Potential (t/y)								
	CH_4	CO_2	N_2O	CO_2E	VOC	CO	NOx	SO_2	PM
Organic Rankin Cycle (ORC) Waste Heat	0.00	176	0.00	177	0.00	0.00	0.00	0.00	0.00
Tuning	0.00	0	0.00	0	0.00	0.00	0.00	0.00	0.00

Capital Cost Details

Control Technology Type	Application description
Organic Rankin Cycle (ORC) Waste Heat Recovery	Waste Heat Recovery

Cost Category	Cost Item Type	Item Description	Rate (USD/Unit)	Quantity (Unit)	Line Total (USD)
Construction	Crane Operation	(Crane 75 ton) Quantity in hours	450.00	10.0	4,500
	Electrical	(Electricians) Quantity in hours	60.00	140.0	8,400
	Freight	(Trucking) Quantity in hours	6,000.00	1.0	6,000
	Inspection and Quality Control	(Project Manager) Quantity in hours	120.00	100.0	12,000
	Instrumentation	(Instrument tech) Quantity in hours	60.00	40.0	2,400
	Labourers	(Insulation Removal) Quantity in hours	60.00	40.0	2,400
		(Labour) Quantity in hours	44.00	140.0	6,160
		(Scaffolding) Quantity in hours	80.00	60.0	4,800
	Mobilization and Demobilization	(Truck and Vans) Quantity in hours	25.00	300.0	7,500
		Garbage Removal	800.00	1.0	800
		Scrape Iron Removal	600.00	1.0	600
	Other Constuction Cost	(Custom Broker) Quantity in hours	1,000.00	1.0	1,000
		(Man lift) Quantity in hours	300.00	10.0	3,000
		(Painting) Quantity in hours	52.00	40.0	2,080
		(Zoom boom) Quantity in hours	480.00	5.0	2,400
		Contingency	34,462.00	1.0	34,462

		Porta Potties	550.00	1.0	550
	Pipefitting	(Pipe Fitters) Quantity in hours	58.00	140.0	8,120
	Shelter	(Office trailer) Quantity in hours	200.00	10.0	2,000
	Supervision (third party consultant)	(Commisioning) Quantity in hours	80.00	40.0	3,200
		(Foreman) Quantity in hours	70.00	80.0	5,600
		(Programming) Quantity in hours	130.00	20.0	2,600
		(Supervisor) Quantity in hours	90.00	100.0	9,000
	Welding	(Welder Helpers) Quantity in hours	44.00	140.0	6,160
		(Welder) Quantity in hour	110.00	140.0	15,400
Engineering and Drafting	Process	Engineering	37,908.20	1.0	37,908
Material	Control Panel	Techcable	10.00	300.0	3,000
	Instruments	Instrumentation	10,000.00	1.0	10,000
	Miscellaneous Material Cost	Cable tray	15.00	300.0	4,500
	Other Material Cost	Consumables	5,000.00	1.0	5,000
		ORC Skid Unit	173,000.00	1.0	173,000
		Synchronizing Gear	20,000.00	1.0	20,000
	Pipes and Fittings	Fittings	110.00	15.0	1,650
		Pipe	90.00	20.0	1,800
	Valves	Control Valves	4,500.00	2.0	9,000

Total	416,990

APPENDIX H GAS ANALYSES

This section presents a copy of all the gas analyses performed during the production facilities study and any gas analyses provided by Ecopetrol.

CLEARSTONE ENGINEERING

Listing of Gas and Vapour Analyses Performed				
Facility	**Substance**	**Composition Name**	**Clearstone ID #**	**Sample Date**
Acacias Oil Battery	Flare Gas	2012-11-10 flare acacias 2.0003.BND	195	11/10/2012
Acacias Oil Battery	Flare Gas	2012-11-10 flare acacias 2.0004.BND	196	11/10/2012
Acacias Oil Battery	Flare Gas	2012-11-10 flare acacias 2.0005.BND	197	11/10/2012
Acacias Oil Battery	Flare Gas	2012-11-10 flare acacias 3.0006.BND	198	11/10/2012
Acacias Oil Battery	Flare Gas	2012-11-10 flare acacias 3.0007.BND	199	11/10/2012
Acacias Oil Battery	Flare Gas	Acacias Flare 1	33	11/10/2012
Acacias Oil Battery	Tank Vapour	2012-11-10 acacias atk 7305	6	11/10/2012
Acacias Oil Battery	Tank Vapour	2012-11-10 acacias atk 7305.0011.BND	203	11/10/2012
Acacias Oil Battery	Tank Vapour	2012-11-10 acacias atk 7305.0012.BND	204	11/10/2012
Acacias Oil Battery	Tank Vapour	2012-11-10 acacias atk 7305.0013.BND	205	11/10/2012
Acacias Oil Battery	Tank Vapour	2012-11-10 acacias atk 7306	5	11/10/2012
Acacias Oil Battery	Tank Vapour	2012-11-10 acacias atk 7306.0008.BND	200	11/10/2012
Acacias Oil Battery	Tank Vapour	2012-11-10 acacias atk 7306.0009.BND	201	11/10/2012
Acacias Oil Battery	Tank Vapour	2012-11-10 acacias atk 7306.0010.BND	202	11/10/2012
Acacias Oil Battery	Tank Vapour	2012-11-13 acacias atk 7301	8	11/13/2012
Acacias Oil Battery	Tank Vapour	2012-11-13 acacias atk 7301.0017.BND	208	11/13/2012
Acacias Oil Battery	Tank Vapour	2012-11-13 acacias atk 7301.0018.BND	209	11/13/2012
Acacias Oil Battery	Tank Vapour	2012-11-13 acacias atk 7302	7	11/13/2012
Acacias Oil Battery	Tank Vapour	2012-11-13 acacias atk 7302.0015.BND	206	11/13/2012
Acacias Oil Battery	Tank Vapour	2012-11-13 acacias atk 7302.0016.BND	207	11/13/2012
Acacias Oil Battery	Tank Vapour	2012-11-13 acacias atk 7311.0019.BND	210	11/13/2012
Acacias Oil Battery	Tank Vapour	2012-11-13 acacias atk 7311.0020.BND	211	11/13/2012
Castilla Oil Battery No.2	Tank Vapour	2012-11-13 Castilla 2 atk 7205b	11	11/13/2012

