CIENCIA, TECNOLOGÍA Y FUTURO

OPTIMIZATION OF ELECTRICAL SUBMERSIBLE PUMP ARTIFICIAL LIFT SYSTEM FOR EXTRAHEAVY OILS THROUGH AN ANALYSIS OF BOTTOM DILUTION SCHEME

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This study presents the analysis of the variables that have the greatest impact on energy requirements for an artificial lift system applied to extra heavy crude oils, considering an uncertainty behavior analysis through their sensitivity in the vertical flow modeling implemented for a Chichimene Field well. The selected variables are the viscosity and fluid density, the required artificial lift system pressure differential, well depth, the flow rate of produced fluids and the dilution percentage.

The oil produced in this field has a density of 7,8 °API, and the well studied features a water cut of about 10% and produces a total of 2400 BOD. For this flow naphtha dilution rates were defined using up to 20% by volume. The ranges of energy required for the lifting system for different scenarios raised by the analysis variables were also determined.

For these conditions a variation of the energy required 20% for a fluid flow incremental of 50 BFOD was obtained, as established from the flow capacity of the well and the pressure required for sustaining a pressure head of 100 psi and 400 psi. Bottom dilution scheme establishes a change in artificial lift system energy requirement, of up to 25% for a 15% of diluter, whereas the relationship between the volumes produced and the system arrays gives an energy efficiency of 40%.

Keywords: *extra heavy oil, viscosity, density, dilution, energy, pressure, artificial lift system, electrical submersible pump.*

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En este estudio se presenta el análisis de las variables que tienen mayor incidencia en los requerimientos de energía para un sistema de levantamiento artificial aplicado a crudos extrapesados considerando un análisis de incertidumbre de su comportamiento mediante la sensibilidad de las mismas en el modelamiento de flujo vertical implementado para un pozo del Campo Chichimene. Las variables seleccionadas son la viscosidad y la densidad del fluido, el diferencial de presión requerido en el sistema de levantamiento artificial, la profundidad del pozo, los caudales de fluidos producidos y el porcentaje de dilución.

El crudo producido en este campo tiene una densidad de 7,8 °API, y el pozo analizado presenta un corte de agua cercano al 10% y produce un total de 2400 BPD. Para este caudal se definieron porcentajes de dilución con nafta hasta en 20% en volumen y se determinó la variación en la energía requerida por el sistema de levantamiento para los distintos escenarios planteados por las variables de análisis.

Para esas condiciones se obtuvo una variación de la energía requerida del 20% para un caudal de fluido incremental de 50 BFPD, lo cual se estableció a partir de la capacidad de aporte del pozo y la presión requerida en fondo para una presión de cabeza entre 100 psi y 400 psi.

La dilución en fondo establece una variación en el requerimiento de energía del sistema de levantamiento artificial de hasta 25% para un porcentaje de diluyente del 15%, considerando que la relación entre los volúmenes producidos y los arreglos del sistema permiten manejar una eficiencia energética del 40%.

Palabras clave: *crudo extrapesado, viscosidad, densidad, dilución, energía, presión, sistema de levantamiento artificial, bombeo electro sumergible.*

INTRODUCTION

In the production of extra heavy oils there is a limitation due to the high viscosities that represents a decrease in the operational energetic efficiency of the production system and among the artificial lifting systems that have shown a good performance in the production of this type of fluids the electrical submersible pumping is found. This system of artificial lifting consists basically of a multistage centrifugal pump, a three-phase induction engine, a seal section, a power cable and surface controls. The triggers of the pump stages give the kinetic energy to the fluid that transforms into the dynamic height required for the lifting of the fluids. The energy is supplied through the power cable to the engine and the energy required by the system is a function of the efficiency that each stage can hold. The performance of the stages is usually given in function of a stage, considering a fluid of specific gravity similar to the unit (water) to a frequency of 50 Hz or 60 Hz and the energetic efficiency of the pump is a function of the handling flow, the total dynamic head, the specific gravity of the fluid and the brake power. This way, it is necessary to analyze the impact on the efficiency due to the handling from a fluid of density higher than that of the water, such as it happens to *T2* oil.

