Defect and Diffusion Forum Vols. 312-315 (2011) pp 935-940
Online available since 2011/Apr/20 at www.scientific.net
© (2011) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/DDF.312-315.935

Non-Isothermal Enhanced Recovery of Heavy Oils by Numerical Simulation

A. Lima Cunha[1,a], S.R.F. Neto[1,b], A.G. Barbosa de Lima[2,c] and E.S. Barbosa[2,d]

[1]Federal University of Campina Grande, Center of Science and technology, Department of Chemical Engineering, Campina Grande, Brazil.
[2]Federal University of Campina Grande, Centre of Science and technology, Department of Mechanical Engineering, Campina Grande, Brazil.

[a]actolimacunha@yahoo.com.br, [b]fariasn@deq.ufcg.edu.br, [c]gilson@dem.ufcg.edu.br, [d]enivaldo.sb@gmail.com

Key words: Heavy oil, flow, porous media, recovery factor, numerical simulation.

Abstract. The world has been witnessing a growing interest in heavy oil fields as a result of a reduction in conventional oil reserves. In this sense, this work aims to study numerically the process of heavy oil recovering in oil reservoir via water injection. Transient three-dimensional numerical simulations, considering isothermal and non-isothermal processes, were performed using the ANSYS CFX 11 commercial code, and its effects upon the oil recovery factor evaluated. The numerical results indicated an increase of 29% (non-isothermal case) and 18% (isothermal case) in the recovery factor when water was injected on the reservoir surface as compared to the water internal injection in the reservoir.

Introduction

One of the most common problems of Petroleum Engineering is the development of heavy oil fields; the interest in developing these kinds of oil fields may be due to the increasing insufficiency of conventional oil, which generates a growing need to develop the sources or reservoirs of heavy oils that are abundant throughout the world [1,2].

For the development of these kinds of reserves some techniques are proven to be effective in order to enhancing the recovery of heavy oil. Amongst the existing techniques, the injection of water stands out as one of the most used [3]. Physically speaking, it is the dislocation of immiscible fluids used to enhance oil production. Moreover, the water injected may be at a different temperature from the initial formation temperature (non isothermal issues). In this case, besides moving the oil towards the producing well, the injection process will also result in fluid temperature changes at the reservoir, with direct influence to the fluid properties. In thermal methods in general, an increase of the reservoir temperature is promoted aiming at decreasing the oil viscosity, which depends fairly on temperature [4-8]. With this accomplished, there is an increase in the reservoir oil mobility and thus an increase of the recovery factor.

This study aims to numerically examine the isothermal and non-isothermal recovery of heavy oils in tridimensional petroleum reservoir by analyzing the influence of the fluid injection section location in the injection wells, as well as the influence of temperature variation on the oil recovery factor.

Geometry

The study domain is represented by a portion of an oil reservoir consisting of 2 (two) central water injection wells and 6 (six) producing wells, arranged in a "five spot" scheme (Fig. 1). The dimensions are 270 meters long, 180 meters wide and 15 meters height. The wells dimensions are 1.5 meters long and 0.2 meters in diameter.

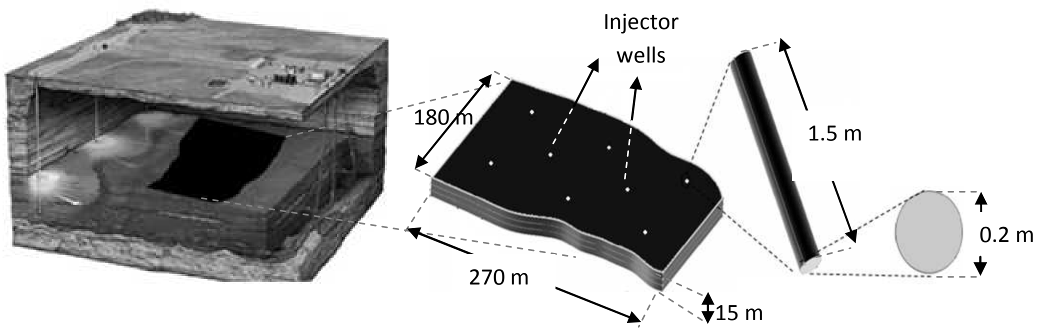

Figure 1 - Considered reservoir layout.

