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Energy Saving and Consumption Reduction of Oilfield Pressurized Water Injection System

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Abstract

According to the principle of energy balance, the energy balance model of the pressurized water injection system is set up. The energy distribution calculation is carried out by taking the actual running condition of the Leijia block pressurized water injection system of Liaohe oil field, combining the energy consumption evaluation standard of the oil field injection system. The energy distribution and energy saving potential of each part of the pressurized water injection system are analyzed, and the energy consumption of the system after the energy saving transformation is predicted.

Keywords: pressurized water injection system, energy consumption evaluation, energy distribution, energy saving

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INTRODUCTION

The power consumption of oil field water injection system is about 1/3 of the total power of the oil field. It is the key point of energy saving in the oil field production system. The energy distribution of the water injection system reflects the utilization of the power of the water injection system in essence. Through studying the energy distribution law of water injection system, we find out the weak link of energy utilization, and then effectively reconstruct the water injection system (Gao 2013, Zhang et al. 2014, Zhou 2015). In the process of water injection development, with the increase of mining time and the change of oil layer pressure, the pressure of water injection in different mining beds is different. If the unified pressure of water injection pipe network is adopted, which can meet the pressure of most injection wells, the requirements of high pressure injection well cannot be met. And if the pressure of the whole pipe is raised, we need to increase the pressure reducing equipment in the low pressure water injection well mouth, which will cause the waste of energy (Yao 2013). Therefore, according to the needs of water injection for different types of wells, some supercharging devices are installed in some distribution or injection wells (Chang et al. 2003). At present, the energy consumption calculation of ordinary water injection system has a relatively mature standard reference. For pressurized water injection system, energy consumption analysis is required based on energy balance model and existing standards. Taking the actual operation status of the pressurized water injection system in the Liaohe oil field Gaosheng oil production plant Leijia block as an example, the energy distribution is calculated and analyzed, the energy saving potential of each part of the system is analyzed, and the energy utilization situation of the system after the energy saving transformation is predicted (Jiang et al. 2003).

ENERGY BALANCE MODEL OF PRESSURIZED WATER INJECTION SYSTEM

Water Injection System Flow

The flow chart of the oil field injection system is illustrated in **Fig. 1**.

Energy Balance Model

The pressurized pump location of the system is located at the water distribution room and wellhead, where the pressure of the water from injection station can not meet the water injection requirements. Based on the conservation of system energy, the energy balance model of pressurized water injection system is established by using the grey box model of system engineering, as shown in **Fig. 2**.

The equation of energy balance is as follows:

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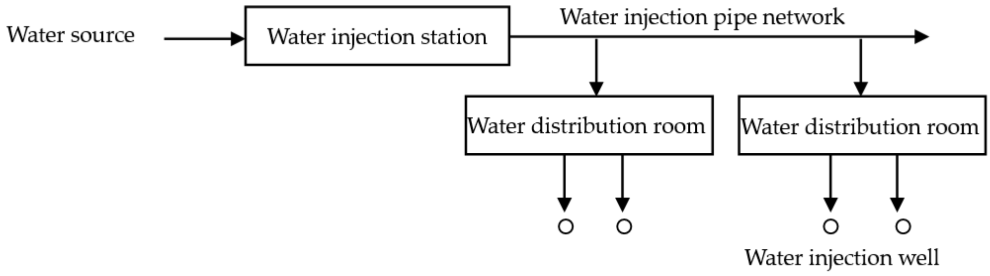

