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EOR Program 2007/2008

Enhanced Oil Recovery Research Program

About: The Enhanced Oil Recovery Research Program (EOR Program) is the cornerstone in the PTRC's drive to research and develop innovative technologies for improved oil production. Starting with technology development and ending with full field deployment, the EOR program is a seedbed for new ideas that have the potential to transform how efficiently and effectively oil is recovered, in Canada, and beyond.

Objectives: The goal of the EOR Program is to develop leading technologies for economic enhanced oil recovery, with an eye to environmental sensitivity. Of utmost importance is ensuring our projects have a practical application: new technology and knowledge that can be taken from the lab and deployed in the field.

Structure: As a non-profit organization, the PTRC solicits the advice of industry to guide and focus our research efforts for each upcoming year. With this industry guidance, proposals are prepared, ranked and selected on an annual basis, becoming the PTRC EOR Program. The projects are carried out by research organizations, primarily the Saskatchewan Research Council and the University of Regina.

EOR Program: 5 Areas of Focus

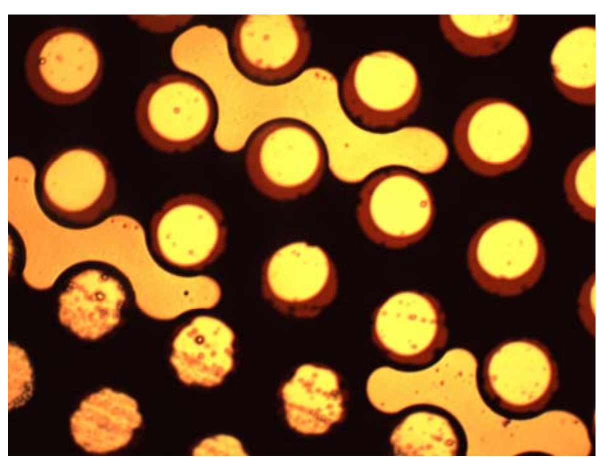
The EOR Program supports projects that fall under the following five areas of EOR:

Heavy Oil (Post) Cold Production
In this technique, heavy oil (along with sand) is pumped out of the reservoir using progressive cavity pumps, maximizing recovery before enhanced techniques are used. However, owing to challenging oil and reservoir characteristics, on average only about 7% of heavy oil can be economically recovered with existing technology.

The PTRC is working with operators to optimize cold production itself and to take advantage of opportunities to extend the life of the reservoir after depletion by developing post-cold production techniques. Before such follow-up techniques are implemented, an understanding of the state of the reservoir and the possible location, extent, and stability of wormholes is required.

Enhanced Waterflooding
When the effectiveness of primary production starts to wane, waterflooding is often the next recovery technique to be employed. Waterfloods can be profitable even when the process water makes up 95% or more of the produced fluids. However, many projects have reached their economic limits and require some kind of enhancement, such as the addition of surfactant chemicals to alter the injected water's interaction with the oil.

A PTRC survey of western Canadian waterfloods revealed that little is understood about the physical and chemical mechanisms underlying this prevalent method. The reason for the success or failure of a waterflood is not usually apparent. As well, waterflooding of heavy oils — a practice nearly unique to the region — differs markedly from that of lighter oils. It requires its own set of operating principles and procedures. The PTRC is shedding valuable new light on an old and reliable technique, renewing its effectiveness.



Example of lobe-shaped water finger in heavy oil waterflooding micromodel test

Solvent Vapour Extraction (SVX)
As a new, economically and environmentally advantageous alternative to SAGD (steam-assisted gravity drainage), the PTRC is investigating SVX — the injection of gaseous solvents (such as carbon dioxide, propane or butane) into an oil reservoir to dilute oil and drive it towards production wells. This technique is being proven as a viable alternative for reservoirs depleted by conventional production, cold production or waterflooding.

Solvent injection offers the benefits of being more energy efficient and environmentally sustainable, and less capital intensive, than SAGD. This focus area is intrinsically linked to the JIVE program.

Gas Flooding (Miscible/Immiscible)
PTRC's research partners have been engaged in gas flooding since the early 80's, from miscible CO_2 injection in southeast Saskatchewan, to conversion of hydrocarbon miscible floods to CO_2 flooding in Alberta, to immiscible gas injection in the heavy oil reservoirs around the Lloydminster area.

The PTRC's expertise in this area rests firmly upon SRC's long-standing expertise in gas flooding for light to heavy oil using CO_2, flue gas and other solvents. SRC's work was integral to the design of EnCana's Weyburn CO_2 flood. As well, the U of R's substantial investment in CO_2 capture provides a cradle-to-grave capability.

