Research and practice on optimal design method of the oilfield water injection system pipeline network

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Abstract—The efficiency of oilfield water injection system is generally low and energy consumption is high. With the deepening of oilfield exploitation, the water cut of the oilfield is increasing, the power consumption of the water injection system is increasing year by year, the oilfield exploitation cost is increasing, and energy conservation and consumption reduction are very important. In order to improve oilfield water injection efficiency and reduce water injection energy loss, this paper puts forward the pipe network optimization design method of partial pressure water injection, establishes the mathematical model of partial pressure water injection pipe network and throttling loss calculation model, compiles the calculation software of partial pressure water injection mathematical model, optimizes the partial pressure interval, calculates the partial pressure points, effectively reduces the energy loss of water injection system and improves the efficiency of water injection system.

1.Introduction
Water injection is an important measure for oilfield development. In order to improve oil recovery and oil production speed, most domestic oilfields use water injection to supplement energy to the oil layer. Generally, oilfield water injection systems have low efficiency and high energy consumption. With the deepening of oilfield exploitation, the water content of oilfield keep rising, the power consumption of water injection system is increasing year by year, and the cost of oilfield exploitation is increasing. Energy saving and consumption reduction are essential. Renovating the water injection pipe network and optimizing the design of the water injection system pipe network can effectively improve the water injection efficiency and achieve the goal of low consumption and stable production.

2.Optimization analysis method of water injection system pipeline network

2.1Description of specimens
The oilfield water injection system consists of a water injection station, a water injection well, a water...
distribution room, and a water injection pipe network.\[7\text{-}9\] The energy loss of the water injection pipeline network is mainly concentrated in the place where the liquid flow direction and pipe diameter change.\[10\]

The matching of water injection pump and pipeline characteristics and the distribution of water injection pressure are particularly important. It is important to match water injection pump and pipeline characteristics and distribute water injection pressure. If the radius of the pipeline is too large or too small, the flow of the liquid will be unstable, and the energy loss will increase in the tube. Because of unreasonable distribution of water injection pressure and excessive pressure range, energy loss will be increased. In order to improve the efficiency of the water injection system, as well as ensure the water injection effect of each well while reducing useless energy consumption, the water injection pressure of the system should be selected to match the oil pressure. The formula of the water injection system efficiency is as follows.

\[
\eta_0 = \frac{P_1 \times \sum Q_1 - P_2 \times \sum Q_2}{3.6 \times \sum \eta_1} \times 100\%
\]

Among them: \(\eta_0\) is the efficiency of the water injection system, \%; \(P_1\) is the average wellhead oil pressure; \(Q_1\) is the water injection volume of a single well, m\(^3\)/h; \(P_2\) is the average inlet pressure of the water injection pump, MPa; \(Q_2\) is the inlet flow rate of a single water injection pump, m\(^3\)/h; \(\eta_1\) is the input power of a single pump motor, kW.

Based on the formula, it can be seen that various factors should be comprehensively considered to optimize the water injection pipe network system. After the pipeline and water injection pump have been determined, the most feasible way to reduce energy loss is to select a reasonable water injection pressure while meeting the water injection requirements, and build multiple partial pressure water injection systems to reduce unnecessary energy consumption and reduce pipeline friction resistance loss. The formula of pipeline friction loss is as follows.

\[
\Delta P = \rho \left( \sum \left( \frac{L_i v_i^2}{d_i^2 g} \right) + \sum \left( \frac{L_j v_j^2}{d_j^2 g} \right) \right)
\]

Among them: \(\Delta P\) is the total pressure drop of the water injection pipe network, MPa; \(\rho\) is the density of the injected water, kg/m\(^3\); \(\lambda\) is the friction coefficient of water; \(d\) is the inner diameter of the pipe, m; \(v\) is the water velocity, m/s; \(L\) is the pipe Equivalent length, m.

2.2 Mathematical model establishment of partial pressure water injection

For systems that can achieve partial pressure water injection in the pipe network, optimizing the pressure demarcation point is essentially optimizing the main line pressure of the low-pressure system metering room or the parameter of the low-pressure system outlet pressure. Such an optimization problem is a mathematical programming problem. The establishment of a mathematical model for the optimization of the partial pressure point includes two parts: the establishment of the objective function and the determination of the constraint conditions. Based on the restrictions and energy loss formula, the throttling loss calculation model is established.

\[
N_0 = \sum_{i=1}^{n} \frac{(P - P_i) \times Q_i}{3.6}
\]

Among them: \(N_0\) is the throttling loss, kW; \(P\) is the water injection pressure, MPa; \(P_i\) is the oil pressure of a single well (the oil pressure is arranged in descending order \(P_1 > P_2 > P_3 > \ldots > P_n\)), MPa; \(Q_i\) is the corresponding water injection volume under oil pressure \(P_i\), m\(^3\)/h, \(n\) is the number of water injection wells. In the water injection pipe network system, the system water injection pressure is \(P\) and the total water injection volume is \(Q\). The oil pressure and water injection volume of each well form a one-to-one correspondence \((P_1, Q_1), (P_2, Q_2), (P_3, Q_3), \ldots (P_n, Q_n)\). For the water injection pipe network system, the system water injection pressure \(P\) and the total water injection volume is \(Q\).

