compatibility refining cut/heavy oil in solvent injection as heavy oil production method

Yefrenck Castro, PDVSA-Intevep; Alida Véliz, PDVSA Intevep; Nelson Rondón, PDVSA-Intevep; Jesus Rodriguez, PDVSA ;Marina Cortez, PDVSA Intevep; Mileydi Rodriguez, PDVSA Intevep

ABSTRACT

This study consists of evaluating effect of two solvents (Solvent 1 and Solvent 2) on the crude oil physicochemical properties from the Orinoco Oil Belt ¨Hugo Chavez¨ (API gravity: 8.4 and viscosity: 20,070 cp). Therefore, it seeks an alternative technology to increase the production of heavy oil, through cyclic solvents injection. It is noteworthy the importance of conducting laboratory tests previously to field applications, since these tests allow selecting accurately a solvent under technical criteria, as well as the optimization of the intrinsic parameters of this technology.

The selected solvents were characterized. Viscosity, SARA and API gravity were measured for these selected solvents. Solvent 1 and Solvent 2 have API gravity of 35.7 and 33.9 respectively. These tests were conducted at reservoir conditions (50°C and 800 psi), which were based in cyclic solvent injection using cells previously conditioned according to field data. Five tests were carried out, with a porosity range between 30 and 31%, oil saturations range between 75 and 80%, and water saturations range between 9.8 and 13.3%. The cyclic solvent injection tests were executed, with one hour as soak period and then placing the cell in production, where production effluents were collected and analyzed.

Results from static tests and dynamic tests showed Solvent 1 had more dissolution effect on the crude oil. Similarly, Solvent 2 allows a greater viscorreduction by dissolution, which decreases with the number of cycles. Oil recoveries around 27.0% were obtained using Solvents in cyclic steam injection and recoveries around 50% were obtained with solvent and steam injection.

KEY WORDS

Cyclic solvent injection, miscible processes, solvents, heavy oil, steam injection.

INTRODUCTION

Worldwide depletion of oil reserves are encouraging oil companies to invest in exploitation of heavy and extra heavy oil reservoirs. The Hugo Chavez Frías Orinoco Oil Belt (FPO HCF) is one of the largest reserves of heavy and extra heavy crude in the world. PDVSA as national oil industry focuses its efforts on strategy research and research and development in order to maximize the Venezuelan heavy oil production.

Under this guideline PDVSA conducts research on enhanced oil recovery methods for their applicability in mature fields of heavy and extra heavy oils, with the goal of stimulating fields, increase the recovery and more efficient recovery methods. These efforts are focused in the called chemical methods, specifically in organic solvents injection at various injection patterns.

Since each reservoir is unique, taking in consideration the petrophysic reservoir and porous media properties, characteristic chemical systems for each application can be designed and evaluated. The chemical used, their concentrations in injection processes, the amount of solvent injected, the injection scheme, depends on fluid and reservoir properties and relevant economic considerations.

The main purpose of this investigation is to evaluate the effects of two refining cuts (organic solvents) on the physicochemical properties of heavy oil. The study consisted to conduct displacement tests using different solvents and steam at reservoir conditions. This will allow predicting the rock fluid behavior, oil recovered physicochemical properties after cyclic solvent injection and the increasing of oil produced for the solvent use.

STATEMENT OF THEORY AND DEFINITIONS

The organic solvents are volatile organic compounds that are used alone or combined with other agents without undergoing any chemical change; furthermore, they allow other substances to be dispersed into them at a molecular level. In the oil industry, the classic solvents are the light crudes, condensate crudes, heavy naphtha and diesel oil, which are all obtained from the atmospheric distillation of desalted crude (Masschelein, 2004).

Solvent injection

In solvent injection, the miscible agent can be mixed in all proportions of the oil to be displaced; nevertheless, some of them just exhibit a partial miscibility to oil, which is why they are defined as solvent. Another important feature is that many of them can be miscible in the oil phase at appropriate conditions, but most of the commercial solvents are immiscible in the water phase.

In the solvent injection method, the main oil recovery mechanism are: extraction, dissolution, vaporization, solubilization, and dispersion, among other important oil recovery mechanisms such as interfacial tension reduction, viscosity reduction, oil swelling and solution gas drive (De Ferrer, 2001). The solvent and the crude are mixed in a reservoir as a result of four main mechanisms, which are: convection, diffusion, dispersion and dissolution. The mixing of the mixture components occurs on a microscopic scale, and the outcomes of molecular diffusion and velocity variations of the fluid in the porous media occur in the pore size scale (Ivory et al. 2009).

