Improved Waterflood Performance Under Bottom Water Conditions

Presenter: Alex Turta
Alberta Research Council

Outline

- Long and Short Distance Oil Displacement
- The Toe-to-Heel (TTH) Displacement Processes
- Toe-to-Heel-Waterflooding (TTHW)
  - Mechanisms, advantages
  - Laboratory and simulation results
  - Screening criteria
  - Current status
- Proposed investigations for TTH displacement in reservoirs with bottom water conditions

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The Three BIG Negative Factors for any LDOD Process in Porous Media

- Gravity segregation
  - displacing / displaced fluid density contrast
  - over-riding / under-riding of the injected fluid
- Rock heterogeneity (usually along bedding planes)
- Displacing fluid / displaced fluid (oil) unfavorable mobility ratio (M_r). $M_r = (Kr/\mu)_d / (Kr/\mu)_{oil}$.

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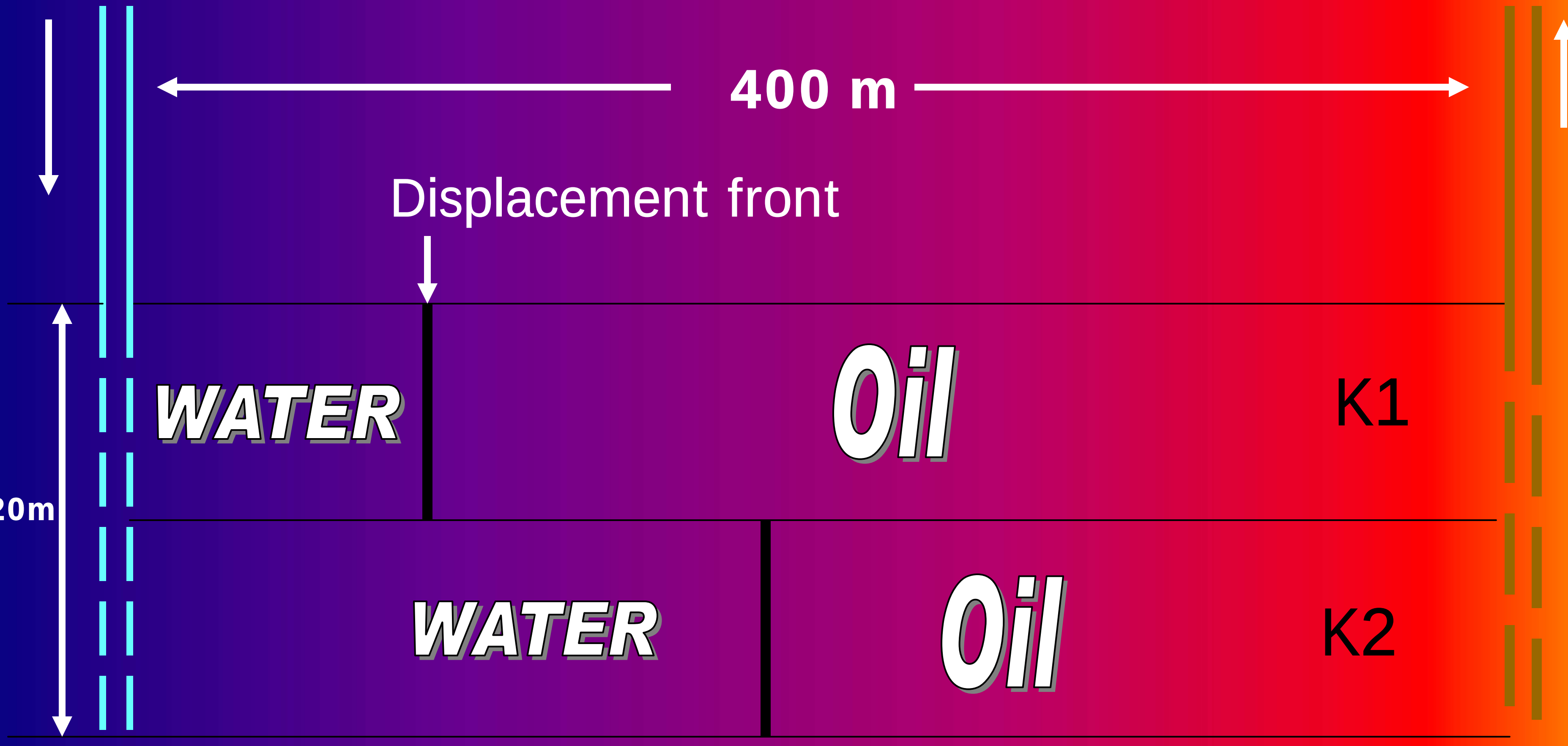
Long-Distance Oil Displacement Waterflood Case. K1<<K2

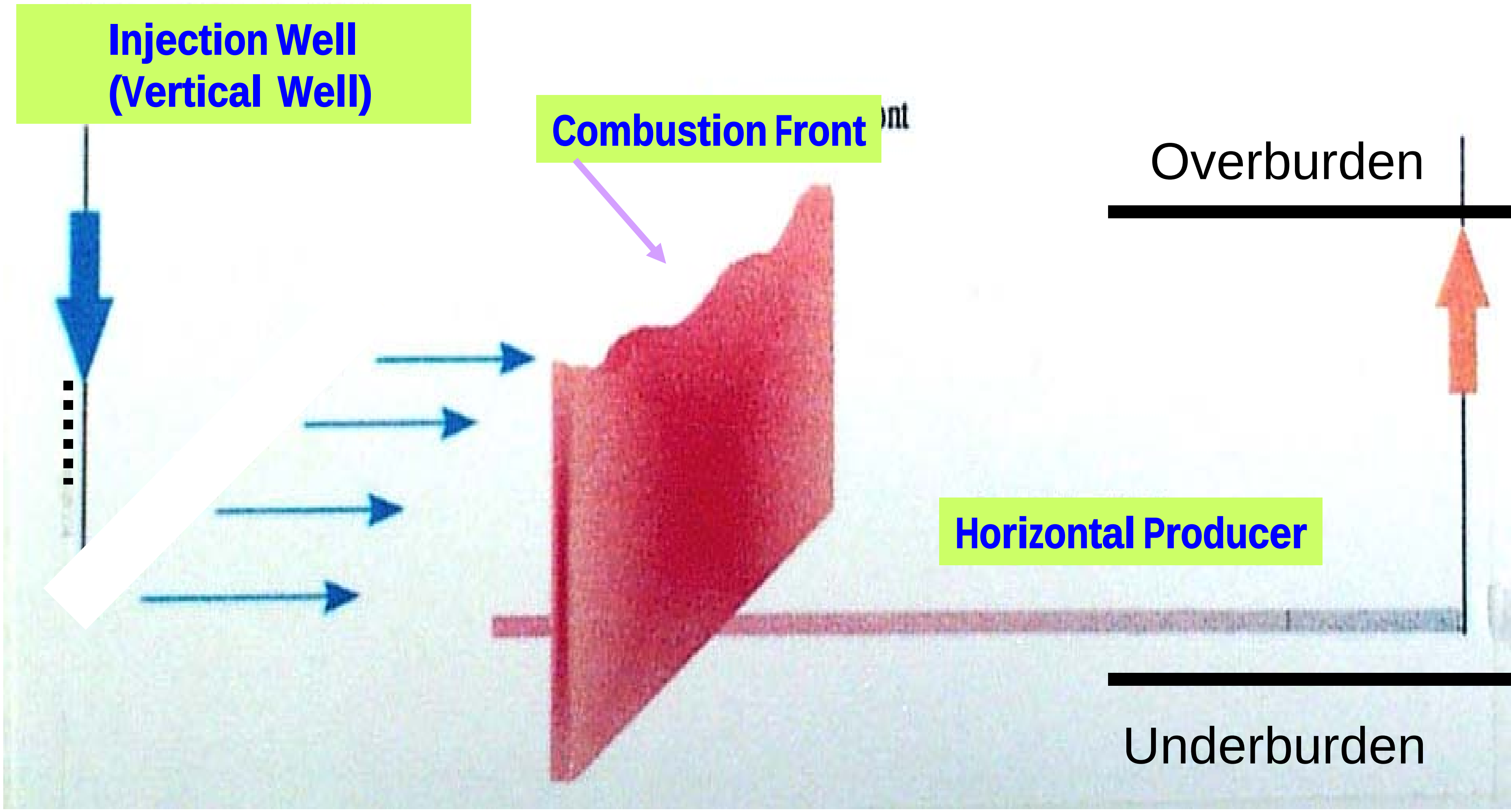


Main Features of the Long Distance Oil Displacement

- Each oil particle travels a long distance before it is produced
- Channeling and/or over-riding are functions of the integrated flow resistance, *all along*; mobility ratio is crucial
- Performance depends on the distribution of properties (mainly permeability, oil viscosity & fluid saturation) for all the reservoir volume between injection and production well

