Experimental and Simulation Constructing of Phase Diagram and Quality Lines for a Lean Gas Condensate Reservoir Fluid

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ABSTRACT: *Constructing phase diagram and its subsequent quality lines for lean gas condensate reservoirs is always crucial and challenging topic in reservoir fluid studies. Due to small amounts of liquid drop-outs in lean gas condensates at reservoir conditions, full experimental tracking of phase diagram and its relevant quality lines is almost impossible for lean gas condensates. On the other hand, EOS models of reservoir fluid characterization softwares are always unable to estimate condensed liquid drop-outs at different pressures and temperatures precisely. This study aims to present a commingled experimental-simulation method which was designed to pinpoint and keep track full phase diagram with correspondent quality lines for a lean gas condensate fluid.*

KEY WORDS: *Phase diagram, Quality line, Gas condensate fluid; Constant Composition Expansion,*

INTRODUCTION

Phase diagrams of hydrocarbon systems always depict phase behaviour of hydrocarbon fluid systems at different pressure and temperature [1]. The main borderline of phase diagram always separate two phase conditions from monophasic criteria. In other words, pressure and temperature conjugates inside the phase diagram correspond to two phase flow region and contour lines in this area are so called quality lines which are drawn to show liquid drop quantities at different pressure and temperature [2].

The critical Point in a phase diagram is an indicator to show the type of fluid. In a gas condensate reservoir, the initial reservoir condition is in the single phase area to the right of the critical point in phase diagram. As reservoir pressure declines, the fluid passes through the dew point and a liquid phase drops out of the gas. The percentage of vapour decreases, but can increase again with continued pressure decline. Presence of heavier components (C4-C7+) expands the phase envelope, so that the reservoir temperature lies between the critical point and cricondentherm in gas condensate reservoirs. Fig. 1 shows the typical phase diagram of gas condensate reservoir fluid.

As a reservoir produced, formation temperature usually doesn't change, but reservoir pressure decreases.

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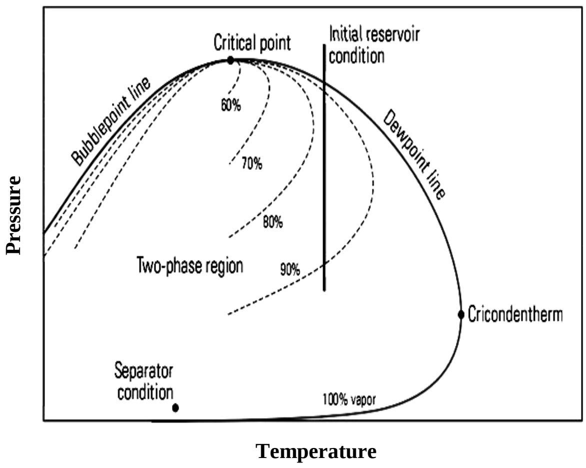

Fig. 1: Typical phase diagram of gas condensate reservoir fluid [3].

When the pressure in a gas condensate reservoir decreases to dew point pressure, a liquid phase rich in heavy ends drops out of solution; the gas phase is slightly depleted of heavy ends. As shown in Fig. 1, a continued decrease in pressures the volume of the liquid phase up to a maximum amount, liquid volume then decreases. When pressure decreases at reservoir temperature, a rich gas forms a higher percentage of liquid than a lean gas. This behaviour can be displayed in a Pressure Volume Temperature (PVT) diagram. Typically a gas condensate system yields from about 30 bbl of condensate per MMscf of gas for lean gas condensate to 300 bbl of condensate per MMscf of gas for rich gas condensate [3].

One of the most important steps in better performance prediction of gas condensate reservoirs is accurate phase behaviour modelling. The phase behaviour of gas condensate mixtures has been extensively studied and reported in literature [4,7]. However, depicting phase diagrams to show phase behaviour, with correspondent quality lines for very high lean gas condensate reservoir fluids is really cumbersome and time-consuming [8].

This study attempts to present a study based on an experimental-simulation method in order to keep track most viewed quality lines inside a phase diagram.