Fig. 1. Flow chart of water injection system

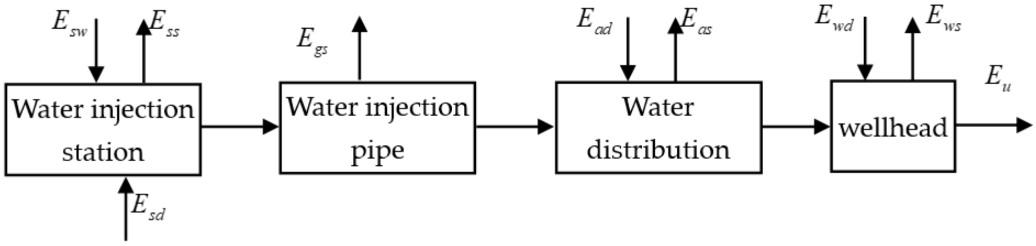

Fig. 2. Energy balance model for pressurized water injection system

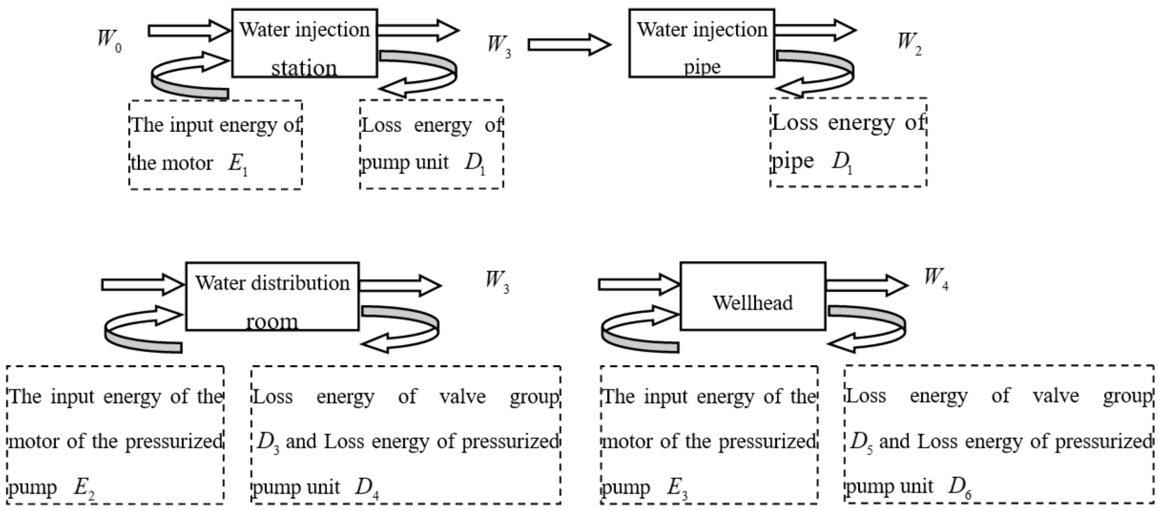

Fig. 3. Energy flow model for pressurized water injection system

$$E_{sd} + E_{sw} + E_{ad} + E_{wd} = E_{ss} + E_{gs} + E_{as} + E_{ws} + E_u$$

In the formula: E_{sd}——The input energy of the motor in water injection station, kW·h; E_{sw}——The energy of the water at the entrance of the pump in the water injection station, kW·h; E_{ad}——The input energy of the motor in water distribution room, kW·h; E_{wd}——The input energy of the motor in wellhead kW·h; E_{ss}——Loss energy of water injection station, kW·h; E_{gs}——Loss energy of pipe, kW·h; E_{as}——Loss energy of water distribution room, kW·h; E_{ws}——Loss energy of wellhead, kW·h; E_u——The energy of water injected into the stratum, kW·h.

ENERGY DISTRIBUTION OF PRESSURIZED WATER INJECTION SYSTEM

On the basis of the energy balance model of the pressurized water injection system, the energy consumption of the pressurized water injection system is analyzed and calculated combined with "energy consumption test and calculation method of oilfield production system" standard (National Energy Administration 2012). The energy consumption of each link is calculated according to the standard, and the energy distribution of the pressurized water injection system is analyzed (Wen 2012).

The energy flow model is shown in **Fig. 3**, the energy of water after each link is expressed in *W*. The loss energy of the water injection system is divided into four parts: the first part is the loss energy of the water injection pump unit in the water injection station $D_1 = E_1 + W_0 - W_1$, the second part is the loss energy of the pipeline $D_2 = W_1 - W_2$, the third part is the loss energy of the water distribution $D_3 + D_4 = E_2 + W_2 - W_3$, and