Fig. 2 shows the two evaluated situations, depicting the vertical placement of the well in the reservoir portion. Henceforth, the term internal injection will symbolize that the section of water entering the reservoir portion is located inside the reservoir (Fig. 2a), whereas surface injection will represent that the input section is located on the surface or at the upper horizontal portion of the reservoir (Fig. 2b).

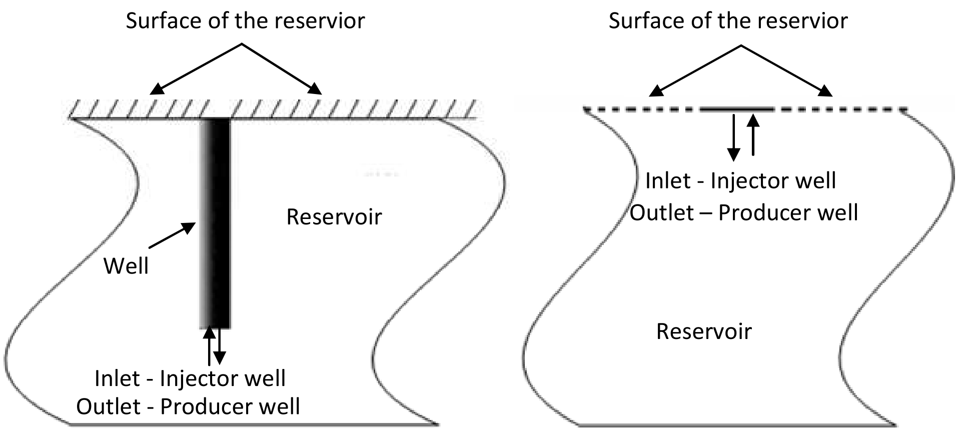

Figure 2 - Placement of the well in the reservoir portion: (a) internal injection and (b) surface injection.

Mathematical Model

The conservation equations used in this study to explain the multiphase water/oil flow in porous medium corresponds to a generalization of the Navier-Stokes equations and the Darcy's law which are commonly used for flows in porous media. Specifically, the conservation equations of mass and momentum are as follows.

$$\frac{\partial}{\partial t}(\phi\rho) + \nabla \bullet (\rho \mathbf{K} \times \vec{U}) = 0 \qquad (1)$$

$$\frac{\partial\,(\rho\phi\vec{U})}{\partial t} + \nabla \bullet (\rho\phi(\mathbf{K}\vec{U}) \otimes \vec{U}) - \nabla \bullet (\mu_e \mathbf{K}(\nabla\vec{U} + \nabla\vec{U}^{T})) = -\phi\mathbf{R}.\vec{U} - \phi\nabla p \qquad (2)$$

where $\vec{U}$ corresponds to the actual velocity vector, t is time, ϕ is the porosity, ρ stands for density, and $\mathbf{K} = (K^{ij})$ is a symmetric tensor of second order called area porosity tensor; μ_e corresponds to the effective viscosity and $\mathbf{R} = (R^{ij})$ represents the flow resistance in porous medium.

In situations of high flow resistance a high pressure gradient must be assigned in order to balance the resistance. In this situation, the two terms of the right side of Eq. 2 are large and of opposite sign, and the convective and diffusive terms in the left side of the equation are insignificant. Thus, Eq. 2 is reduced to:

$$U = -\mathbf{R}^{-1} \times \nabla p \quad (3)$$

Thus, at the high resistance limit, an anisotropic version of Darcy's law is obtained, with proportional permeability to the opposite of resistance tensor. The energy transfer in porous media is defined as:

$$\frac{\partial}{\partial t}(\phi \rho H) + \nabla \bullet (\rho \mathbf{K} \times \vec{U} H) - \nabla \bullet (\Gamma_e \mathbf{K} \times \nabla H) = \phi S^H \quad (4)$$

The first term on the left side of Eq. 4 corresponds to the accumulation of energy, the second term refers to heat transfer by convection and the third term is related to heat transfer by diffusion, where Γ_e is the effective thermal diffusivity; H is the enthalpy and S^H contains a heat source (which may be positive or negative).