Castilla Oil Battery No.2	Tank Vapour	2012-11-13 Castilla 2 atk 7205b.0038.BND	226	11/13/2012
Castilla Oil Battery No.2	Tank Vapour	2012-11-13 Castilla 2 atk 7205b.0039.BND	227	11/13/2012
Chichimene Station	Casing Gas	2012-11-13 chimene well 21.0042.BND	230	11/13/2012
Chichimene Station	Casing Gas	2012-11-13 chimene well 21.0043.BND	231	11/13/2012
Chichimene Station	Casing Gas	2012-11-13 chimene well 50.0040.BND	228	11/13/2012
Chichimene Station	Casing Gas	2012-11-13 chimene well 50.0041.BND	229	11/13/2012
Chichimene Station	Casing Gas	2012-11-13 chimene well 6.0044.BND	232	11/13/2012
Chichimene Station	Casing Gas	2012-11-13 chimene well 6.0045.BND	233	11/13/2012
Chichimene Station	Flare Gas	2012-11-13 chimene flare1.0036.BND	224	11/13/2012
Chichimene Station	Flare Gas	2012-11-13 chimene flare1.0037.BND	225	11/13/2012
Chichimene Station	Flare Gas	2012-11-13 chimene flare2.0034.BND	222	11/13/2012
Chichimene Station	Flare Gas	2012-11-13 chimene flare2.0035.BND	223	11/13/2012
Chichimene Station	Flare Gas	2012-11-13 chimene flare3.0030.BND	218	11/13/2012
Chichimene Station	Flare Gas	2012-11-13 chimene flare3.0031.BND	219	11/13/2012
Chichimene Station	Flare Gas	2012-11-13 chimene flare4.0032.BND	220	11/13/2012
Chichimene Station	Flare Gas	2012-11-13 chimene flare4.0033.BND	221	11/13/2012
Chichimene Station	Flare Gas	2012-11-13 chimene secondary flare 5.0048.BND	236	11/13/2012
Chichimene Station	Flare Gas	2012-11-13 chimene secondary flare 5.0049.BND	237	11/13/2012
Chichimene Station	Flare Gas	2012-11-13 chimene secondary flare 6.0053.BND	238	11/13/2012
Chichimene Station	Flare Gas	2012-11-13 chimene secondary flare 6.0054.BND	239	11/13/2012
Chichimene Station	Flare Gas	2012-11-13 chimene secondary flare.0046.BND	234	11/13/2012
Chichimene Station	Flare Gas	2012-11-13 chimene secondary flare.0047.BND	235	11/13/2012
Chichimene Station	Fuel Gas	2012-11-13 chimene heater 1 fuel	25	11/13/2012
Chichimene Station	Fuel Gas	2012-11-13 chimene heater 1 fuel.0055.BND	240	11/13/2012
Chichimene Station	Fuel Gas	2012-11-13 chimene heater 1 fuel.0056.BND	241	11/13/2012
Chichimene Station	Tank Vapour	2012-11-13 chimene atk 7401b.0026.BND	214	11/13/2012
Chichimene Station	Tank Vapour	2012-11-13 chimene atk 7401b.0027.BND	215	11/13/2012
Chichimene Station	Tank Vapour	2012-11-13 chimene atk 7403a	14	11/13/2012
Chichimene Station	Tank Vapour	2012-11-13 chimene atk 7403a.0028.BND	216	11/13/2012
Chichimene Station	Tank Vapour	2012-11-13 chimene atk 7403a.0029.BND	217	11/13/2012
Chichimene Station	Tank Vapour	2012-11-13 chimene atk 7463.0021.BND	212	11/13/2012
Chichimene Station	Tank Vapour	2012-11-13 chimene atk 7463.0022.BND	213	11/13/2012
Chichimene Station	Tank Vapour	2012-11-13 chimene flare1	18	11/13/2012
Chichimene Station	Tank Vapour	2012-11-13 chimene flare2	17	11/13/2012

Chichimene Station	Tank Vapour	2012-11-13 chimene atk 7401b Air Free	296	11/13/2013
Monterrey Station	Fuel Gas	Station Fuel Gas	56	2/7/2013

Calculated or Reported Compositions				
Facility	**Substance**	**Composition Name**	**Clearstone ID #**	**Data Entry Date**
Acacias Oil Battery	Fuel Gas	Propane	59	6/14/2013
Chichimene Station	Fuel Gas	Propane	58	6/14/2013

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-10 flare acacias 2.0003.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/10/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	195

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001600	0.001600	0.001632
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.074385	0.074385	0.075857
Isobutane	0.104255	0.104255	0.106318
Isopentane	0.066085	0.066085	0.067393
Methane	0.288661	0.288661	0.294372
n-Butane	0.090304	0.090304	0.092091
n-Hexane	0.080175	0.080175	0.081761
Nitrogen	0.093865	0.093865	0.080123
n-Pentane	0.060333	0.060333	0.061527
Oxygen	0.004103	0.004103	0.000000
Propane	0.136232	0.136232	0.138927
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-10 flare acacias 2.0004.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/10/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	196

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.000640	0.000640	0.000650
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.074539	0.074539	0.075753
Isobutane	0.104372	0.104372	0.106072
Isopentane	0.065762	0.065762	0.066833
Methane	0.291238	0.291238	0.295981
n-Butane	0.090233	0.090233	0.091703
n-Hexane	0.080824	0.080824	0.082141
Nitrogen	0.092600	0.092600	0.081268
n-Pentane	0.060223	0.060223	0.061204
Oxygen	0.003389	0.003389	0.000000
Propane	0.136178	0.136178	0.138396
Total	1.000000	1.000000	1.000000

CLEARSTONE ENGINEERING

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-10 flare acacias 2.0005.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/10/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	197

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001480	0.001480	0.001521
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.073633	0.073633	0.075659
Isobutane	0.104145	0.104145	0.107011
Isopentane	0.066372	0.066372	0.068198
Methane	0.287498	0.287498	0.295410
n-Butane	0.090093	0.090093	0.092572
n-Hexane	0.080969	0.080969	0.083197
Nitrogen	0.094933	0.094933	0.075847
n-Pentane	0.060493	0.060493	0.062157
Oxygen	0.005665	0.005665	0.000000
Propane	0.134721	0.134721	0.138428
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-10 flare acacias 3.0006.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/10/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	198

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001640	0.001640	0.001665
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.074209	0.074209	0.075325
Isobutane	0.100907	0.100907	0.102425
Isopentane	0.064183	0.064183	0.065149
Methane	0.296998	0.296998	0.301466
n-Butane	0.087976	0.087976	0.089299
n-Hexane	0.085906	0.085906	0.087198
Nitrogen	0.093606	0.093606	0.083152
n-Pentane	0.058896	0.058896	0.059782
Oxygen	0.003135	0.003135	0.000000
Propane	0.132544	0.132544	0.134538
Total	1.000000	1.000000	1.000000