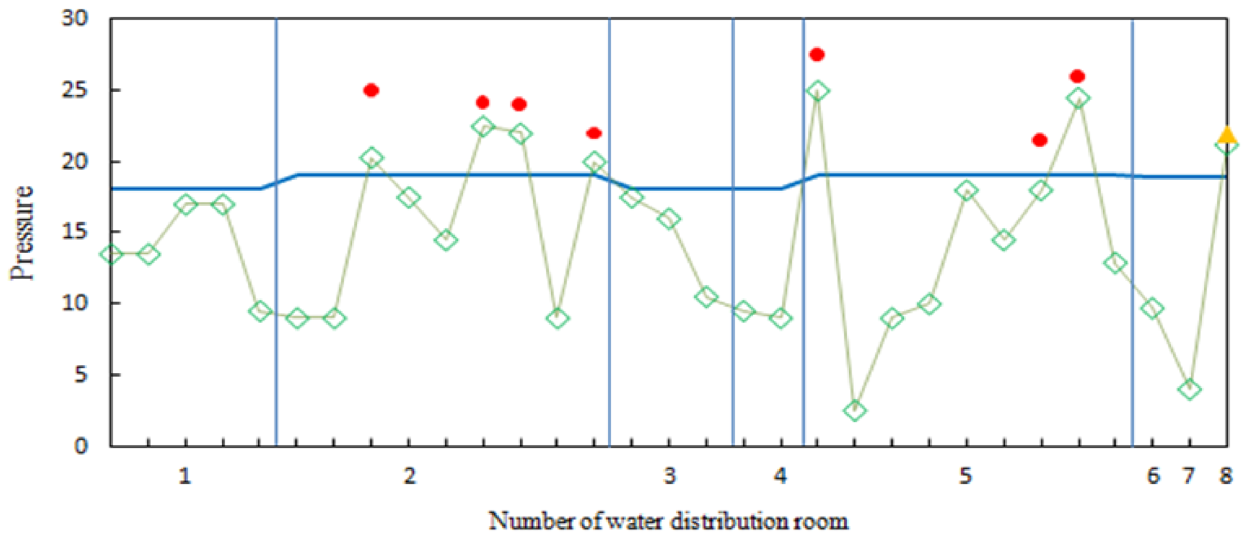

Fig. 4. Pressure distribution of pressurized water injection system
Trunk pressure of distribution room; ▲ Pump pressure of distribution room;
● Pump pressure of well; water injection pressure

Table 1. Calculation results of energy distribution of pressurized water injection system

project	W0	E1	D1	W1	D2	W2	E2
value(KW)	10.00	566.48	96.75	479.73	31.37	448.36	6.64
Input / output		+	-		-		+
Energy loss rate(%)			14.11		4.57		
project	D3	D4	W3	E3	D5	D6	W4
value(KW)	21.19	5.97	427.84	112.72	136.99	89.88	313.69
Input / output	-	-		+	-	-	
Energy loss rate(%)	3.09	0.87			19.97	13.11	

the fourth part is the wellhead loss energy $D_5 + D_6 = E_3 + W_3 - W_4$.

On the basis of the "energy consumption test and calculation method of oilfield production system" standard, according to the actual running condition of the pressurized water injection system, the energy of each part of the water injection system is calculated. After the energy loss of each part of the water injection system is obtained, the energy loss rate of each part and the efficiency of the water injection system are calculated. The formula is expressed as and $\varepsilon = D/(E_1 + E_2 + E_3)$ and $\eta = (W_4 - W_0)/(E_1 + E_2 + E_3)$. The efficiency of the water injection system and the energy loss rate of each link can directly reflect the energy loss of the water injection system and the energy saving potential of each link of the water injection system.

CASE ANALYSIS

Current Situation of Water Injection System

Taking the actual operation of the water injection system in the Liaohe oil field Gaosheng oil production plant Leijia block as an example, the energy distribution of the system is analyzed. The injection pump in the water injection station is a reciprocating pump, and the pressurized water injection pump between the water distribution station and the wellhead is a centrifugal pump. The water injection system has a water injection station, 8 water distribution rooms and 31 injection wells. During the operation of the system parameters, the outgoing pressure of the water injection station 19.2Mpa, the trunk pressure and wellhead injection pressure when transported to the water distribution stations are shown in **Fig. 4**. It can be seen from the chart that the water inflow from the water injection station can not satisfy all the water injection requirements of all injection wells. There are some pressurized pumps in the No. 8 water distribution room and some injection wells to pressurize the water before injecting water into the formation.

Energy Distribution in Water Injection System

The energy distribution results of the water injection system are calculated as shown in **Table 1**. The water injection system in the table is represented by "+" when "energy input" is "energy input", and the "energy output" is expressed in "-".