EXPERIMENTAL SECTION

Experimental procedure

In order to generate some experimental data, PVT experiments were designed and considered. In PVT lab, different pressure depletion tests are designed and performed in order to monitor thermodynamic properties changes respect to reservoir pressure declination inspired by production scenarios. Each experiment should mimic some real phenomena of reservoir production. Constant Composition Expansion (CCE) or Constant Mass Expansion (CME) test is carried out in virtually all PVT studies irrespective of fluid type. To do so, fixed amount of monophasic subsurface sample or recombined surface sample is transferred into the PVT cell and brought to reservoir temperature and a pressure above the reported initial reservoir pressure. After that, pressure is declined gradually and then fixed in some pre-designed pressure steps and some fluid parameters such as liquid condensate volume, gas volume, compressibility and densities are recorded very precisely for each pressure step manually or automatically. The number of pressure reduction steps and the total pressure range covered is generally determined by consultation between the Engineer who commissions the study and the laboratory personnel. For a black oil or volatile oil, the transition from single to a two-phase System is apparent in the plot. For gas condensates the separation of the liquid phase is not readily apparent from the experimental volumetric data and it must be determined visually. It should be remind that this process is started from one phase condition of real gas condensate sample and phase changes continuously recorded by taking some snapshots from inside the PVT cell periodically. Dew point pressure is one of the most important output parameters of CCE experiment. Dew point pressure is measured by looking inside the PVT cell during pressure depletion process in conventional PVT cells or interpreting recorded pictures during CCE experiment in modern PVT cells. The CME experiment may also be carried out at other temperatures in addition to the reservoir temperature to help model the producing conditions for subsequent process calculations.

As mention above first of all, saturation pressure test was done at pre-defined temperatures so that borderline of the phase diagram could be kept tracked and pinpointed very precisely. Measuring dew point pressure at each temperature led to find a conjugate of pressure and temperature and after finishing of dew point pressure tests, a bunch of pressure and temperature conjugates were obtained.

Table 1 shows the components of reservoir fluid in which the C7+ molar mass in this sample is about 111.9 g/mol.

The cricondentherm and cricondenbar points of this sample were measured about 305ºF and 3420 psia respectively.

Finally all the saturation pressure data were inserted in reservoir fluid simulation software and borderline of the phase diagram were continuously drawn using a well-known reservoir fluid simulator.

Second part of the PVT experiments was allocated to measure experimental data needed for generating quality lines. Hence, some constant composition expansion or CCE experiments were designed and done at pre-defined temperatures. Briefly, CCE experiments is done in order to monitor thermodynamic parameter changes i.e. condensed liquid drop-outs due to pressure depletion process. To do so, CCE experiments were done at five different temperatures and the results showed condensed liquid volumes respect to pressure changes at each predefined temperature.

A magnified snapshot of a typical liquid drop-out formation through CCE experiment has been shown in Fig. 2. The results of the CCE experiments were used to generate candidate quality lines. it should be noted that the experimental set up to do PVT tests in this study was designed and developed in DBR-Canada in 2005 which is shown in Fig. 3 and all the experimental parts have been calibrated in accompany with DBR experts. It should be remind that calibration tests have been periodically repeated by some skilful technician in lab and it can be claim that quality of all experimental data has been checked many times by teamwork members. This experimental set up is under commercial services for many important phase behavior studies projects for internal and international companies since 2005.

Simulation procedure

Winprop-CMG is a well-known reservoir simulator which is able to predict reservoir fluid phase behaviour based on PVT experimental data. The point is that using reservoir simulators without any precise experimental data is really useless. Therefore it was already tried to measure experimental data as accurate as possible [9].

To perform simulation procedure, CCE experimental data i.e. liquid drops-out volume versus pressure were

Table 1: Reservoir Fluid component

Component	Reservoir Fluid
N2	5.27
CO2	0.37
H2S	0.0005
C1	86.44
C2H6	4.36
C3	1.47
iC4	0.33
nC4	0.45
iC5	0.21
nC5	0.15
C6	0.22
C7+	0.73
Total	100.00

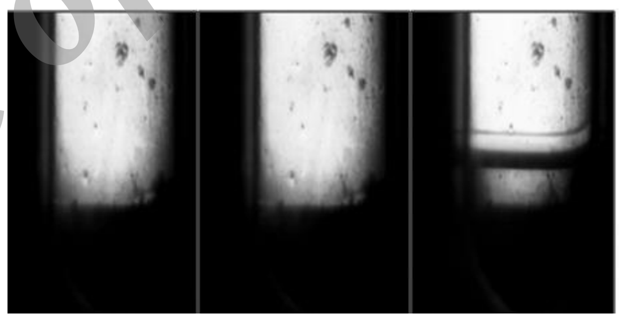

Fig. 2: Snapshot of liquid drop-out forming process for lean gas condensates.

