

Semi-Synthetic PVT with atmospheric wellhead crude samples.

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We present an operative and calculation Technique to estimate thermodynamic behaviour of reservoir fluid (black oil) from easily obtainable wellhead samples.

Using a specially designed vessel for that purpose, it is possible to obtain a sample containing atmospheric oil and a part of its associated gas, during production testing, without interfering with normal workover operations.

In the laboratory, the compositions of atmospheric oil and gas trapped in the recipient are determined and all routine experimental measurements on atmospheric oil are performed (measurements of density, molecular weight, viscosity vs. temperature curve, interfacial tension, etc.).

Using an extensive database of experimental PVT reports, we adjusted a calculation methodology that, using a thermodynamic simulator based on equilibrium constants, allows to estimate with an acceptable degree of accuracy, the thermodynamic behaviour for black oil reservoirs with moderate GOR (no more than 150 m³/m³).

This paper presents the comparison between the results obtained in conventional PVT studies and those generated by this new simplified technique. It also presents preliminary statistical analysis, with which the adjustment of the thermodynamic simulator was made for this technique.

The simplicity of this technique brings the possibility of having reasonably reliable thermodynamic data, in scenarios in which, usually, a standard PVT would not be done.

Although the technique was designed especially to characterize individual production levels in multilayer systems in the San Jorge Gulf Basin, and is more representative with viscous oils, an adaptation to light oil systems it's also included.

Introduction

Conducting an experimental PVT study of a reservoir fluid is usually a task of some complexity. This type of study involves, for instance, the extraction of a representative sample of reservoir fluid (bottom hole or surface separator sample). Many times, this procedure requires stopping, or significantly decreasing, the production rate of the well for stabilisation before extraction of the sample to be analyzed.

Under these circumstances, reservoir engineering studies are conducted with a small number, and even with a single PVT study for the entire reservoir, assuming homogeneity of reservoir fluids.

In this context emerged the need for developing a technique to predict the thermodynamic behaviour of the reservoir fluid more simply and economically. The basic purpose was to enable a greater number of independent samples and generate comparative PVT data for different areas, individual layers or different depths of the same reservoir.

To achieve these goals, we developed a technique that allows obtaining PVT parameters acceptably representative from:

- An oil sample (including foam accompanying depressurization to atmospheric conditions) extracted in the manifold during a swabbing test in the workover of the well or in wellhead, in the case of completed wells.
- Simple information, including reservoir temperature, and initial production GOR (gas oil ratio possibly recorded during the start of production) or estimated reservoir fluid bubble pressure. This data can come from a previous related PVT study or, more commonly, from binding information, such as the existence of gas caps or typical behaviours of reservoirs in the area.

Sampling is performed in a sealed container, closing it immediately after capturing the oil sample with associated foam. Later, when the sample remains inside the container at rest, the phases are stabilized and the gas trapped in the foam is released. As result we obtain two equilibrium separated phases (gas and liquid) inside the container. The more viscous oil sampled, the smaller the amount of light gas components that escape from the foam before sampling, and the sample obtained in this way is more representative.

In the laboratory, gas and liquid compositions are determined by chromatography, and all routine measurements on atmospheric oil are performed (density, molecular weight, C₂₀₊ mole %, viscosity vs. temperature curve, interfacial tension, etc.). Then, using a pre-adjusted simulator, the volumes of gas and liquid to recombine numerically are calculated to match the bubble point or GOR specified condition. Once estimated the reservoir fluid composition, thermodynamic behaviour is simulated using the same pre-adjusted simulator and the parameters included in standard experimental PVT study are all obtained.

Development

Equilibrium constants and calculation tool

The liquid-vapour equilibrium constant K_i associated to “ i ” component of a hydrocarbon is defined by $K_i = y_i/x_i$ where y_i is the molar fraction of that component in vapour and x_i is the molar fraction of the same component in liquid phase.

When there are changes in pressure or temperature, the equilibrium phases change their molecular composition (some components are more "volatile" than others). Therefore, despite its name, the vapour-liquid equilibrium constants are really a function of pressure and temperature at which equilibrium is established (and naturally of the composition of hydrocarbon), and are defined over the entire range of pressures and temperatures at which the two phases can coexist in equilibrium. The set of curves of equilibrium constants associated with the components of a hydrocarbon, for a fixed temperature can be plotted as a function of pressure and typically takes the form of **Figure 1**. As can be seen, all the curves converge to the unit for a given pressure. This value is defined as the Convergence Pressure and its equivalent to Critical Pressure when we work at Critical Temperature. Hydrocarbon convergence pressure depends on its molecular composition and on the temperature to which it is subjected (the temperature at which the phase equilibrium is established).

If, for a given temperature, the complete set of equilibrium constants curves as a function of pressure for all the components of a hydrocarbon mixture it is known, it is possible to predict thermodynamic behaviour (PVT) thereof. The equilibrium constants based thermodynamic simulators use this concept in the calculation and adjustment of the thermodynamic properties.

Most of the commercial thermodynamic simulators are based on equations of state (Peng Robinson, SRK, etc.). In order for these simulators describe adequately the thermodynamic behaviour of a hydrocarbon in particular, is necessary to adjust the coefficients of the equation of state being used. Similarly, simulators based on equilibrium constants, "fit" by modifying the shape of the set of curves of the equilibrium constants for the hydrocarbon components. In this study, we used a compositional simulator developed at Inlab SA (www.inlab.com.ar) that it's based on equilibrium constants. This simulator it's based on a simple parameterisation of the equilibrium constants set of curves published for the NGAA², corrected using a great number of experimental results obtained in the laboratory. The control parameter of this simple parameterisation is the convergence pressure. So the simulator used, is adjusted to experimental thermodynamic behaviour, finding the value of convergence pressure corresponding to the sample under study, at the test temperature.

Is worth mentioning that, for this particular development, we have used a simplified version of our multi-parametric simulator that we use commonly in our simulation studies, in order to generate adjustments dependent only on convergence pressure. As result of this simplification we obtained a tool less "flexible" but much more robust and reproducible for generic calculations. During sensitivity studies we found that this simple tool introduced much less dispersion of results that the uncertainty associated with the information (GOR or P saturation).