Improving Heavy Oil Predictability
The PTRC is embarking upon a new initiative to characterize and correlate properties for heavy oils so that EOR projects can be screened accurately. Correlations that predict oil properties such as solvent solubility — and the resulting viscosity and density — for conventional oils will often just not work well with heavy oils. The knowledge developed in this area will allow reservoir engineers to predict the outcomes of heavy oil field projects with greater confidence.

SUMMARIES OF PROPOSALS FOR 07/08

Coupling Gas and Polymer Injection to Improve Heavy Oil Recovery
Patrick Zhang, SRC
This project will advance prior research at SRC to improve the recovery efficiency of immiscible gas injection/polymer floods through the design of optimal gas and polymer slug size/concentration and injection strategies. The specific objectives of the proposed research are to: 1) measure PVT properties of CO_2–oil systems at given conditions; 2) select compatible polymers; and 3) conduct coreflood tests in sandpacks to investigate the technical feasibility of the proposed polymer-alternating-gas process for recovering heavy crude.

Optimal Solvent Properties in Immiscible Gas Flooding for Improved Heavy Oil Recovery
Patrick Zhang, SRC; Mingzhe Dong, U of R
The main goal of this research is to provide the optimal solvent composition to improve the recovery efficiency of immiscible floods. A full characterization of solvent properties in contact with both oil and porous media could help to optimize the flood process. Several investigations, including the overall effects of solvent components, injection rate, slug size, and injection sequence, and of the effect of solvent characteristics on wetting tendencies, are to be conducted to improve solvent sweep efficiency and increase oil recovery.

Equation-of-State Characterization of Heavy Oils — Year 1
Norman Freitag, SRC
This project's aim is to establish a firm basis for characterizing heavy oils. The benefits of establishing reliable correlations for design and field simulation are ultimately expected to be very widespread, especially for the screening and optimization of any composition-sensitive enhanced recovery projects in heavy oil fields. The work will begin with the assembly and evaluation of existing data on heavy oil property measurements, and will continue with a detailed investigation of suitable analytical methods.

Scaled Physical Model of Post-Cold Production
Bernard Tremblay, SRC
Solvent based processes are being considered to further recover heavy oil after cold production. Cyclic solvent stimulation of wormholed reservoirs under gravity drainage conditions will be investigated in physical models. A numerical simulator will be used to history match the experimental production data and to predict field recoveries.

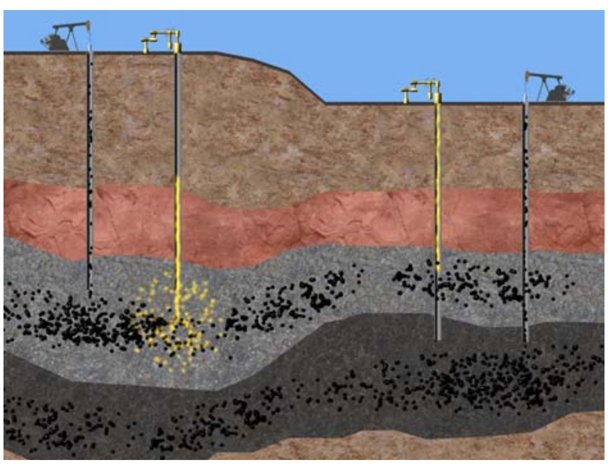
Post Cold Production EOR: Air-Injection Pilot Preparations
Norman Freitag, SRC
This project's aim is to support an anticipated field pilot for a new air-injection process that is expected to perform well in cold-produced heavy oil reservoirs. If successful, the process will open up a large portion of the Lloydminster fields to enhanced oil recovery. The projected operating conditions will be screened through the use of new in-house software for simulating cold production. Additional data for the development of a new chemical reaction model — a key prerequisite for future simulation support of the air-injection process — will be obtained.

Gas Relative Permeability Measurements for Solution-Gas Drive
Bernard Tremblay, SRC
The goal of this project is to improve the numerical simulation of the primary oil recovery process by incorporating relative permeability curves performed at field capillary numbers (velocities). Three solution gas pressure depletion experiments will be performed at

capillary numbers (velocities) spanning the range in capillary numbers calculated by the multi-well cold production model. A correlation will then be obtained between capillary number (velocity) and relative permeability to gas for a heavy oil.