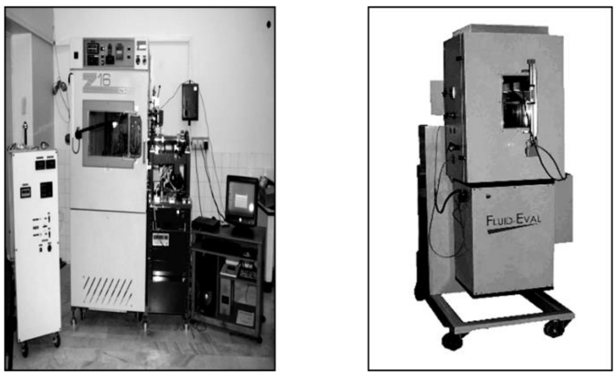

Fig. 3: PVT apparatus used in this study.

Table 2: 0.5% Vol. Liquid percent.

Pressure(psia)	Temperature(F)
560	15
560	40
580	72
680	104
1100	140
1400	152
1700	155
2950	15
3080	40
3150	72
3020	104
2600	140
2100	155

Table 3: 0.7% Vol. Liquid percent.

Pressure(psia)	Temperature(F)
760	15
760	40
780	72
950	104
1250	130
1600	140
1800	142
2750	15
2880	40
2900	72
2700	104
2400	130
2100	140

inserted in regression process of the software in order to tune an EOS for each reservoir fluid and after that some new liquid drop outs data versus pressure and temperature were generated. Hence, the number of reliable liquid drop-outs data versus pressure and temperature were increased considerably and there was possibility of experimental keep tracking of quality lines by interpolating and extrapolating between liquid drop data [10].

Construction of quality lines using experimental-simulation Procedure

The proposed method involved combination of experimental and simulation data to generate candidate quality lines. To do so, all volumetric liquid drop-outs percent of CCE experiments and simulation process were listed versus pressure and temperature. Finally pressure and temperature conjugates of the same volumetric liquid drop-out percents i.e. 0.5%, 0.7% and 1.3% were picked among all experimental and simulation data. To match the experimental data with simulation values, the Soave-Redlich-Kwong (SRK 1978) equation of state is used. The matching parameters to tune experimental and simulation data were selected as critical pressure (P_c), critical temperature (T_c), acentric factor and also volume shift factor.

Smoothed experimental and simulation data has been gathered in Tables 2, 3 and 4 and final construction of quality lines based on achieved experimental-simulation data has been depicted in Fig. 4.

RESULTS AND DISCUSSION

Tables 1, 2 and 3 include combination of experimental and simulation data for three important quality lines of the phase diagram and Fig. 3 depicts final construction of phase diagram simultaneous with three candidate quality lines. According to the Fig. 3, quality lines are really scattered inside the phase diagram since liquid drop volumes are really small in two phase region for lean gas condensate fluids. In this study three quality lines i.e. 0.5%, 0.7% and 1.3% volumetric percent were constructed using the proposed experimental-simulation method. Needless to say that other quality lines could be roughly interpolated or extrapolated using the available quality lines data.

The most important experimental observation of this study is that quality lines in lean gas condensates converge with each other at very low temperature and this temperature is somehow allegorical. In other words, critical points of these fluids could not be detected experimentally due to exclusive phase behaviour of gas condensate reservoir fluids and this only can be estimated by allegorical extrapolating of accessed quality lines.