TTH Displacement Processes: Status

- TTH displacement processes
  - new IOR technologies using (typically) vertical injectors and horizontal producers
- Thermal TTH processes (THAI, and CAPRI)
  - proven in 3-D laboratory model tests and through simulation; a field test is in preparation
- Non-thermal TTH processes – TTHW
  - proven in 3-D laboratory model tests and through simulation; a field test is under consideration

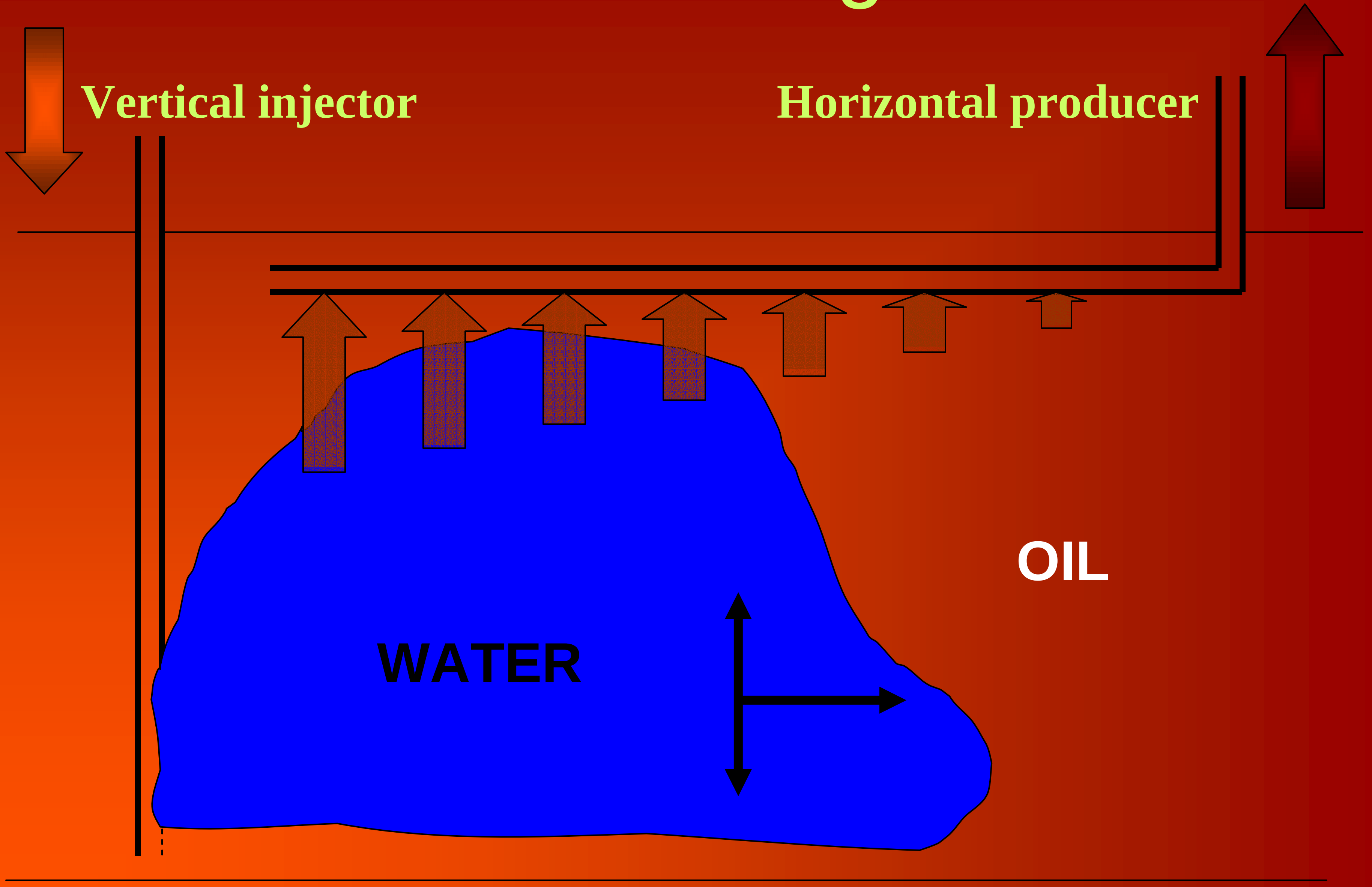


Concept of a Thermal TTH Process: Toe-to-Heel Air Injection Process (THAI)

Toe-to-Heel Waterflooding (TTHW)

- Non-thermal toe-to-heel displacement
- Main feature
  - controlled water breakthrough - always in the toe region
- Applicability to both light and intermediate heavy oil reservoirs

TTH Waterflooding Process



Mechanisms/Advantages

- Water-oil gravity segregation tends to cause water to under-ride
- Horizontal well as a sink causes oil to be “pushed up” and produced; it causes water to flow upwards
- Advantages:
  - **Gravity stable**; with watering-out from toe to heel
  - Negative effect of heterogeneity – reduced
  - Negative effect of unfavorable mobility ratio - reduced

Summary of Work to Date

- Hele Shaw tests
- 3D model tests
- Simulation
    - Lab scale
    - Field scale

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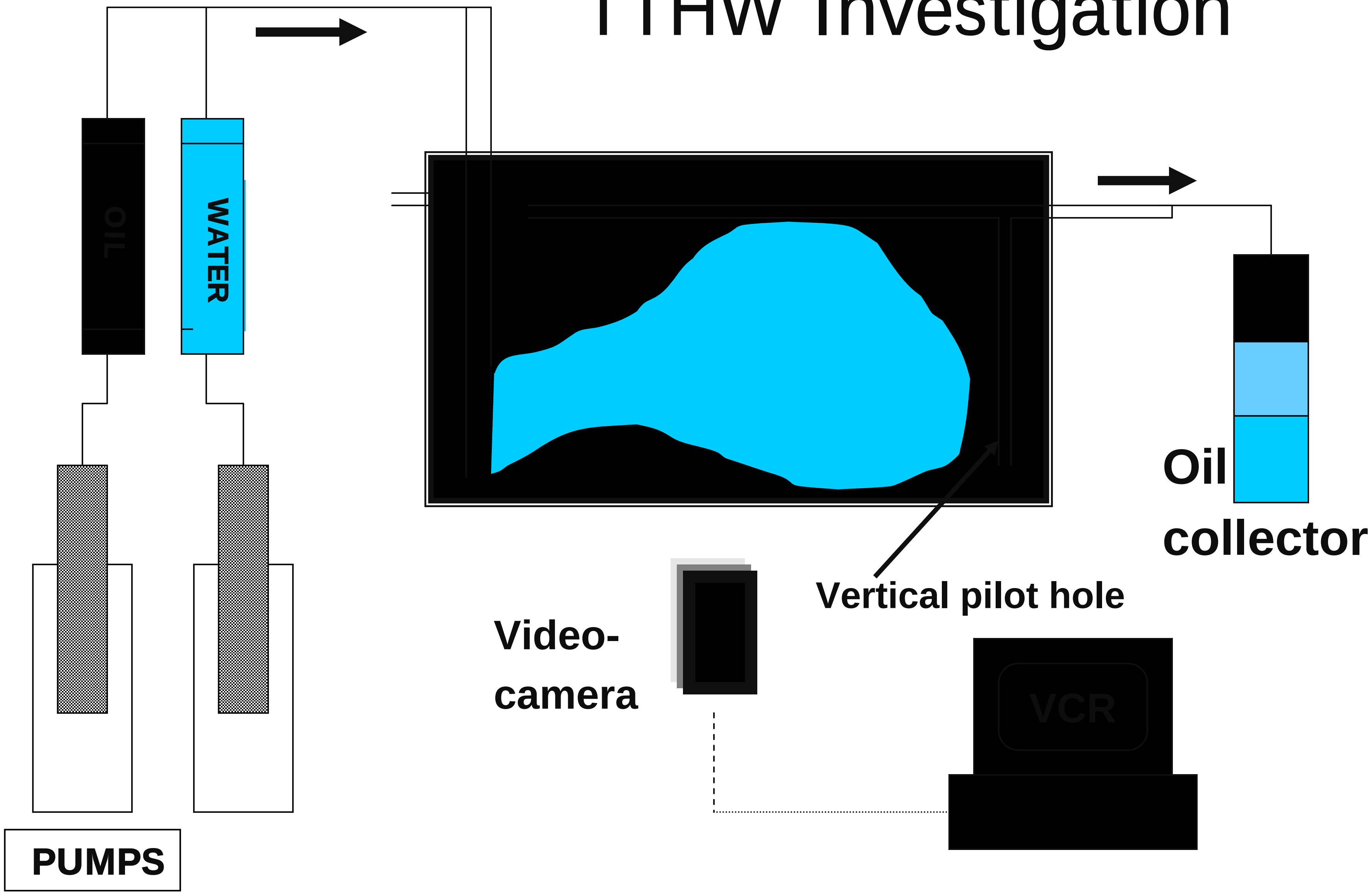
Hele Shaw Laboratory Set up for TTHW Investigation