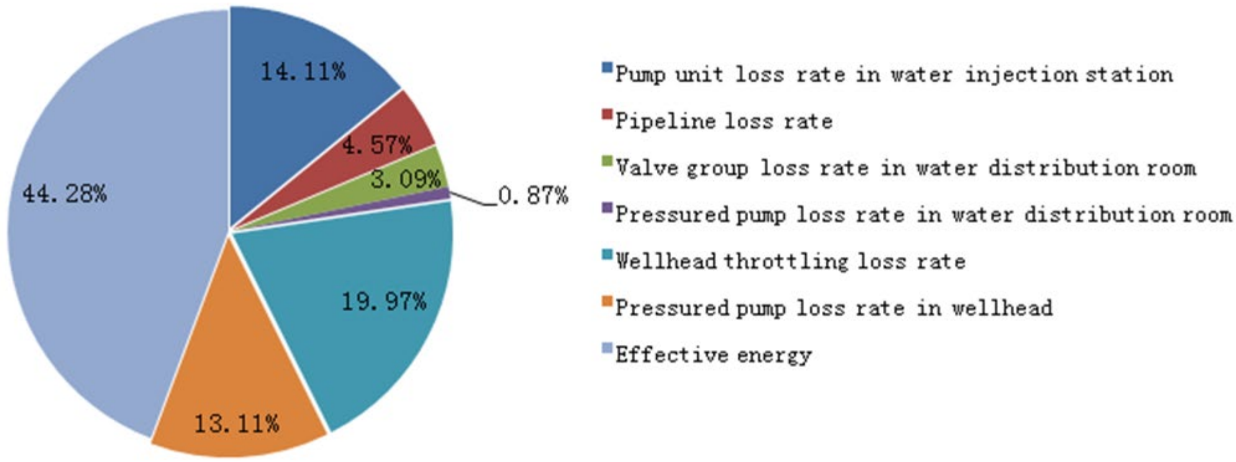

Fig. 5. Energy distribution diagram of pressurized water injection system

Table 2. Operation parameters and efficiency of pump unit in water injection station

Pump number	Voltage (V)	current (A)	power factor	inlet pressure (Mpa)	outlet pressure (Mpa)	Flow (m^3/h)	Efficiency (%)
1	381	320	0.63	0.4	19.6	18.6	74.57
2	389	400	0.77	0.4	19.4	33.6	85.45
3	385	440	0.77	0.4	18.8	37.8	85.52

Table 3. Operating parameters and efficiency of pressurized water injection pump

Pump number	Voltage (V)	current (A)	power factor	inlet pressure (Mpa)	outlet pressure (Mpa)	Flow (m^3/h)	Efficiency (%)
No. 8 room	383	13	0.77	18.9	21.9	0.8	10.04
Well (8#)	381	17	0.93	18	25	2.1	39.13
Well (11#)	384	10	1	19	24.1	1.09	23.22
Well (12#)	378	69	0.91	19	24	1.22	3.99
Well (14#)	370	15	0.99	12	22	0.8	23.35
Well (20#)	369	30	0.97	18	27.5	1.23	17.45
Well (26#)	375	21	0.77	18.2	21.5	4.07	35.52
Well (27#)	378	27	0.9	18	26	2.87	40.09

Efficiency of the pressurized water injection system: $\eta = (W4 - W0) / (E1 + E2 + E3) = 44.28\%$, Single consumption of system is 7.62KW·h/m^3.

The energy distribution of the pressurized water injection system is shown in **Fig. 5**. It can be seen that the larger energy loss links are the injecting water pump unit in the water injection station, the pressurized water injection unit and the throttling loss at the wellhead. The operating parameters and efficiency of the pump unit are shown in **Tables 2-3**.