Multi-Well Cold Flow Numerical Model
Bernard Tremblay, SRC
A multi-well cold flow (production) model is being developed to optimize the exploitation of cold production fields and to characterize the wormholed reservoirs for post-cold production processes. This year, the multi-well model will be tested against multi-well field data on the reservoir section scale. The SRC cold production model will be modified to incorporate capillary number dependent gas relative permeability curves and water phase flow equations.

Evaluation of Solvent Vapour Extraction (SVX) Processes Using a 3D Physical Model Year 3
Kelvin (Kelly) D. Knorr, SRC
The third year of this four-year program comprises two experimental tests using a 2.5-m thick 3D scaled physical model apparatus. The tests will investigate the relationship between oil production rates and recoveries, and solvent-to-oil mass transfer dispersivity for two different oil–solvent systems. Horizontal wells will be used to inject/produce mixed solvents to recover diluted oil. A new live-oil resaturation and residual oil mapping procedure will be used. Semi-analytical and numerical simulation history matches will be conducted.



Vertical solvent injection for SVX processes.

Improved Waterflooding of Heavy Oil
Cindy Jackson, SRC; Koorosh Asghari, U of R
SRC statistical studies showed that conventional waterflooding theory for medium and light oils is not appropriate for heavy oils, for which theoretical knowledge is scarce. SRC proposes to advance the use of a micromodel to visually reveal oil-brine interactions at the pore scale. These qualitative data will help to determine the fundamental mechanisms. This research includes a collaborative study on CO_2-assisted flooding: adding CO_2 to the injection water to improve oil viscosity and mobility and hence recovery by heavy oil waterflooding. The fundamental knowledge research along with the expanded scope would enhance numerical simulation and may also result in operational improvements.

Success of Heavy Oil Waterfloods ─ Factors and Predictions
G. Renouf, SRC
This is the third phase of SRC's statistical work on heavy oil waterfloods. Multivariate analysis of 168 western Canadian waterfloods indicated that waterflooding heavy oil reservoirs differs markedly from waterflooding their lighter counterparts. New reservoir and operating parameters will be investigated for their effects on heavy oil waterflooding ─ including injectivity characteristics and factors involved in operations that combine waterflooding and gas injection. The multivariate models will be advanced from a descriptive phase to a predictive phase. Pools currently on primary production will have their waterflooding suitability predicted, and the most similar waterflood identified.

Waterflood Additives for Improved Heavy Oil Recovery
Patrick Zhang, SRC; Mingzhe Dong, U of R
The study is aimed at advancing development of a technically and cost-effective enhanced heavy oil recovery process that uses the mechanism of interfacial instability. The proposed research will examine, in a more realistic setting, the in-situ dispersion triggered by the reaction of an injected chemical solution with the natural acids in oil to create interfacial instability and mild mechanical shear. To understand in-situ dispersion in porous media, the study includes emulsification screening, interfacial tension measurements, examination of the effect of chemicals on wetting tendencies, micromodel tests, and a series of corefloods with 1-D sandpacks.

Modified VAPEX Process for Wormhole Reservoirs
Koorosh Asghari, U of R
The unknown nature and extent of wormholes in wormholed reservoirs make it difficult to implement EOR processes. This is the second year of a two-year program to develop a modified Vapex process which treats the reservoir as a black-box and requires no mapping of wormholes to ensure the success of the process. The proposed technique is based on utilizing vertical wells drilled on top of the formation as injection wells, and wormholes as producing pathways.

Phase Separation of a Solvent-Saturated Heavy Oil during Solvent-Based Heavy Oil Recovery Processes
Yongan (Peter) Gu, U of R
Solvent-based recovery processes, such as vapor extraction (Vapex), are among the most promising heavy oil recovery techniques. The physical and chemical properties of a solvent-saturated heavy oil will change dramatically after its phase separation occurs, i.e., solvent-enriched liquid phase formation and/or asphaltene precipitation. This project's goals are to quantify these property changes and study their detailed effects on the solvent-based heavy oil recovery. Extensive experimental studies and thermodynamic modeling will be undertaken to assist the petroleum industry to design and optimize its solvent-based heavy oil recovery processes.

Optimization of Reservoir Performance in a CO_2 Flooding Reservoir under Uncertainty
Daoyong (Tony) Yang, U of R
In CO_2 injection, displacement efficiency is a key factor that needs to be optimized for achieving high oil recovery, but this is still a challenge in the presence of physical and/or financial uncertainties. This project's aim is to provide a pragmatic approach and theoretical models for optimizing reservoir performance in a CO_2 flooded reservoir under uncertainty. The research will not only provide direct technical support for industry implementation of CO_2 enhanced oil recovery, but also generate new knowledge useful for other EOR processes.