TTHW in a Hele Shaw Model. Water invaded zone for a light heavy oil (780 mPa.s), before watering out *(tape 19)*

3 D (Laboratory) Displacement Tests

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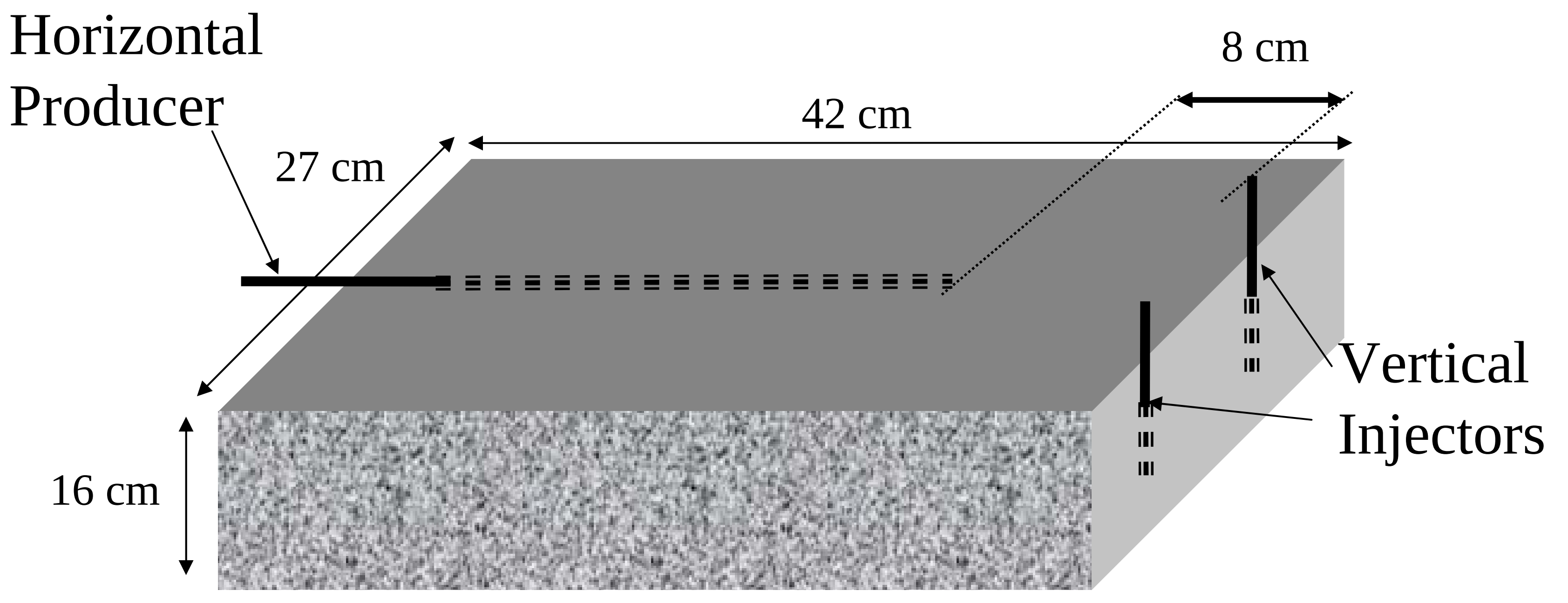
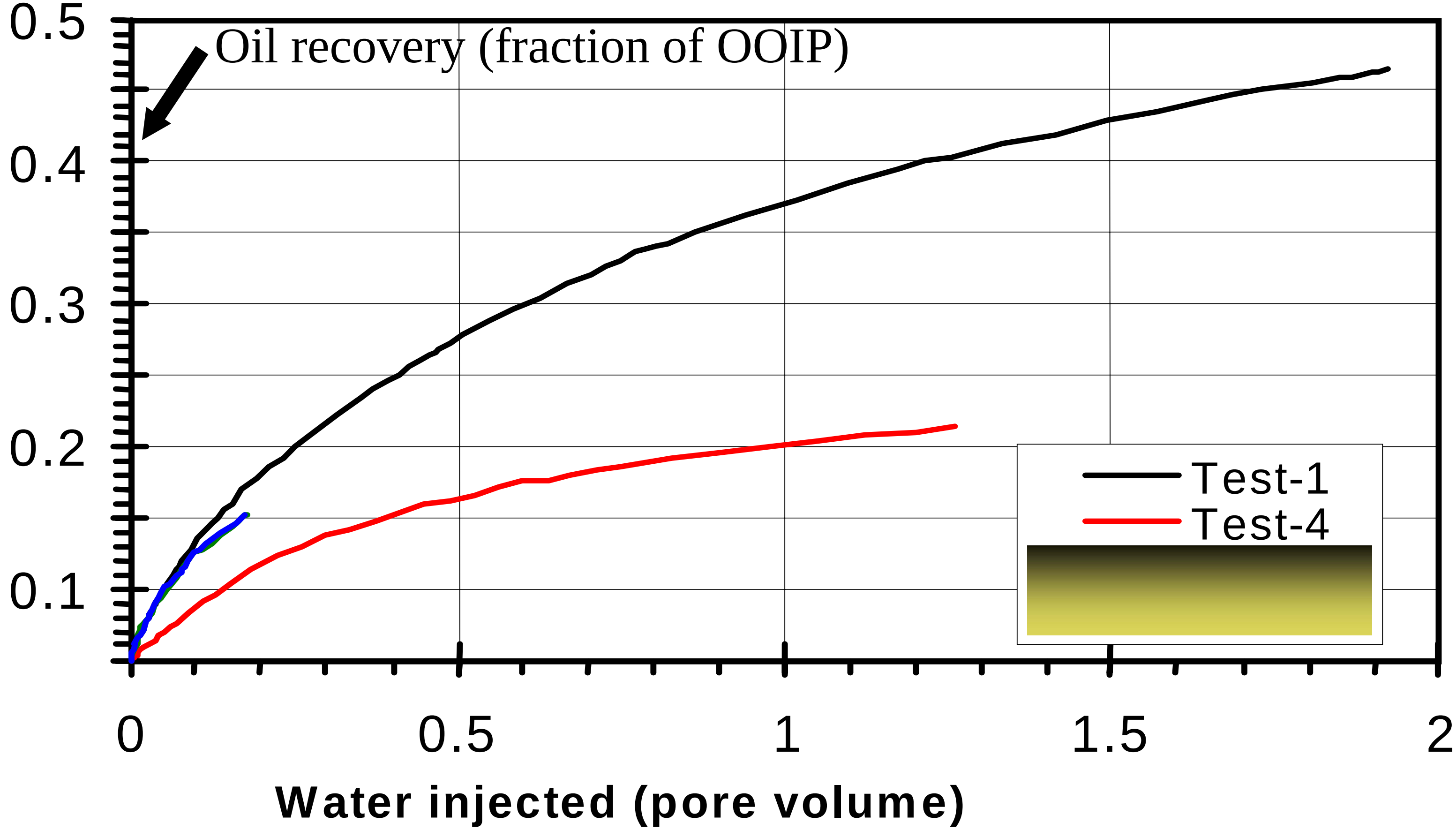
The 3D lab model configuration for toe-to-heel waterflooding (TTHW)



