Phase behaviour diagram for Complex Gas Condensate Reservoir

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Abstract :

In this report, the study on Gas Condensate Reservoir has been carried out as they are complex reservoirs so, different computational methods need to be implemented. The different parameters are estimated and compositional changes are observed. To mathematically obtain all these parameters such as repulsion factor, attraction factor, compressibility factor, etc. different Cubic Equations of State which include the Van der Waals Equation, Redlich-Kwong, Soave-Redlich and Peng Robinson are programmed in the IDE for CPP Programming language for which the code and the console-based calculations are mentioned in the report. The Peng-Robinson (1978) equation of state is used in this case study, and it is modified using regression to fit the PVT behaviour of a specific gas condensate reservoir fluid. Hydrocarbon analysis of separator products and constant composition expansion and constant volume depletion laboratory tests were used to get PVT data for the gas condensate reservoir fluid. The findings of the CCE and CVD tests were fed into a phase behaviour simulator for EOS characterization (CMG WinProp phase behaviour & fluid properties program). The programme creates an EOS model that can be used to simulate condensate fluid flow in a reservoir. EOS was validated using the mass balance test, Hoffman plot, and CCE/CVD (Constant composition expansion and Constant volume depletion) comparative plots. The layout of the CCE/CVD comparison plot revealed that in the CVD experiment, liquid dropout occurred later in the depletion process than in the CCE experiment. PVT tests aid in confirming the system's gas oil ratio and the richness of the gas condensate fluid. Obtaining representative reservoir fluid samples and conducting reliable laboratory tests to provide PVT data for reservoir characterisation and consistency checks ensures that accurate findings from reservoir simulation models are generated, leading to proper reservoir management.

1.INTRODUCTION

The relevance of gas-condensate reservoirs has continuously increased since the late 1930s. The engineering and operations methods necessary to create and run these reservoirs for maximum recovery differ significantly from those required to develop and operate crude-oil and dry-gas reservoirs. The presence of gas-condensate networks in ponds and reservoirs is the most remarkable aspect. The reservoir was wholly or mostly in the vapour phase when it was discovered. In an era of gas-based economies, where the world looks to natural gas as a source of energy, natural gas is the most environmentally friendly and cleanest fuel, emitting exceptionally low levels of carbon dioxide compared to other fuels like coal and oil. Gas condensate reservoirs come in a variety of sizes. In essence, they behave differently than regular gas reservoirs, and optimising hydrocarbon recovery needs extensive reservoir research, planning, and management. Gas condensates are currently routinely detected in reservoirs as single-phase gas at the time of discovery. Later on, I'll give a quick overview of compositional modelling for gas condensate reservoirs using EOS characterisation. Thermodynamic characteristics and phase behaviour are frequently predicted using equations of state (EOSs). Peng-Robinson (PR) and Soave-RedlichKwong (SRK) (Soave, 1972) (PR) Because of their reliability, the simplicity of their 12 Pressure-Volume-Temperature (PVT) relationships, and the relative ease with which thermodynamic functions such as enthalpy, entropy, and heat capacity may be stated, EOSs are more often utilised. When it comes to calculations involving Equations of state (EOSs) are commonly used in reservoir modelling, process simulation, gas processing, and natural gas transportation. EOSs have a critical role in anticipating the phase envelope, particularly natural gas dew points. Because they have a larger concentration of intermediate components than other liquids, gas condensate and volatile oils are compositionally sensitive (C2, C3, and C4). The component can easily partition into equilibrium gas and condensate/oil below dew point pressure, making fluid properties dependent on temperature and pressure, which is a need in an EOS based on When compared to an EOS, a lot of effort is put into ensuring that PVT data is accurate. The behaviour of gas condensate reservoirs is influenced by fluid properties, and accurate knowledge of the PVT data is required. The classic characterisation approach is utilised in Winprop to describe reservoir fluid, with the Peng Robinson or Suave-Redlich-Kwong (SRK) EOS being the most typically used. In order for EOS to predict fluid phase behaviour, it required a perfect match of laboratory results