CLEARSTONE ENGINEERING

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-10 flare acacias 3.0007.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/10/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	199

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001660	0.001660	0.001690
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.073099	0.073099	0.074436
Isobutane	0.100420	0.100420	0.102257
Isopentane	0.064664	0.064664	0.065848
Methane	0.295787	0.295787	0.301199
n-Butane	0.088052	0.088052	0.089663
n-Hexane	0.088884	0.088884	0.090510
Nitrogen	0.093057	0.093057	0.080332
n-Pentane	0.059710	0.059710	0.060802
Oxygen	0.003801	0.003801	0.000000
Propane	0.130867	0.130867	0.133262
Total	1.000000	1.000000	1.000000

CLEARSTONE ENGINEERING

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	Acacias Flare 1
Description and Comments	N/A
Data Entry Date	2013/03/05
Sample Date	11/10/2012
Sample Type	Unknown
Substance Type	Flare Gas
Clearstone ID	33

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001523	0.001523	0.001554
Ethane	0.074018	0.074018	0.075491
Isobutane	0.102297	0.102297	0.104334
Isopentane	0.064775	0.064775	0.066064
Methane	0.294840	0.294840	0.300710
n-Butane	0.088864	0.088864	0.090633
n-Hexane	0.082006	0.082006	0.083638
Nitrogen	0.094413	0.094413	0.080594
n-Pentane	0.059141	0.059141	0.060319
Oxygen	0.004129	0.004129	0.000000
Propane	0.133994	0.133994	0.136662
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-10 acacias atk 7305
Description and Comments	N/A
Data Entry Date	2013/01/08
Sample Date	11/10/2012
Sample Type	Unknown
Substance Type	Tank Vapour
Clearstone ID	6

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001697	0.001697	0.002364
Ethane	0.038917	0.038917	0.054222
Isobutane	0.075529	0.075529	0.105233
Isopentane	0.087576	0.087576	0.122018
Methane	0.170294	0.170294	0.237268
n-Butane	0.096855	0.096855	0.134946
n-Hexane	0.076975	0.076975	0.107248
Nitrogen	0.184935	0.184935	0.000000
n-Pentane	0.077116	0.077116	0.107445
Oxygen	0.097336	0.097336	0.000000
Propane	0.092770	0.092770	0.129256
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-10 acacias atk 7305.0011.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/10/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	203

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001680	0.001680	0.002250
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.041473	0.041473	0.055549
Isobutane	0.082534	0.082534	0.110544
Isopentane	0.079565	0.079565	0.106568
Methane	0.196141	0.196141	0.262708
n-Butane	0.087710	0.087710	0.117477
n-Hexane	0.087980	0.087980	0.117839
Nitrogen	0.172544	0.172544	0.000000
n-Pentane	0.072261	0.072261	0.096785
Oxygen	0.080843	0.080843	0.000000
Propane	0.097269	0.097269	0.130280
Total	1.000000	1.000000	1.000000

Composition Source Data

CLEARSTONE ENGINEERING

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-10 acacias atk 7305.0012.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/10/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	204

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001700	0.001700	0.002514
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.033470	0.033470	0.049500
Isobutane	0.062967	0.062967	0.093125
Isopentane	0.096076	0.096076	0.142091
Methane	0.118349	0.118349	0.175032
n-Butane	0.114858	0.114858	0.169868
n-Hexane	0.079341	0.079341	0.117341
Nitrogen	0.202536	0.202536	0.000000
n-Pentane	0.085842	0.085842	0.126956
Oxygen	0.121306	0.121306	0.000000
Propane	0.083555	0.083555	0.123573
Total	1.000000	1.000000	1.000000

Composition Source Data

CLEARSTONE ENGINEERING

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-10 acacias atk 7305.0013.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/10/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	205

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001710	0.001710	0.002341
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.041807	0.041807	0.057237
Isobutane	0.081085	0.081085	0.111013
Isopentane	0.087086	0.087086	0.119229
Methane	0.196391	0.196391	0.268877
n-Butane	0.087997	0.087997	0.120475
n-Hexane	0.063604	0.063604	0.087079
Nitrogen	0.179726	0.179726	0.000000
n-Pentane	0.073246	0.073246	0.100281
Oxygen	0.089860	0.089860	0.000000
Propane	0.097488	0.097488	0.133469
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-10 acacias atk 7306
Description and Comments	N/A
Data Entry Date	2013/01/08
Sample Date	11/10/2012
Sample Type	Unknown
Substance Type	Tank Vapour
Clearstone ID	5

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001590	0.001590	0.001720
Ethane	0.045251	0.045251	0.048939
Isobutane	0.114801	0.114801	0.124159
Isopentane	0.182940	0.182940	0.197852
Methane	0.073453	0.073453	0.079440
n-Butane	0.117824	0.117824	0.127428
n-Hexane	0.080592	0.080592	0.087161
Nitrogen	0.073240	0.073240	0.014940
n-Pentane	0.162471	0.162471	0.175714
Oxygen	0.015941	0.015941	0.000000
Propane	0.131896	0.131896	0.142647
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-10 acacias atk 7306.0008.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/10/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	200

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001650	0.001650	0.001789
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.043979	0.043979	0.047682
Isobutane	0.115222	0.115222	0.124923
Isopentane	0.182119	0.182119	0.197453
Methane	0.071242	0.071242	0.077240
n-Butane	0.118559	0.118559	0.128541
n-Hexane	0.080151	0.080151	0.086900
Nitrogen	0.076727	0.076727	0.016801
n-Pentane	0.162286	0.162286	0.175950
Oxygen	0.016425	0.016425	0.000000
Propane	0.131639	0.131639	0.142722
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-10 acacias atk 7306.0009.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/10/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	201

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001470	0.001470	0.001571
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.045792	0.045792	0.048946
Isobutane	0.115614	0.115614	0.123577
Isopentane	0.185193	0.185193	0.197948
Methane	0.074129	0.074129	0.079235
n-Butane	0.118917	0.118917	0.127108
n-Hexane	0.082241	0.082241	0.087906
Nitrogen	0.065398	0.065398	0.015595
n-Pentane	0.165228	0.165228	0.176608
Oxygen	0.013629	0.013629	0.000000
Propane	0.132389	0.132389	0.141508
Total	1.000000	1.000000	1.000000

Composition Source Data

CLEARSTONE ENGINEERING

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-10 acacias atk 7306.0010.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/10/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	202