Analysis of Energy Saving Potential of Pressurized Water Injection System

Taking the calculation results of the pressurized water injection system in the case analysis as an example, the utilization of energy (electricity) supplied to the water injection system. Can be seen from the energy distribution of the system. The effective energy of water injected into the stratum accounts for 44.28%, and the remaining 55.72% energy is lost in some links of the system. The loss energy of wellhead throttle is the largest proportion, followed by the pump unit in water injection station and the pressurized pump unit. According to the calculation results and the actual operation of the water injection system, the energy saving potential of the corresponding links of the system is analyzed：

(1) Too much energy loss of the wellhead throttling is due to the high pressure at the outlet of the injection station, and the pressure needed by the injection well is small. The residual pressure at the wellhead is too high to reduce throttling through the valve group, resulting in the loss energy of valve group. The general solution to the excessive throttle loss energy of the water injection wellhead is to reduce the pressure of the outgoing station in the water injection station, and to use the wellhead pressurized injection pump for the wells with high pressure (Zhao 2011). But through the energy analysis of the pressurized water injection system, it is known that the pressurized pump operation efficiency is low because the flow of the pump

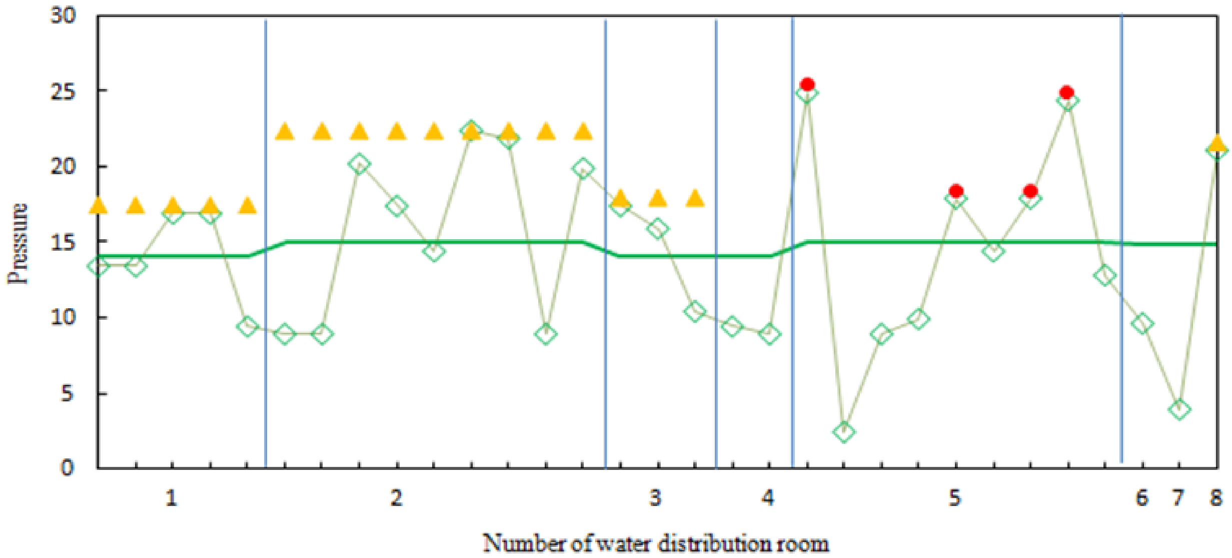

Fig. 6. Pressure distribution after nergy saving transformation
Trunk pressure of distribution room; ▲ Pump pressure of distribution room;
● Pump pressure of well; water injection pressure

is generally far less than the rated flow of the pump, and the energy saving effect is not ideal.

(2) According to "economic operation standard for oilfield water injection system", the efficiency of the reciprocating pump unit is qualified when it is above 76%, it is excellent when it is above 85%. For centrifugal pump units, the corresponding standards are 58% and 69% (National Energy Administration 2017). From **Table 1**, it can be seen that the water injection pump unit has been working in good condition, so the loss energy of the pump unit in the water injection station can be seen as the necessary energy loss.

(3) It is known from **Table 2** that the efficiency of pressurized water injection pump is not qualified. The main reason for the high energy consumption of the pump unit is that the displacement and lift of the actual working condition are far smaller than the rated value, causing the pump to work in the low efficiency area (Song and Guo 2004).

Energy Saving Transformation of the Water Injection System

Energy saving transformation methods

In view of the above situation, it is proposed to reduce the overall pressure of the system and improve the efficiency of the pressurized injection pump units by reasonably adjusting some of their location. The specific scheme is as follows, and the pressure distribution of the adjusted water injection system is shown in **Fig. 6**.