The change of density of the fluid also outlines a phenomenon of heat transfer between the pump and this fluid, and two variables are high-priority in the analysis of the phenomenon. The first of them is the density of the fluid, which is related with the specific heat of the fluid and as for the oils it takes values between 0,40 and 0,52. The second is the power required by the system that is a function of the total dynamic head.

For a fluid of higher density than water, as the case of *T2*, the heating capacity affects the temperature of the engine in direct relationship with the power that demands the system for the pressure required in head, this is, the pressure that represents the dynamic total head, and this last one is bigger for a fluid of more density. This is then translated in the hypothesis that the extra heavy oils properties provoke a low efficiency of the system for electrical submersible pumping due to their density, and the confirmation of such hypothesis is in function of the possibility of analyzing the variation of the energetic efficiency of the system by means of the sensibility of the density of the fluid when a bottom dilution approach is implemented.

Under normal conditions of operation this system can work in a range between 40% and 50% of efficiency for fluids of this density, so a possibility to optimize its operation is given by the reduction of the density by well bottom dilution and to establish the effect of this dilution in the energy demanded by the system at different dilution percentages.

To carry out this analysis the extra heavy oil properties should be adjusted, since the variations of pressure and temperature throughout the production pipe define the necessity to re-evaluate the PVT properties, especially the solubility of the gas, since the experience has demonstrated that *T2* extra heavy oil can reach supersaturation conditions. It is required to select a flow correlation in vertical pipe that predicts in a reliable way the pressure profile in the pipe and a mixtures scale should be used to establish the viscosity for the different dilution approaches. For the case of *T2* oil the method of mixtures index is used where the viscosity is calculated by means of the summatory of VBN (Viscosity Blend Number) of each one of the components of the mixture. The adjustment of the pattern establishes the possibility to determine which it is the differential of pressure that should generate the artificial lifting system to arrive to well head with a certain pressure, and this differential determines the energy required by the combined engine pump. This possibility was implemented for the case of different dilution percentages.

Besides to the effect of the density variation by means of the dilution is the phase change that can have the diluter when it reaches the conditions of pressure and temperature, causing an increment in the presence of free gas associated to the production. However, the high value of GOR in solution the oil admits, establishes a possible supersaturation condition where a small increment in the volume of naphtha that changes of phase is admitted by the oil without problem.

The analysis was proposed for an 7,8 °API oil, with a near cut of water to 10% that produces a total of 2400 BOD. Percentages of Naphtha of 5%, 10%, 15% and

20% were managed in volume and the variation was determined in the energy required by the lifting system for the different scenarios outlined by the analysis variables. It was possible to determine that for a dilution percentage to 5% a reduction of 20% is obtained in the energy consumption.

METHODOLOGY

The methodology implemented for the optimization of the energy required by the lifting system by means of electrical submersible pumping of extra heavy oils is defined in the following diagram:

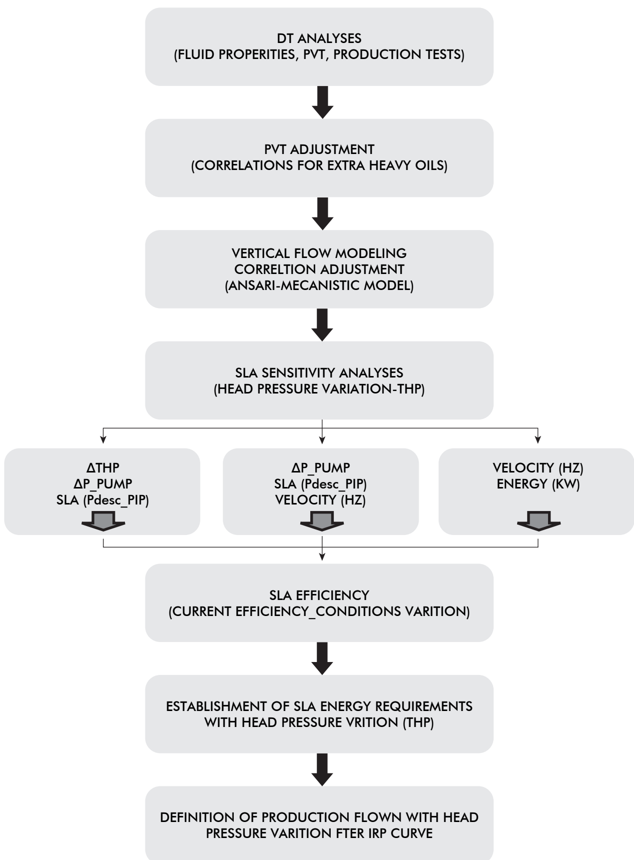

Figure 1. Analysis methodology

The methodology allows relating the main elements of the production system from the well bottom to the well head and it determines the necessity to carry out an adjustment of the PVT properties of the fluid and of the vertical Flow Correlation.

The adjustment of the PVT properties of the fluid is needed since the pressure and temperature variations associated to the flow through the vertical pipe and the of artificial lifting system allows to establish the group of correlations that allows to model the variation of the properties with the best adjustment regarding the data measured in laboratory. The correlation adjustment considers the smallest error that is generated respect to the measured data.

The correlation adjustment for vertical flow considers the fall of pressure generated by the losses by friction and gravity between the bottom of the well and the level reached by the fluid, established starting from the settling depth and the pump level, as well as the relationship between the differential generated by the electrical submersible pump and the well head pressure.

The adjustment of these correlations allows modeling the behavior of the properties of the fluid before the variation of the conditions of the well, reason why it is intended to carry out an analysis of sensibility of variables to establish the energy requirements of the pump, by the following steps:

- A sensibility analysis of the head pressure and calculations of the required differential by the electrical submersible pump to reach the well head pressure values are carried out.
- The differential of the electrical submersible pump establishes a relationship among the discharge pressure and the system entrance pressure of artificial lifting that considers the volumetric requirement of production.
- This differential defines a required velocity operation (Hz) and this way a required power is established.
- The requirements of power are expressed in terms of Kw-h and the energy of consumption of the system is established.
- The variation of the required energy is determined in function of the variation of the head pressure requirements, determining in each case the relationship between the variation of the conditions and the efficiency of the pump of the system of artificial lifting.

- Finally the production flows are determined for the system by means of the curve of contribution of fluids of the location in function of the sensibility of the head pressure.

The developed methodology allows carrying out the analysis of the energy requirements of the production system from bottom up to head before the pressure variation, establishing a flow assurance of production fluids.

ADJUSTMENT OF THE FLUIDS PROPERTIES

Adjustment of PVT Properties

For the PVT properties adjustment a comparison was established among the data obtained in laboratory for a San Fernando oil sample produced in the Chichimene 18 well and whose data were registered in the year 2006 by the Instituto Colombiano del Petróleo (ICP), the correlations of more applicability in the industry (Banzer, 1996) and the correlations of more applicability for the extra heavy oils according to the literature (De Ghetto, Giambattista, Paone, Francesco & Villa, Marco, 1995) were used.

Bubble Pressure

For the comparison with the measured data, the correlation of Standing, Vásquez, Kartoatmodjo (Banzer, 1996) and the one suggested for extra heavy oils (De Ghetto, 1994) were used. The modified correlation of Standing whose formulation are shown next represents the best adjustment:

$$P_b = 15{,}7286\left[\left(\frac{R_s}{\gamma_g}\right)^{0{,}7885}\frac{10^{0{,}00020T}}{10^{0{,}0142API}}\right] \quad (1)$$

The comparison among these gave the following result (Figure 2).

