Optimization of oil and gas recovery process for light crude oil containing sulfur

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Abstract. In order to study the oil and gas recovery of Middle East sours crude oil imported from China, the condensing recovery method is adopted. The process of recovery process is simulated by Aspen, and the condensing recovery process is optimized. The results show that the condensation temperature has the greatest influence on the recovery of oil and gas components in the oil and gas recovery process, and the three-stage condensing process is used in the condensation process. The recovery rate of oil and gas increases to more than 84% at the temperature of 2 ℃, -50 ℃, -130 ℃.

1. Introduction
Crude oil is composed of various hydrocarbon components such as methane and ethane, which are volatile, flammable and explosive [1]. The Middle East oils imported from China also contains sulfur, which may cause corrosion and other adverse effects on coastal areas with high humidity. The large and small breathing lead to the loss of oil evaporation, In the process of loading, unloading, storage and transportation of crude oil. The VOCs generated will not only pollute the environment, but also reduce the quality of oil [2-3]. In order to build enterprises that meet the requirements of health, safety, environmental protection, energy conservation and emission reduction, various pollutant indexes of oil and gas emissions need to meet the relevant national standards [4-7]. At present, it is commonly used to recover oil and gas in the form of adsorption, absorption, membrane separation and condensation, but each has its own advantages and limitations [8-11]. The principle of the condensation method is easy, that is, the refrigerant is used to condense and separate the oil, gas and air in heat exchanger. The method is suitable for the recovery of high concentration and medium flow of oil and gas [12]. Condensate recovery of oil and gas to control the temperature in a lower level (-100℃), which makes the condensation process of high energy consumption, high input costs. Therefore, it is necessary to optimize the process of condensing oil and gas recovery and reduce the cool load on the premise of ensuring a certain recovery rate.

Hamad A mentioned that transferring the quantity of heat of condensation can greatly reduce the cost of the condensation device [13]. Zheng xin studied the recovery performance of toluene condensation. They concluded that the improvement of cool stage temperature, lowering of the condensation temperature and the inlet gas temperature, was conducive to the improvement of system performance...
By analyzing the recovery law of oil and gas by condensation method, Li Cheng believes that the higher the content of C4 in the oil-gas two-phase mixture is, the lower the temperature required for condensation will be\textsuperscript{[15]}. By using Aspen plus 8.4 simulation software, the law of oil and gas recovery rate changes in condensation temperature\textsuperscript{[16-18]} is studied, and the condensation process is optimized to provide theoretical support for oil and gas recovery by adsorption and condensation.

2. Aspen simulation

In Aspen simulation, Flash2 separator was used to replace the condensing device, and middle eastern crude oil and gas samples S1, S2, S3 and S4 (table 1) were selected, which contained H2S and CH4S. The sample is a non-polar real component, so formula (1) (cubic equation of state PR-BM) is selected as the thermodynamic calculation method\textsuperscript{[19]}:

\[
P = \frac{RT}{V - b} = \frac{a(T)}{V(V + b) + b(V - b)}
\]

\[
a = a_c \alpha(T) = 0.45724 \frac{R^2 T^2}{P_c} \alpha(T)
\]

\[
b = 0.0778 \frac{R T}{P_c}
\]

\[
\alpha^{0.5}(T) = 1 + m(1 - T_r^{0.5})
\]

Table 1. Hydrocarbon composition of sample

| Stream name | \(S_1\) | \(S_2\) | \(S_3\) | \(S_4\) |
|-------------|---------|---------|---------|---------|
| Logistics name | The feed of oil and gas mol% | The feed of oil and gas mol% | The feed of oil and gas mol% | The feed of oil and gas mol% |
| \(N_2\) | 58.559 | 25.327 | 57.961 | 24.805 |
| \(O_2\) | 5.280 | 5.347 | 5.284 | 5.346 |
| \(CO_2\) | 10.498 | 10.630 | 10.505 | 10.629 |
| \(AR\) | 0.200 | 0.202 | 0.200 | 0.202 |
| \(H_2O\) | 1.500 | 1.519 | 1.501 | 1.518 |
| Methane (CH\(_4\)) | 1.198 | 2.838 | 1.198 | 2.837 |
| Ethane(C\(_2\)H\(_6\)) | 3.593 | 8.513 | 3.595 | 8.512 |
| Propane(C\(_3\)H\(_8\)) | 5.988 | 14.188 | 5.992 | 14.186 |
| Butane (C\(_4\)H\(_10\)-1) | 8.383 | 20.488 | 8.388 | 20.445 |
| Pentane (C\(_5\)H\(_12\)-1) | 3.593 | 8.513 | 3.595 | 8.512 |
| Hexane+ (C\(_6\)H\(_14\)-1) | 1.198 | 2.425 | 1.198 | 2.425 |
| \(H_2S\) | 0.005 | 0.005 | 0.005 | 0.005 |
| Mercaptan (CH\(_4\)S) | 0.005 | 0.005 | 0.578 | 0.578 |

3. Optimize condensation temperature

In the simulation experiment, the volume flow of oil and gas exported to different condensation temperatures was obtained according to four samples of \(S_1-S_4\), and the corresponding oil and gas recovery rate was calculated according to formula (2).
\[ n = \frac{V_{in} - V_{out}}{V_{in}} \times 100\% \]

\( (V_{in} \text{--- Oil and gas volume flow at the inlet of the condenser Flash2 module; } V_{out} \text{--- Oil and gas volume flow at the outlet of the condenser Flash2 module} ) \)

Set the condensation temperature to -100°C, -90°C, -80°C, -70°C, -60°C, -50°C, -40°C, -30°C, so the multiple control variable is simulated. The inlet temperature, inlet flow rate and inlet pressure change within a certain range, and the relative volume recovery rate is almost unchanged.