OIL RECOVERY for TTHW (test 1) AND CONVENTIONAL WATERFLOODING (test 4)

780 mPa.s OIL



Numerical Simulation

- CMG's STARS simulator was used to simulate the lab tests
- Shape of water displacement front, both in a vertical and a horizontal plane, was determined.
- Main mechanisms for gravity stable displacement revealed
- Effect of main parameters (pay thickness, oil viscosity, injection rate, K_V/K_H, etc) was investigated.

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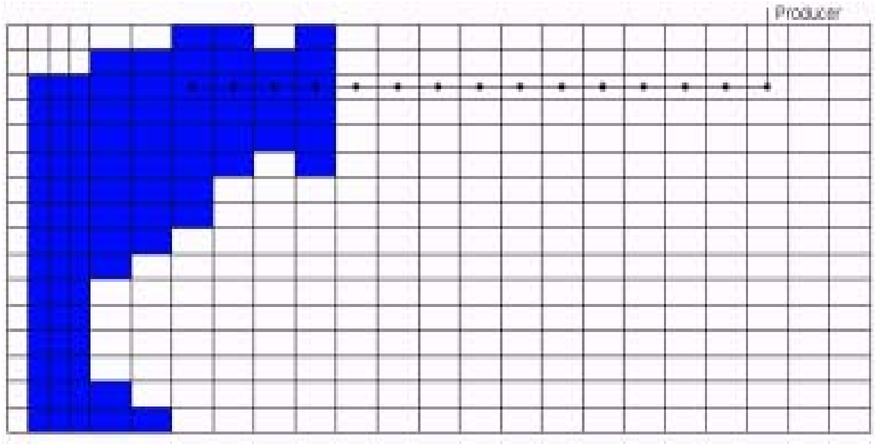
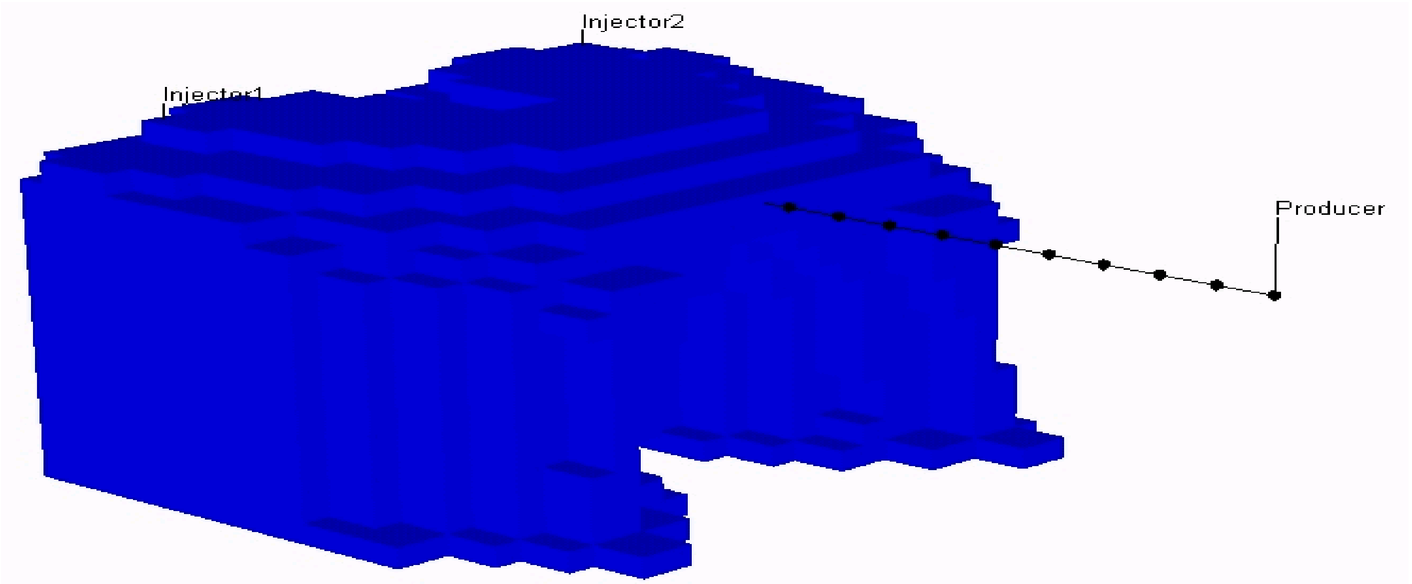
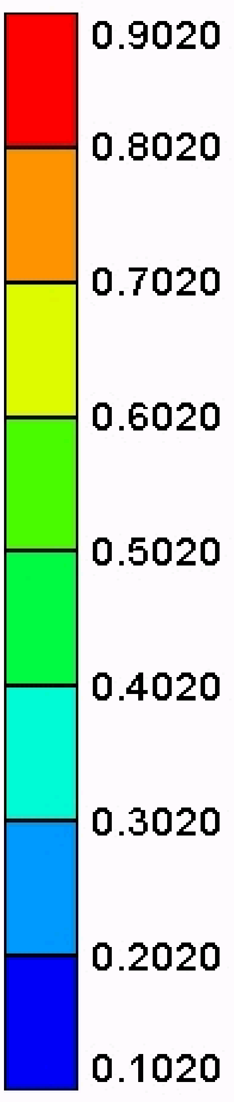
3-D Lab Test Simulation : Water Saturation at 2 hours, test 1