Mass transfer by convection is a mass transfer mechanism between a surface and a flowing fluid where either mass diffusion or fluid mass flow is involved. The fluid movement also improves considerably mass transfer by removing the fluid with a high concentration near the surface and replacing it for the one with the lowest concentration that is further away. In mass convection, a concentration limit cap is defined. It has been proven that mass convection can significantly affect the components distribution in some oil reservoirs. Depending on fluid mixtures, a weak convection can drastically change the variation, but if the convection is stronger, the composition remains more homogeneous (Ghorayeb & Firoozabadi, 2000). Natural convection is the convective circulation due to the density gradient. This density gradient is established due to the temperature and concentration gradients. The steady-state convection in oil reservoirs is caused by the horizontal temperature gradient (Ghorayeb & Firoozabadi, 2001).

Mass transfer by diffusion is a phenomenon where displacement of atoms or molecules of two mixing liquid substances occurs (Masschelein, 2004). It has been proven that the diffusion coefficient is not a constant value for different oil solvent (Salama & Kantzas, 2005). The molecular diffusion coefficient is small, usually for the gas phase is approximately 10-8 m^2/sec and for the oil phase is approximately 10-10 m^2/sec.

Mass transfer by dispersion is the mixing of fluids caused by molecular diffusion in the flow direction, local velocity gradients, lengths of streamlines locally heterogeneous, and the mechanic mixing due to the complex nature of pore structure (Lake, 1989). The dispersion coefficient in porous media is a second order tensor that depends on local variations of the velocity field (Salama & Kantzas, 2005). Velocities variations are not easy to measure; thus, dispersion coefficient has been frequently linked to more easily measurable quantities such as apparent lineal velocity and some characteristic lengths of the porous medium, e.g., particle diameter or porous medium length. For laboratory scaling the combined effects of diffusion and dispersion can be represented by dispersion coefficients. Dispersion coefficient is commonly reduced to a longitudinal component parallel to the net flow direction and a transverse component perpendicular to the net flow direction, which are controlled by dispersion at low velocities and by convection at high velocities.

Mass transfer by dissolution is the process in which the solvent acts on the substance to be dissolved, which in this case is the crude, in order to increase its state of distribution (Ullmann, 2005), forming a mixture or solution. The attractive forces act between the molecules of pure components and between different molecules in the solution. If the attractive forces in the solution are larger than those of the pure components, the dissolution is accompanied by a decrease in internal energy of the system. The process is exothermic and heat is released. However, if the forces of attraction between the molecules of the pure components are larger than those in the solution, the internal energy of the system increases with the absorption of heat. In a closed system, the endothermic dissolution process is accompanied by cooling. In open systems the heat is absorbed from the surroundings. Most of the dissolution processes are endothermic and they are promoted by an increase in temperature: solubility has a positive temperature coefficient, while in the exothermic processes they have a negative temperature coefficient, i.e. the solubility decreases with the rise of temperature.

Factors involved in the injection of solvents.

In the solvent injection processes, it must be taken into account the properties of the fluids and the porous medium as well as the physical effects involved in the process, which are listed below (Paez, 1963):

•Fluid viscosity, the displacer fluid is less viscous than the displaced fluid. Such condition causes the phenomenon of viscous interdigitation (fingering), defined as the irregular advance of the displacing material through the displaced phase, that is, the protrusions of the injected material are ahead of the main mass of the displacing material.

•Mobility ratio, if the ratio is greater than 1, the ratio is unfavorable or adverse, and in this condition the viscous lumps are formed; and if it is less than or equal to 1 the ratio is favorable.

•Fluid density.

• Flow characteristics of the porous medium.

DATA AND OBSERVATIONS

The heavy crude used to carry out the tests comes from The Hugo Chávez Frías Orinoco Oil Belt, Ayacucho Division, which was dehydrated and characterized. It was determined the viscosity through a rotational rheometer and the density by ASTM D5002-9 standard. Likewise the solvents used and test effluents were characterized according to the schematic methodology in Figure 1.

Characterization of reservoir formation water was carried out and synthetic reservoir water was prepared following the procedure of the American Petroleum Institute (API) RP 45: Recommended Practice for Analysis of Oil-field Waters and its composition is shown in Table A-1.

