Study on the change law of dew point pressure after gas injection in fracture-cavity condensate gas reservoir

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Abstract. In this paper, taking a condensate gas reservoir in the Middle Tarim Basin as an example, the fluid of the condensate gas reservoir was calculated according to the provided condensate oil sample, and the accuracy was verified by PVT experiment. The regularity of dewpoint pressure after adding different proportion of light component gas (produced gas) into the condensate gas was tested under reservoir conditions.

1. Introduction

At present, the degree of oil and gas exploration and development in China is getting higher and higher, and the difficulty is also getting more and more difficult. Fractured-vuggy carbonate reservoirs account for a large proportion and have great development potential.[1] The fracture-vuggy carbonate reservoir is a kind of special reservoir system, which is mainly controlled by karst fracture-vuggy reservoir and mainly controlled by karst fracture-vuggy reservoir, which is formed by multi-stage tectonic movement and palaeokarst interaction.[2] This type of hydrocarbon reservoir is characterized by diverse reservoir space types, deep burial, complex structure, strong reservoir heterogeneity, poor connectivity, and great difference in natural energy among different reservoirs, etc. It is characterized by network reservoir, and can be called the most complex and special carbonate reservoir in the world.[3]

Different from conventional gas reservoirs, reverse condensate occurs when the local pressure is lower than the dew point pressure, which is the main characteristic of condensate gas reservoirs.[4,5] When the pressure of condensate gas reservoir drops below the dew point pressure, condensate will be precipitated out of the reservoir. The precipitated condensate will be adsorbed on the pore surface of the rock, so it is difficult to recover.[6,10] For condensate gas reservoirs, the production method of maintaining formation pressure is the mainstream of the current production method, among which the gas injection to maintain pressure is more studied, but the influence of gas injection of different components on the dew point is less studied.[11] The determination of dew point pressure is an important basis to judge the saturation degree and fluid characteristics of condensate gas reservoir, so it is very important to calculate the dew point pressure accurately for the efficient development of condensate gas reservoir.[12,15]
2. The experiment to prepare

2.1. Formation fluid recombination
Two oil samples (2×1L) and two gas samples (2×15L) were obtained from the separator after stable production in order to realize the change of fluid properties and phase characteristics of the gas reservoir in the production of this well. According to the field sampling conditions: gas reservoir pressure 65.65MPa, gas reservoir temperature 134.6℃; After the sample is sent to the laboratory with the separator pressure of 1.01MPa and the temperature of 6.5℃, the sample is reduced and preset after heating and stirring. The original data of the samples are shown in Table 1.

| Sample data                        |       |
|-----------------------------------|-------|
| Gas reservoir pressure/MPa        | 65.65 |
| Gas reservoir temperature/℃       | 134.6 |
| Producing gas oil ratio/m³/m³     | 1491  |
| Gas oil ratio of separator/m³/m³  | 1527  |
| Tank oil density (20℃)/g/cm³      | 0.768 |
| Separator pressure/MPa            | 1.01  |
| Separator temperature/℃           | 6.5   |
| Separator gas deviation coefficient| 0.9747|

The gas composition of the separator is shown in Table 2. According to the composition of the gas in the separator, the compound calculation of the medieval condensate gas was carried out.

| Component | Gas separator |
|-----------|---------------|
| Component | mol% | g/m³ |
| CO₂       | 2.333 | /    |
| N₂        | 1.858 | /    |
| C₁        | 89.807| /    |
| C₂        | 3.587 | 44.839|
| C₃        | 1.336 | 24.491|
| iC₄       | 0.298 | 7.200 |
| nC₄       | 0.482 | 11.646|
| iC₅       | 0.125 | 3.749 |
| nC₅       | 0.101 | 3.029 |
| C₆        | 0.059 | 2.060 |
| C₇        | 0.013 | 0.519 |
| C₈        | 0.001 | 0.044 |