The recovery factor is equally defined by:

$$F_r = \frac{\sum_i \Delta V_i}{V_{o_i}} = \frac{\text{Accumulate oil volume}}{\text{Initial oil volume}} = \sum_i \Delta S_i \quad (5)$$

where (V_{o_i}) stands for the initial oil volume; ΔV_i is the accumulated oil volume throughout time and ΔS_i is the saturation variation in a time step.

The original oil volume was calculated by:

$$V_{o_i} = V_R . \phi \quad (6)$$

where V_R is the reservoir volume (695,755 m^3).

Initial and boundary conditions. The reservoir was initially considered as having pressure (P_i), temperature (T_i), and oil saturation (S_{o_i}) homogeneously distributed throughout the reservoir with the following values: P_i = 120 atm, T_i = 310.95 K and S_{o_i} = 1.0 (consequently the water saturation is $S_{w_i} = 0.0$). The adopted boundary conditions are represented in Table 1.

Table 1 - Boundary Conditions.

	Isothermal					Non-isothermal	
Boundary	ω (kg/s)	f_o	f_w	P (atm)	$\vec{v}$ (m/s)	T (K)	Q (J/s)
Inlet	0.25	0	1	-	-	370.20	-
Outlet	-	-	-	100	-	-	-
Walls	-	-	-	-	0	-	0

Where ω corresponds to the injected water mass flow rate; f_o and f_w are volumetric fractions of oil and water, respectively, P is the static pressure at the outlet boundary of the producing well; $\vec{v}$ is the boundary velocity vector; T is the input water temperature in the injection well and Q, the heat flux (adiabatic condition) through reservoir wall. The adopted properties of porous media and fluids are represented in Table 2.

Table 2 - Properties.

	Cp (J/kg.K)	ρ (kg/m^3)	k (W/m.K)	PM (kg/kmol)	K (m^2)	ϕ	τ (N/m)
Porous media	-	-	-	-	2x10^{-12}	0.25	
Water	4181.70	942.50	0.6198	18.02	-	-	0.03
Oil	2092.00	868.70	0.143	105.47	-	-	

*Cp corresponds to the specific heat, k is the thermal conductivity, K is the permeability, PM is the molecular weight e τ is the water/oil surface tension.

Results and Discussions

Fig. 3 illustrates the mesh representing the study domain, which was crafted with the support of ICEM-CFD 11.0, this mesh was obtained after various refinements and resulted in a non structured mesh of 760.786 tetrahedral elements. The simulations were performed on a Quad Core 2.66 GHz, 8 GB RAM and 1 TB physical memory (HD) computer. A residual convergence criterion (RMS) of less than 10^{-6} was adopted. The simulation time of the studied cases ranged from 43 to 46 hours.

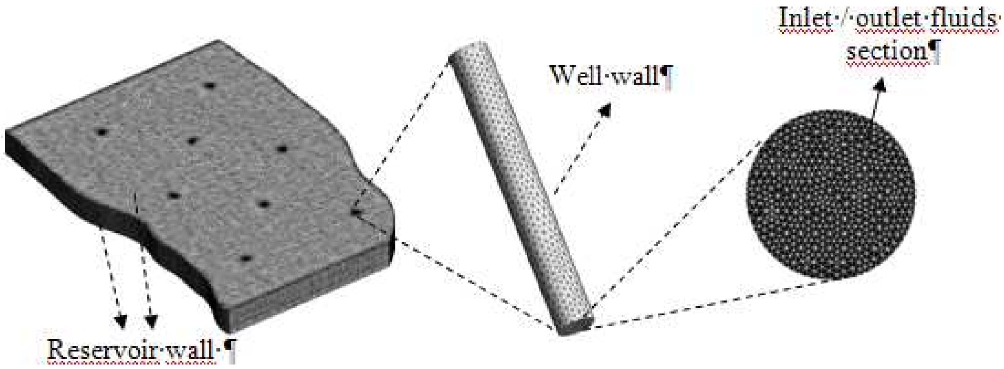

Figure 3 - Studied reservoir showing different sections with meshes.