(1) System overall reduction of pressure 4 Mpa;

(2) The pressurized water injection pumps 12#, 14# and 11#, which have low operating efficiency in the water injection system, are allocated to No.1, No.2 and No.3 water distribution rooms which are not satisfied with the water injection pressure of most wells. The pump flow rate is close to the rated flow rate, and the efficiency of the pump unit is raised to more than 50%. The 8# wellhead pressurized injection pump is configured to the 24# wellhead. After analysis, these adjustments can increase the average efficiency of the injection pump unit from 19.7% to 44.1%.

Energy distribution of the system after energy saving transformation

The energy distribution of the adjusted water injection system is calculated as shown in **Table 4**.

Table 4. Calculation results of energy distribution of pressurized water injection system after nergy saving transformation

project	**W0**	**E1**	**D1**	**W1**	**D2**	**W2**	**E2**
value(KW)	10.00	457.37	77.13	389.83	34.78	355.05	6.64
Input / output		+	-		-		+
Energy loss rate(%)			12.68		5.72		
project	D3	D4	W3	E3	D5	D6	W4
value(KW)	9.81	45.62	393.67	144.45	98.69	38.78	313.68
Input / output	-	-		+	-	-	
Energy loss rate(%)	1.61	7.5			16.22	6.37	

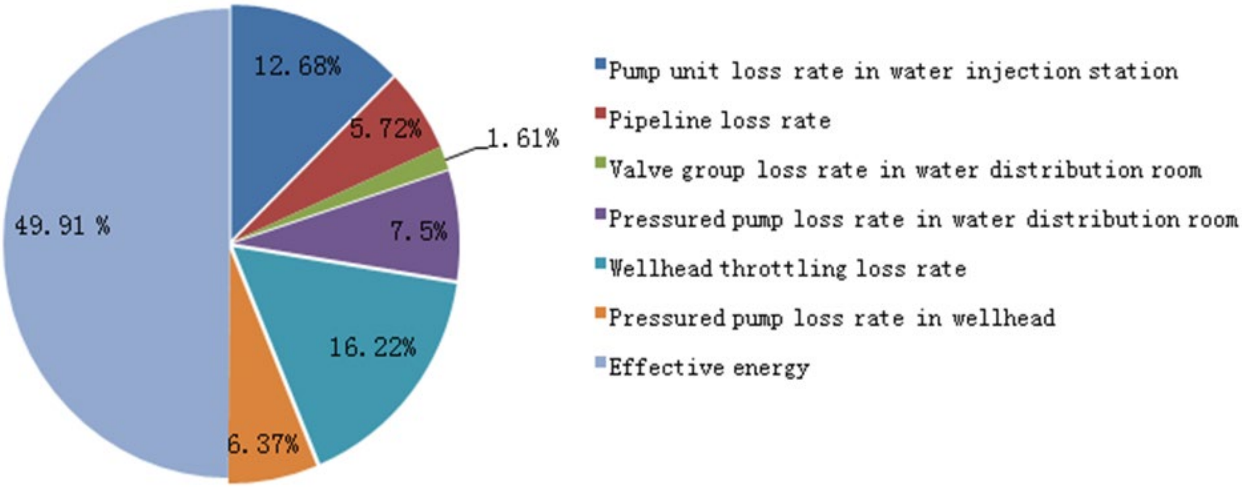

Fig. 7. Energy distribution diagram of pressurized water injection system after nergy saving transformation

Efficiency of the pressurized water injection system: $\eta = (W4 - W0) / (E1 + E2 + E3) = 49.91\%$, Single consumption of system is 6.76KW·h/m^3.

After energy saving transformation, the efficiency of the pressurized water injection system is increased by 5.63%, the consumption of water injection system is reduced by 0.86 KW / h/m. The annual power saving is 677968.8KW h according to the current water injection amount, and the electricity cost can be saved by 406.8 thousand yuan per year.

CONCLUSION

The principle of energy balance is used to study the energy use of the water injection system in detail, and it is clear that the energy distribution law is the basis for analyzing whether the energy use is reasonable and the energy-saving transformation of the system. According to the specific results of energy distribution calculation, reasonable energy-saving reform measures are proposed, which will help improve the efficiency of the system, reduce the unit consumption of the system, and then increase the profits of the oilfield enterprises.

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