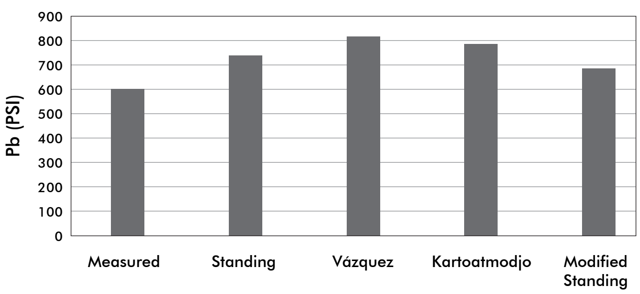

Figure 2. Correlation selection to calculate the Bubble Pressure of T2 oil (Bp)

GOR in solution

The used correlations were those of Standing, Vásquez, Glaso, Kartoatmodjo (Banzer, 1996) and the Modified Standing (De Ghetto, 1994), the one which, due to the pressures required for the simulation, showed better adjustment:

$$R_s = \gamma_g\left[\frac{P_b}{10{,}7025} * 10^{(0{,}0169API - 0{,}00156T)}\right]^{1{,}1128} \quad (2)$$

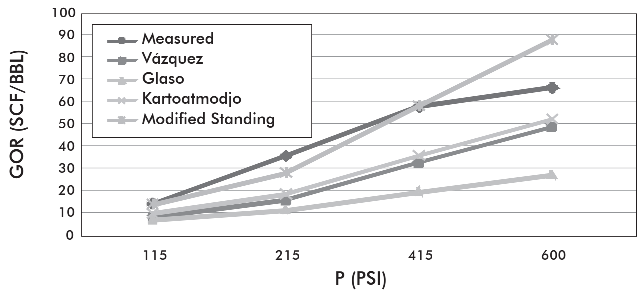

Figure 3. Correlation selection to calculate GOR in solution of oil T2 (Pb)

The importance of accurately determining the gas in solution for this type of oil is sufficiently justified by the supersaturation conditions that the fluid can reach (Sheng & Hayes, 1995; Romero & Fernández, 2001; Maini, 2001).

Oil Compressibility

In this case, the used correlations were those of Vásquez, Petrosky, Kartoatmodjo (Banzer, 1996) and the modified Vásquez & Beggs (De Ghetto, 1994) that is of better adjustment for

$$c_o = \frac{-889{,}6 + 3{,}1374R_s + 20T_g - 627{,}3\gamma_{gcorr} - 81{,}4476API}{P_g 10^5} \quad (3)$$

Where,

$$\gamma_{gcorr} = \gamma_g P_{sep}\left[1 + 0{,}5912API * T_{sep} * Log\left(\frac{P_{sep}}{114{,}7}\right)10^{-4}\right] \quad (4)$$

Due to the variation of the value of the compressibility, a sensibility analysis of the parameter was carried out, where Vázquez's correlation and that the modified Vázquez & Beggs (De Ghetto, 1994) were considered.

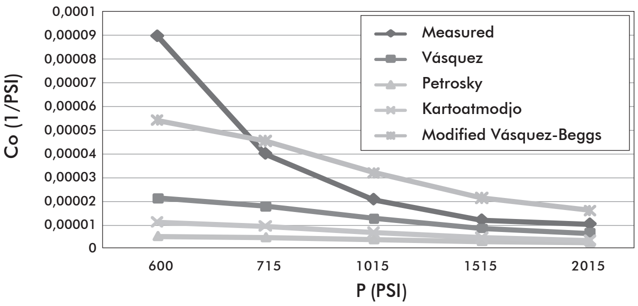

Figure 4. Correlation selection to calculate the compressibility of T2 oil (Pb)

Oil Viscosity

The viscosity of the oil was determined starting from the correlation of Mehrotra, which uses a direct relationship with regard to the temperature expressed in Kelvin grades (Barrufet & Gabitto, 2003):

$$\mu = 10^{\left[102093433 \cdot T^{-2,93}\right]} - 0,8 \quad (5)$$

For the viscosity case of the emulsions the pattern of Woelflin was implemented with a formulation as the following:

$$\mu = \exp\left(a\phi^2 + b\phi\right) \quad (6)$$

The parameters a and b depend on the emulsion type and the value they take for the case of emulsions of T2 oil of 10,13 for a and of -0,069 for b.