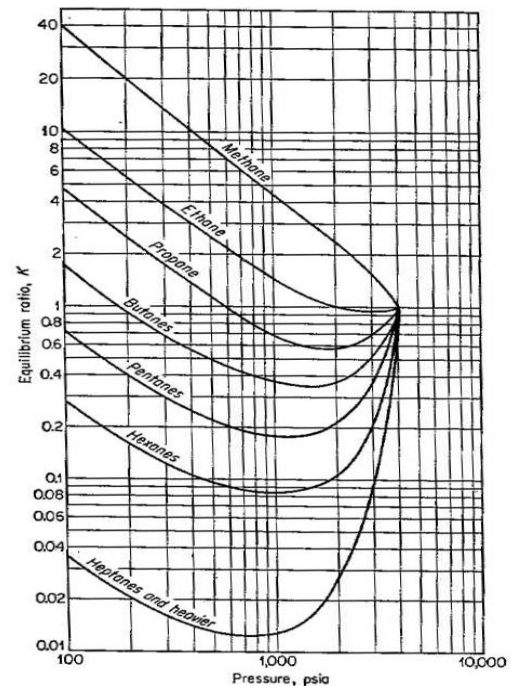


Figure 1: Hydrocarbon equilibrium constants¹

Basics

When PVT studies are performed on black oil samples, especially when studying samples with low gas content, bubble pressure of reservoir fluid, at reservoir temperature, is usually far below the convergence pressure of the sample. Therefore, in these cases, all vapour-liquid equilibrium involved in PVT test and studied in the simulator by equilibrium constants, are established at low pressures compared with the convergence pressure.

As shown in **Figure 2**, for low pressures relative to the convergence pressure, the shape of the equilibrium constants curves is slightly dependent upon the value of convergence pressure. Under these conditions, the thermodynamic behaviour of the sample is "slightly dependent" of the convergence pressure value and the thermodynamic behaviour can be acceptably predicted using a single fixed value for the convergence pressure. In this development we have found that a convergence pressure near to 5,000 psia proved to be adequate to characterize the extensive database with which we have worked. Therefore, in cases where the fluid under study has the characteristics detailed, the "pre-set" simulator with that convergence pressure value is adequate to predict thermodynamic behaviour. In other words, we can acceptably predict the thermodynamic behaviour without adjusting the simulator for each particular case.

Pre-setting the calculation tool

As mentioned above, to apply this technique is necessary to know the approximate bubble pressure of the fluid in the reservoir, or the GOR of it. In fact, this is the variable that allows us to estimate the gas volume which is necessary to recombine with atmospheric oil to predict thermodynamic behaviour of the original reservoir fluid.

It is also necessary to count with a pre-adjusted thermodynamic simulator. The pre-setting of the simulator is a critical piece in this technique, since it is this which establishes a biunivocal correspondence between: mole fraction of gas / liquid to be recombined (molecular composition of reservoir fluid), and bubble pressure at reservoir temperature or separator GOR specified.

In order to obtain the pre-adjustment of the simulator we worked with 35 conventional experimental PVT tests performed on black oil samples, bottom hole or surface, with less than 150 m³/m³ of GOR.

For each of the 35 samples:

- The thermodynamic parameters reported in the experimental PVT reports were loaded into the thermodynamic simulator
- Thermodynamic simulator was adjusted using the best adjust criterion to reproduce the experimental results.
- We recorded the corresponding convergence pressure value.

Then, the average convergence pressure was calculated between the 35 values obtained from the adjustment of each experimental PVT study, resulting in a value that will remain fixed for all the simulations involved in the technique. In summary, this average value is what enables to use a simulator that doesn't require additional adjustments for each particular case.

As a preliminary analysis, and in order to analyze the representativeness of the results obtained with the technique, we apply it to the 35 samples, proceeding in each case as follows:

- We took, from each PVT report, the molecular composition of atmospheric gas and oil obtained from the atmospheric flash separation test of the reservoir fluid to determine its composition. Although these fluids are not formally equivalent to those that we obtain at manifold or wellhead samplings, those are a good representation of these.
- We also considered the bubble pressure as known. In the practical application of the technique, this value, or the surface GOR, will be provided by the specialist interested in characterizing the reservoir fluid.

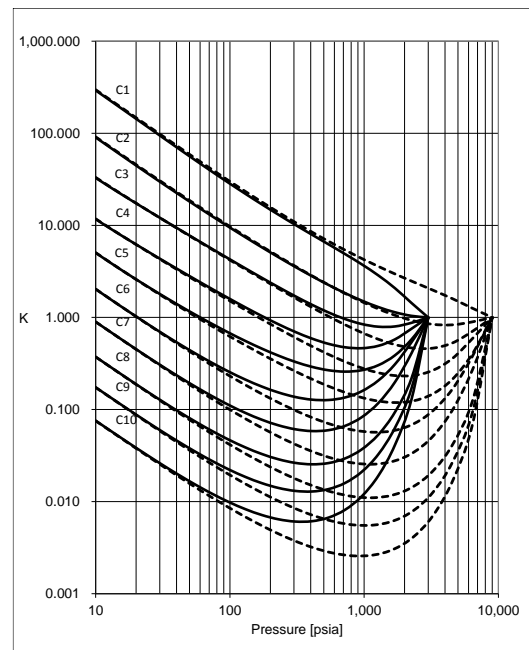


Figure 2: Comparison of equilibrium constants curves for $P_{conv} = 3,000$ psia and $P_{conv} = 9,000$ psia (generated with the thermodynamic simulator developed at Inlab S.A.)

- Using the pre-set thermodynamic simulator, we calculated the proportions of atmospheric oil and gas to recombine numerically to match the bubble pressure predicted by the pre-set simulator with the experimental bubble pressure. It should be noted that the reservoir fluid composition thus estimated is not exactly equal to the composition of reservoir fluid experimentally determined, since the proportions of gas and liquid numerically recombined are not determined using a flash separation test of a sample reservoir fluid, but it is estimated using the pre-set thermodynamic simulator.
- Once the reservoir fluid composition was estimated, all the thermodynamics parameters included in a standard PVT report were simulated using the pre-set simulator.
- The curve of viscosity versus pressure at reservoir temperature for the differential liberation test was constructed using Beal³ correlations for saturated and undersaturated oil, and using, for the viscosity of the oil at atmospheric pressure, the experimentally determined value for each PVT test. In this process we have extracted this value from the PVT reports because, by having the atmospheric oil sample obtained in the container, is contemplated in the technique the possibility of making all the standard experimental measurements on the atmospheric oil, including the viscosity vs. temperature curve. The alternative was to correlate the viscosity with the oil API or density, but this technique is not very suitable for many Argentines oils.