2.GAS CONDENSATE RESERVOIRS:

Gas condensate reservoirs, also known as retrograde gas condensate reservoirs, are gas reservoirs with initial reservoir temperatures that fall between the critical temperature (TC) and the critical condensate temperature (cri-condentherm) (Tmax). The reservoir fluid's peculiar thermodynamic behaviour is a key aspect in the development and depletion process, as gas condenses to liquid instead of expanding when pressure decreases.
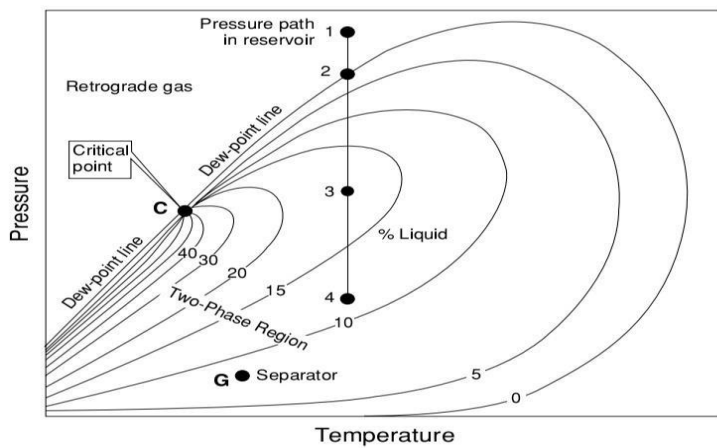
Fig 1: Phase behaviour diagram of retrograde reservoir

The following graph depicts the liquid shrinkage volume curve, also known as the liquid dropout curve, for a condensate system. The condensed liquid volume in most gas-condensate reservoirs ranges from 15% to 19% of the total pore volume. There isn't enough liquid saturation to allow any liquid to flow. However, because the pressure drop around the wellbore is significant, liquid dropout may accumulate, resulting in a two-phase flow of gas and retrograde liquid.
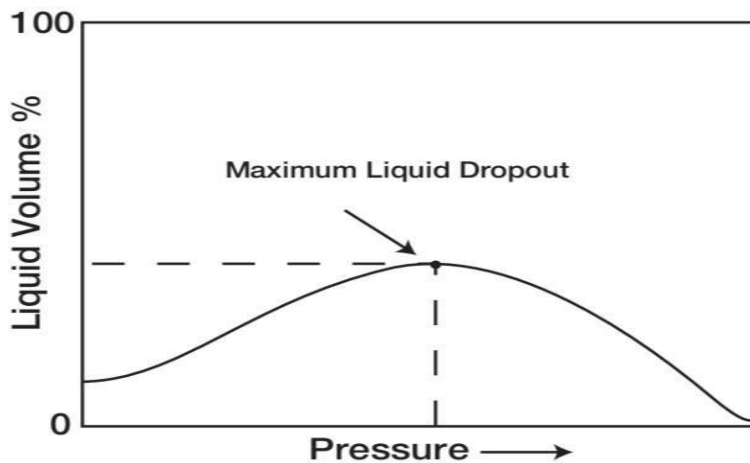

Fig 2: liquid dropout curve for retrograde reservoir.

Gas-oil ratios in gas condensate reservoirs range from 8,000 to 70,000 scf/STB. Because to liquid dropout and the loss of heavy components in the liquid, the GOR for a gas condensate system usually increases over time. The condensate gravity is greater than 50 degrees API. The liquid in stock tanks is usually clear or slightly coloured.

3.CCE AND CVD TESTS:

PVT MEASUREMENTS ON GAS CONDENSATES ARE USUALLY DONE THROUGH TWO TESTS:

Constant composition expansion (CCE) test: This test is also known as the Constant Mass Expansion test. It is used to measure the dew point pressure and can provide volumetric data both above and below the dew point pressure. The test begins with a pressure above dew point at a specific reservoir temperature. As the pressure decreases, the volume increases, providing volumetric data in the process. The CCE test also provides the Z-factor, total volume (relative to volume at dew point), and liquid phase volume.