Table4. 1.3% Vol. Liquid Percent

Pressure(psia)	Temperature(F)
1200	15
1200	40
1300	72
1550	104
1850	115
2400	15
2500	40
2430	72
2200	104

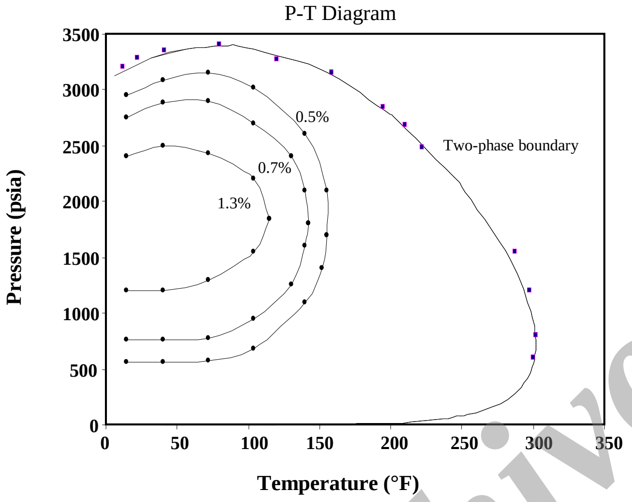

Fig. 4: Constructed full phase diagram with experimental volumetric quality lines.

CONCLUSION

Due to small amounts of liquid drop-outs in lean gas condensates at reservoir conditions, full experimental constructing of phase diagram and its relevant quality lines is almost impossible for lean gas condensates fluids. Also tuned EOS models of reservoir fluid softwares are often unable to estimate condensed liquid drop-outs at different pressures and temperatures for lean gas condensates. On the other hand, an efficient phase diagram reflects some of the most important production criteria i.e. operating pressure and temperature in surface facilities to achieve optimum production. Therefore the unique procedure introduced in this paper presents a reliable experimental procedure for constructing phase diagrams and correspondent quality lines for lean gas condensates. It should be remind that increasing the number of CCE experiments helps to increase the accuracy of quality lines tracks considerably since the numbers of experimental points are increased and interpolating between experimental points will be more accurate.

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Nomenclature

bbl	barrel
CCE	Constant Composition Expansion
EOS	Equation of State
MMscf	Billion standard cubic feet
P	Pressure (Psia)
T	Temperature (F)
V	Volume (cc)

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REFERENCES

[1] Shi Li, Kai Luo, Xitan Zheng, Gang Chen, Ning Liu, Wenyue Sun ; "Experimental Investigation into Revaporization of Retrograde Condensate", Society of Petroleum Engineering(*SPE*), 67283-MS:13-18 (2001).

[2] Fang,Yisheng. Li.Boazhu. Hu.Yongle. Sun.Zhidao. Zhu.Yuxin; "Condensate Gas Phase Behavior and Development", Society of Petroleum Engineering (SPE), 50925-MS:2-11 (1998).

[3] Li Fan, Billy Harris, A.(Jamal) Jamaluddn, Jairam Kamath, Robert Mott, Gray A.Pope, Alexander Shandrygin, Curtis Hays Whitson, "Understanding Gas-Condensate Reservoirs", *Oil Field Review*, Schlumberger; Winter (2005/2006).

[4] Ahmed T.H., "Comparative Study of Eight Equations of State for Predicting Hydrocarbon Volumetric Phase Behavior", *SPE Reservoir Engineering*. **3**:337–348 (1988).

[5] Sarkar R., Danesh A., Todd A.C., Phase Behavior Modelling of Gas Condensate Fluids Using An Equation of State, "SPE22714, 66th Annual Technical Conference and Exhibition of the SPE", Dallas, Texas, (1991).

[6] Wang P., Pope G.A., Sepehr noori K., Development of Equations of State for Gas Condensates for Compositional Petroleum Reservoir Simulation, *In Situ*, **24**: 183-217 (2000).

[7] Bang V., "Phase Behavior Study of Hydrocarbon-Water-Alcohol Mixtures", B.Sc.Thesis, Austin, Texas: The University of Texas at Austin, (2005).

[8] Kai Luo, Shi Li, Xitan Zheng, Henian Liu, Taixian Zhong, Yuxin Zhu, "Phase Behavior of Highly Waxy Gas Condensate Systems", Society of Petroleum Engineering (SPE), 68228 MS:6-14 (2001).

[9] Jawad Azeem-Shaikh. Pashupati Sah, "Experimental PVT Data Needed to Develop EOS Model for EOR Projects", Society of Petroleum Engineering (SPE), 144023-MS:17-33 (2011).

[10] Li. Yau-Kun,Nghiem, "The Development of a General Phase Envelope Construction Algorithm for Reservoir Fluid Studies", Society of Petroleum Engineering (SPE), 11198-MS:5-11 (1982).