Research on Energy Saving and Consumption Reduction Technology of Underground Gas Storage Compressor

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Abstract: Suqiao Gas Storage Group is a seasonal peaking gas storage in North China, where energy consumption cost of the compressor gas injection is more than 30% of the operation cost of the gas storage. In the Suqiao Gas Storage, the main energy consumption equipment is the electrically driven compressor. Aimed at the problem of high energy consumption of compressor, the influencing factors of compressor energy consumption are found out by analyzing the formula of compressor indicated power. According to the gas injection status of the gas storage, the main influencing factors are the inlet pressure, outlet pressure, clearance and compression ratio of the compressor. The relationship between power consumption and various influencing factors is obtained by testing the power consumption of compressor and the main influencing factors. Based on the above analysis results, the optimization model of compressor energy consumption is established, the compressor energy optimization software was compiled by C#, and the calculation results of the software were applied on site, which reduced the energy consumption of the on-site compressor, saved the gas production and operation cost of the gas storage, and provided the basis for scientific storage of gas storage.

1. Introduction
Underground gas storage plays an irreplaceable role in seasonal peak shaving and guaranteeing the safety of gas supply. In recent years, it has been developed vigorously in China. Suqiao gas storage group belongs to the underground gas storage group of seasonal peak shaving type for guaranteeing the use of gas in North China. The gas storage group uses electric drive reciprocating compressor for gas injection, the compressor gas injection energy consumption is the main energy consumption equipment of gas storage, and its electricity consumption cost accounts for more than 50% of the operation cost of gas storage. How to rationally adjust compressor parameters, improve compressor utilization ratio and reduce operation cost is of great significance for reducing cost and increasing efficiency of gas storage¹-³.
2. Compressor indicator power calculation
The index of evaluating compressor energy consumption generally refers to the indicator power of compressor, which is the indicator work consumed in unit time. The indicator work of the compressor generally refers to the total work consumed by compressor cylinder in working cycle. The indicator work is expressed in L, the indicator power is expressed in N[4-5].

The calculation formula of indicator work is:

\[
L = \frac{P_s V_b \lambda_v}{k - 1} \left[ \frac{P_d}{P_s} \right]^\frac{k-1}{k} - 1
\]

The calculation formula of indicator power is:

\[
N = 1.634 n P_s V_b \lambda_v \frac{k}{k - 1} \left[ \varepsilon \left( 1 + \sigma \right)^\frac{k-1}{k} - 1 \right]
\]

\[
\lambda_v = 1 - \alpha \left( e^n - 1 \right)
\]

In the equation: \( P_s \) is inlet pressure of cylinder, kgt/cm²; \( V_b \) is stroke volume of cylinder, m³; \( \lambda_v \) is Volume coefficient, means degree of reduction in utilization of cylinder working volume; \( \alpha \) is relative clearance volume, means ratio of clearance space volume to total cylinder volume; \( m \) is gas expansion index; \( k \) is gas adiabatic exponent; \( \varepsilon \) is pressure ratio, means ratio of cylinder exhaust pressure to intake pressure; \( n \) is the speed of compressor; \( \sigma \) is relative pressure loss,%.

3. Influence factor of compressor power
According to the indicator power formula of compressor, the main influencing factors of compressor power are gas property, compressor inlet pressure, outlet pressure, compression ratio, clearance, cylinder size and speed. According to the gas injection status of the gas storage, the cylinder stroke volume, speed and gas properties of the compressor can not be changed, only the inlet pressure, outlet pressure, clearance and compression ratio are studied.

3.1. Impact of inlet pressure
The rated power of compressor used in Suqiao Gas Storage Station is 4500KW, three-stage compression mode. The adjusting range of inlet pressure is 4.0-4.6MPa. The outlet pressure is 34 MPa fixed and the clearance is closed. The compressor power consumption and gas injection under different inlet pressure are collected through field experiments, and the influence of inlet pressure on power consumption and gas injection volume of compressor is analyzed.

As shown in Fig.1, with the increase of the compressor inlet pressure from 4.0MPa to 4.6MPa, the gas injection volume increases gradually. The gas injection volume is the largest at 4.6MPa. With the increase of inlet pressure 0.1MPa, the gas injection volume increases by 2.7%-8.6%. As shown in Fig.2, with the increase of the inlet pressure, the power consumption increases, and with the increase of the inlet pressure 0.1MPa, the power consumption increases, 2.5%-11.4%. The increase rate slows down with the increase of the inlet pressure. Because the pressure ratio decreases with the increase of the inlet pressure, the indicating power decreases. At the same time, the indicating power increases with the increase of the inlet pressure. When the pressure ratio is greater than 1.1, the increasing power of the compressor is more than the decreasing power. Therefore, the inlet pressure increases. When the pressure ratio is less than 1.1, the inlet pressure increases and the compressor power decreases[6-7].
The gas injection unit consumption of the compressor is calculated by power consumption * electricity price / gas injection. As shown in Figure 3, with the increase of the inlet pressure of the compressor, the gas injection unit consumption of the compressor decreases gradually, and at 4.6MPa, the unit consumption of the compressor is the lowest.