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001650	0.001650	0.001801
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.045980	0.045980	0.050197
Isobutane	0.113568	0.113568	0.123984
Isopentane	0.181508	0.181508	0.198155
Methane	0.074988	0.074988	0.081865
n-Butane	0.115998	0.115998	0.126636
n-Hexane	0.079383	0.079383	0.086663
Nitrogen	0.077596	0.077596	0.012398
n-Pentane	0.159900	0.159900	0.174565
Oxygen	0.017769	0.017769	0.000000
Propane	0.131660	0.131660	0.143735
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 acacias atk 7301
Description and Comments	N/A
Data Entry Date	2013/01/08
Sample Date	11/13/2012
Sample Type	Unknown
Substance Type	Tank Vapour
Clearstone ID	8

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.017885	0.017885	0.018783
Ethane	0.076065	0.076065	0.079882
Isobutane	0.140698	0.140698	0.147758
Isopentane	0.075394	0.075394	0.079178
Methane	0.187795	0.187795	0.197219
n-Butane	0.109457	0.109457	0.114950
n-Hexane	0.071530	0.071530	0.075119
Nitrogen	0.074623	0.074623	0.038800
n-Pentane	0.065562	0.065562	0.068852
Oxygen	0.010107	0.010107	0.000000
Propane	0.170885	0.170885	0.179460
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 acacias atk 7301.0017.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	208

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.033790	0.033790	0.035274
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.073891	0.073891	0.077136
Isobutane	0.138408	0.138408	0.144485
Isopentane	0.075515	0.075515	0.078830
Methane	0.181419	0.181419	0.189385
n-Butane	0.108673	0.108673	0.113444
n-Hexane	0.074458	0.074458	0.077727
Nitrogen	0.071497	0.071497	0.040015
n-Pentane	0.066530	0.066530	0.069451
Oxygen	0.008896	0.008896	0.000000
Propane	0.166923	0.166923	0.174252
Total	1.000000	1.000000	1.000000

CLEARSTONE ENGINEERING

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 acacias atk 7301.0018.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	209

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001980	0.001980	0.002092
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.078238	0.078238	0.082661
Isobutane	0.142988	0.142988	0.151071
Isopentane	0.075274	0.075274	0.079529
Methane	0.194172	0.194172	0.205148
n-Butane	0.110241	0.110241	0.116473
n-Hexane	0.068602	0.068602	0.072480
Nitrogen	0.077748	0.077748	0.037569
n-Pentane	0.064593	0.064593	0.068245
Oxygen	0.011317	0.011317	0.000000
Propane	0.174847	0.174847	0.184731
Total	1.000000	1.000000	1.000000

Composition Source Data

CLEARSTONE ENGINEERING

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 acacias atk 7302
Description and Comments	N/A
Data Entry Date	2013/01/08
Sample Date	11/13/2012
Sample Type	Unknown
Substance Type	Tank Vapour
Clearstone ID	7

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.010895	0.010895	0.018792
Ethane	0.044852	0.044852	0.077363
Isobutane	0.052048	0.052048	0.089775
Isopentane	0.054899	0.054899	0.094694
Methane	0.115043	0.115043	0.198434
n-Butane	0.079085	0.079085	0.136411
n-Hexane	0.090036	0.090036	0.155300
Nitrogen	0.275947	0.275947	0.000000
n-Pentane	0.047837	0.047837	0.082513
Oxygen	0.144298	0.144298	0.000000
Propane	0.085060	0.085060	0.146717
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 acacias atk 7302.0015.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	206

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.018550	0.018550	0.032438
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.044182	0.044182	0.077261
Isobutane	0.050912	0.050912	0.089030
Isopentane	0.053245	0.053245	0.093110
Methane	0.114212	0.114212	0.199722
n-Butane	0.077215	0.077215	0.135025
n-Hexane	0.084007	0.084007	0.146903
Nitrogen	0.282633	0.282633	0.000000
n-Pentane	0.046226	0.046226	0.080835
Oxygen	0.145514	0.145514	0.000000
Propane	0.083305	0.083305	0.145676
Total	1.000000	1.000000	1.000000

CLEARSTONE ENGINEERING

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 acacias atk 7302.0016.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	207

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.003240	0.003240	0.005513
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.045522	0.045522	0.077463
Isobutane	0.053184	0.053184	0.090501
Isopentane	0.056553	0.056553	0.096235
Methane	0.115875	0.115875	0.197181
n-Butane	0.080956	0.080956	0.137760
n-Hexane	0.096065	0.096065	0.163471
Nitrogen	0.269260	0.269260	0.000000
n-Pentane	0.049449	0.049449	0.084146
Oxygen	0.143082	0.143082	0.000000
Propane	0.086815	0.086815	0.147730
Total	1.000000	1.000000	1.000000

CLEARSTONE ENGINEERING

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 acacias atk 7311.0019.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	210

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001910	0.001910	0.002441
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.019075	0.019075	0.024383
Isobutane	0.075182	0.075182	0.096102
Isopentane	0.198999	0.198999	0.254372
Methane	0.011586	0.011586	0.014810
n-Butane	0.117086	0.117086	0.149666
n-Hexane	0.089385	0.089385	0.114256
Nitrogen	0.145449	0.145449	0.000000
n-Pentane	0.181963	0.181963	0.232596
Oxygen	0.072237	0.072237	0.000000
Propane	0.087129	0.087129	0.111373
Total	1.000000	1.000000	1.000000

CLEARSTONE ENGINEERING

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 acacias atk 7311.0020.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	211

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001900	0.001900	0.002415
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.018965	0.018965	0.024107
Isobutane	0.074861	0.074861	0.095157
Isopentane	0.199652	0.199652	0.253782
Methane	0.011237	0.011237	0.014284
n-Butane	0.117355	0.117355	0.149172
n-Hexane	0.093426	0.093426	0.118755
Nitrogen	0.143161	0.143161	0.000000
n-Pentane	0.182505	0.182505	0.231986
Oxygen	0.070131	0.070131	0.000000
Propane	0.086807	0.086807	0.110342
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Castilla Oil Battery No.2
Location	N/A
ID	Ecopetrol-Castilla2
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 Castilla 2 atk 7205b
Description and Comments	N/A
Data Entry Date	2013/01/08
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	11

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001765	0.001765	0.002130
Ethane	0.073181	0.073181	0.088332
Isobutane	0.082089	0.082089	0.099084
Isopentane	0.065423	0.065423	0.078968
Methane	0.275571	0.275571	0.332624
n-Butane	0.079017	0.079017	0.095376
n-Hexane	0.069298	0.069298	0.083645
Nitrogen	0.126038	0.126038	0.000000
n-Pentane	0.061946	0.061946	0.074771
Oxygen	0.045487	0.045487	0.000000
Propane	0.120185	0.120185	0.145068
Total	1.000000	1.000000	1.000000

