VAPOUR EXTRACTION OF HEAVY OIL AND BITUMEN

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Key Words : *Heavy oil and Bitumen, Vapour Extraction, In Situ Upgrading.*

Introduction

The world's total estimated proved reserve of conventional oil is one trillion bbl and the world average of the reserves-to-production ratio is only 46 years at 1990 production levels[1]. This excludes the reserves of heavy oil, tar sands and bitumen that amounts to 6 trillion barrels of oil in place which are not economically recoverable with present technologies. If the proper technology is developed for extracting these resources it can supply the fuel demand for the next few centuries.

Heavy oil and bitumen have high viscosity and low API gravity. In some reservoirs, such as Athabasca, the oil viscosity is in millions of mPa.s at reservoir conditions making conventional recovery impossible. Flooding techniques cannot enhance recovery substantially, due to the adverse mobility ratio.

The viscosities of the heavy oil and bitumen decrease drastically with increase in temperature. Among the thermal recovery processes applied to produce these crudes, the Steam Assisted Gravity Drainage[2] proved to be very successful. In this process steam is injected through a horizontal well and the hot oil being less viscous drains by gravity to the horizontal production well. Using long horizontal wells, very high production rates can be achieved in this process.

In steam processes the energy efficiency is poor due largely to heat losses to the underburden and overburden (specially in thin reservoirs). Enormous amount of effluent is to treated, a huge source for the supply of fresh water is required, clay swelling due to contact with fresh water from the condensed steam causes formation damage. However, instead of steam, if solvent is used to dilute bitumen some of these problems can be eliminated.

Butler and Mokrys[3] studied the extraction of bitumen with toluene in a line source Hele-Shaw cell. On the basis of the magnitude of different physical properties affecting the production rates, it was concluded that the solvent leaching would be slower than the thermal processes. It was anticipated that vaporized solvent in combination with deasphalting may enhance the rate considerably.

Concept of the Vapex Process

In the Vapex (vapour extraction) process vaporized hydrocarbon solvents are injected in the reservoir through a horizontal injection well. The solvent initially dissolves in bitumen around the injection well until diluted oil breaks through the horizontal production well placed vertically below the injection well. Solvent vapour rises slowly to form a vapour chamber in the extracted sand matrix above the injection well. Solvent vapour dissolves in bitumen at the solvent bitumen interface, diffuses through the bulk of bitumen and the diluted oil drains to the production well by gravity. The use of vaporized solvent produces higher driving force in gravity drainage and also reduces the residual amount of solvent in the extracted reservoir. The concept of the process is shown schematically in Figure 1. Several other configurations of injector and producer wells are also possible.

Selection of Solvent and Conditions

In this process production rate is directly related to the amount of solvent dissolved and diffused into bitumen. One important aspect of this process is deasphalting that yields in situ upgraded oil reducing many down stream problems. The extent of deasphalting also depends on the amount of solvent. The solubility of a vaporized solvent is maximum near its dew point pressure. Hence, the solvent pressure should be as close as possible to its vapour pressure at the reservoir temperature. If the dew point pressure of the solvent is lower than the reservoir pressure solvent liquefies and fill the extracted sand matrix with liquid solvent. Thus a barrel of oil is replaced by a barrel of liquid solvent which is not economic. Hence, to be suitable for the process, the solvent should have a dew point pressure slightly higher than the reservoir pressure so that it can be safely injected without liquefaction and the maximum solubility can be achieved at the same time. This criteria combined with the abundant reservoir pressures and the cost and availability of the solvents limits the choice of solvent to ethane, propane and butane. In our experiments it was observed that performance of the process with ethane is inferior to that for propane and butane. Propane and butane yields comparable rates. However, propane upgrades the oil by deasphalting which is less prominent with butane. There are many heavy oil and bitumen reservoirs where the pressure is in the range of propane dew point pressure. In shallow reservoirs butane may be suitable.