3.2. **Impact of outlet pressure**

According to present work situation of the compressor unit in the gas storage, keep the compressor inlet pressure 4.5MPa unchanged, change the outlet pressure from 24MPa to 35MPa, and collect the corresponding power consumption of a single compressor. As shown in Figure 4, the outlet pressure increases, the indicated power of the compressor increases, and the power consumption increases, and the outlet pressure increases by 0.1MPa each time the outlet pressure increases. Indicative power increases by 1.5%~2.3%. With the increase of outlet pressure, the compressor's air injection decreases. For every 0.1MPa increase of outlet pressure, the gas injection volume decreases by 1%~1.4%, as shown in Fig. 5. According to the relationship between power consumption, air injection and outlet pressure, the unit consumption of gas injection decreases with the increase of outlet pressure, as shown in Fig. 6.
3.3. Impact of clearance

Compressor clearance is fully opened. Comparing with the data of clearance closed, under different inlet pressures, the volume of gas injection affected by clearance is obtained. The inlet pressure rises in the range of 4MPa to 4.6MPa, and the volume of gas injection affected by clearance keeps rising, changing from 170,000 m$^3$ per day to 210,000 m$^3$ per day. Keeping the outlet pressure unchanged and the inlet pressure changing from 4MPa to 4.6MPa, the daily power consumption of compressors with full clearance opened and full clearance closed is compared and analyzed. The average daily power consumption of compressors with full clearance opened is about 12,000 kwh/day lower than that with full clearance closed, as shown in Figure 7.
3.4. Impact of compression ratio

Through the analysis of the operation data of the compressor unit in 2017, removing the data loss, unit power outages and other accidental factors, the compression ratio and compressor power consumption trend basically, the greater the compression ratio, the greater the power consumption of the compressor power, and the compression ratio is proportional to the actual operation, and the actual situation is consistent with the theoretical formula.

4. Establishment of power consumption optimization model for compressor units and development of power consumption optimization software

By analysis the factors which is affecting the compressor energy consumption, we use compressor inlet pressure as a design variable, taking the minimum gas injection consumption of the compressor as the objective function, Establish an energy optimization model as below:

\[
\begin{align*}
\min d &= \frac{f(x) \cdot y}{Q_i} \\
\text{s.t.} & \quad x \in [4.0, 4.6] \\
& \quad y \in [0.8, 1], \quad y \in Z
\end{align*}
\]

In the equation: “d” is the unit consumption of gas injection, degree/ m³; “f(x)” is the power consumption of daily gas injection with Su 4 and Su 49 reservoir compressors, KWh; “x” is the inlet pressure, and the value is between 4.0 and 4.6 MPa; “Q1” is the daily gas injection of Su 4 and Su 49, m³; “y” is the number of compressors which is started in Su 4 and Su 49, taking values from 0 to 8, taking integers; “Qz” is the gas injection of daily production from Su 4 and Su 49, m³.

Use the collected compressor power consumption, gas injection volume and inlet pressure data to fit a curve. According to the formula of compressor indicating power, the indicated power and the inlet pressure are linear, and by the fitting is obtained a formula about indicating power and inlet pressure while the clearance cleared or the full clearance.

According to the current injection, the equation of the indicated power and the inlet pressure and the compressor injection in full clearance and in fully closed clearance, solving the objective function, finally obtain the compressor working condition with the minimum unit consumption.

Using the energy consumption optimization model of the compressor unit which is already established, compile an energy optimization software by C#, through entering the daily gas injection calculate the best compressor starting scheme, including the number of compressor starting units, inlet pressure, switch of clearance and return, estimated value of the electricity and gas consumption.

5. Field application

In August, the daily gas injection of Su 4 was 2.4 million square meters. In the first half of the month, we injecting gas with experience, running two compressors, the inlet pressure is 4.4 MPa, the clearance is fully closed, the total power consumption is 2931240kW•h; in the second half of the month, using the program which is provided by the energy optimization software, running two compressors, the inlet pressure is 4.2MPa, the clearance is fully closed, after half a month of testing, the total power consumption is 2776980kW • h, the power consumption after optimization in the second half of the month is significantly lower than before. The average optimization is 10284kW•h per day, that means we can save 308520kW•h per month. As the sheet 1 shows.
Table 1. The Power consumption of compressor before and after optimization.

| Date       | Power consumption (kwh/d) | Date       | Power consumption (kwh/d) |
|------------|---------------------------|------------|---------------------------|
| 20180801   | 20660                     | 20180816   | 184800                    |
| 20180802   | 19300                     | 20180817   | 176300                    |
| 20180803   | 190200                    | 20180818   | 186500                    |
| 20180804   | 197800                    | 20180819   | 182400                    |
| 20180805   | 193300                    | 20180820   | 180200                    |
| 20180806   | 198900                    | 20180821   | 188700                    |
| 20180807   | 192400                    | 20180822   | 183200                    |
| 20180808   | 192500                    | 20180823   | 179600                    |
| 20180809   | 195400                    | 20180824   | 187480                    |
| 20180810   | 193100                    | 20180825   | 182600                    |
| 20180811   | 197200                    | 20180826   | 188300                    |
| 20180812   | 195300                    | 20180827   | 189700                    |
| 20180813   | 196300                    | 20180828   | 187600                    |
| 20180814   | 197480                    | 20180829   | 190700                    |
| 20180815   | 197700                    | 20180830   | 188900                    |

6. The conclusion

By analyzing the indicate power formula of compressor, According to the gas injection status of the Gas Storage, we can sure the main influencing factors are the inlet pressure, outlet pressure, clearance and compression ratio of the compressor. So, after analyzing and testing the various influencing factors, the compressor energy optimization model was finally established, and as well the compressor energy optimization software was compiled. The application showed that the daily power consumption was optimized to 10284kW•h when the gas injection was 2.4 million square meters per day. That means, if it is equivalent to 30 days, it can save 308520kW.h a mouth, which just verified the calculation results’ reliability of the software. Using energy optimization software can reasonably adjust the compressor parameters, improve the compressor utilization, reduce the operating costs, and it must have great significance to the cost reduction and the efficiency increasing of the Suqiao Gas Storage.

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