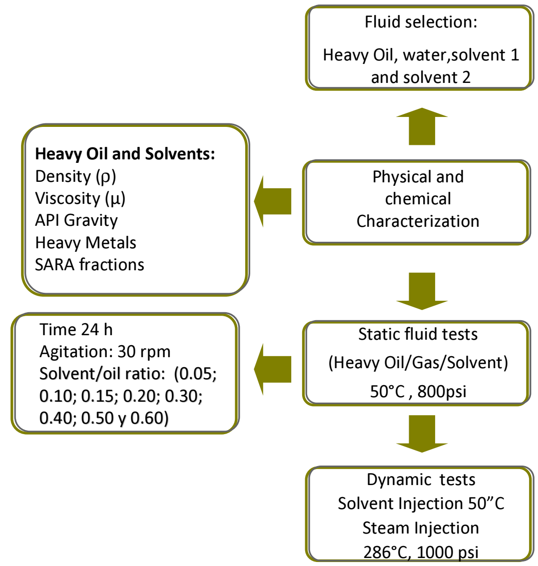

Figure 1. Methodological scheme

First, the fluid selection. We used Heavy oil from Bare field in Ayacucho block, water, and two solvents (light and medium refining cuts) from a refinery close to de exploitation area. Second, The measuring of physical and chemical properties as Density, viscosity, API Gravity, Heavy metals and Sara (Saturates, aromatics, resins and asphaltenes) factions. Then, the static tests were carried out at fifty degrees and eight hundred psi. The time was 24 hours and 30 rpm of stirring. We used solvent –oil concentration from 5% to 60 % of solvent.

Finally, Once the displacement cell is conditioned at reservoir conditions (saturation, porosity, permeability, temperature and pressure) began the cyclic solvent and steam injection tests. Cyclic steam injection, cyclic Solvent injection with solvent 1, cyclic Solvent injection with solvent 2, steam and solvent 1 injection and steam and solvent 2 injection at 50°C and 800 psi.

Test
Steam
Steam+Solvent 1
Steam+Solvent 2
Solvent 1
Solvent 2

Table 1. Experimental Matrix

The solvent injection involves the injection of fluid at a constant injection rate of 0.5 mL/min for a certain period of time until having a porous volume collected from the cell. It was carried out an experimental matrix (Table 1), consisting in five core flood tests, using reservoir sand and making duplicates to determine reproducibility.

RESULTS

It was characterized the crude (Table 2) and the solvents (as shown in Table 3) used in conducting the cyclic solvent and steam injection displacement tests.

<table>
<tr><th></th><th>PROPERTY</th><th>Value</th></tr>
<tr><td rowspan="2"></td><td>Viscosity @ 50 °C (cP)</td><td>20,070</td></tr>
<tr><td>API Gravity</td><td>8.4</td></tr>
<tr><td rowspan="3">METALS (ppm)</td><td>Iron (Fe)</td><td>51</td></tr>
<tr><td>Vanadium (V)</td><td>140</td></tr>
<tr><td>Nickel (Ni)</td><td>23</td></tr>
<tr><td rowspan="4">SARA fractions (%P/P)</td><td>Saturates (S)</td><td>9</td></tr>
<tr><td>Aromatics (A)</td><td>45</td></tr>
<tr><td>Resins (R)</td><td>36</td></tr>
<tr><td>Asphaltenes (A)</td><td>10</td></tr>
<tr><td rowspan="2">C/H Analysis</td><td>Carbon (C)</td><td>83.7 %</td></tr>
<tr><td>Hydrogen (H)</td><td>10.6 %</td></tr>
</table>

Table 2. Characterization of heavy oil

PROPERTY	Solvent 1	Solvent 2
Physical state	Liquid	Liquid
Viscosity @ 50 °C (cP)	1.35	2.43
Density (g/mL)	0.84191	0.85131
API Gravity	35.7	33.9
Boiling point (°C)	263.3	328.5
Flashpoint (°C)	72	98,5
C/H ratio	9.33	9.13