CVD (Constant Volume Depletion) Test: We use CVD tests instead of CCE tests below the dew point pressure because CVD tests provide more reliable results. The CVD test induces actual changes in behaviour as the pressure decreases, allowing us to determine the actual quantity of gas condensate at the surface. The amount of gas created at the surface (in mole fractions), the Z-factor, C7+ characteristics, and liquid saturation are all provided by the CVD test.

Both the CCE and CVD tests combine to provide an accurate estimate of gas and condensate recovery as well as variations in behaviour as pressure is depleted.

4. VAN DER WAALS EQUATIONS OF STATE:

Cubic van der Waals As the gas compresses, EOS can represent the liquid-condensation phenomena and the transition from gas to liquid phase. It may be expressed numerically in terms of volume, which is as follows::

$$V^3 - \left(b + \frac{RT}{p}\right)V^2 - \left(\frac{a}{p}\right)V - \left(\frac{ab}{p}\right) = 0$$

The above equation can be expressed more practically in terms of the compressibility factor Z. This can be expressed as following:

$$Z^3 - (1 + B)Z^2 + AZ - AB = 0$$

Where $A = \frac{ap_2}{R\,T}$

$B = \frac{bp}{RT}$

5. REDLICH-KWONG EQUATION OF STATE:

In 1949, Redlich and Kwong devised their equation of state. They used a generalised temperature dependency term to replace the Vander Waals attractive pressure term a/V2. As an example, consider the following equation: $p = \frac{RT}{V-b} - \frac{a}{V(V+b)\sqrt{T}}$

Where T is the system temperature in $°R$

In terms of compressibility factor Z, the above equation can be written as:

$$Z^3 - Z^2 + (A - B - B^2)Z - AB = 0 \quad, A = \frac{ap_{2.5}}{R\,T^2}$$

$B = \frac{bp}{RT}$

The application of Redlich - Kwong EOS is extended to hydrocarbon liquid and gaseous mixtures by incorporating the mixing rules:

$$am = \left[\sum_{i=1}^{n} x_i \sqrt{a_i}\right]^2$$

$bm = \sum n i = 1 \; x_i b_i$

where n = number of components in mixture a_i= Redlich-Kwong a

parameter for the i'th component b_i = Redlich-Kwong b parameter for

the i'th component a_m = parameter a for mixture b_m = parameter b for

mixture x_i = mole fraction of component i in the liquid phase

Replace xi with yi for gaseous mixes. For all substances, Redlich-Kwong EOS yields a universal critical compressibility factor (Zc) of 0.333. For most substances, the critical gas compressibility varies from 0.23 to 0.31, but this is not true for heavy hydrocarbon components.

6. PENG ROBINSON EQUATION OF STATE:

Peng Robinson improved the equation of state in 1976, making it easier to forecast liquid densities and other fluid parameters in the neighbourhood of the critical area. The following is the equation that has been proposed:

$$p = \frac{RT}{V - b} - \frac{a\alpha}{V(V + b) + b(V - b)}$$

Peng and Robinson have also used the same approach for calculating α as in SRK EOS. i.e.:
$$2 \; \alpha = [1 + m(1 - \sqrt{T_r})]$$

here, $m = 0.3796 + 1.54226\omega - 0.2699\omega^2$

For heavier components, Peng and Robinson proposed a modified expression for calculating m with acentric values $\omega > 0.49$ $m = 0.379642 + 1.48503\omega - 0.1644\omega^2 + 0.016667\omega^3$

Peng and Robinson EOS can be written in terms of compressibility factor through the following equation:

$Z^3 + (B - 1)Z^2 + (A - 3B^2 - 2B)Z - (AB - B^2B^3) = 0$

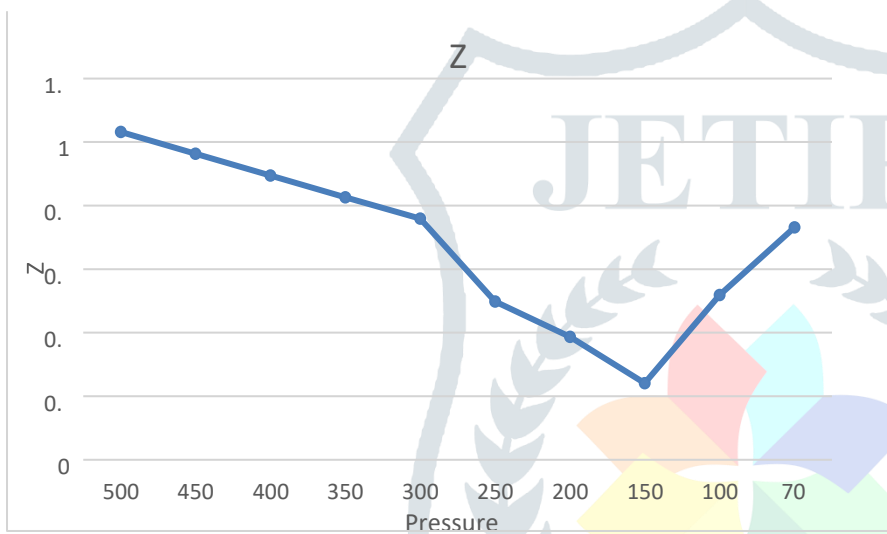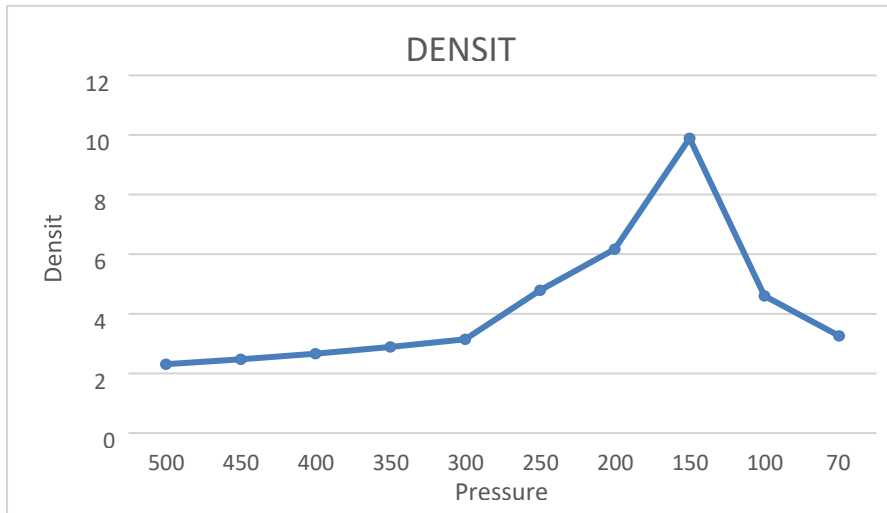Where A $= (\underline{\quad}^{(RT^{a\alpha)})p}2$

$B = \underline{\quad} bpRT$
and for hydrocarbon liquid and gaseous mixtures

$(a\alpha)_m = \sum i \sum j [x_i x_j \sqrt{a_i a_j \alpha_i \alpha_j}(1 - k_{ij})]$, $b_m = \sum i[x_i b_i]$

With A $= (\underline{\quad}(aRT\alpha)m)2p$, $B = b_m p$

7. **RK EQATION OF STATE COMPARISON**

DENSIT

Z

- As for the Rk equation of state which has only advantage over van der wall s equation is that they replaced van der walls attraction pressure terms with temperature dependent terms.

- Now comparing with the final graph of gas and liquid compressibility of CMG and   equation of state calculation we found that:

a) As the pressure decreases in the compressibility also decreases up to the certain points after that it will again starts to increase proportionally.

b) In CMG final results we didn't saw the sharp points in graph but in manually calculation there is sharp curve on the graph which didn't match with CMG.

c) This equation of state has a certain drawback over others equations of state.