780 mPa.s OIL

Mid vertical plane



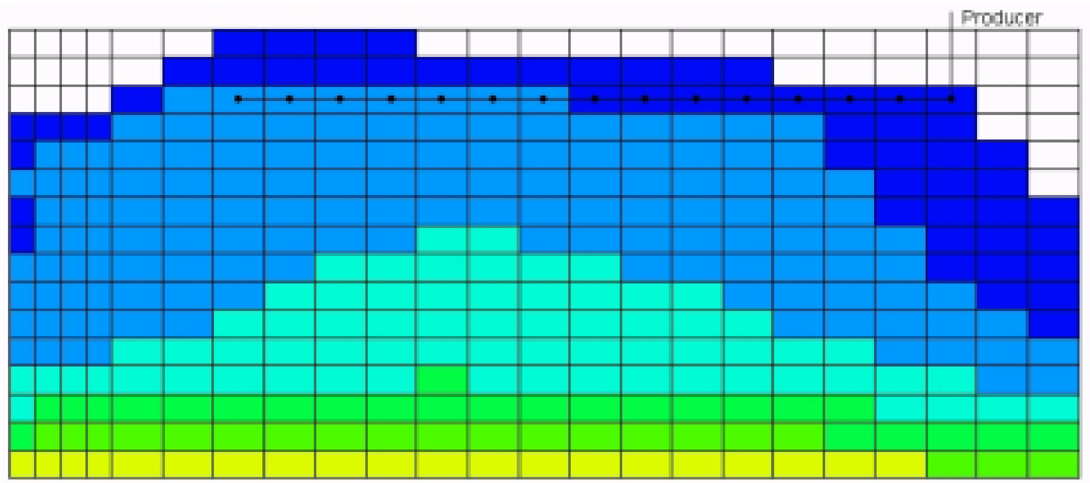


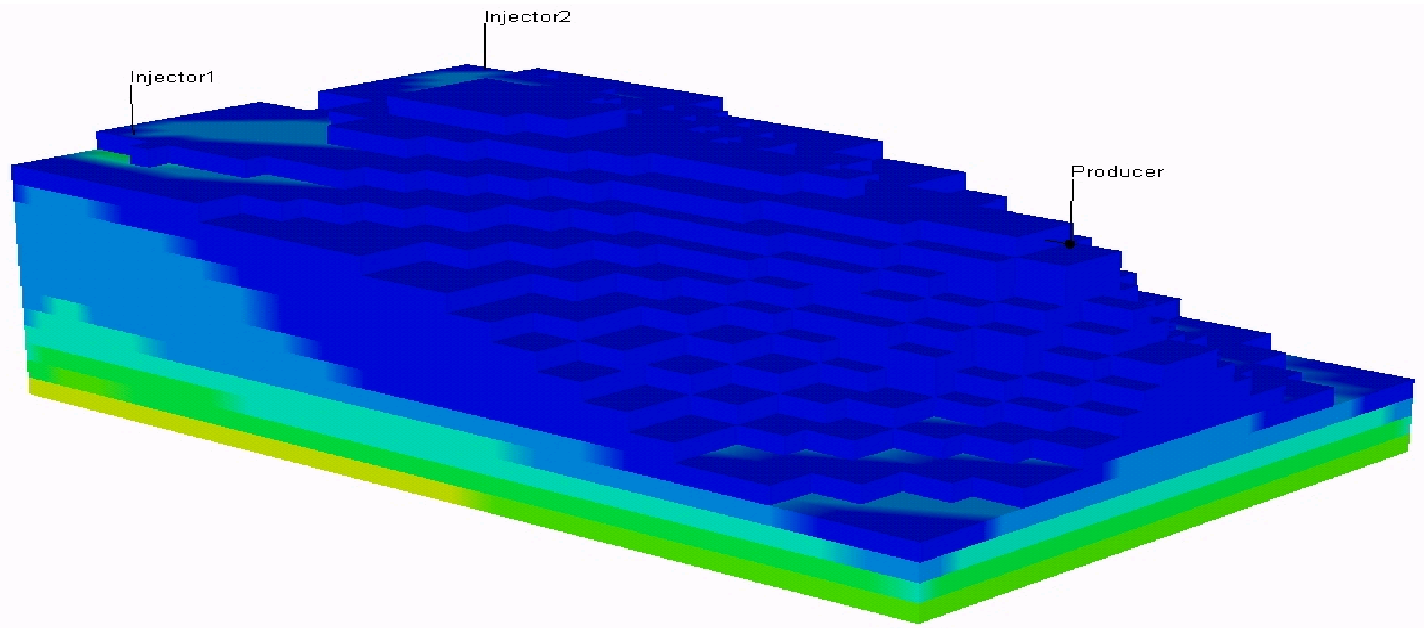


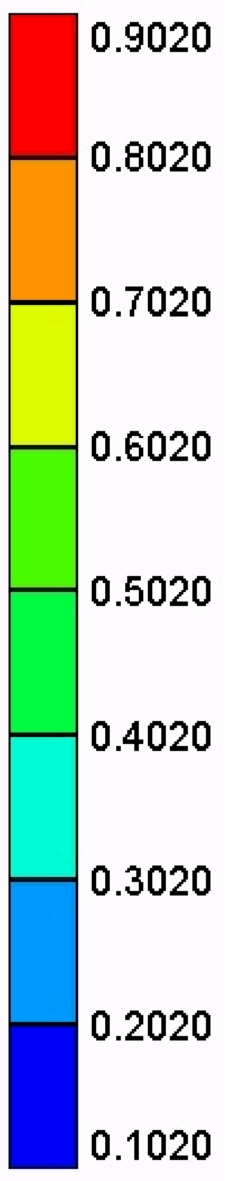
3-D Lab Test Simulation: Water Saturation at 50 hrs, test-1