Figures 3 to 6 show the comparative crossplots between experimental PVT values reported on each case, and the values predicted by the Semi-Synthetic PVT technique for most representative thermodynamic parameters at bubble pressure.

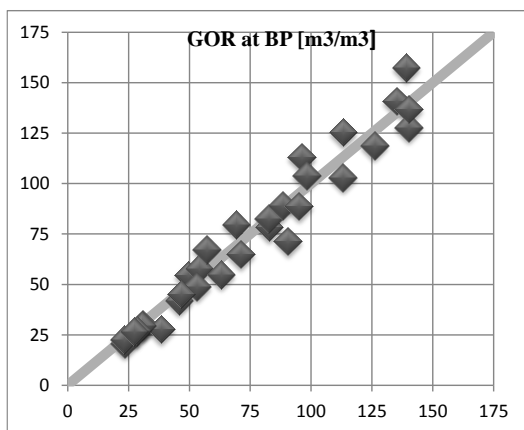


Figure 3: Crossplot of dissolved gas volume (GOR) at bubble pressure from differential liberation test. Experimental values from PVT reports vs values obtained with semi-Synthetic PVT technique.

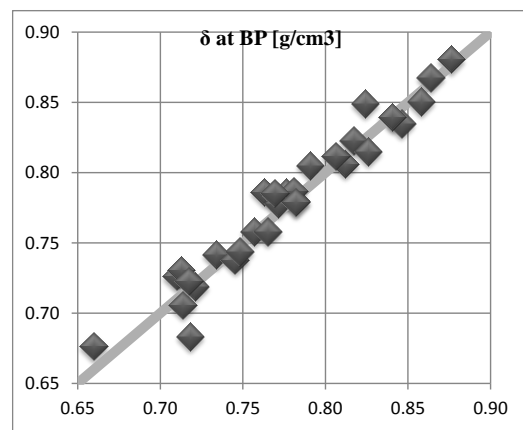


Figure 4: Crossplot of oil density (δ) at bubble pressure from differential liberation test. Experimental values from PVT reports vs values obtained with semi-Synthetic PVT technique.

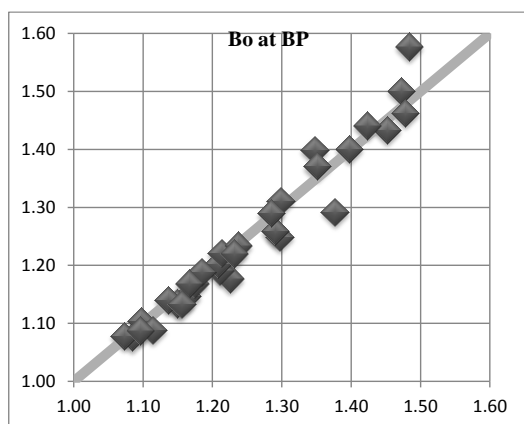


Figure 5: Crossplot of oil volume factor (B_o) at bubble pressure from differential liberation test. Experimental values from PVT reports vs values obtained with semi-Synthetic PVT technique.

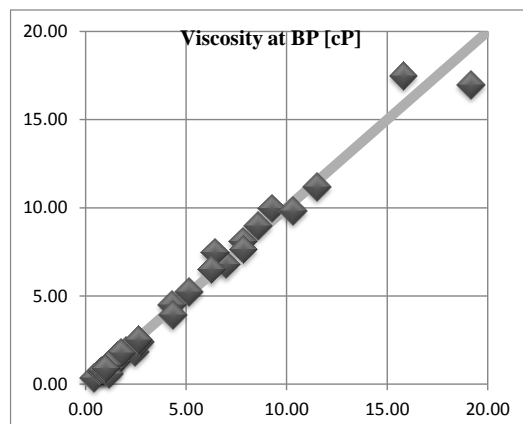


Figure 6: Crossplot of oil viscosity at bubble pressure from differential liberation test. Experimental values from PVT reports vs values obtained with semi-Synthetic PVT technique.

Pilot study

In April 2012, leveraging opportunity of a bottom hole sampling performed by the company Sinopec, with whom we have been working on similar technical developments (eg (4)), it was agreed to test the PVT semi-synthetic technique. The test was designed with the aim of comparing the results obtained in a conventional PVT study of a bottom hole sample with those obtained applying the semi-Synthetic PVT technique to a sample obtained during a swabbing test of the same oil.

For this purpose we selected a well of the *Mina del Carmen* formation, located in the *Golfo de San Jorge* basin, from which a bottom hole sample was taken for a conventional PVT experimental study. Sampling for semi-Synthetic PVT study was conducted from the manifold during swabbing test of the layer, prior to the closing of the well for pressure stabilization and subsequent bottom hole sampling. It is interesting to note that such sampling, done directly from the manifold, did not involve any delay in workover operations, which continued its course normally.

Upon arrival of samples to the laboratory, we worked as follows:

On the bottom hole sample:

- A conventional PVT experimental test.

On the swabbing test sample:

- The molecular composition of gas trapped in the upper chamber of the container was determined chromatographically. At the sampling moment that gas was trapped on the oil foam, then it was released from it within the vessel as the gas phase remaining in equilibrium with atmospheric oil.
- We determined the atmospheric oil composition. By chromatography and determining the C20 + fraction by distillation.
- Average molecular weight and density of atmospheric oil and the distillation residue (fraction C20 +) was determined.
- Curve of atmospheric oil viscosity versus temperature was measured.

Following the steps detailed in previous statistical analysis, we used pre-adjusted thermodynamic simulator to calculate the proportions of gas and liquid to numerically recombine in order to obtain a fluid whose bubble pressure (calculated using the same adjustment of the simulator) match the experimentally determined bubble pressure on the bottom hole sample determined on the experimental PVT test. The molecular composition obtained from such numerical recombination is the reservoir fluid composition estimated by the technique.

All standard PVT tests were simulated using the pre-set thermodynamic simulator and viscosity curve for differential liberation test were constructed based on the viscosity of atmospheric oil at reservoir temperature experimentally determined and using Beal correlations for saturated and undersaturated oil (using as input the volume of gas released at each stage calculated in the simulation).