The blending process was carried out at atmospheric pressure of 0.101MPa and temperature of 20℃. According to the equation of state of gas, the molar volume of gas under atmospheric pressure of 20℃ was obtained:

\[ v_{20} = \frac{T_{20}}{T_0} v_0 = \frac{20 + 273}{273} \times 22.4L = 24.04L / mol \] (1)

According to the original data of the sample, the gas volume of 1mL condensate corresponding to the separator condition is 1527cm³, and the corresponding amount of substance is 0.0635g/mol, so as to obtain the molar number of single component gas of the separator gas. By referring to the molecular weight of the gas above C₅ and the compression factor under the sample pressure of 20℃, the volume of the gas corresponding to 1mL of the separator oil under the sample pressure can be obtained.
For liquid components above C₅, by referring to their molecular weight and liquid component density at 20°C atmospheric pressure, the volume of liquid components above C₅ in the separated gas corresponding to 1mL of separator oil at 20°C atmospheric pressure can be obtained. The calculation data is summarized in Table 3.

Table 3. Calculation and composition of gas mixture in separator.

| Component | The number of moles of gas per component/g/mol | The molecular weight/Mi | Compression factor at 20°C sample pressure | Sample pressure was assigned to each group/MPa | Volume of gas corresponding to 1mL separator oil at sample pressure/mL | Liquid component density at atmospheric pressure of 20°C g/cm³ | The volume of liquid components above C₅ corresponding to 1mL of separator oil in the separated gas/mL |
|-----------|-----------------------------------------------|-------------------------|-------------------------------------------|-----------------------------------------------|-----------------------------------------------------------------|-----------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| CO₂       | 0.001482                                      | 44                      | 0.96226                                   | 0.7                                           | 4.3367                                                          | /                                                              | /                                                                 |
| N₂        | 0.001180                                      | 28                      | 0.99544                                   | 2.5                                           | 1.1003                                                          | /                                                              | /                                                                 |
| C₁        | 0.057045                                      | 16.04                   | 0.94589                                   | 3                                             | 42.3869                                                        | /                                                              | /                                                                 |
| C₂        | 0.002278                                      | 30.07                   | 0.91631                                   | 1                                             | 4.6192                                                         | /                                                              | /                                                                 |
| C₃        | 0.000849                                      | 44.09                   | 0.90959                                   | 0.5                                           | 3.1287                                                         | /                                                              | /                                                                 |
| C₄        | 0.000495                                      | 58                      | 0.96200                                   | 0.15                                          | 4.6257                                                         | /                                                              | /                                                                 |
| C₅        | 0.000144                                      | 72                      | /                                         | /                                             | /                                                              | 0.6326                                                         | 0.01634                                                          |
| C₆        | 0.000037                                      | 86                      | /                                         | /                                             | /                                                              | 0.672                                                          | 0.00480                                                          |
| C₇        | 0.000008                                      | 100                     | /                                         | /                                             | /                                                              | 0.684                                                          | 0.00121                                                          |
| C₈        | 0.000001                                      | 114                     | /                                         | /                                             | /                                                              | 0.703                                                          | 0.00010                                                          |

According to the calculation results in the table above, 20mL of separator oil was taken for the mixture of condensate gas samples.

2.2. Experimental conditions and process
The dew point pressure was measured by the condensate gas fluid PVT phase analyzer. The experimental conditions/parameters were as follows: the working pressure was 0-70MPa, the volume of the visual PVT cylinder was 120mL, the accuracy was 0.01ml, and the working temperature was up to 150°C. The device diagram of the phase analyzer is shown in Figure 1.

Figure 1. Condensate gas fluid phase analyzer.

The experimental flow of phase analysis in PVT instrument is shown in Figure 2. Condensate gas samples are prepared in the sample mixer, V9, V12, V15 and V16 are opened and V13 and V10 are kept closed. At the same time, gas samples from the sample transfer pump and sample preparation pump are controlled to maintain pressure and transferred to the sample intermediate container through the sample transfer interface. After the sample transfer operation is completed, V9, V11 and V14 are closed and the pressure of V10 is controlled by controlling the sample transfer pump and pressure pump to transfer a certain volume of samples into the PVT cylinder. Then the inlet valve V10 is closed for the
experiment. At the end of the experiment or when sampling is needed, the gas can be discharged through the sample discharge port by controlling V10, V12 and V13 valves.