Table 3. Characterization of the solvents

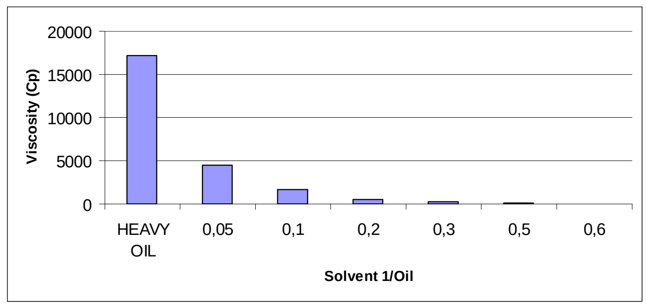

Figure 2. Viscosity behavior in heavy oil for solvent 1 effect

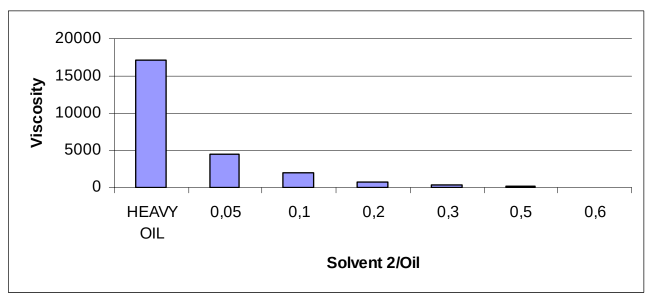

Figure 3. Viscosity behavior in heavy oil for solvent 2 effect

The viscosity behavior of heavy oil by adding solvent in static tests are showed in figures 2 and 3. Heavy dead oil form Ayacucho block has 20,070 cP as inicitial value of viscosity and decrease almost 92 % until 4500 cP with solvent 1. In the case of solvent 2 the viscosity decrease 90% using 5% proportion of solvent 2.

Five percent was selected as optimum amount to be used in the dynamic tests

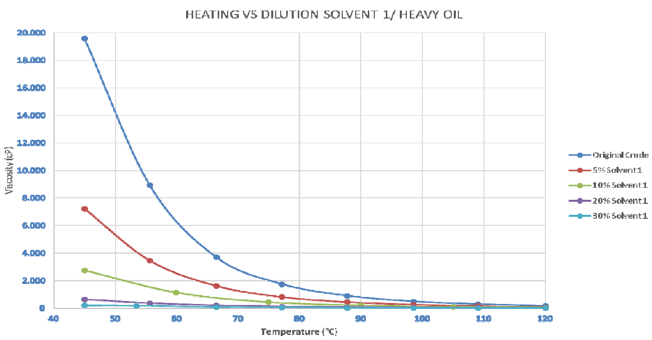

Figure 4. Heating vs dilution effect for solvents in heavy oil

In figure 4, It can be observed how viscosity decrease while the solvent concentration increase and while temperature increases also. It seems to be that dilution effect is more efficient than thermal effect in viscosity reduction.

Test	Kg (D)	Sg (%)	Sw (%)	So (%)	VP(ml)	ø (%)
Steam	4.8	15.0	9.9	75.1	109	32
Steam+Solvent1	4.9	14.5	13.3	72.3	105	30
Steam+Solvent2	4.9	15.0	10.0	75.0	103	31
Solvent 1	4.7	9.8	10.1	80.1	100	30
Solvent 2	4.7	9.8	9.8	78.1	103	32

Table 4. Petrophysical properties in displacement cells

The conditioning of displacement cells was performed for each test (Table 4). An average porosity (Ø) of 30% was obtained, having a relative deviation of 3.5%. Nitrogen gas permeabilities (K_g) were measured, reporting an average of 4.8 Darcies. In tests with formation sand, grains have better fit characteristics, since the probability that there is more variety of particle sizes increases and this allows a better arrangement of the porous medium. Subsequently, it was saturated with formation water to 100% and the water permeability (K_w) was measured, reporting average values of 6 Darcies.

Finally, displacement cells were saturated with crude oil to the point of irreducible water (S_{irrw}) was measured casting an average of 11.6 %.

Once conducted the solvent and steam injection displacement tests, the effluents are collected, they represent a mixture of crude with the solvent injected, in order to determine the amount of oil recovered it should be performed a mass balance. These values are used to calculate the oil crude recovery for each test. It can be observed the percentage of oil recovered from the six tests carried out. It shows that the greatest oil recovery was obtained with naphtha injection.