\[
Q = \sum_{i=1}^{n} Q_i
\]

In order to reduce system throttling loss, reduce energy consumption, and improve system efficiency, the water injection system is divided by three. Assuming that the medium partial pressure...
point is $P_{low}$ medium and the low partial pressure point is $P_{low}$, satisfying $P > P_{mid} > P_{low} > P_n$, the overall throttling loss $N_1$ calculation formula of the partial pressure system is as follows.

$$N_1 = \sum_{i=1}^{m} \frac{(P-P_{i})Q_i}{3.6} + \sum_{j=m+1}^{l} \frac{(P_{mid}-P_j)Q_j}{3.6} + \sum_{k=l+1}^{n} \frac{(P_{low}-P_k)Q_k}{3.6} \quad (5)$$

In the formula (5), $m < l < n$. The injection well oil pressure is in the range of $(0, P_{low})$, there are $n-1$ wells. The oil pressure of injection well is in the range of $(P_{low}, P_{mid})$, there are $l-m$ wells. The oil pressure of injection wells is in the interval $(P_{mid}, P)$, and there are $m$ wells.

2.3 Numerical solution of partial pressure water injection mathematical model

The VBA language of Visual Basic software is used to compile the numerical solution command stream of the partial pressure water injection mathematical model, so as to realize the numerical simulation of the throttling loss in the partial pressure water injection process. The water injection system is divided into three sub-injection pressure systems: high pressure water injection system, medium pressure water injection system and low pressure water injection system. The numerical solution process of the partial pressure water injection mathematical model is shown in Figure 1 ($i,j \geq 0$). When $i \neq 0$ and $j=0$, $P_{mid}=P_{low}$. Besides, $P_{mid} > P_{low}$.

![Numerical solution process of partial pressure water injection mathematical model](image-url)

Fig.1 Numerical solution process of partial pressure water injection mathematical model
3. Implementation and effect analysis of optimization design method for water injection system pipe network

There are 5 development units in oil production area C, including 216 oil wells under its jurisdiction, 177 open wells, 2855 tons of daily liquid production, 400 tons of daily oil production, 81 water wells, 72 open wells, water injection pressure of 23.5mp, 9 water injection pumps, 5 normally started, 4 standby, and daily water injection volume of 2350m³.

3.1 Application effect of partial pressure water injection mathematical model

At present, in the water injection wells, the water injection pressure of single well has medium and low pressure. The partial pressure can effectively improve the pump efficiency and reduce the unit consumption and standard consumption of water injection. Through software analysis and calculation, the partial pressure points of the two partial pressure system are 16.1MPa, and the partial pressure points of the three partial pressure system are 11.6MPa and 18.1MPa. The partial pressure scheme of oil production area C is obtained as follows.

| Partial pressure scheme | No partial pressure | the two partial pressure system | the three partial pressure system |
|-------------------------|---------------------|---------------------------------|----------------------------------|
| Pressure dividing point/MPa | none | 16.1 | 11.6 |
|                          |        |      | 18.1 |

3.2 Application effect analysis

According to the calculation and analysis, the energy consumption loss of different pressure sharing systems is shown in Table 2. The energy consumption loss of three pressure sharing system is the smallest, followed by two pressure sharing, which can effectively reduce the system energy consumption. The energy consumption loss of the three partial pressure system can be reduced by 66%, and the energy consumption loss of the two partial pressure system can be reduced by 46%.

| Partial pressure scheme | No partial pressure | the two partial pressure system/MPa | the three partial pressure system/MPa |
|-------------------------|---------------------|-------------------------------------|--------------------------------------|
| Throttling loss/kW       | 215.06              | 115.39                              | 72.87                                |

Due to the small number of wells in this work area, the method of two partial pressure water injection is adopted. The results before and after optimization are shown in Table 3. Through the comparison of table data, we get that after optimization, the system efficiency and pipe network efficiency of the pressure distribution system are significantly improved, and the unit consumption and standard consumption of water injection are significantly reduced. Partial pressure water injection can effectively improve the efficiency of the water injection system.

| Partial pressure scheme | Pipe network loss kW | system efficiency % | Unit consumption of water injection kWh/m³ | Water injection standard consumption kWh/m³ MPa |
|-------------------------|----------------------|---------------------|-------------------------------------------|-----------------------------------------------|
| 16.1MPa                 | 41.86                | 55.9                | 5.55                                      | 0.49                                          |
| 22MPa                   | 16.06                | 69.28               | 7.18                                      | 0.39                                          |
| No partial pressure     | 104.3                | 55.23               | 7.29                                      | 0.5                                           |

4. Conclusion

Based on the results and discussions presented above, the conclusions are obtained as below:

1) The mathematical model of partial pressure water injection pipe network and throttling loss calculation model are established, and the energy consumption loss nodes are calculated and analyzed.
(2) Compile the calculation software of partial pressure water injection mathematical model, reasonably divide the partial pressure of water injection, optimize the partial pressure interval, and obtain the partial pressure point through calculation.

(3) It is concluded that the application of the pipe network optimization design method can effectively reduce the energy loss of the water injection system, which is up to 66%, improve the utilization rate of the pipe network and effectively improve the efficiency of the water injection system.

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