Once all the thermodynamic parameters were estimated by semi-Synthetic PVT technique, we compared that with the experimental results of the PVT test performed on the bottom hole sample. In **Figures 7 a 11** can be observed the comparison for most relevant thermodynamic parameters:

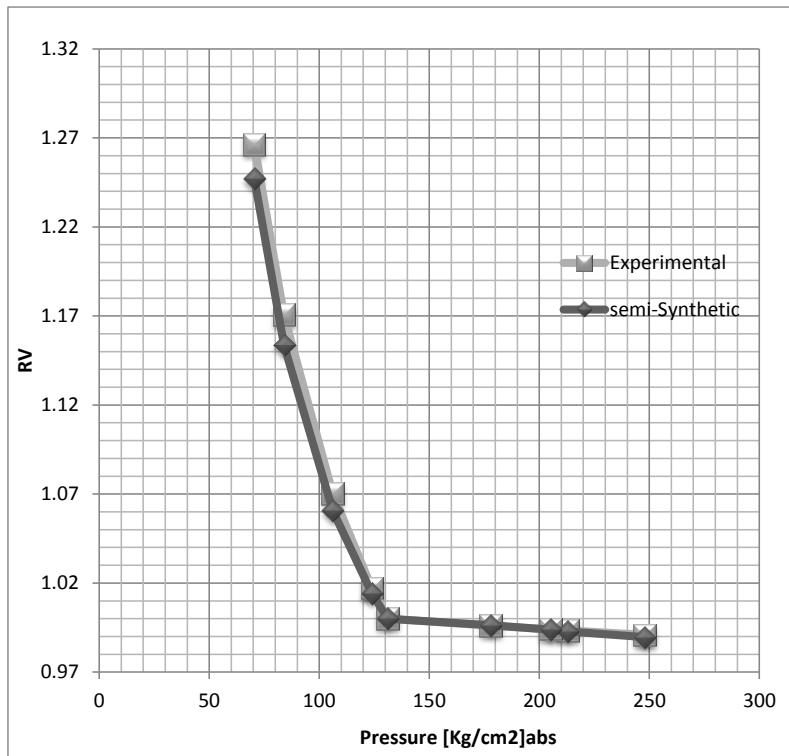


Figure 7: Relative Volume Comparison on the CCE test.
Experimental results obtained on the bottom hole sample and values estimated with semi-Synthetic PVT technique on the swabbing test sample.

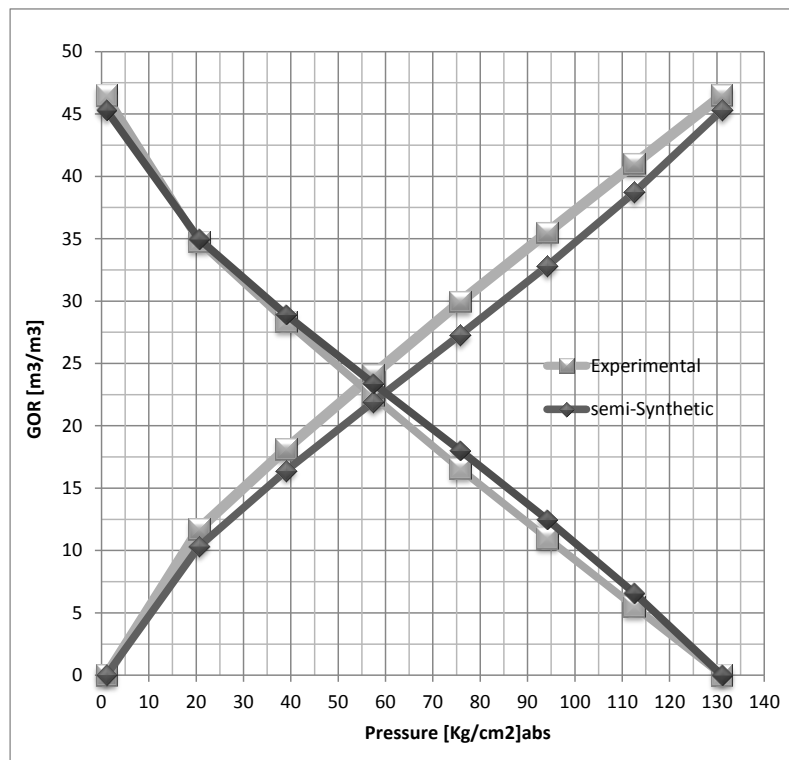


Figure 8: Comparison of Dissolved and Liberated Gas on the Differential Liberation test.
Experimental results obtained on the bottom hole sample and values estimated with semi-Synthetic PVT technique on the swabbing test sample.

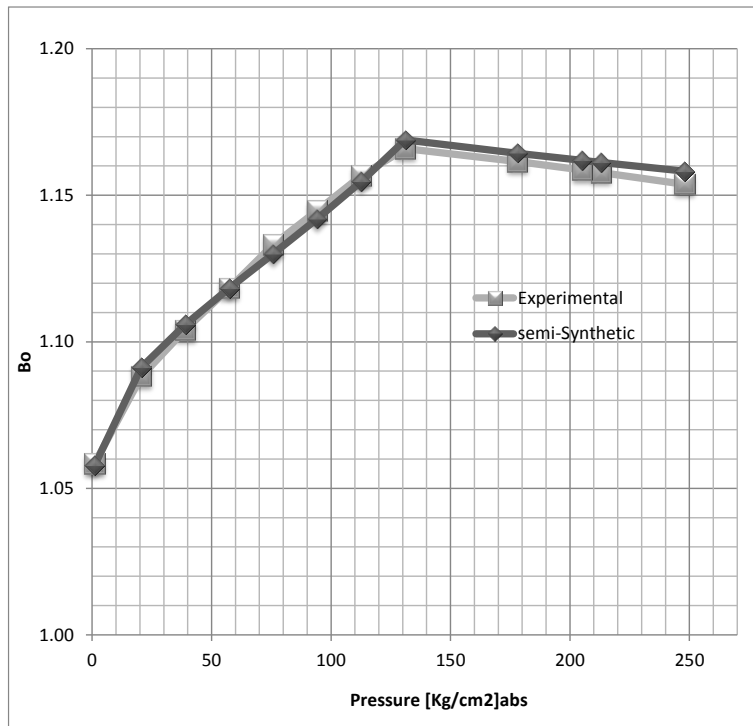


Figure 9: Comparison of Oil Volume Factor on the Differential Liberation test. Experimental results obtained on the bottom hole sample and values estimated with semi-Synthetic PVT technique on the swabbing test sample.