780 mPa.s OIL

mid vertical plane

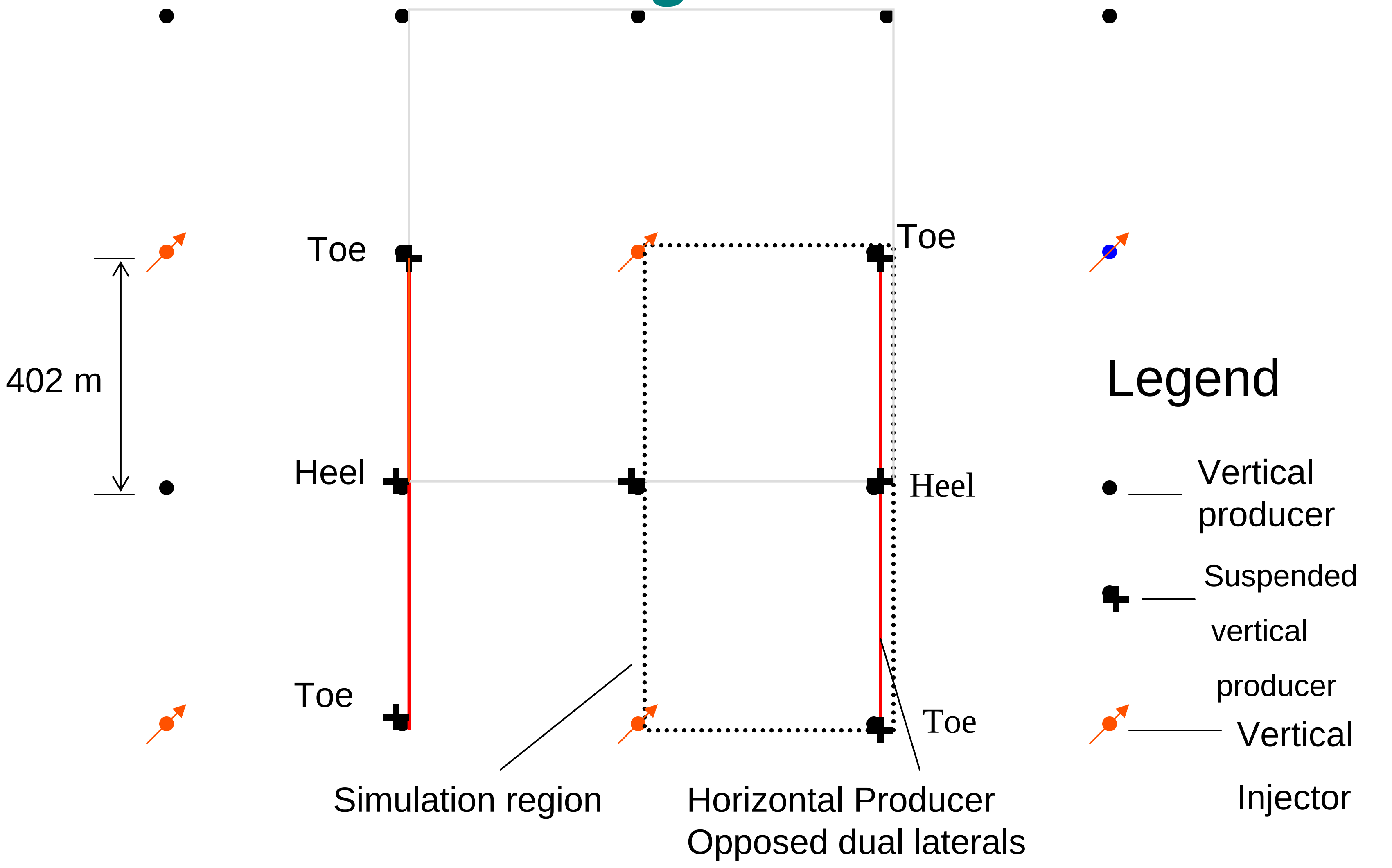


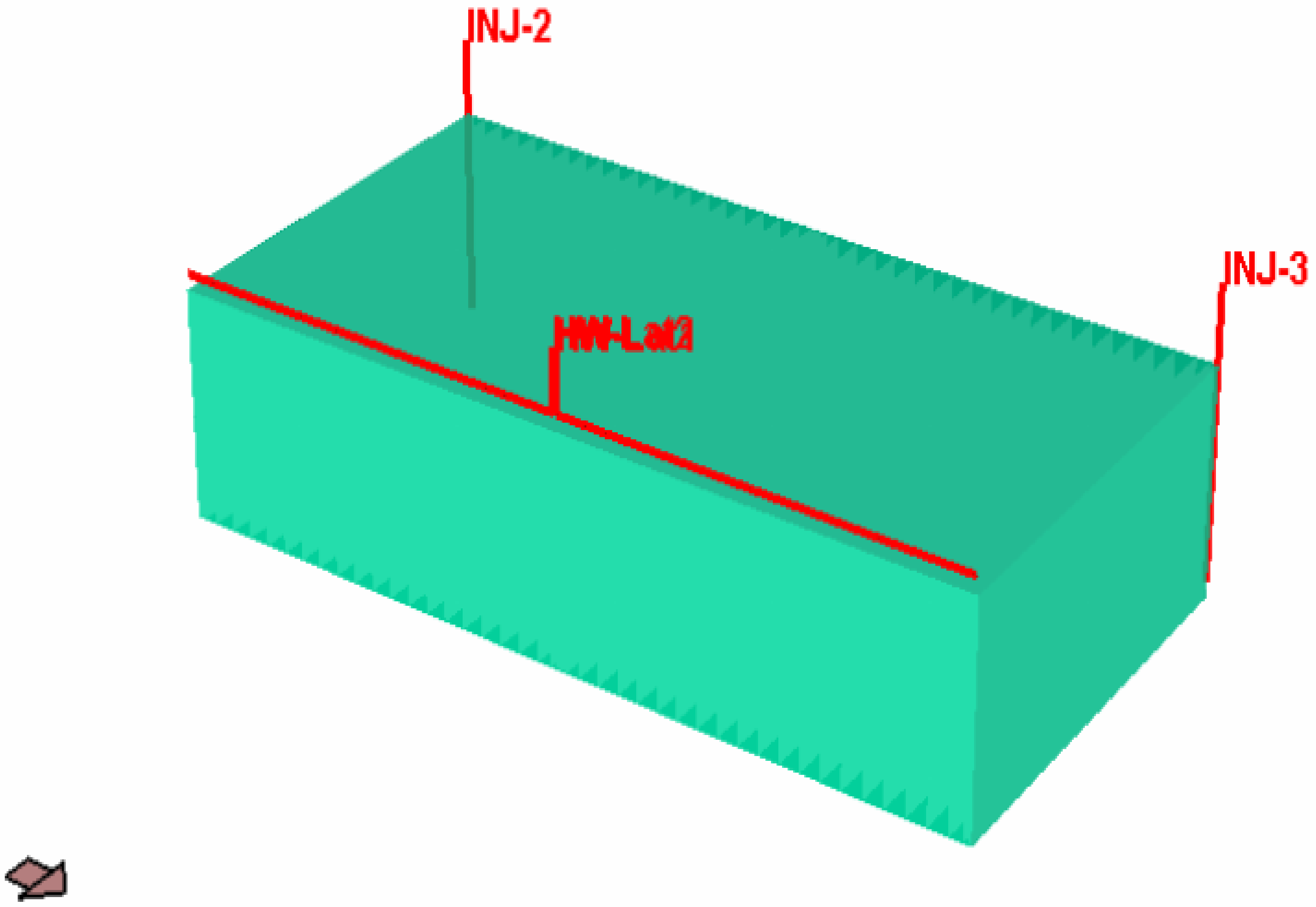




Field Scale Simulation

Switching From an Inverted Nine-Spot to a TTH Configuration





INJ-2
INJ-3
HW-Lat2

Optimization Options for TTHW

- Toe-region successive blocking as it gets watered –out

- Use of small diameter casing (slim hole) for the horizontal leg

- Application of polymer flood as a tertiary EOR method

Gravity Stable Waterflooding Next Steps

- Form a consortium for a TTHW field pilot/joint venture through a co-ownership agreement
- Generalize the TTHW process by application to reservoirs with bottom water conditions

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Screening criteria for TTHW

- No gas cap
- Pay thickness > 6m
- Oil viscosity < 2,000 mPas
- Oil density < 980 kg/m^3
- Oil saturation > 50%
- Horizontal permeability > 200 mD
- Vertical permeability > 100 mD

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Screening criteria for TTHW

Notes

- The last 2 conditions can be relaxed if permeability increases downwards or there is a high permeability streak at bottom
- TTHW and conventional waterflooding (CW) processes are complementary to each other
- TTHW works the best where the CW has the most unfavorable conditions for application (high salinity, high pay thickness, higher permeability at bottom, etc).

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Proposed Project for 2003/2004

Improved Waterflooding Performance Under Bottom Water Conditions

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Two classes of Reservoirs with Bottom Water

- Weak bottom water reservoirs
  - Limited water table
  - Reservoir pressure diminishes with time
- Strong bottom water reservoirs
  - Large (infinite) bottom water aquifer
  - Reservoir pressure maintained at high value