The implementation of this equation allowed to establish that the emulsion inversion shows up when a percentage of BSW of 50% is reached (García, 2009), value that was considered in the hydraulic analysis carried out.

MIXTURES APPROACHES

For the analysis of the mixtures between T2 oil and the diluter, the method of index of mixtures proposed by Sutton (Sutton & Bergman, 2008) was implemented. Viscosity Blend Number (VBN) to determine the mixture index has the following formulation:

$$VBN = K1 + K2 + LN\left(LN\left(\mu_{(cSt)} + K3\right)\right) \quad (7)$$

The values obtained for *K1* are of 10,975, for *K2* of 14,535 and for *K3* of 1,03.

This way, the value of VBN was calculated for each one of the components of the mixture and the mixture (IM) index, or *VBNmixture* was calculated in function of the diluter percentage:

$$VBN_{MIXTURE} = \%_{diluter} * VBN_{diluter} + \%T_2 * VBN_{T_2} \quad (8)$$

This way the viscosity of the mixture was calculated starting from the same VBN, being expressed in the following way:

$$\mu_{MIXTURE} = \exp\left(\exp\left(\frac{VBN_{MIXTURE} - K1}{K2}\right)\right) - K3 \quad (9)$$

CORRELATION DEFINITION OF THE VERTICAL FLOW FOR EXTRA HEAVY OIL

For the correlation definition of the vertical flow for T2 extra heavy oil an analysis of sensibility was carried out where the following elements were kept:

- IPR (Inflow Performance Relationship) = Contribution of fluids of the location.
- Level of fluid.
- Entrance and discharge pressure of the pump of the artificial lifting system.
- THP (Tubing Head Pressure)

These elements represented the reference points to establish the correlation that better adjusted to the values of pressure that each one establishes for the well. The IPR curve was adjusted according to the static Pressure value and a pressure test for the well.

This way, the selection of the correlation takes into account the bottom Pressure, estimated in 1580 PSI, and the level that reaches the fluid, estimated in 4000 ft, establishing that the best approach to the conditions of flow was given by the Ansari correlation, such as it is appreciated in the following figure:

When establishing the electrical submersible pumping artificial lifting system, the selection of the Ansari correlation was corroborated taking into account an entrance pressure to the pump of 225 PSI and a discharge pressure of 2220 PSI, obtaining the following pressures profile inside the vertical pipe:

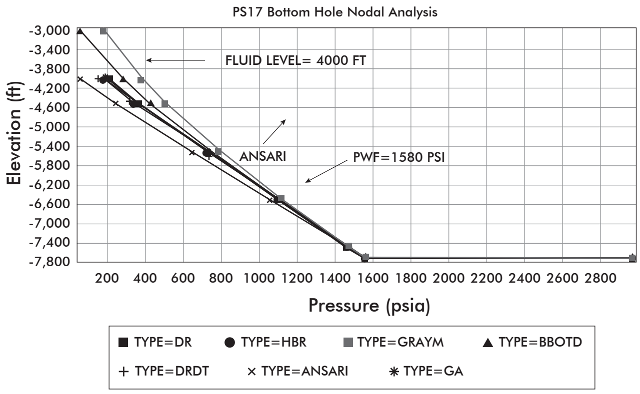

Figure 5. Correlation selection for modeling of vertical flow of extra heavy T2 oil