With the aim of highlighting the influence of non-isothermal and isothermal conditions (with internal water injection) in the oil recovery process, Fig. 4a depicts a distribution water volume fraction over 4 vertical planes, passing through all the wells for the non-isothermal (Fig. 4a) and isothermal (Fig. 4b) cases. A similar behavior can be observed in the dislocation of the injected water to the lower layers of the reservoir; however, the area invaded by hot water (Fig. 4a) was wider if compared to the isothermal situation (Fig. 4b) after 24,000 hours of injection. This occurs due to the heat transfer between water and heavy oil, allowing a viscosity reduction of the heavy oil, with subsequent increase in mobility in porous medium toward the producing wells.

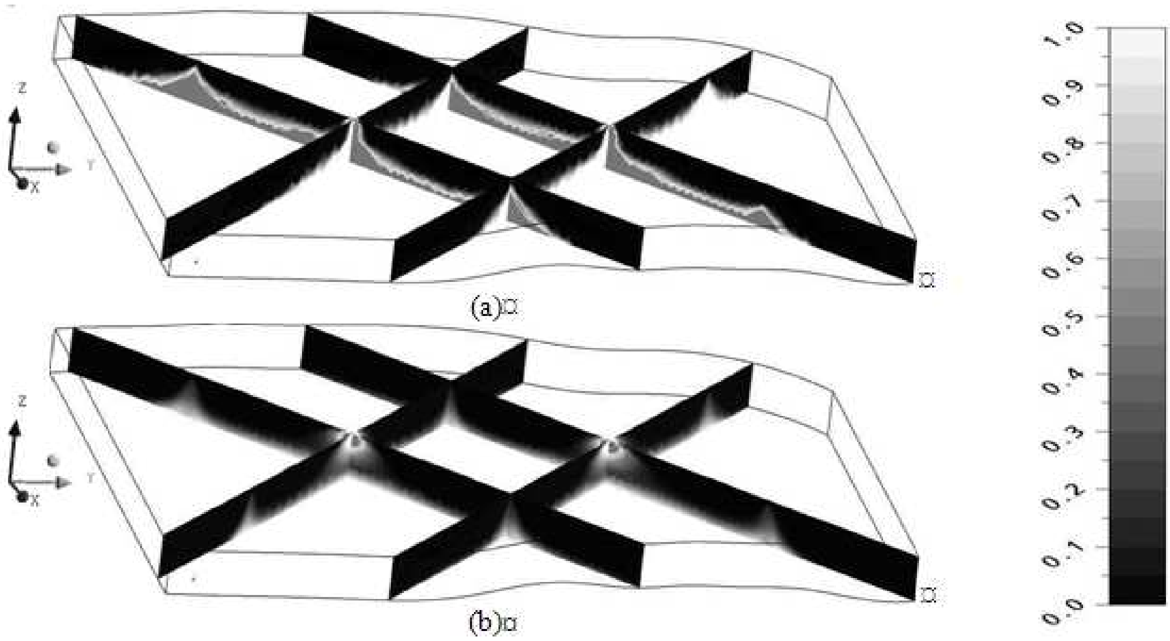

Figure 4 - Water volume fraction distribution of on vertical planes passing through all the wells and with internal injection water: (a) non-isothermal case, (b) isothermal case (t =24000h).

Figure 5 shows the evolution of recovery factor, determined with the support of Eq. 5, versus time, in non-isothermal and isothermal cases. These results illustrate that the injection of hot water in the reservoir portion presents better recovery factor whether compared to the isothermal method. This fact can be explained by the increased oil mobility caused by heat exchange in the medium, which leads to elevated oil dislocation, and consequent increase in the recovery factor. The value of recovery factor for the isothermal case was 0.13, while for the non-isothermal case, 0.16, which is equivalent to a 23% increase.

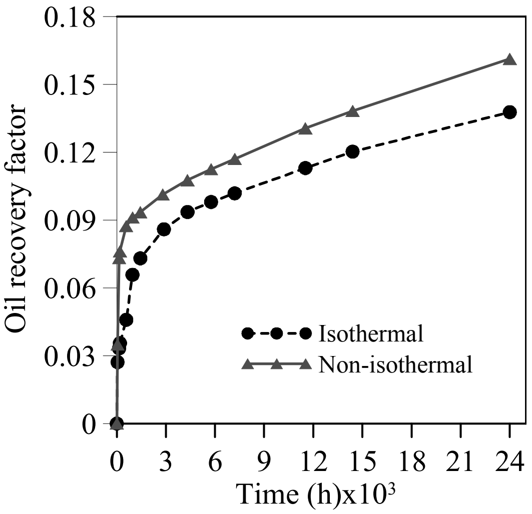

Figure 5 – Recovery factor, obtained with the isothermal and non-isothermal recovery methods for internal water injection.