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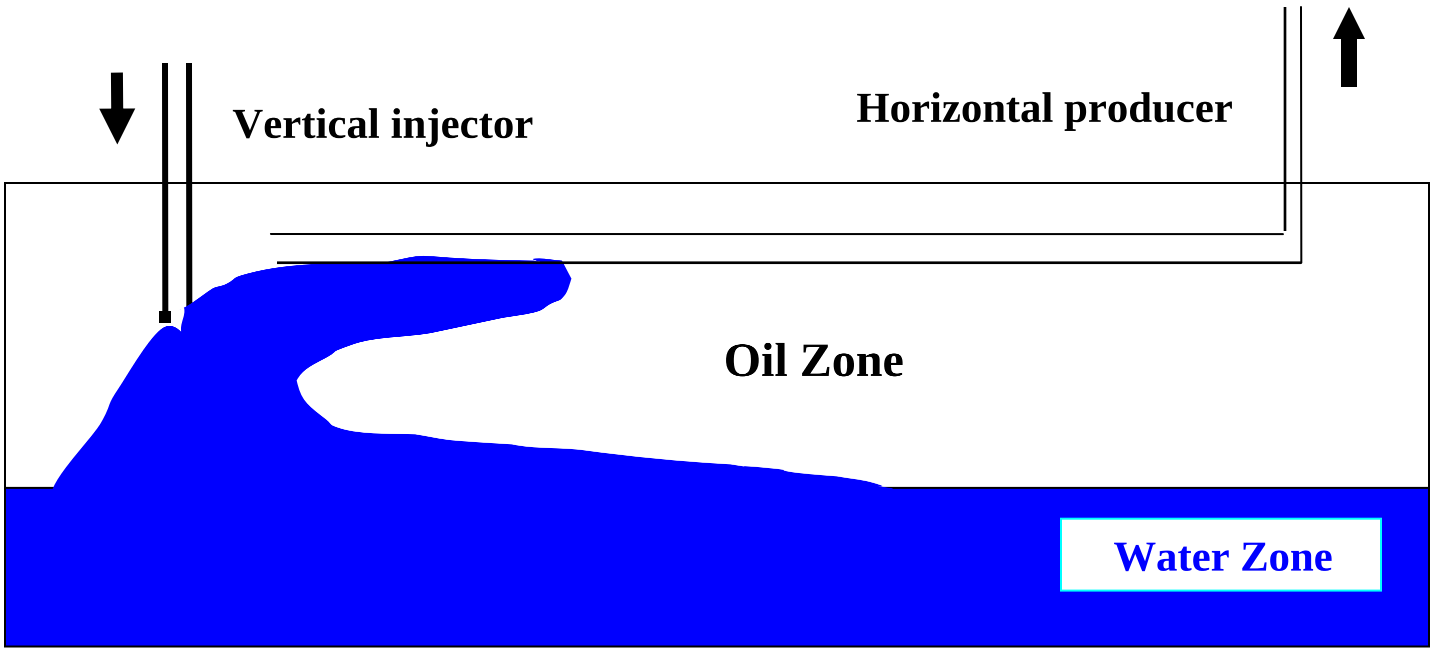
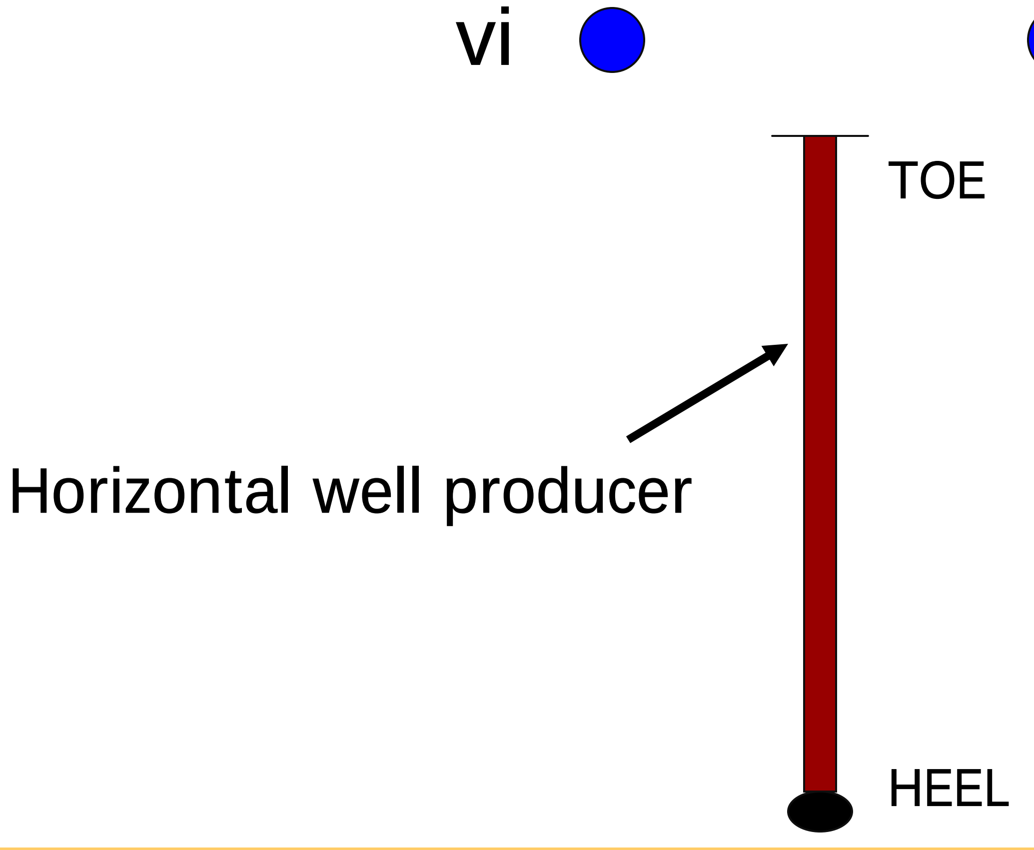
TTHW Application for Weak Bottom Water Conditions



TTHW Field Application. Well Configuration, plan view



Exploitation of reservoirs with strong aquifer

- Waterflooding not common; water disposal, deep into aquifer is practiced
- Crucial question: Is the water flood in a TTH configuration more efficient than upward displacement, done naturally by the water from aquifer? Likely, but this is still to be proven.

- Until this question is answered, **i**nvert-**t**rajectory **h**orizontal **w**ell (ITHW) will be examined

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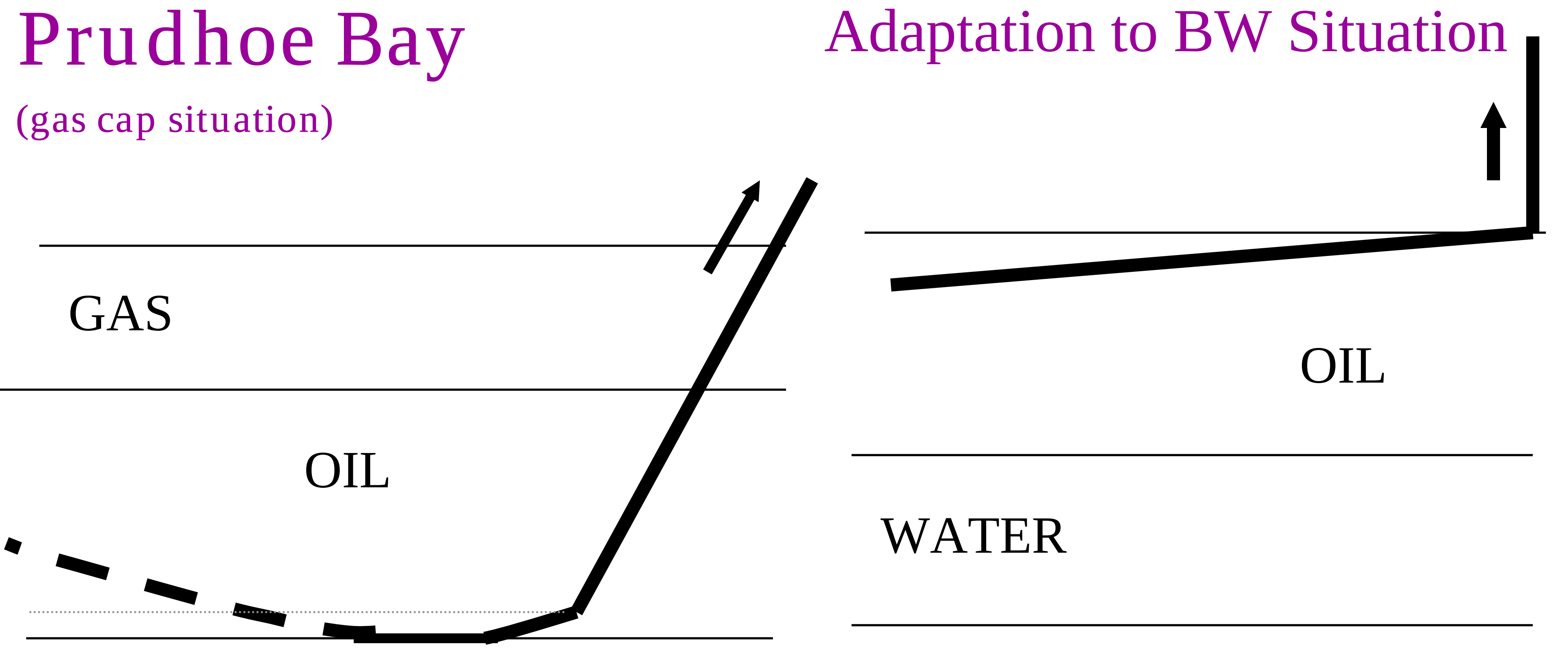
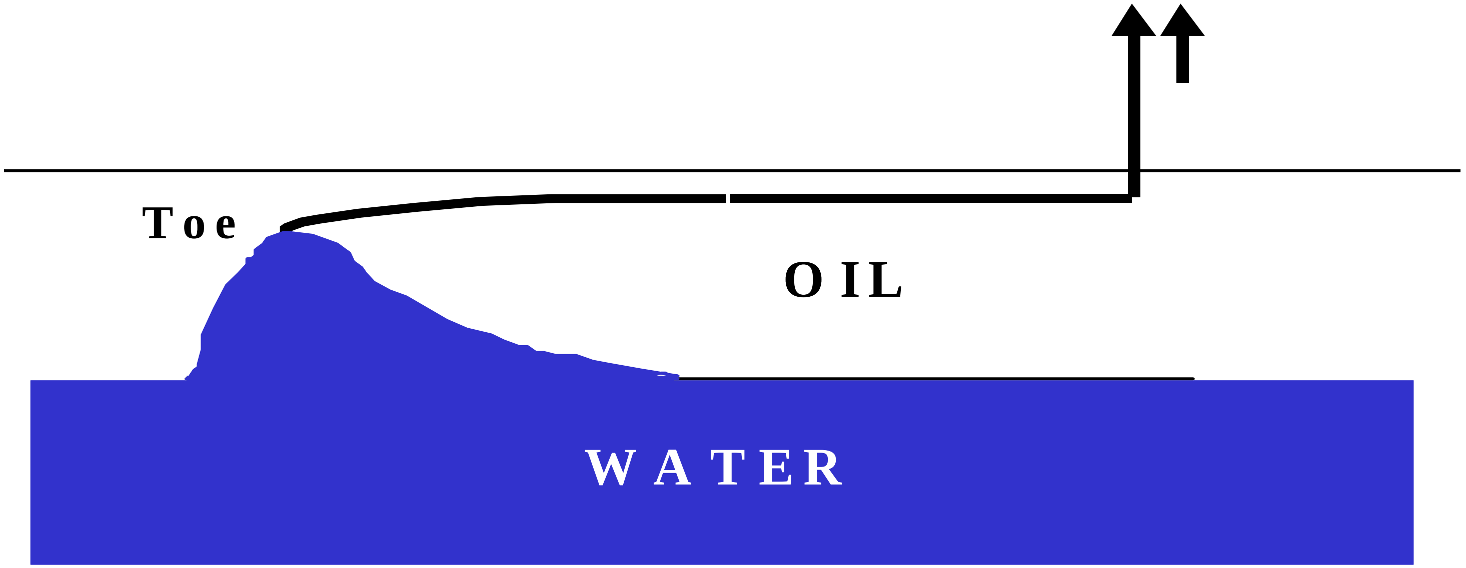
How the Idea of ITHW Appeared: Special HW for the Gas-Cap Situation in Prudhoe Bay Alaska