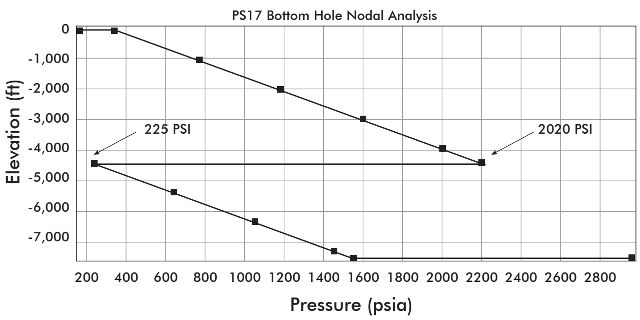

Figure 6. Setting the selected correlation to operating conditions

POWER REQUIREMENTS ANALYSIS OF THE SYSTEM

The implementation of the selected correlation allowed determining the differential that should generate the system to reach a certain pressure in head (Figure 6).

This differential of pressure is associated to an operational velocity required in the pump (González & Reina, 1994; González, 1996), which can be considered from the following relationship found for the system operating in the well (Figure 7).

In turn, the operational velocity of the pump is associated with the power requirement, so the relationship among the variation in pressure in head with the requirements of energy of the system is the following one shown in Figure 8.

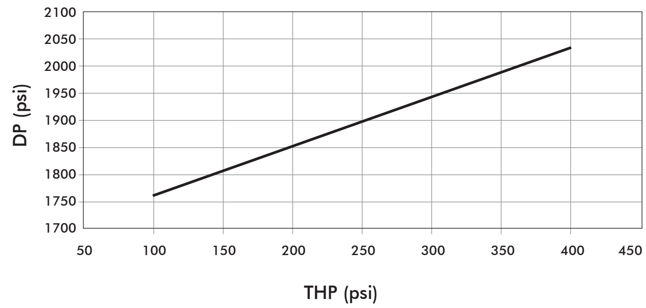

Figure 7. Differential of pressure required in the pump for a certain pressure in head

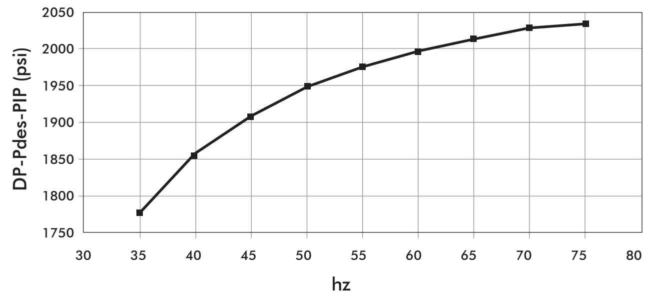

Figure 8. Relationship among velocity of the pump and differential of required pressure

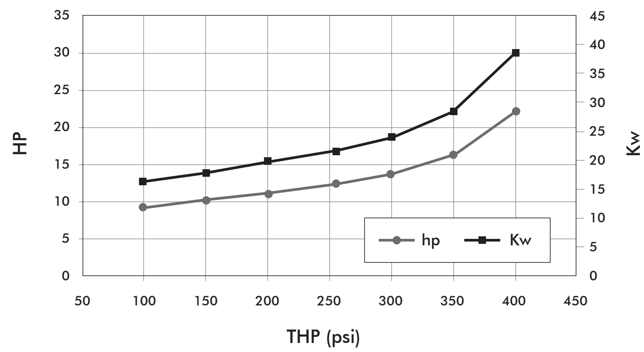

Figure 9. Energy requirements in function of THP

ANALYSIS OF DILUTION APPROACHES

For the modeling of the bottom dilution scheme and the determination of the effects in the energy required in the system, a naphtha was used as diluter, with a density of 58°API, whose mixture with *T2* oil, of 7,8°API, threw the following mixture densities, according to the mixtures scheme presented previously for a temperature of 186°F, considered as the well bottom temperature, and of 161°F that corresponds to the fluid temperature at the pump entrance, real location of the dilution:

Table 1. Densities of mixtures for the dilution scheme in bottom

186°F		161°F	
NAPHTHA %	ρ mixture (lb/ft^3)	NAPHTHA %	ρ mixture (lb/ft^3)
5	60,05	5	60,52
10	59,31	10	59,78
15	58,54	15	59,01
20	57,76	20	58,23

The density of the fluid establishes a direct relationship among the energy that should be used for its lifting, and its properties, being among them the most important the viscosity. These properties define the velocity that should reach the pump to assure a certain flow to a pressure in head, according to the efficient management of the differential that the pump can offer to the system. This results in that the energy required by the system for the lifting of a fluid of lower density should be smaller, and the quantification of this threw the following results:

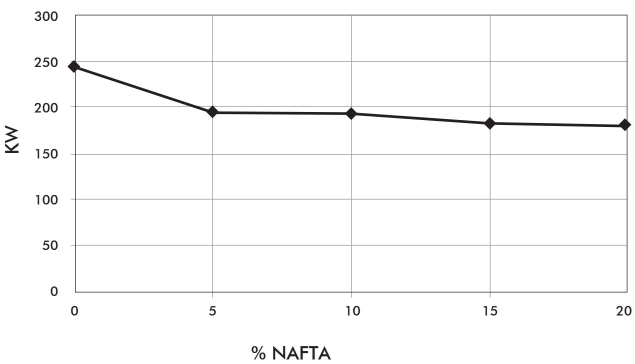

Figure 10. Relationship among the dilution percentage with naphtha and the requirements of energy of the system

This observation allowed to establish that there is a reduction in the energy required by the system and their relationship with the diluter percentage is expressed in the following way (Figure 10).

In such a way, it was determined that a reduction of 20% can be implemented in the consumption of energy thru the implementation of a dilution scheme

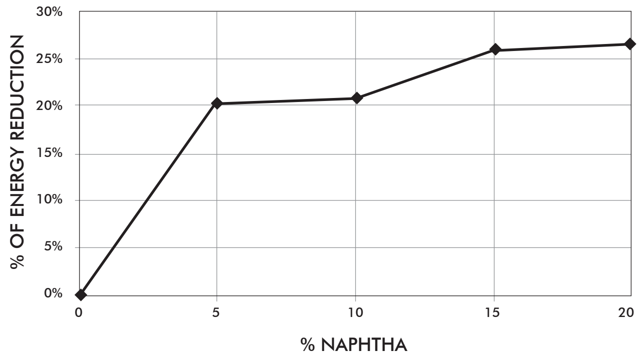

Figure 11. Energy reduction for different dilution outlines in bottom

in bottom of *T2* with Naphtha to 5% in volume, and a reduction of about 25% can be reached with a dilution of 15%.

ANALYSIS OF RESULTS

The development of the proposed methodology allowed for the possibility to optimize a system of artificial lifting by means of electrical submersible pumping for extra heavy oils, considering the best use in the energy that requires the system by means of the bottom dilution scheme, and it was concluded that by means of this dilution approach a reduction of 20% can be reached in the energy thru a dilution of 5% with Naphtha. The reduction is not very significant for the case of 10% diluter but it does for 15% where 25 % of reduction is reached, being this the biggest percentage that can be reached with this dilution approach, since a bigger percentage of diluter does not represent a notorious decrease in the energy. This is the energy required by the system for the lifting of a fluid of certain properties, such as a certain density, but the fluid also has a behavior established by the temperature variation that can be given by the use of a number of stages in the pump required for the pressure differential needed to reach to well head. The effect of this condition is related with the phase change of the Naphtha in the injection point for the dilution and therefore, the pattern variation of present flow in the production pipe.

The phenomenon of heat transfer between the pump of the lifting system and the production fluid is determined by the heating capacity of the fluid and the increment of temperature that takes place in each stage of the pump. The relationship that allows estimating the increment of temperature of the fluid is the following :

T_ engine operation = T_media (fluid) + Temperature Increment

Also, the heat produced by the engine can only be transferred to the production fluid and the efficiency of this transfer depends on the operation velocity, which, as it was determined, is in function of the requirements of pressure in the system.