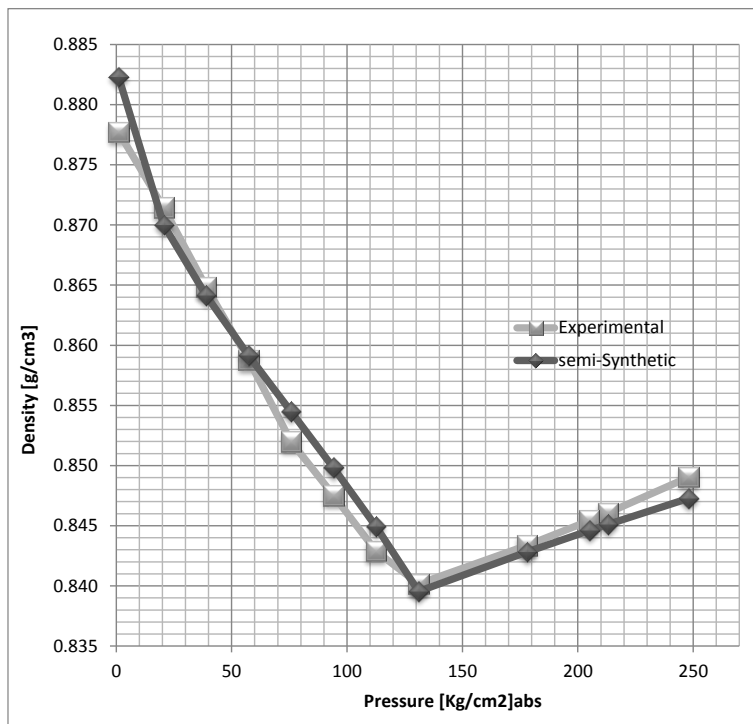


Figure 10: Comparison of Oil Density on the Differential Liberation test. Experimental results obtained on the bottom hole sample and values estimated with semi-Synthetic PVT technique on the swabbing test sample.

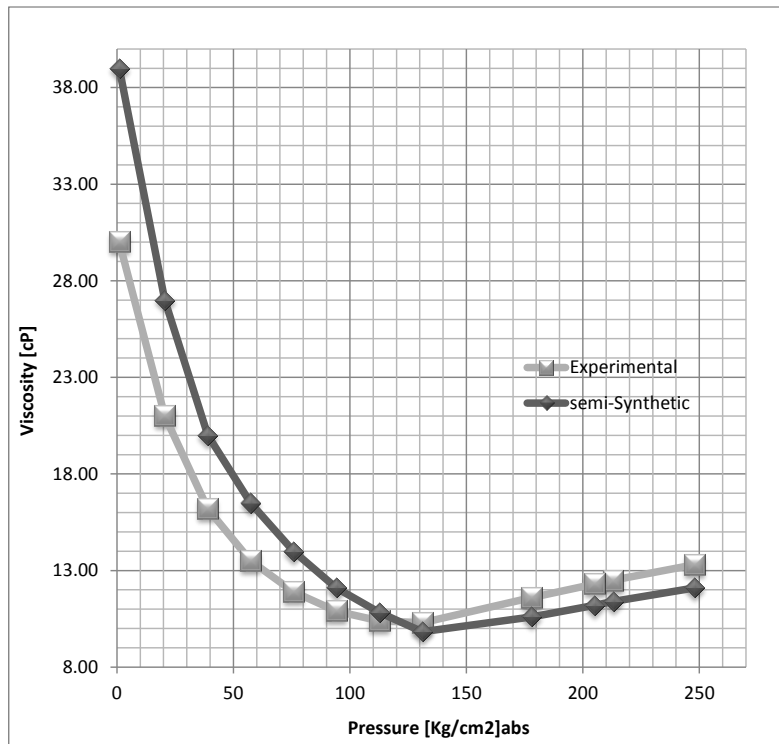


Figure 11: Comparison of Oil Viscosity on the Differential Liberation test. Experimental results obtained on the bottom hole sample and values estimated with semi-Synthetic PVT technique on the swabbing test sample.

Sensitivity Analysis

As mentioned throughout the work, in order to estimate the thermodynamic behaviour of reservoir fluid from a wellhead sample, applying semi-Synthetic PVT technique, it is necessary to know the approximate value of the bubble pressure of reservoir fluid or, alternatively, the initial production GOR. Therefore, it is necessary to determine how sensitive are the estimates on possible deviations of these parameters of the actual value.

In order to perform the sensitivity analysis of the results with respect to the value of fixed bubble pressure, we repeated the analysis conducted in the pilot test using for all calculations (numerical recombination of gas and liquid to estimate the reservoir fluid composition, all thermodynamic simulation of thermodynamic parameters, construction of the viscosity curve, etc.), a bubble pressure 10, and 20 kg/cm² lower, and 10, and 20 kg/cm² higher than that determined in the experimental PVT study.

In **Table 1** below can be seen variations on the composition of the reservoir fluid estimated with the technique on the swabbing test sample using the different bubble pressures for the calculation of recombination.