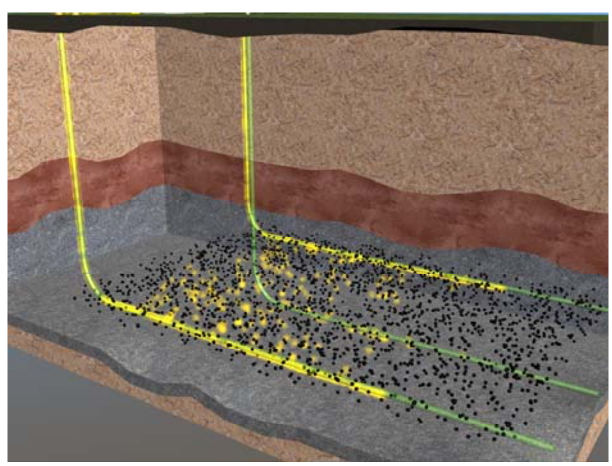
PVT, Viscosity Modeling of Gas or Liquid Diluted Heavy Oils
Amr Henni, U of R
Predicting heavy oil properties and gas solubility in these oils is important for formation evaluation, reservoir management, surface facility design, and project economics. Gas solubility properties will be modeled using friction theory based on the Peng-Robinson equation of state. The model will be used to predict the onset of asphaltene with/without dilution in other hydrocarbons. A modification of the regular solution theory based on solubility parameters will be used to predict gas solubility in heavy oil mixtures, using available solubility data of different gases. Physical and transport properties of heavy oils, including viscosity, will be predicted using available empirical and semi-empirical models.

Modeling and Simulation of Isothermal/Non-Isothermal Combustion Experiments
Nader Mahinpey, U of R
The reaction kinetics of coke combustion need to be better understood for numerical simulation purposes. Four sets of thermogravimetric analysis runs will be done to examine the thermal behavior of Fosterton field asphaltenes, whole oil, and differently derived coke. These runs will provide useful combustion rate data and help to gain a better understanding of an in-situ combustion process. The behavior of the cokes derived from asphaltenes and from from whole oil will be compared. The reaction kinetics of these samples and the energy of activation and pre-exponential factor will be evaluated and the kinetic models will be proposed.

Solvent Dispersion Effect on the VAPEX Heavy Oil Recovery Process
Yongan(Peter) Gu, U of R
A key technical issue with solvent injection into a heavy oil reservoir is that solvent dispersion may greatly accelerate the solvent dissolution into oil. Several important operational factors, e.g., solvent type and injection conditions, horizontal well spacing and configuration, and reservoir characteristics, are found to strongly affect solvent dispersion. This project will examine the effects of these factors on the heavy oil and solvent production rates using an existing Vapex physical model at PTRC and CMG's GEM simulator. A novel theoretical model will be developed to predict the heavy oil production during solvent vapour extraction.

Asphaltene Precipitation and Its Effects on the Vapour Extraction (VAPEX) Heavy Oil Recovery Process
Yongan (Peter) Gu, U of R
When a solvent contacts heavy oil at a high reservoir pressure during a solvent vapour extraction (Vapex) heavy oil process, asphaltene precipitation occurs so that the heavy oil in the reservoir is upgraded in-situ. Meanwhile, some asphaltenes may be deposited onto the reservoir sand grains, and thus reduce reservoir permeability. Among the key factors are operating pressure, reservoir permeability, solvent type, and oil composition. This project will study the asphaltene precipitation and deposition and their beneficial (i.e., in-situ upgrading) and adverse (i.e., reservoir plugging) effects on Vapex.

Application of Horizontal Well Testing in Heavy Oil Reservoirs for Estimating Chamber Size for VAPEX and SAGD Process
Ezeddin Shirif, SRC
The swept volume in SAGD (steam-assisted gravity drainage) and Vapex processes is an early measure of their progress. The pressure analysis of the falloff test — commonly used to estimate swept volume for vertical wells — is based on the pesudosteady state method. Due to the large contrast in mobility between the swept and unswept zones, the flood front behaves like a closed boundary. The accuracy and applicability of the pseudosteady state method in estimating swept volume for fluid injection through a horizontal well will be investigated. A numerical simulator will be used to generate pressure falloff data. A simple correlation for estimating chamber volumes for SAGD/Vapex will be developed.



Horizontal solvent injection for SVX processes.

For more information on the EOR Program visit: www.ptrc.ca
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