Ideally, when the condensation temperature dropped to -100°C, The oil and gas recovery rate of all four samples exceeded 80%, as shown in figure 1. In reality, when the intake amount of oil and gas mixture phase is large, the proportion of air occupies a large proportion. The reaction time of oil and gas in the condenser is insufficient. Limited heat transfers area of heat exchanger; Exist in the process of condensation heat resistance will make the condensation temperature lower than ideal 10 to 15°C.[20].

Among the oil and gas components, the hydrocarbon component recovery rates increase with the increase of the number of carbon atoms, and the components do not interfere with each other independently. The oil and gas concentration will affect the recovery rate (Figure 2-5). When the C4H10-1 molar percentage is 8.4%, the recovery temperature is -50°C and the recovery rate is 54%. When the C4H10-1 molar percentage is 20.5%, the condensation temperature is The recovery rate at -50°C was 85.2%. When the second-stage temperature t2 is -10°C, the oil and gas components are almost not condensed. t2=-50°C, the C6 component is 98% condensed. t2=-80°C, almost all of the components above C4 are recovered. When the secondary temperature is -100°C, almost all of the components above C3 are recovered, and methyl mercaptan and hydrogen sulfide are also condensed. t2 = -20°C, the sulfur component begins to condense, and the recovery curve of hydrogen sulfide is close to that of ethane. The recovery curve of methyl mercaptan is similar to n-butane. Comparing the S3 and S4 samples, the higher the concentration of methyl mercaptan, the higher the recovery at the same condensation temperature.

**Fig. 1** Variation of oil and gas volume recovery n with condensation temperature  
**Fig. 2** The relationship between recovery rate of hydrocarbon components and condensation temperature in S1
Optimize condensation recovery process

The high energy consumption and investment cost of the system make it impossible to popularize the condensation method to recover oil and gas. It is necessary to ensure a certain recovery rate and the lowest energy consumption of the system. According to the actual measurement results of an oil depot, the volume flow rate of oil and gas at the inlet of the condenser is set at 5000 m$^3$/h (about 176575 scfh). One-off condensation recovery of oil and gas directly from 25°C to -100°C, will lead to water frosting leading to thermal resistance, increasing the energy consumption of the recovery unit. The condensation process should be divided into three stages (Fig. 6). pre-cooling is carried out first, the first-stage condensation temperature is 2°C, and most of the water vapor in the two phases of the oil and gas is condensed to recover a part of heavy hydrocarbons, the second stage is the intermediate condensation section. The third-stage condensing temperature is tentatively set at -100°C, in order to ensure the oil and gas recovery rates arrived 80%.
4.1. **Optimize the second stage condensation temperature**

Simulates the relationship between oil and gas recovery $n$, total energy consumption (the sum of energy consumed by the three-stage condensation process) and the second-stage condensation temperature $T_2$ (Fig. 7). Sample curve is parabola, S1 and S3, the second stage condensation temperature is $-60^\circ$C, the total condensation energy consumption is the lowest, at this time S1 oil and gas recovery rate is of 76.84%, S3 recovery rate is of 78.88%, S2 and S4 curve, when $T_2 = 50^\circ$C, the total condensation energy consumption is the lowest, at this time $n_{S2} = 84.98\%$, $n_{S4} = 85.21\%$.

The total energy consumption of the second stage condensation is not a function of the oil-gas volume recovery (Fig. 9). With the increase of the second stage condensation temperature, there are two total energy consumption values. There are turning points $A_1$ and $A_2$ between $-20^\circ$C and $-30^\circ$C. The curve after $A_2$ point is a parabola. The tangent slope of the curve is about 2.5 at $-50^\circ$C and the slope of the second ($T_2>-50^\circ$C) increases sharply. In order to reduce the refrigeration temperature difference and the total energy consumption of the compressor, the $T_2$ temperature should be designed as $-50^\circ$C.
4.2. Optimize the condensation temperature of the third section

In order to reduce condensation energy consumption, Aspen is used to simulate the variation of oil and gas recovery rate with the third stage condensation temperature (Fig. 10, 11). As shown in Fig. 12, the recovery rates of S1 and S2 are about 88% and 84% respectively at point A (-130 °C). The slope of curve increases sharply after point A, and the energy consumption increases little with the recovery rate. In the case of high oil and natural gas emission standards, the third stage condensing temperature is set to -130 °C.

5. Conclusion

(1) The recovery rate of oil and gas condensation increases with the reduction of condensation temperature, and the higher the concentration of oil and gas within a certain range, the better the recovery effect is, and the pressure, temperature and flow of oil and gas inlet have little influence on it. The relationship between the recovery rate of methyl mercaptan and the condensation temperature is similar to that of C₄. At -100 °C, it almost condenses, and the hydrogen sulfide recovery rate is also above 54%.

(2) The optimization of condensation process is three stage condensation. The three-stage condensation temperatures are set to be -2 °C, -50 °C, and -130 °C. The oil and gas recovery rates of S1...
and S3 are over 88%, the condensation energy consumption is under 750 kw, the oil and gas recovery rates of S2 and S4 are over 84%, and the condensation energy consumption is about 1200 kw. When the third stage condensing temperature is -170 °C, the recovery rate of oil and gas can reach more than 95%.

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