The quantity of heat the fluid can absorb can be determined in function of the specific heat, property that allows measuring the increment of temperature in this process. This way, the more specific heat the more capacity of transfer of heat it has. For water, this value is of 1,0 while oil has a value average of 0,4. This is important to be accounted for since an increment in the water cut represents a bigger capacity of absorption of heat coming from the combined engine-pump. The specific heat of the fluid that constitutes the means of immersion of the equipment can be considered in the following way:

Fluid Specific Heat = Water Cut x 1 + (1- Water Cut) x Petroleum Specific Heat

In the previous analysis was considered that the inversion of the emulsion happens when reaching a BSW of 50% and this value constitutes the limit value for the analysis of the effect of the transfer of heat in the energy requirements. For such a purpose the increment of temperature generated by the combined engine-pump is established, with which the diluter percentage is determined, and which can change to gassy phase for those conditions of pressure and temperature, and when adding the quantity of free gas that flows in the flow current, the variation in the energy that requires the system for the lifting of the fluids was determined.

Considering the averages specific heats for the water and the oil, the specific heat is obtained for the production fluid is:

Specific heat = 0,5 x 1 + (1,00. 0,5) * 0,4 = 0,7

And the increment of the temperature of the fluid is given by:

Temperature Increment = 220. 187 = 33 °F

And as the specific heat is of 0,7 it was assumed that the increment by concept of the transfer with the heat produced by the combined engine-pump is of approximately 20°F. This increment is reflected in a naphtha percentage that changes phase, and it corresponds to a small percentage regarding the total volume, of 3% maximum.

This way, the effect in the energy required by the system by concept of the heat transfer of the fluids, both production and diluter, is not as notorious as the one produced by the effect of the reduction of density, and the increment of gas in the current is not enough to alter the operation of the multistage centrifugal pump that presents the system.

CONCLUSIONS

- For the extra heavy oil that constituted the object of analysis of the present work, *T2*, the correlations that better adjusted for the calculation of the PVT properties are those of Modified Standing for the calculation of the bubble pressure and of GOR in solution, and the modified Vázquez-Beggs for the calculation of the oil Compressibility.

- The real possibility of an optimization of a system of artificial lifting is given providing that the system is analyzed integrally, including the adjustment of the IPR curve, the correlation for the modeling of the vertical flow and the pressure required in head by the gathering system. In the analyzed case, the correlation that better is adjusted is that of Ansari. If the phenomenon of the transfer of heat is incorporated this model should be re-evaluated, since it can show up a variation in the pattern of flow.

- The oil presents a high value of GOR in solution regarding the prediction that can be achieved by means of the correlations of conventional use, which is an indication that the oil can reach supersaturation conditions, and this should be considered when modeling the flow patterns since the gas can alleviate the column of liquid remaining dissolved instead of flowing as free gas.

- The bottom dilution scheme defines a reduction of 20% in energy with a dilution to 5% in volume with Naphtha. This percentage represents the optimum volume of dilution since an increment in the same one does not constitute an important reduction in the energy requirements.

- The reduction of the oil density by effect of the dilution constitutes the most important element to estimate the requirement in energy of the system. However, for the modeling of flow the phenomenon of heat transfer that happens between the combined engine-pump and the production fluid should be considered, especially to establish the adjustment of the conditions of high saturation that reaches the fluid.

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NOMENCLATURE

P	Pressure, psi
T	Temperature, °F
γ_g	Gravity of the gas
γ_{gcorr}	Gravity of the corrected gas
Rs	Solubility of the gas, SCF / STB
C_o	Compresibilidad of the oil, psi-1
μ	Dynamic viscosity, cp.
$\mu_{(cst)}$	Cinematic Viscosity, centiStokes

SUBINDEXES

b	Saturation Condition
g	Gas
Sep	Separator Conditions