Composition Source Data

CLEARSTONE ENGINEERING

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Castilla Oil Battery No.2
Location	N/A
ID	Ecopetrol-Castilla2
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 Castilla 2 atk 7205b.0038.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	226

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001840	0.001840	0.002241
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.073633	0.073633	0.089692
Isobutane	0.079767	0.079767	0.097163
Isopentane	0.067647	0.067647	0.082400
Methane	0.278479	0.278479	0.339213
n-Butane	0.076988	0.076988	0.093779
n-Hexane	0.058963	0.058963	0.071822
Nitrogen	0.129987	0.129987	0.000000
n-Pentane	0.063754	0.063754	0.077659
Oxygen	0.049058	0.049058	0.000000
Propane	0.119885	0.119885	0.146031
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Castilla Oil Battery No.2
Location	N/A
ID	Ecopetrol-Castilla2
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 Castilla 2 atk 7205b.0039.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	227

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001690	0.001690	0.002022
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.072730	0.072730	0.086998
Isobutane	0.084411	0.084411	0.100971
Isopentane	0.063200	0.063200	0.075598
Methane	0.272663	0.272663	0.326154
n-Butane	0.081045	0.081045	0.096945
n-Hexane	0.079633	0.079633	0.095255
Nitrogen	0.122089	0.122089	0.000000
n-Pentane	0.060137	0.060137	0.071935
Oxygen	0.041916	0.041916	0.000000
Propane	0.120486	0.120486	0.144122
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene well 21.0042.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Casing Gas
Clearstone ID	230

Analysis Results

Component Name	Mole Fraction		
	Entered	Normalized	Air Free
Carbon dioxide	0.001740	0.001740	0.002425
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.037647	0.037647	0.052471
Isobutane	0.003729	0.003729	0.005197
Isopentane	0.006742	0.006742	0.009397
Methane	0.626144	0.626144	0.872696
n-Butane	0.006637	0.006637	0.009251
n-Hexane	0.011246	0.011246	0.015675
Nitrogen	0.183858	0.183858	0.000000
n-Pentane	0.008755	0.008755	0.012203
Oxygen	0.098660	0.098660	0.000000
Propane	0.014841	0.014841	0.020685
Total	1.000000	1.000000	1.000000

Composition Source Data

CLEARSTONE ENGINEERING

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene well 21.0043.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Casing Gas
Clearstone ID	231

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001680	0.001680	0.002330
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.036645	0.036645	0.050815
Isobutane	0.004136	0.004136	0.005736
Isopentane	0.012540	0.012540	0.017389
Methane	0.608471	0.608471	0.843752
n-Butane	0.008244	0.008244	0.011431
n-Hexane	0.018264	0.018264	0.025327
Nitrogen	0.181281	0.181281	0.000000
n-Pentane	0.016181	0.016181	0.022438
Oxygen	0.097570	0.097570	0.000000
Propane	0.014987	0.014987	0.020782
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene well 50.0040.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Casing Gas
Clearstone ID	228

Analysis Results

Component Name	Mole Fraction		
	Entered	Normalized	Air Free
Carbon dioxide	0.001800	0.001800	0.002256
Carbon monoxide	0.000450	0.000450	0.000564
Ethane	0.021191	0.021191	0.026554
Isobutane	0.062342	0.062342	0.078118
Isopentane	0.100831	0.100831	0.126347
Methane	0.090137	0.090137	0.112947
n-Butane	0.116306	0.116306	0.145738
n-Hexane	0.162730	0.162730	0.203909
Nitrogen	0.225560	0.225560	0.083108
n-Pentane	0.098022	0.098022	0.122827
Oxygen	0.042715	0.042715	0.000000
Propane	0.077915	0.077915	0.097632
Total	1.000000	1.000000	1.000000

Composition Source Data

CLEARSTONE ENGINEERING

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene well 50.0041.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Casing Gas
Clearstone ID	229

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001740	0.001740	0.002201
Carbon monoxide	0.000410	0.000410	0.000519
Ethane	0.021494	0.021494	0.027193
Isobutane	0.064169	0.064169	0.081182
Isopentane	0.099541	0.099541	0.125931
Methane	0.094324	0.094324	0.119331
n-Butane	0.118479	0.118479	0.149890
n-Hexane	0.148998	0.148998	0.188501
Nitrogen	0.227680	0.227680	0.078997
n-Pentane	0.098967	0.098967	0.125205
Oxygen	0.044325	0.044325	0.000000
Propane	0.079873	0.079873	0.101049
Total	1.000000	1.000000	1.000000

CLEARSTONE ENGINEERING

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene well 6.0044.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Casing Gas
Clearstone ID	232

Analysis Results

Component Name	Mole Fraction		
	Entered	Normalized	Air Free
Carbon dioxide	0.001750	0.001750	0.002281
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.041581	0.041581	0.054195
Isobutane	0.007631	0.007631	0.009946
Isopentane	0.012296	0.012296	0.016026
Methane	0.635839	0.635839	0.828726
n-Butane	0.014407	0.014407	0.018777
n-Hexane	0.016488	0.016488	0.021490
Nitrogen	0.157235	0.157235	0.000000
n-Pentane	0.014067	0.014067	0.018334
Oxygen	0.075517	0.075517	0.000000
Propane	0.023189	0.023189	0.030224
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene well 6.0045.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Casing Gas
Clearstone ID	233

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001850	0.001850	0.002407
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.042266	0.042266	0.054998
Isobutane	0.007550	0.007550	0.009825
Isopentane	0.010215	0.010215	0.013292
Methane	0.644001	0.644001	0.837993
n-Butane	0.014005	0.014005	0.018224
n-Hexane	0.013753	0.013753	0.017896
Nitrogen	0.156366	0.156366	0.000000
n-Pentane	0.011459	0.011459	0.014910
Oxygen	0.075130	0.075130	0.000000
Propane	0.023406	0.023406	0.030456
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene flare1.0036.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	224

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001700	0.001700	0.001717
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.047822	0.047822	0.048302
Isobutane	0.021091	0.021091	0.021303
Isopentane	0.114404	0.114404	0.115554
Methane	0.475088	0.475088	0.479866
n-Butane	0.047469	0.047469	0.047946
n-Hexane	0.074369	0.074369	0.075117
Nitrogen	0.051964	0.051964	0.044557
n-Pentane	0.113530	0.113530	0.114672
Oxygen	0.002106	0.002106	0.000000
Propane	0.050458	0.050458	0.050965
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene flare1.0037.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	225