		Molecular Compositions estimated with semi-Synthetic PVT technique using:					
		Reservoir Fluid	Exp. BP	Exp. BP	Exp. BP	Exp. BP	Exp. BP
		Exp. Molecular	- 20 kg/cm2	- 10 kg/cm2	Exp. BP	+10 kg/cm2	+ 20 kg/cm2
		Composition					
Component		[% Molar]	[% Molar]	[% Molar]	[% Molar]	[% Molar]	[% Molar]
N ₂	Nitrogen	0.291	0.403	0.431	0.459	0.487	0.515
CO ₂	Carbon Dioxide	0.943	1.372	1.468	1.564	1.659	1.754
C ₁	Methane	30.340	26.530	28.394	30.242	32.080	33.911
C ₂	Ethane	5.734	6.059	6.472	6.882	7.289	7.695
C ₃	Propane	3.457	3.143	3.330	3.516	3.700	3.884
iC ₄	i-Butane	0.780	0.622	0.649	0.675	0.701	0.727
nC ₄	n-Butane	2.056	1.385	1.428	1.471	1.513	1.556
iC ₅	i-Pentane	0.898	0.589	0.591	0.593	0.595	0.598
nC ₅	n-Pentane	1.781	1.144	1.139	1.135	1.131	1.126
C ₆	Hexanes	3.103	2.322	2.251	2.182	2.112	2.043
C ₇	Heptanes	3.690	2.611	2.511	2.411	2.312	2.213
C ₈	Octanes	3.389	3.308	3.163	3.019	2.875	2.733
C ₉	Nonanes	2.934	2.787	2.662	2.537	2.413	2.290
C ₁₀	Decanes	2.218	2.229	2.127	2.026	1.925	1.824
C ₁₁	Undecanes	2.006	1.993	1.901	1.809	1.718	1.627
C ₁₂	Dodecanes	1.958	1.934	1.844	1.755	1.667	1.578
C ₁₃	Tridecanes	2.307	2.291	2.185	2.079	1.974	1.870
C ₁₄	Tetradecanes	2.096	2.132	2.033	1.935	1.838	1.740
C ₁₅	Pentadecanes	2.149	2.149	2.049	1.950	1.852	1.754
C ₁₆	Hexadecanes	1.907	1.937	1.847	1.758	1.670	1.581
C ₁₇	Heptadecanes	1.735	1.737	1.656	1.576	1.497	1.417
C ₁₈	Octadecanes	1.783	1.774	1.691	1.610	1.529	1.448
C ₁₉	Nonadecanes	1.703	1.712	1.632	1.554	1.475	1.397
C ₂₀₊	Eicosanes Plus	20.744	27.836	26.544	25.263	23.989	22.719
Total :		100.000	100.000	100.000	100.000	100.000	100.000

Table 1: Experimental and estimated with semi-Synthetic PVT technique molecular compositions for different bubble pressures analyzed.

Furthermore, in *Figures 12 to 15* we present a comparison between the experimental, and estimates by the semi-Synthetic PVT technique results using the different bubble pressures. It shows the comparison of the parameters: Rs (dissolved gas), Bo (oil volume factor) δ (oil density) and oil viscosity on Differential Liberation test in each case.

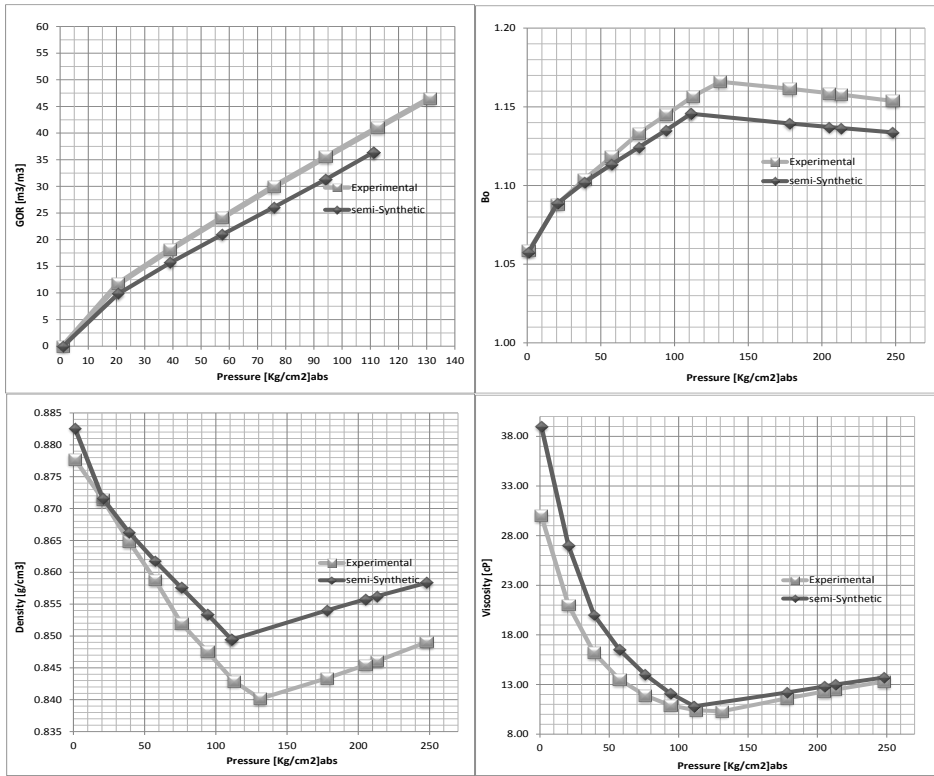


Figure 12: Sensitivity analysis. Comparison of the main thermodynamic parameters from Differential Liberation Test. Experimental results obtained on the bottom hole sample and values estimated with semi-Synthetic PVT technique on the swabbing test sample with a bubble pressure 20kg/cm² less than the experimental one.