Downward-Bent Horizontal Well for Strong Bottom Water Situation



Weak BW Reservoirs: Work proposed

Laboratory tests

- Models to be used: 3D sand box models, modified for the weak bottom water situation
- Intermediate heavy oil (viscosity between 100mPas and 2000 mPas)
- Basic tests (conventional waterflood versus TTHW) and optimization tests

Simulation Tests

- Simulation of the 3D laboratory tests

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Strong BW Reservoirs: work proposed

Laboratory work

- Exploratory Hele Shaw (HS) model tests to mimic a 2D simulated porous medium
- A proper representation of the strong aquifer is necessary
- Just a few 2D and 3D confirmatory tests
- One special inverted trajectory - horizontal well test and one plain TTHW testing (vertical injector coupled with one horizontal producer waterflood)

Simulation work

- Comparative simulation of the natural bottom water recovery and of TTH waterflood recovery for a generic field case, when using either special trajectory single well or TTH configuration

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Deliverables

- An improved waterflooding technique for reservoirs with weak bottom water conditions
- An improved exploitation technique for reservoirs with strong bottom water conditions using a single horizontal well of a special architecture or by using a straight TTHW configuration (vertical injector – horizontal producer)
- Guidance for field application of the improved waterflooding methods for reservoirs with bottom water conditions

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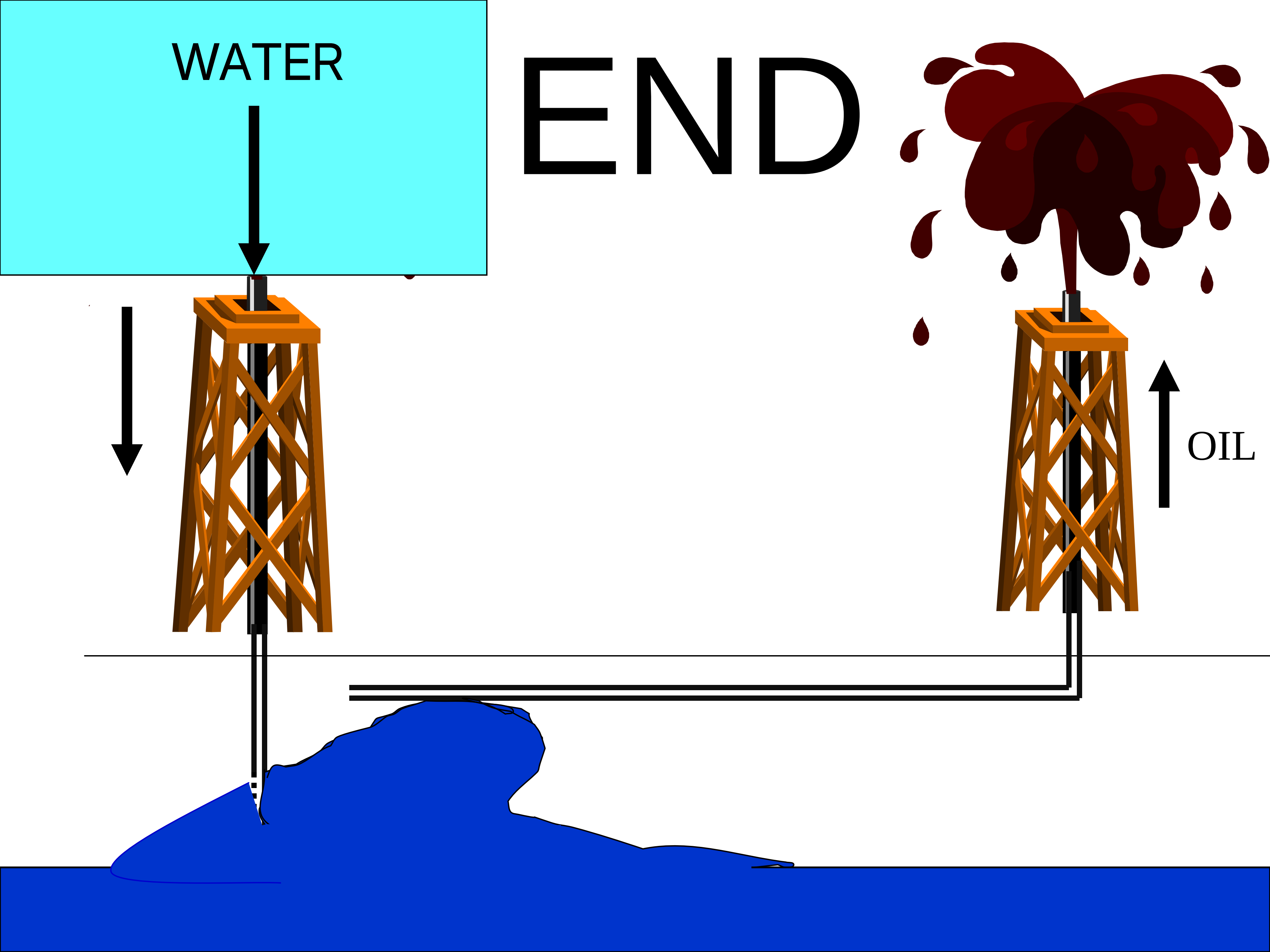
WATER
END
OIL

Proposal

- Propose a JIP project to investigate the concept
- Example funding arrangement
  - Project value $200,000
  - Five or more companies at $20,000
  - ARC investment $50,000
  - AERI investment $50,000

Advantages

- Leverage of investment
- Eligible for Scientific Research and Experimental Development tax credit
- Royalty free license to apply technology

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Contacts

- Alex Turta
  (403) 210-5207
  turta@arc.ab.ca
- Elena Tzanco
  (403) 210-5205
  tzanco@arc.ab.ca
- Ashok Singhal
  (403) 210-5202
  singhal@arc.ab.ca
- Blaine Hawkins
  (403) 210-5249
  hawkinsB@arc.ab.ca

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