8. SRK EQUATION OF STATE COMPARISON

Z(liquid)


Density(liquid)

Z(gas)

Density(gas)
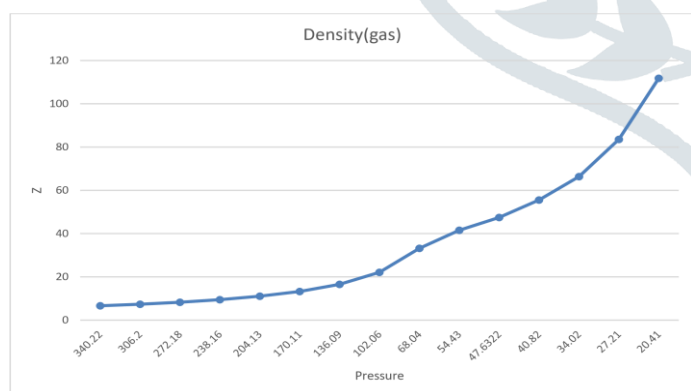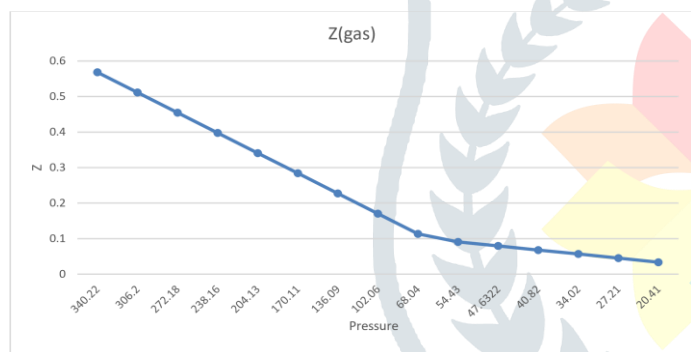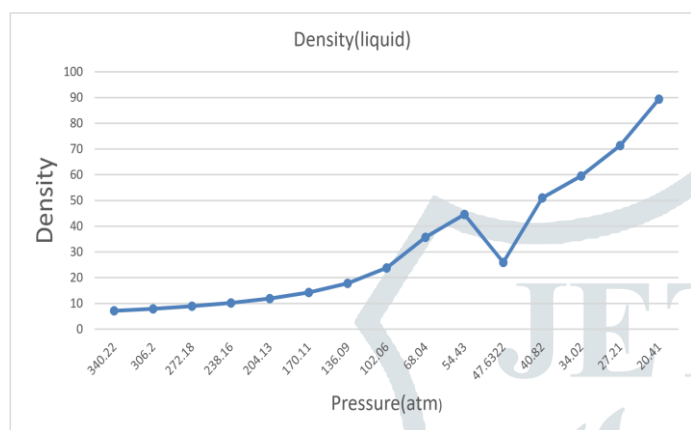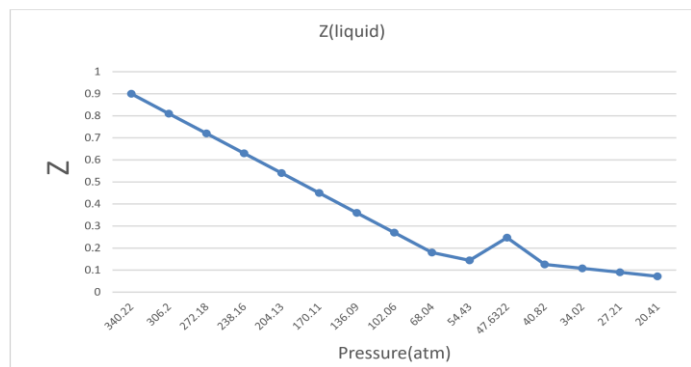
- This equation of state is more dependent on the temperature dependent terms. Here with the introduction of the vapour pressure of pure components to develop a generalised expression for the temperature correction parameter.