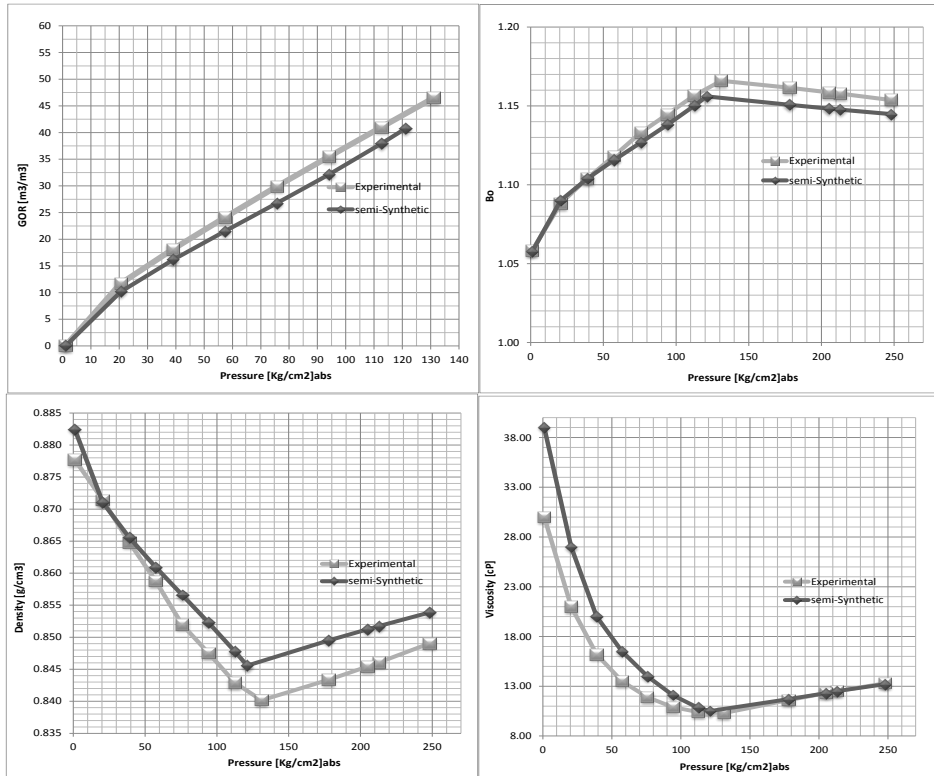


Figure 13: Sensitivity analysis. Comparison of the main thermodynamic parameters from Differential Liberation Test. Experimental results obtained on the bottom hole sample and values estimated with semi-Synthetic PVT technique on the swabbing test sample with a bubble pressure 10kg/cm² less than the experimental one.

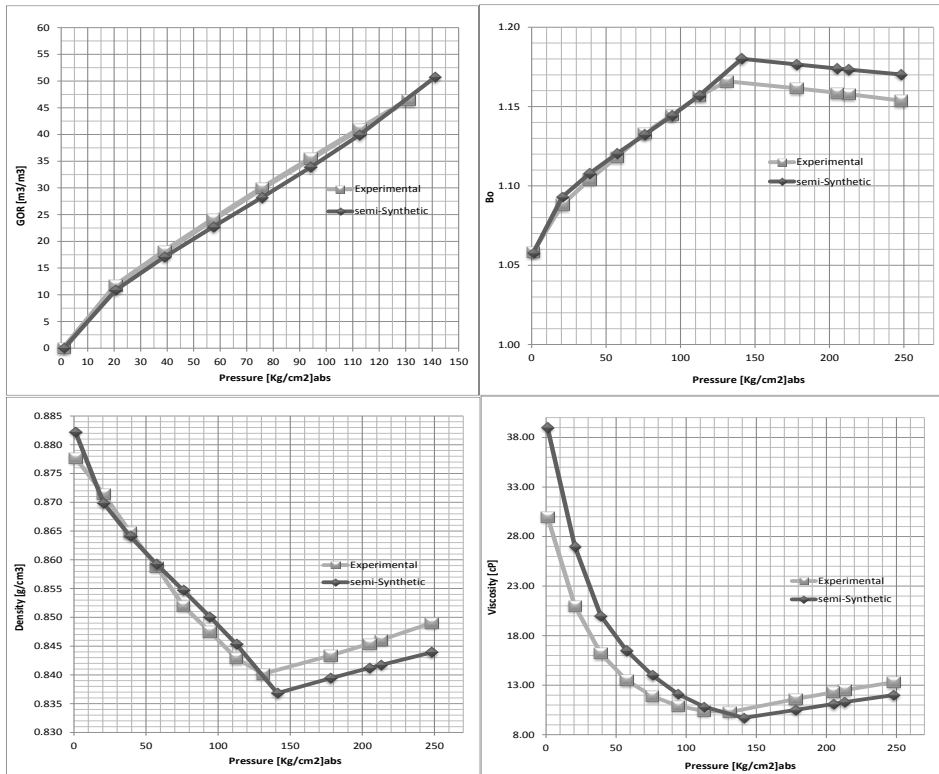


Figure 14: Sensitivity analysis. Comparison of the main thermodynamic parameters from Differential Liberation Test. Experimental results obtained on the bottom hole sample and values estimated with semi-Synthetic PVT technique on the swabbing test sample with a bubble pressure 10kg/cm² higher than the experimental one.

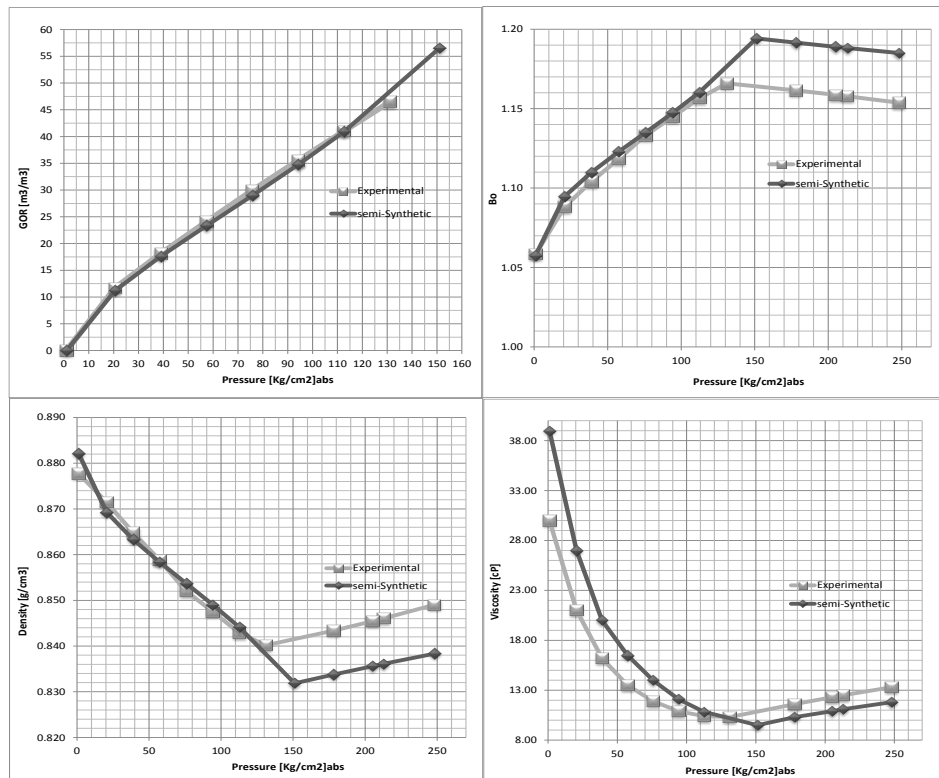


Figure 15: Sensitivity analysis. Comparison of the main thermodynamic parameters from Differential Liberation Test. Experimental results obtained on the bottom hole sample and values estimated with semi-Synthetic PVT technique on the swabbing test sample with a bubble pressure 10kg/cm² higher than the experimental one.