![Figure 2. Phase analyzer experiment flow.](image)

For the injected light component gas, the produced gas of the gas reservoir is selected in this paper and the parameters of the prepared light component gas are shown in Table 4.

### Table 4. Light component gas parameters.

| Component | Sample pressure was assigned to each group/MPa | The volume of a gas under sample pressure/mL |
|-----------|-----------------------------------------------|-------------------------------------------|
| CO₂       | 0.7                                           | 65                                        |
| N₂        | 2.5                                           | 16                                        |
| C₁        | 3                                             | 636                                       |
| C₂        | 1                                             | 69                                        |
| C₃        | 0.5                                           | 47                                        |
| C₄        | 0.15                                          | 69                                        |

The experimental procedures are as follows:

1. The configured condensate sample (134.6°C, 65MPa) was transferred to the PVT phase analyzer. After the pressure stabilized, the pressure was depressed by hand pump, and the phenomenon was observed after stabilizing for one hour until the dew point was observed.
2. Fill a certain volume of light component natural gas (at room temperature, the pressure is P₀, higher than the pressure in the sample preparation cylinder) into the PVT cylinder (the pressure remains P₀ after sampling conversion) to calculate the number of moles of the gas transferred;
3. Test the dew point pressure of condensate gas after adding light component natural gas;
4. Repeat steps (2) to (3) until no further hypotension can be achieved.

3. **Experimental results and analysis**

Constant mass expansion experiment, also known as P-V relation test experiment. It simulates the experiment of the P-V relationship and phase state change process of the pore space of the hydrocarbon reservoir with the gradual depressurized pressure when the condensate gas reservoir is in the unexploited and closed state.
To the analyzer PVT barrel to transfer a certain amount, compound with good condensate gas constant temperature to formation temperature, formation temperature in constant quality of condensate gas reservoir fluid samples were determined under the volume and pressure, the relationship between the dew point pressure of condensate gas reservoir fluid is obtained under different pressure, gas compressibility factor and fluid parameters such as the relative volume, its value shown in table 4, The P-V relationship of formation fluid is shown in Figure 3.

Table 5. Fluid pressure and volume relationship in condensate gas reservoir (134.6℃).

| Pressure/MPa | Relative volume $V_i/V_d$ | Deviation coefficient |
|--------------|---------------------------|-----------------------|
| 65.65        | 0.9410                    | 1.441                 |
| 60.00        | 0.9696                    | 1.357                 |
| 55.46        | 1.0000                    | 1.293                 |
| 50.00        | 1.0431                    | /                     |
| 45.00        | 1.0963                    | /                     |
| 40.00        | 1.1658                    | /                     |
| 35.00        | 1.2604                    | /                     |
| 30.00        | 1.3983                    | /                     |
| 25.00        | 1.6057                    | /                     |
| 20.00        | 1.9335                    | /                     |

Note: $V_i/V_d$: Volume ratio at grade I pressure to dew point pressure

![Figure 3. P-V relationship of formation fluids.](image)

It is found through experimental tests that when the pressure drops to 55.46MPa, white fog begins to appear in the observation window, and the gas-liquid two-phase state is formed, as shown in Figure 4. Therefore, the dew point pressure of the medieval condensate gas reservoir is 55.46MPa. Compared with PVT report, the dew point pressure is 55.45MPa, which verifies the accuracy of the experimental mixture.

![Figure 4. Analyzer window observation under dew point pressure.](image)

After the dew point pressure was observed, 10mL of light component gas was injected each time. After the pressure stabilized, the pressure was lowered and observed until the dew point phenomenon appeared again. The amount of substances added to the light component gas was recorded. The above steps were repeated until the dew point pressure was minimized. The experimental data were shown in
Table 5. When light component is added corresponding to dew point pressure, the observation window phenomenon of the analyzer is shown in Figure 5.