Theory

The pseudo-steady state model developed by Butler and Mokrys[3] modified for the process using vaporized solvents predicts the production rates as

$$q = 2La\sqrt{H} \tag{1}$$

where $$a = \sqrt{2kg\phi^{1-m}\Delta S_o N_s}$$

and $$N_s = \int_{c_m}^{c_i} \frac{\Delta\rho D_s(1-c_s)}{\mu c_s} dc_s$$

H = height of the reservoir
L = length of horizontal well
q = production rate
k = Permeability
g = acceleration due to gravity
ϕ = porosity
ΔS_o = change in oil saturation
μ = viscosity of mixture at solvent concentration, c_s
$\Delta\rho$ = density difference between solvent and bitumen
D_s = intrinsic diffusivity of propane in bitumen
c_s, c_i, c_m = mole fraction of solvent at different points in the boundary layer (Fig. 1)
m = cementation factor

Since the production rates are directly proportional to the vapex parameter, 'a', it can be used to evaluate the performance of the process at different conditions[4]. Both the production rates and 'a' are proportional to the square root of permeability and this relation can be used to scale up the production for different permeabilities.

Experiments in Hele-Shaw cell and Packed Visual Model

Several experiments were carried out in Hele-Shaw cell by Das and Butler to assess the impact of asphaltene deposition on the performance of the process. The experimental set up, procedures and the method of analysing data were described else where[4]. The photograph of the Hele-Shaw cell at the end of one interesting experiment carried out with Lloydminster heavy oil and propane is shown in Figure 2. The propane pressure in this experiment was varied by approximately 10 psi by varying the temperature of the propane supply cylinder between 19 and 22°C as shown in Figure 3. It was observed that at higher pressure, close to the dew point of the solvent, asphaltenes were deposited and at a lower pressure diluted oil drained without asphaltene precipitation. The alternate dark bands (deposited asphaltenes) and white bands (clean swept area) in Figure 2 clearly show the history of the pressure cycles. The corresponding vapex parameters, plotted in Figure 3, shows that the production rate is enhanced when asphaltene precipitation takes place. This due to the tremendous reduction of viscosity caused by deasphalting. Results of some experiments carried out in Hele-Shaw cell with different permeabilities are presented in Table 1. These show that under identical temperature of cell and propane, vapex parameters are proportional to the square roots of permeability.

Several experiments were carried out in visual packed cell using sands of different permeabilities and butane as a solvent. Experimental set up and procedure are described elsewhere[5]. Cumulative productions from one of this experiment carried out with Peace River bitumen is shown in Figure 4, which is similar to the production profile in all of these packed cell experiments. As expected it is observed that the solvent vapour initially rises to form the solvent chamber, chamber grows to the top of the packed cell and then spreads sideways.

Comparison of Hele-Shaw and Packed Cell Results

Table 2 shows some results of the experiments in Hele-Shaw and Packed cell with Peace River bitumen. The production rates predicted for the packed cell on the basis of the results of the Hele-Shaw cell experiments and the experimental rates are presented in column 4 and 5 respectively. It shows that in the porous media the process goes approximately 10 times faster than expected.

Mechanism of the Vapex Process in Porous Media

The basic mechanism of the process involves the following steps:

1. Dissolution of solvent vapour at the solvent-bitumen interface
2. Diffusion of the dissolved solvent into the bulk of bitumen
3. Dissolved and diffused solvent dilutes the viscous oil and reduce the viscosity
4. If the solvent concentration is high enough the oil is deasphalted in situ
5. The diluted (and deasphalted) oil drains to the production well by gravity

Although the basic process mechanism is same in Hele-Shaw cell and in porous media in the later, the process takes place in a contact zone, instead of at a smooth interface as is the case in the former. This provides a very high interfacial contact area that yields a high mass transfer rate of solvent into bitumen[5]. The mass transfer is enhanced by capillary imbibition and the corresponding surface renewal. Although the diluted bitumen has a lower surface tension, due to its low viscosity it is quickly drawn away from the interface exposing a renewed interface of fresh bitumen to the solvent. If we consider diffusion of a solvent in a semi-infinite slab of bitumen, the transient concentration profiles and the corresponding mass flux at the solvent-bitumen interface with time are shown in Figure 5 and 6 respectively. It should be noted that as the concentration profile builds up, the mass transfer rate drops drastically. In the Butler Mokrys model it is assumed that a pseudo steady concentration profile is developed in the diffusion boundary layer and each point on the interface moves at a constant rate. This pseudo- steady profile represents a lower mass transfer rate which is probably true in case of Hele-Shaw cell. However, in porous media, with the periodic surface renewal, the early transient mass transfer is more prominent. Even with the periodic renewal, the interface will move at a constant rate resembling the pseudo-steady state. Hence the overall pseudo-steady state analysis will still be valid, although a very high diffusion coefficient is to be used to match the actual mass transfer rate.