This sensitivity study shows that, despite the obvious dependence on PVT parameters with saturation pressure, the general trends of the most significant curves remain constant. Thus, it appears that the ability of this tool to model the reservoir fluid properties, is less dependent on auxiliary parameters (saturation pressure or GOR) than the sampling and thermodynamic simulation with pre-set simulator.

Extension of the technique to oils with higher GORs

The limit on the max GOR established for oils that we consider suitable to be treated with this technique is due mainly to two reasons. The first, and less important, is that the oils with more dissolved gas often have higher convergence pressures, and therefore the pre-set simulator are less representative as the GOR increases. The second is the fundamental reason and it is associated with the viscosity of oils. Although there are exceptions, oils with moderate GOR usually have higher viscosities than those with lighter oils higher GOR. The oil viscosity is an extremely important factor when making the sampling on the manifold. At the time of obtaining the sample during swabbing test, oil reaches the manifold as foam, with some associated gas retained therein. When the foam remains time within the vessel, the emulsion breaks and the final result is two separate phases, gas and liquid in equilibrium inside. The representativeness of the sampled gas is closely related to the viscosity of the oil. Higher viscosity oil goes with a greater stability of the emulsion, and a lower possibility of fractioning of the gas phase, derived from the escape of light components of the gas from the foam.

As result, in the case of higher viscosity oils, we obtain within the container a gas whose composition is closer to the composition of the "complete" gas associated with the oil (substantially equivalent to the composition of the gas that would result from a flash separation test at atmospheric pressure of the reservoir fluid). In the case of less viscous oils a part of the light components of oil escape from the foam before the sample reach the surface resulting, the foam gas, a gas significantly heavier than the "complete" gas associated with the oil. Although the technique was developed specifically for low GOR oils, generally more viscous, it is possible to extend the scope to lighter oils if, besides the foam sample of oil, it is possible to sample the "free" gas stream that reaches surface.

As evidence of this possibility, we performed a test of the technique sampling on wellhead, in a surging oil well of a "shale oil" horizon in *Vaca Muerta* formation. In this case, we took a sample of oil "foam" in a sampling point prior to the orifice and a sample of the "free" gas stream in another location after the orifice. The gases obtained in both cases showed distinctly different molecular compositions. Then, applying certain criteria, numerical recombination was performed in two stages between oil and both atmospheric gases, using the pre-set simulator. The estimates obtained were consistent with production data, but results are not presented in the body of this work because it has not yet performed the experimental PVT test on the oil of that horizon, therefore, we have no results to compare. However, this initial experience suggests that it is possible to extend the methodology to situations not originally contemplated.

As future development we plan to work with what we call "selective escape curve" of the gas components from the oil foam sampled. In other words, we seek to achieve a better estimate of the "complete" gas composition analyzing the gas trapped in the oil foam at the sampling, considering certain oil and reservoir properties. The ultimate goal is to extend the technique to lighter oils without applying different sampling or complex recombination that require choosing and applying certain additional criteria.

Conclusions

Observing crossplots obtained during the pre-setting of the technique we can conclude, first, that using a unique adjustment of the thermodynamic simulator is possible to estimate reasonably well the behaviour of a variety of black oils with moderate GORs (less than 150 m³/m³) based on the molecular compositions of gas and liquid obtained on the atmospheric flash separation test of the reservoir fluid. Highlight the good fitting achieved for the viscosity values of bubble pressure, taking into account that this is a thermodynamic parameter especially difficult to correlate or simulate. As mentioned above, the good approximation achieved in viscosity is due to the technique provides experimental measurement of atmospheric oil viscosity. This relieves us of using correlations to estimate the viscosity of dead oil, avoiding large errors associated with them.

Concerning the pilot test, there are several points to note:

- The swabbing test sample for the semi-Synthetic PVT study was obtained by INLAB staff. As mentioned, the sample was extracted directly from the manifold during the last race of swabbing test of the studied layer before closing the well for stabilization and bottom hole sampling. The procedure was extremely simple, fast, economical (low cost of the sampling bottles), and completely independent of the tasks performed by workover team, who practically doesn't realized our

operations. Therefore we think that, with a minimum of instructive material, workover operations staff itself can successfully perform this operation.

- Representativeness of the estimates using the technique can be seen with the naked eye in **Figures 7 to 10**, where they are compared with the results obtained in the experimental PVT test. Particularly in the case of the viscosity (**Figure 10**), we note some deviation in the values at atmospheric pressure (approx. 9 cp). This difference is not generated by the calculation methodology since both are experimental values (in semi-Synthetic PVT, atmospheric oil viscosity is also an experimentally measured value). Previous races of the swabbing test of the same layer were sampled too and viscosities of atmospheric oils presented variations from sample to sample. This important variation of viscosity suggests some heterogeneity on the fluids of the sampled layer (scenario already observed in the *Golfo de San Jorge* basin). In these cases, the uncertainty in the representative value of viscosity is transferred to the PVT sample itself (the bottom hole sample itself) and should be taken as a feature of some accumulations and not as a limitation of the technique presented in this study.

Regarding the sensitivity analysis we highlight the following points:

- Concerning the dependence of thermodynamic parameters estimated using the different bubble pressures, shown in **Figures 11 to 14** which, as we expected, main changes occur in parameter values at bubble pressure and in the single phase region obtaining the best fit when bubble pressure used is equal to the "real" one. However it should be noted that in all cases, the estimated behaviour for pressures below the bubble pressure has minor variations with changes in the bubble pressure and remains reasonably representative.
- The previous point suggests that the technique can be applied even in cases where the bubble pressure (or alternatively, the GOR) is not known too precisely. Is possible to perform all calculations using an estimated value of the bubble pressure or GOR, and then, if it is desired to correct the bubble pressure value, correct single phase behaviour by extrapolating the values of the curves to the "new" pressure bubble and, from the new value of the parameter at bubble pressure, keeping the single phase area trends for higher pressures.

In general the studies show that, in the case of black oil reservoirs with moderate GOR is possible to estimate the thermodynamic behaviour of the reservoir fluid with reasonable representativeness from a sample obtained during swabbing tests, or in wellhead (in the case of completed wells). Since the semi-Synthetic PVT study involves fewer laboratory tests than a conventional PVT, has virtually no costs associated sampling, and doesn't implies workover operations or production delays, the technique opens up the possibility of having reasonably reliable thermodynamic information in scenarios in which a conventional PVT test are not normally performed.

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