Test	1st Cicle	2nd Cicle	3rd Cicle	Total Rec
Steam	25.6	4.9	1.2	32
Steam+Solvent 1	46.4	3.7	0.9	51
Steam+Solvent 2	43.2	3.6	1.3	48
Solvent 1	23.6	2.4	0.9	27
Solvent 2	22.5	1.9	0.9	25

Table 5. Total recovery in displacement tests

In the displacement tests, we observed three cycles as optimum cycle number (Table 5). Above three cycles we didn´t recover enough quantity of oil produced. The maximum amount of heavy oil was recovered in the first cycle. Second and third cycle complement the total recovery in the test. Total recovery was between 25 to 50% for all the displacement tests. We recovered more heavy oil using steam and solvent injection where we 50% of total recovery.

DISCUSSION

As it is shown in Table 4, tests with solvent 1 gave an average recovery percentage of 27%, whereas tests with solvent 2 gave an average crude recovery percentage of 25%. Comparing the percentages of recovered crude oil, there is not a variation between these two solvents that makes a difference, stating that an injection of solvent is not a method to increase the recovery, but a method of stimulation that allows the improvement of the physicochemical properties of oil by a dilution effect.

API gravity of production 1 is larger than the one of the original crude oil, approaching to the values of the solvent, and it decreases with every production, approaching to the original crude oil conditions. In other words, as for the third production, the produced fluid tends to decrease its gravity because the dilution effect decreases as the productions are performed.

CONCLUSION

The solvent proportion to be used in cyclic solvent injection at laboratory scale has been optimized for solvents between 5% and 10% respectively , in that range it was observed a viscosity reduction of 90 % for dilution effect.

The content of saturates, aromatics , resins and asphaltenes in the system solvent / crude showed slight changes from the original crude.

Solvents showed very similar results heavy oil/solvent interaction during the static and dynamic tests.

The use of solvents as chemical additive in steam injection is favorable for increasing heavy oil production obtaining total recovery of 50%.

The order of additives effectiveness under saturated steam injection conditions depending on the effect on the physicochemical properties was as follows : Solvent 1 (Light refining cut) > Solvent 2 (Medium refining cut).

NOMENCLATURE

K_g= gas permeability, D

K_o= oil permeability, D

K_w= water permeability, D

ρ = density, g/cm^3

Ø = porosity, %

P = pressure, psi

S_{irrw}= irreducible water saturation, %

T = temperature, °C.

μ = viscosity, cp

REFERENCES

Castro Y., Veliz A. Rondon N. Rodriguez J. (2012). Efecto de solventes sobre las propiedades fisicoquímicas del petróleo del pozo MFB-717/Campo Bare a condiciones de temperatura y presión de vapor saturado mediante pruebas estáticas y dinámicas (2012). Technical report INT-13773. PDVSA Intevep Venezuela.

De Ferrer P. (2001). *Inyección de agua y gas en yacimientos petrolíferos*. Ediciones Astro Data S.A., Venezuela.

Ivory J., Chang J., Coates R. and Forshener K. (2010). *Investigation of Cyclic Solvent Injection Process for Heavy Oil Recovery*. **SPE 140662**.

Ghorayeb K. & Firoozabadi A. (2000). *Modeling Multicomponent Diffusion and Convection in Porous Media*. **SPE 62168**.

Ghorayeb K. & Firoozabadi A. (2001). *Features of Convection and Diffusion in Porous Media for Binary Systems.* **PETSOC-01-02-01**.

Qazvini Firouz (2012). Feasibility study of solvent-based huff and puff method to enhanced oil recovery. **SPE 157853.**

Lake L. (1989). *Enhanced Oil Recovery*. Prentice Hall. Inc. USA.

Masschelein L. (2004). *Los solventes*. DIBAN, Chile.

Páez J. (1963). *Aspectos de la industria petrolera en Venezuela*. Sucre Editorial, Venezuela.

Salama D. & Kantzas A. (2005). *Experimental Observations Of Miscible Displacement Of Heavy Oils With Hydrocarbon Solvents*. **SPE 97854**.

Ullmann F. (2005) *Ullmann's Encyclopedia of Industrial Chemistry: Solvents*. Wiley-VCH.

TABLES

Formulation	Concentration (ppm)
Calcium, Ca^{+2}	41.6
Magnesium, Mg^{+2}	54.4
Sodium, Na^{+}	2,586
Potassium, K^{+}	44.0
Bicarbonates, HCO_3^{-}	5,600
Carbonates, CO_3^{-2}	<0.1
Sulphates, SO_4^{-2}	8.0
Chlorides, Cl^{-}	2,750

Table A-1. Formation water