- It has an advantage over van der walls and Rk equation of state.

- We used mole fractions of the pure primary and secondary components, for more efficiency.

○ On comparing the CMG results and equation of state results the compressibility of liquid it increases very slowly but at certain points it gives sharp graph and again it increases uniformly. All the sharp points in the graph shows the two phase condensate reservoir.

○ In gas phase compressibility increases slowly at low pressure as we increase pressure higher compressibility increases rapidly and higher.

○ For the density comparison it doesn't provides accurate values with the CMG. For the liquid density it decreases with pressure but for the gas it is reverse.

9. PENG-ROBINSON'S EQUATION OF STATE COMPARISON

Z(gas)

Density(gas)
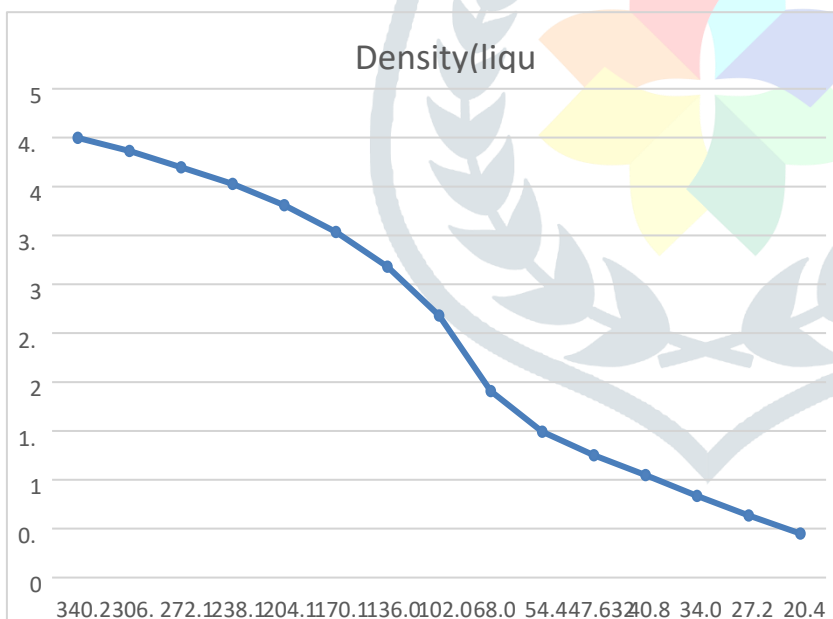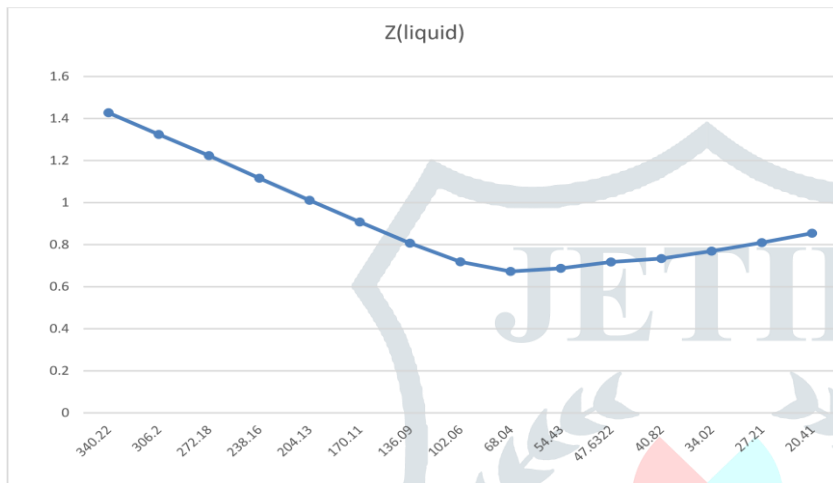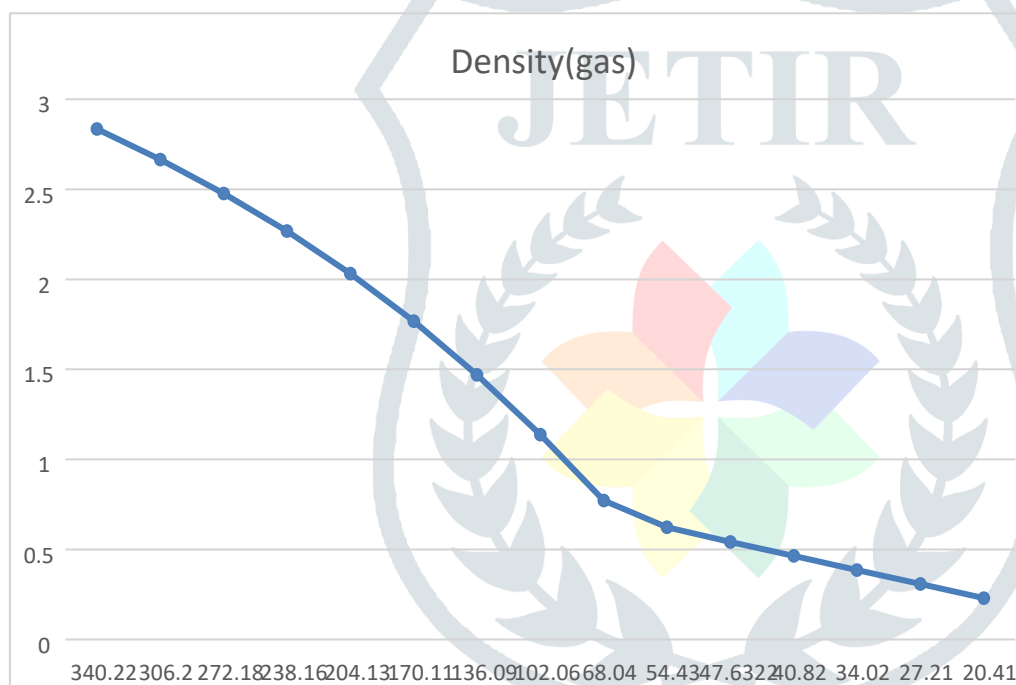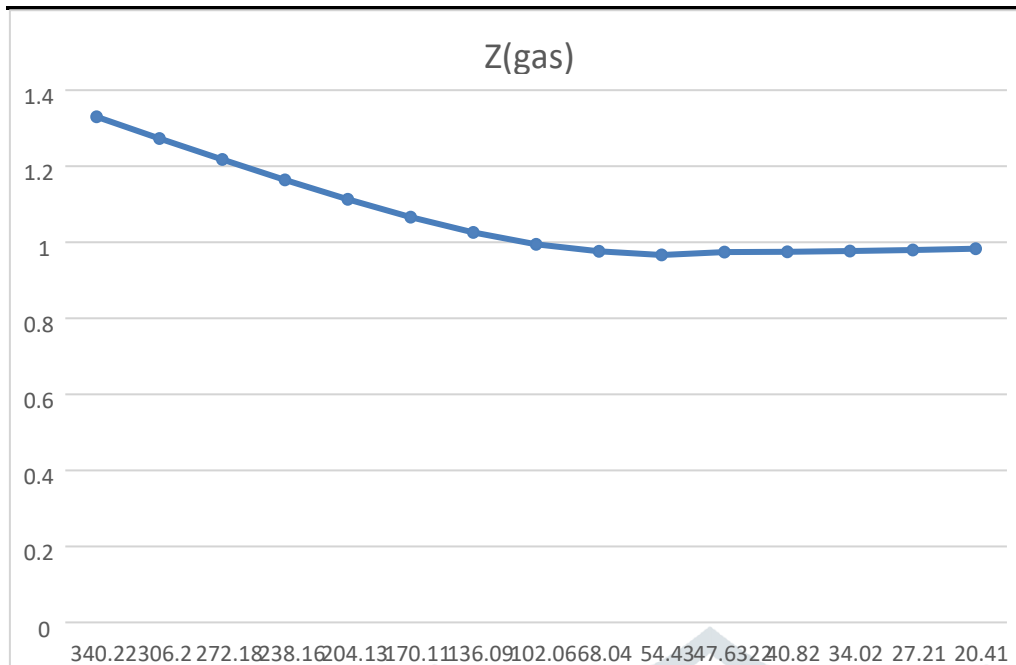
- ○ PR equation of state modified the SRK equation of state. PR introduced well defined terms which gives more accurate values for pure components.
- ○ It also uses the mole fractions for pure components, xi and yi.
- ○ It uses more temperature dependent values like Tr(relative temperature).
- ○ Peng Robinson's proposed the expression m for heavier component.