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001690	0.001690	0.001739
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.048730	0.048730	0.050147
Isobutane	0.021170	0.021170	0.021786
Isopentane	0.109322	0.109322	0.112502
Methane	0.483056	0.483056	0.497109
n-Butane	0.046820	0.046820	0.048182
n-Hexane	0.060187	0.060187	0.061937
Nitrogen	0.067792	0.067792	0.046825
n-Pentane	0.104030	0.104030	0.107056
Oxygen	0.005979	0.005979	0.000000
Propane	0.051225	0.051225	0.052716
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene flare2.0034.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	222

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001680	0.001680	0.001711
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.047905	0.047905	0.048790
Isobutane	0.020513	0.020513	0.020892
Isopentane	0.108885	0.108885	0.110897
Methane	0.479894	0.479894	0.488760
n-Butane	0.046287	0.046287	0.047142
n-Hexane	0.068720	0.068720	0.069990
Nitrogen	0.065337	0.065337	0.051976
n-Pentane	0.106709	0.106709	0.108680
Oxygen	0.003837	0.003837	0.000000
Propane	0.050233	0.050233	0.051161
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene flare2.0035.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	223

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001750	0.001750	0.001779
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.048020	0.048020	0.048805
Isobutane	0.021129	0.021129	0.021474
Isopentane	0.111286	0.111286	0.113105
Methane	0.481989	0.481989	0.489867
n-Butane	0.047068	0.047068	0.047837
n-Hexane	0.065716	0.065716	0.066790
Nitrogen	0.061875	0.061875	0.050000
n-Pentane	0.107006	0.107006	0.108755
Oxygen	0.003401	0.003401	0.000000
Propane	0.050758	0.050758	0.051588
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene flare3.0030.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	218

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001610	0.001610	0.001650
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.046520	0.046520	0.047686
Isobutane	0.019379	0.019379	0.019864
Isopentane	0.104110	0.104110	0.106718
Methane	0.497171	0.497171	0.509624
n-Butane	0.044277	0.044277	0.045386
n-Hexane	0.066150	0.066150	0.067807
Nitrogen	0.066785	0.066785	0.048708
n-Pentane	0.101512	0.101512	0.104055
Oxygen	0.005168	0.005168	0.000000
Propane	0.047317	0.047317	0.048502
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene flare3.0031.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	219

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001720	0.001720	0.001736
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.046773	0.046773	0.047202
Isobutane	0.020127	0.020127	0.020312
Isopentane	0.108582	0.108582	0.109579
Methane	0.496594	0.496594	0.501154
n-Butane	0.045449	0.045449	0.045866
n-Hexane	0.069607	0.069607	0.070247
Nitrogen	0.054221	0.054221	0.047479
n-Pentane	0.106846	0.106846	0.107827
Oxygen	0.001925	0.001925	0.000000
Propane	0.048156	0.048156	0.048598
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene flare4.0032.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	220

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001630	0.001630	0.001662
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.046056	0.046056	0.046964
Isobutane	0.020958	0.020958	0.021372
Isopentane	0.111818	0.111818	0.114023
Methane	0.470468	0.470468	0.479747
n-Butane	0.046836	0.046836	0.047760
n-Hexane	0.076205	0.076205	0.077708
Nitrogen	0.060442	0.060442	0.046082
n-Pentane	0.111361	0.111361	0.113558
Oxygen	0.004091	0.004091	0.000000
Propane	0.050135	0.050135	0.051124
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene flare4.0033.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	221

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001850	0.001850	0.001894
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.046153	0.046153	0.047245
Isobutane	0.022007	0.022007	0.022528
Isopentane	0.115338	0.115338	0.118068
Methane	0.470061	0.470061	0.481186
n-Butane	0.048412	0.048412	0.049558
n-Hexane	0.067506	0.067506	0.069104
Nitrogen	0.061296	0.061296	0.044086
n-Pentane	0.111638	0.111638	0.114280
Oxygen	0.004890	0.004890	0.000000
Propane	0.050849	0.050849	0.052052
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene secondary flare 5.0048.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	236

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001700	0.001700	0.002006
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.048793	0.048793	0.057576
Isobutane	0.038319	0.038319	0.045217
Isopentane	0.203771	0.203771	0.240452
Methane	0.079247	0.079247	0.093513
n-Butane	0.079711	0.079711	0.094060
n-Hexane	0.110378	0.110378	0.130247
Nitrogen	0.108976	0.108976	0.000000
n-Pentane	0.211365	0.211365	0.249413
Oxygen	0.043574	0.043574	0.000000
Propane	0.074165	0.074165	0.087516
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene secondary flare 5.0049.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	237

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001740	0.001740	0.002122
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.055122	0.055122	0.067236
Isobutane	0.040554	0.040554	0.049466
Isopentane	0.196109	0.196109	0.239206
Methane	0.087589	0.087589	0.106838
n-Butane	0.081761	0.081761	0.099730
n-Hexane	0.083208	0.083208	0.101495
Nitrogen	0.123995	0.123995	0.000000
n-Pentane	0.192085	0.192085	0.234298
Oxygen	0.056175	0.056175	0.000000
Propane	0.081662	0.081662	0.099609
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene secondary flare 6.0053.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	238

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001620	0.001620	0.001866
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.054629	0.054629	0.062926
Isobutane	0.041831	0.041831	0.048184
Isopentane	0.205509	0.205509	0.236722
Methane	0.088903	0.088903	0.102405
n-Butane	0.083263	0.083263	0.095909
n-Hexane	0.100998	0.100998	0.116338
Nitrogen	0.097891	0.097891	0.000000
n-Pentane	0.208528	0.208528	0.240200
Oxygen	0.033964	0.033964	0.000000
Propane	0.082864	0.082864	0.095450
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene secondary flare 6.0054.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	239

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001650	0.001650	0.001861
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.045792	0.045792	0.051661
Isobutane	0.040022	0.040022	0.045151
Isopentane	0.222998	0.222998	0.251576
Methane	0.073001	0.073001	0.082356
n-Butane	0.083808	0.083808	0.094548
n-Hexane	0.108952	0.108952	0.122914
Nitrogen	0.086058	0.086058	0.000000
n-Pentane	0.236834	0.236834	0.267185
Oxygen	0.027537	0.027537	0.000000
Propane	0.073348	0.073348	0.082748
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene secondary flare.0046.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	234