Viability of the Process

The production rate scaled up for a pair of 1000 m long horizontal injector and producer in a 5-darcy Lloydminster reservoir (10 m thick) is 850 BOPD and Peace River bitumen reservoir (40 m thick) is 450 BOPD using propane as a solvent. These production rates seem to be economic for field operation. For reservoirs of different thickness and permeability, the rate would vary in proportion to the square root of the vertical thickness and permeability. Although the solvent requirement is 0.5 g/g of oil produced, most of this is recycled back and only a tenth of the solvent vapour is left behind to fill the reservoir. The energy requirement for this process is only ~3% of that in the steam process. Hence, the process can be successfully implemented for field operations.

Conclusion

1. The Vapex process can avoid many inherent problems of thermal processes.
2. Better quality oil is produced due to in situ upgrading caused by deasphalting.
3. Production rates could be economic.

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Vapour Extraction of Heavy oil and Bitumen

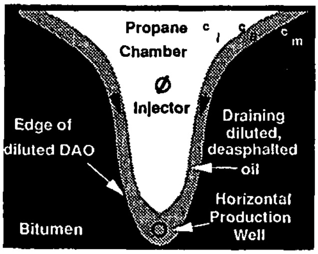

Figure 1. Concept of the Vapex Process

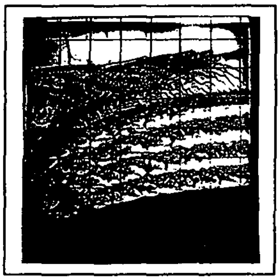

Figure 2. Pressure variation in Hele-Shaw cell (Lloydminster oil and propane).

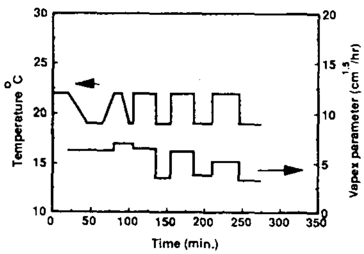

Figure 3. Pressure cycles and corresponding Vapex parameters.

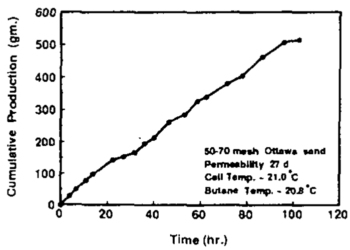

Figure 4. Extraction of Peace River bitumen in 27 d sand.

Table 1. Effect of Permeability on the Vapex Parameter

Crude & solvent	Cell and propane Temperatures (°C)	Cell permeability (d)	Vapex parameter ($cm^{1.5}$/hr)
PR and propane	25.0 / 21.7	1344 5376	1.28 2.47
PR and propane	25.0 / 20.8	3441 5376	1.27 1.76
LM and propane	25.0 / 20.8	1344 5376	1.66 3.56

Table 2. Comparison of Results of experiments with Peace River bitumen and butane in Packed Cell and Hele-Shaw Cell.

Cell/ solvent Temp. °C	Cell & permeability (d)	Vapex Parameter ($cm^{1.5}$/hr) Exptl.	Flow rates Predicted (gm /hr)	Stabilized rates Exptl. (gm /hr)
25.0 / 25.0	Hele-Shaw (5400)	0.68	-	-
21.0 / 20.6	Visual (830)	1.39	2.22	20.6
22.8 / 22.1	Visual (217)	0.64	1.13	9.5
21.5 / 20.8	Visual (43.5)	0.29	0.47	4.3
21.0 / 20.8	Visual (27)	0.17	0.41	2.5

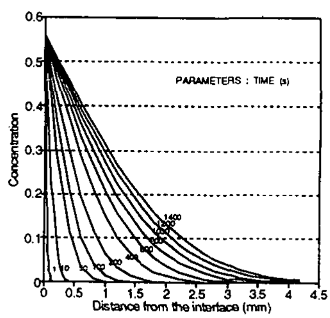

Figure 5. Transient Concentration Profiles

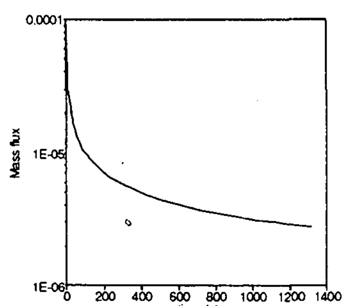

Figure 6. Transient mass flux at the interface