- ○ On comparing the compressibility of gas and liquid equation of state and CMG, PR gives the most accurate values and accurate graph.

In Gas compressibility it increases uniformly with increase in pressure. This is the only graph which doesn't gives you sharp points in graph.

a) For liquid compressibility in starting it decreases with increase in pressure due to gas condensate but further it also started to increase with pressure.

b) While comparing the density of liquid and gas from CMG graph, it gives the most closest for liquid density. With increase in pressure density of liquid increases gradually throughout.

This is the most accurate graph amongst the all equation of state we have seen.

10. RESULTS AND CONCLUSION:

The Winprop component of CMG software is used to characterise the gas condensate reservoir fluid and draw a phase behaviour diagram of the reservoir. The EOS parameters were retrieved using the cpp software. Experimental volumetric (e.g., density and bulk modulus), thermal (heat capacity), and phase behaviour (melting temperature and solubility) data are well represented by the Peng-Robinson equation of state. By altering the methodologies outlined in this work, it can be applied to various energetic materials ranging in complexity from pure components to multicomponent mixes. In comparison to the other equations of state, the Peng-Robinson equation of state yielded more clear values after applying all of these equations in the programme.

a) As the pressure decreases in the PR equation of state compressibility also decreases up to the certain points after that it will again starts to increase proportionally.

b) In CMG final results we didn't saw the sharp points in graph but in manually calculation   there is sharp curve on the graph which didn't match with CMG.

c) This equation of state has a certain drawback over others equations of state.

d) On comparing the CMG results and SRK equation of state results the compressibility of liquid it increases very slowly but at certain points it gives sharp graph and again it increases uniformly. All the sharp points in the graph shows the two phase condensate reservoir.

e) In gas phase compressibility increases slowly at low pressure as we increase pressure higher compressibility increases rapidly and higher.

f) For the density comparison it doesn't provides accurate values with the CMG. For the liquid density it decreases with pressure but for the gas it is reverse.

➢ On comparing the compressibility of gas and liquid equation of state and CMG, PR gives the most accurate values and accurate graph.

e) In Gas compressibility it increases uniformly with increase in pressure. This is the only graph which doesn't gives you sharp points in graph.

f) For liquid compressibility in starting it decreases with increase in pressure due to gas condensate but further it also started to increase with pressure.

g) While comparing the density of liquid and gas from CMG graph, it gives the most closest for liquid density. With increase in pressure density of liquid increases gradually throughout.

h) This is the most accurate graph amongst the all equation of state we have seen.

11.REFERENCE:

- Ahmed, T. (2010) Reservoir Engineering Handbook, Elseiver

- Ahmed, T. (2007) Equations of State and PVT Analysis: Applications for Improved Reservoir Modeling. Gulf Publishing Company.

- Howard, B Bradley (1987) Petroleum Engineering Handbook

- Panja, P. et al (2020) 'Understanding and modelling of gas condensate flow in porous media'

- Agarwal et al(1990) ' A regression technique with dynamic parameter selection for phase behavior matching

- Kumar, A. and Henni, A. (2011) 'Three-parameter cubic equation of state for pure components of heavy oils'.