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001930	0.001930	0.002513
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.043206	0.043206	0.056259
Isobutane	0.034173	0.034173	0.044497
Isopentane	0.191015	0.191015	0.248721
Methane	0.073564	0.073564	0.095788
n-Butane	0.075915	0.075915	0.098849
n-Hexane	0.092537	0.092537	0.120493
Nitrogen	0.152645	0.152645	0.000000
n-Pentane	0.188684	0.188684	0.245686
Oxygen	0.079366	0.079366	0.000000
Propane	0.066964	0.066964	0.087195
Total	1.000000	1.000000	1.000000

CLEARSTONE ENGINEERING

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene secondary flare.0047.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Flare Gas
Clearstone ID	235

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001710	0.001710	0.002110
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.048736	0.048736	0.060144
Isobutane	0.037579	0.037579	0.046376
Isopentane	0.195912	0.195912	0.241772
Methane	0.080134	0.080134	0.098892
n-Butane	0.078614	0.078614	0.097016
n-Hexane	0.096504	0.096504	0.119095
Nitrogen	0.128981	0.128981	0.000000
n-Pentane	0.196958	0.196958	0.243063
Oxygen	0.060702	0.060702	0.000000
Propane	0.074170	0.074170	0.091533
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene heater 1 fuel
Description and Comments	N/A
Data Entry Date	2013/01/08
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Fuel Gas
Clearstone ID	25

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001640	0.001640	0.001705
Ethane	0.040937	0.040937	0.042552
Isobutane	0.013576	0.013576	0.014112
Isopentane	0.092795	0.092795	0.096458
Methane	0.528976	0.528976	0.549854
n-Butane	0.033074	0.033074	0.034379
n-Hexane	0.060806	0.060806	0.063206
Nitrogen	0.092440	0.092440	0.064968
n-Pentane	0.093122	0.093122	0.096797
Oxygen	0.008031	0.008031	0.000000
Propane	0.034604	0.034604	0.035970
Total	1.000000	1.000000	1.000000

Composition Source Data

CLEARSTONE ENGINEERING

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene heater 1 fuel.0055.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Fuel Gas
Clearstone ID	240

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001690	0.001690	0.001774
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.040477	0.040477	0.042495
Isobutane	0.014459	0.014459	0.015180
Isopentane	0.097766	0.097766	0.102641
Methane	0.508928	0.508928	0.534306
n-Butane	0.035386	0.035386	0.037150
n-Hexane	0.063934	0.063934	0.067122
Nitrogen	0.093393	0.093393	0.058731
n-Pentane	0.098269	0.098269	0.103169
Oxygen	0.010046	0.010046	0.000000
Propane	0.035652	0.035652	0.037430
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene heater 1 fuel.0056.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Fuel Gas
Clearstone ID	241

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001590	0.001590	0.001637
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.041396	0.041396	0.042608
Isobutane	0.012692	0.012692	0.013064
Isopentane	0.087824	0.087824	0.090395
Methane	0.549025	0.549025	0.565097
n-Butane	0.030762	0.030762	0.031662
n-Hexane	0.057678	0.057678	0.059367
Nitrogen	0.091487	0.091487	0.071083
n-Pentane	0.087974	0.087974	0.090550
Oxygen	0.006016	0.006016	0.000000
Propane	0.033556	0.033556	0.034538
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene atk 7401b.0026.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	214

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001960	0.001960	0.002254
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.063330	0.063330	0.072818
Isobutane	0.050690	0.050690	0.058285
Isopentane	0.195057	0.195057	0.224280
Methane	0.087479	0.087479	0.100585
n-Butane	0.089871	0.089871	0.103335
n-Hexane	0.089249	0.089249	0.102621
Nitrogen	0.096503	0.096503	0.000000
n-Pentane	0.182360	0.182360	0.209681
Oxygen	0.033794	0.033794	0.000000
Propane	0.109706	0.109706	0.126142
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene atk 7401b.0027.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	215

Analysis Results

Component Name	Mole Fraction		
	Entered	Normalized	Air Free
Carbon dioxide	0.001800	0.001800	0.002050
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.062545	0.062545	0.071230
Isobutane	0.050222	0.050222	0.057196
Isopentane	0.197604	0.197604	0.225042
Methane	0.086679	0.086679	0.098714
n-Butane	0.089603	0.089603	0.102044
n-Hexane	0.093400	0.093400	0.106369
Nitrogen	0.092097	0.092097	0.000000
n-Pentane	0.187864	0.187864	0.213948
Oxygen	0.029824	0.029824	0.000000
Propane	0.108362	0.108362	0.123408
Total	1.000000	1.000000	1.000000

Composition Source Data

CLEARSTONE ENGINEERING

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene atk 7403a
Description and Comments	N/A
Data Entry Date	2013/01/08
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	14

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001795	0.001795	0.003023
Ethane	0.004319	0.004319	0.007274
Isobutane	0.017992	0.017992	0.030301
Isopentane	0.175530	0.175530	0.295618
Methane	0.001114	0.001114	0.001876
n-Butane	0.056153	0.056153	0.094570
n-Hexane	0.137190	0.137190	0.231048
Nitrogen	0.258625	0.258625	0.000000
n-Pentane	0.177466	0.177466	0.298879
Oxygen	0.147602	0.147602	0.000000
Propane	0.022213	0.022213	0.037409
Total	1.000000	1.000000	1.000000

Composition Source Data

CLEARSTONE ENGINEERING

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene atk 7403a.0028.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	216

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001780	0.001780	0.003097
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.004401	0.004401	0.007657
Isobutane	0.017952	0.017952	0.031232
Isopentane	0.172708	0.172708	0.300464
Methane	0.001218	0.001218	0.002120
n-Butane	0.055746	0.055746	0.096982
n-Hexane	0.125515	0.125515	0.218362
Nitrogen	0.275604	0.275604	0.000000
n-Pentane	0.173155	0.173155	0.301242
Oxygen	0.149594	0.149594	0.000000
Propane	0.022328	0.022328	0.038845
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene atk 7403a.0029.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	217

Analysis Results

Component Name	Mole Fraction		
	Entered	Normalized	Air Free
Carbon dioxide	0.001810	0.001810	0.002954
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.004237	0.004237	0.006915
Isobutane	0.018032	0.018032	0.029429
Isopentane	0.178353	0.178353	0.291073
Methane	0.001010	0.001010	0.001648
n-Butane	0.056560	0.056560	0.092307
n-Hexane	0.148865	0.148865	0.242950
Nitrogen	0.241647	0.241647	0.000000
n-Pentane	0.181777	0.181777	0.296661
Oxygen	0.145611	0.145611	0.000000
Propane	0.022097	0.022097	0.036063
Total	1.000000	1.000000	1.000000