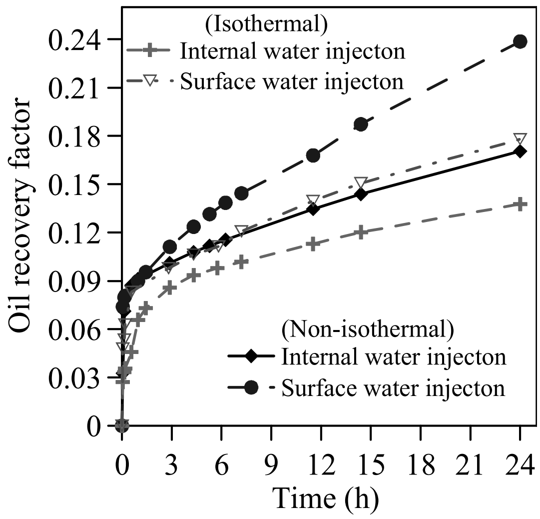

Figure 6 – Recovery factor for the isothermal and non-isothermal recovery methods with internal and surface water injection.

The results of the oil recovery factor for isothermal and non-isothermal cases, considering whether the water injection is performed on the inside or surface portion of the reservoir are exposed in (Fig. 6). These results indicate that the recovery factor with injection of water on the reservoir surface produces better results when compared to the internal injection system in both cases (isothermal and non-isothermal). This is due to the fact that the water injected on the reservoir surface has a larger vertical path down to the bottom of the reservoir, dislocating more oil horizontally, compared to what happens when the section of the water injection of the well is within the reservoir portion. Therefore, it is possible to state that the way the water is injected in the reservoir has an important influence on the process of oil production in a petroleum reservoir.

Conclusion

The simulations performed revealed the importance of considering the influence of heat transfer on the flow process, especially for high viscosity oils, where the temperature increase promotes a significant reduction in viscosity, increasing its mobility, thus resulting in a higher recovery factor. The water injection position (either internal or on the surface) at the reservoir was proven to be an important parameter in the recovery factor. A difference of 29% of the recovery factor was obtained when using the injection at the reservoir surface under non-isothermal condition and 18% when isothermal condition was taken into consideration.

Acknowledgments

The authors would like to express their thanks to Brazilian agencies ANP/UFCG-PRH-25, CNPq, CAPES, FINEP, PETROBRAS S/A and JBR Engenharia Ltda. for supporting this work, and are also grateful to the authors of the references in this paper that helped in the improvement of quality.

References

[1] J. Chen: Heavy oils, SIAM News Vol. 39 (2006), p. 1

[2] T. H. Ahmed: *Reservoir Engineering Handbook* (Gulf Professional Publishing, USA, 2001)

[3] C.R, Smith: *Mechanics of secondary oil recovery* (Reinhold Publishing Corp, USA 1966).

[4] T. Babadagli: J. Coll. Inter Sci. Vol.246 (2002), p. 203

[5] T. Babadagli and A. Al-Bemani: J. Petroleum Sci. Eng. Vol.58 (2007), p. 259

[6] K.T. Elliot and A.R. Kovscek: *Western Regional Meeting* (Anchorage, Alaska, SPE 54618, 1999)

[7] J.M. Schembre, G.Q. Tang and A.R. Kovscek: J. Petroleum Sci. Eng. Vol.52 (2006), p. 131

[8] C.T. Hsu: *Handbook of Porous Media* (edited by K. Vafai, Chapter, 2, CRC Taylor & Francis, 2005).

Diffusion in Solids and Liquids VI
doi:10.4028/www.scientific.net/DDF.312-315

Non-Isothermal Enhanced Recovery of Heavy Oils by Numerical Simulation
doi:10.4028/www.scientific.net/DDF.312-315.935