Table 6. Change of gas injection pressure and dew point pressure.

| Gas injection pressure (MPa) | Gas injection pressure (MPa) | Dew point pressure (MPa) |
|-----------------------------|-----------------------------|-------------------------|
| 0.391                       | 56.00                       | 49.84                   |
| 0.667                       | 50.00                       | 39.89                   |
| 0.918                       | 40.00                       | 22.88                   |
| 1.164                       | 23.00                       | 2.00                    |

Figure 5. Gas injection corresponds to the observation window phenomenon of the dew point pressure analyzer.

When the experimental pressure drops to 2MPa, the minimum pressure has been reached and the experiment is stopped. The relation data between gas composition of condensate gas and injection pressure is shown in Table 7. The relationship curves between the molar number of the injected light component gas and the dew point pressure and the relationship curves between the gas composition of the condensate gas and the injection pressure are shown in Figure 6.

Table 7. The relation between gas composition of condensate gas and injection pressure.

| Component/Pressure | 56.00MPa | 50.00MPa | 40.00MPa | 23.00MPa | 2.00MPa |
|--------------------|----------|----------|----------|----------|---------|
| CO₂                | 1.794    | 1.719    | 1.642    | 1.621    | 2.173   |
| N₂                 | 2.051    | 2.056    | 2.080    | 2.091    | 1.871   |
| C₁                 | 89.833   | 90.360   | 91.005   | 92.223   | 91.067  |
| C₂                 | 3.648    | 3.477    | 3.210    | 2.640    | 3.332   |
| C₃                 | 1.595    | 1.469    | 1.297    | 0.920    | 1.097   |
| C₄                 | 1.080    | 0.918    | 0.765    | 0.504    | 0.461   |
Figure 6. The relation curve of gas molar number, condensate gas composition and dew point pressure was added.

It can be seen from the image that the dew point pressure of the condensate gas is greatly affected by the composition. With the addition of the light component gas, the dew point pressure shows a downward trend, which is slow in the early stage and increases in the later stage and gradually shows a linear trend. Gas composition except carbon dioxide and methane content eventually decreases, but the change trend of gas is different and there will be inflection point. Through analysis, this is because the compression factor of different gases varies with the injection pressure. The relation between the compression factor of condensate gas and the injection pressure is shown in Table 8, and the relation curve between the compression factor and the injection pressure is shown in Figure 7.

Table 8. The relation between compression factor and injection pressure of condensate gas.

| Component/Pressure | 56.00MPa | 50.00MPa | 40.00MPa | 23.00MPa | 2.00MPa |
|--------------------|----------|----------|----------|----------|--------|
| CO₂                | 0.956    | 0.895    | 0.800    | 0.711    | 0.966  |
| N₂                 | 1.369    | 1.319    | 1.237    | 1.113    | 1.006  |
| C₁                 | 1.241    | 1.187    | 1.102    | 0.996    | 0.992  |
| C₂                 | 1.265    | 1.167    | 1.003    | 0.740    | 0.945  |
| C₃                 | 1.486    | 1.353    | 1.126    | 0.722    | 0.875  |
| C₄                 | 1.725    | 1.562    | 1.283    | 0.788    | 0.744  |
Figure 7. The relation curve between gas compression factor and injection pressure of condensate gas.

A comprehensive understanding of the various influencing factors of dew point pressure is not only of guiding significance for experimental research, but also can reasonably explain various physical phenomena in the actual reservoir during production, which plays a key role in the field optimization of injectors and when to carry out gas injection and pressure retention production.

4. Conclusion

(1) The dew point pressure is greatly affected by the composition of condensate gas.
(2) The injection of light component gas will lead to the decrease of dew point pressure.
(3) Gas composition except carbon dioxide and methane content eventually decreases, but there will be inflection point in different trends of gas, which is caused by the mutation of gas compression factor.
(4) A comprehensive understanding of various influencing factors of dew point pressure not only has guiding significance for experimental research and optimization of human injection agent, but also can reasonably explain various physical phenomena in actual reservoirs during production.

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