CLEARSTONE ENGINEERING

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene atk 7463.0021.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	212

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001930	0.001930	0.002049
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.041899	0.041899	0.044490
Isobutane	0.026579	0.026579	0.028224
Isopentane	0.129857	0.129857	0.137889
Methane	0.389991	0.389991	0.414116
n-Butane	0.057101	0.057101	0.060634
n-Hexane	0.084335	0.084335	0.089552
Nitrogen	0.075065	0.075065	0.030932
n-Pentane	0.127660	0.127660	0.135557
Oxygen	0.012322	0.012322	0.000000
Propane	0.053261	0.053261	0.056555
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene atk 7463.0022.BND
Description and Comments	Automatically entered raw data.
Data Entry Date	2013/08/30
Sample Date	11/13/2012
Sample Type	As Sampled
Substance Type	Tank Vapour
Clearstone ID	213

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001290	0.001290	0.001352
Carbon monoxide	0.000000	0.000000	0.000000
Ethane	0.043416	0.043416	0.045493
Isobutane	0.026659	0.026659	0.027935
Isopentane	0.128184	0.128184	0.134317
Methane	0.404461	0.404461	0.423815
n-Butane	0.056915	0.056915	0.059638
n-Hexane	0.082675	0.082675	0.086632
Nitrogen	0.067685	0.067685	0.033193
n-Pentane	0.124956	0.124956	0.130936
Oxygen	0.009659	0.009659	0.000000
Propane	0.054100	0.054100	0.056689
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene flare1
Description and Comments	N/A
Data Entry Date	2013/01/08
Sample Date	11/13/2012
Sample Type	Unknown
Substance Type	Tank Vapour
Clearstone ID	18

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001695	0.001695	0.001728
Ethane	0.048276	0.048276	0.049216
Isobutane	0.021130	0.021130	0.021542
Isopentane	0.111863	0.111863	0.114043
Methane	0.479072	0.479072	0.488407
n-Butane	0.047145	0.047145	0.048063
n-Hexane	0.067278	0.067278	0.068589
Nitrogen	0.059878	0.059878	0.045680
n-Pentane	0.108780	0.108780	0.110900
Oxygen	0.004043	0.004043	0.000000
Propane	0.050842	0.050842	0.051832
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene flare2
Description and Comments	N/A
Data Entry Date	2013/01/08
Sample Date	11/13/2012
Sample Type	Unknown
Substance Type	Tank Vapour
Clearstone ID	17

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.001715	0.001715	0.001745
Ethane	0.047963	0.047963	0.048798
Isobutane	0.020821	0.020821	0.021184
Isopentane	0.110086	0.110086	0.112002
Methane	0.480942	0.480942	0.489314
n-Butane	0.046677	0.046677	0.047490
n-Hexane	0.067218	0.067218	0.068388
Nitrogen	0.063606	0.063606	0.050987
n-Pentane	0.106857	0.106857	0.108718
Oxygen	0.003619	0.003619	0.000000
Propane	0.050495	0.050495	0.051374
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	2012-11-13 chimene atk 7401b Air Free
Description and Comments	Air free version of atk 0401b tank vapour for flashing loss calculation.
Data Entry Date	2013/09/08
Sample Date	11/13/2013
Sample Type	Computed
Substance Type	Tank Vapour
Clearstone ID	296

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Carbon dioxide	0.002151	0.002151	0.002151
Ethane	0.072020	0.072020	0.072020
Isobutane	0.057738	0.057737	0.057737
Isopentane	0.224662	0.224662	0.224662
Methane	0.099645	0.099645	0.099645
n-Butane	0.102687	0.102687	0.102687
n-Hexane	0.104504	0.104504	0.104504
n-Pentane	0.211825	0.211825	0.211825
Propane	0.124769	0.124769	0.124769
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	N/A
Name	Monterrey Station
Location	Monterrey-Casanare
ID	MonterreyStation
Category	Pump Station
Type	Oil
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	Station Fuel Gas
Description and Comments	N/A
Data Entry Date	2013/04/01
Sample Date	2/7/2013
Sample Type	As Sampled
Substance Type	Fuel Gas
Clearstone ID	56

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Ethane	0.082500	0.082500	0.087246
Isobutane	0.004680	0.004680	0.004949
Isopentane	0.000575	0.000575	0.000608
Methane	0.825081	0.825081	0.872547
n-Butane	0.004203	0.004203	0.004445
n-Heptane	0.000295	0.000295	0.000311
n-Hexane	0.000116	0.000116	0.000123
Nitrogen	0.042190	0.042190	0.000000
n-Pentane	0.000429	0.000429	0.000454
Oxygen	0.012210	0.012210	0.000000
Propane	0.027722	0.027722	0.029317
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Acacias Oil Battery
Location	N/A
ID	Ecopetrol-Acacias
Category	Wells
Type	Conventional Oil (Pumping)
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	Propane
Description and Comments	Fuel gas (Flare). Assuming 0.8 propane and 0.2 ethane based on reported HHV (2373 BTU/scf)
Data Entry Date	2013/06/14
Sample Date	N/A
Sample Type	Computed
Substance Type	Fuel Gas
Clearstone ID	59

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Ethane	0.200000	0.200000	0.200000
Propane	0.800000	0.800000	0.800000
Total	1.000000	1.000000	1.000000

Composition Source Data

Facility	
Clearstone Client	PTAC
Data Client	Ecopetrol
Operator	Ecopetrol
Name	Chichimene Station
Location	N/A
ID	Ecopetrol-Chichimene
Category	Battery
Type	Oil Multi-Well
Government ID	N/A
Operator BA Code	N/A
Licensee BA Code	N/A
Licensee Name	N/A

Sample Data	
Name	Propane
Description and Comments	Fuel gas (Flare). Assuming 0.8 propane and 0.2 ethane based on reported HHV (2373 BTU/scf)
Data Entry Date	2013/06/14
Sample Date	N/A
Sample Type	Computed
Substance Type	Fuel Gas
Clearstone ID	58

Analysis Results			
Component Name	**Mole Fraction**		
	Entered	**Normalized**	**Air Free**
Ethane	0.200000	0.200000	0.200000
Propane	0.800000	0.800000	0.800000
Total	1.000000	1.000000	1.000000