The Successful Application of PCPs’ Personalized Design in Hailar Oilfield
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Abstract
Hailar Oilfield is a new block of Daqing Oilfield developed from the end of last century. In the beginning of the development, beam pumping unit was the only lifting method of the Oilfield. Due to the low pump efficiency and higher rod failure rate as well as the 2000m lift, beam pumping system was not as economic as other in blocks of Daqing Oilfield. As the result, PCP was put into production from 2005. Though all the four wells had a good performance with high pumping efficiency in the beginning, after several months’ operation, rod strings suffered from severe oscillation and resulted in fatigue failures in a short period. Theoretical and experimental study indicated that, high working temperature (85 centigrade) and special oil characteristics caused much higher swelling degree of elastomer than in other blocks, which led to the increment of interference fit and friction force between rotor and stator.

In the initial application, although pump parameter and elastomer formula were adjusted before treatment to reduce the swelling effect, these adjustments didn’t take into effect as predicted. In that case, a personalized PCP design was brought forward which gave an integrated methodology for PCP application in Hailar Oilfield. In this design, all the lifting parts from surface to downhole equipments were considered as a whole system. FEM analysis was applied to make a detailed description of the pump for different operating temperature. Based on deeper adjustment of elastomer and pump’s structure parameters, the optimum design of rod and other equipments were take into consideration as well. In the end of 2006, 4 new personalized design pumps were put into production. In the following year, despite of small oscillation in the first few days due to the influence of treatment water, all PCP systems performed stably with high efficiency.

Background
Hailar Oilfield located in the northeast of Inner Mongolia Autonomous Region, near the frontier of China and Mongolia. It was a continental facies deposit basin which was developed from 1980s. See Fig. 1. Till the mid of 2007, the oil production rate has reached 250,000 tons. In the beginning, the lifting methods of the oilfield were beam pumping system and bailing lift system. The production rate per well was around 10 m³/day, and many of them were under 5 m³/day. The lift of producers ranged from 1600m to 2500m, and temperature was from 70 to 90℃. Due to the low displacement and higher lift on the average, beam pump system and bailing lift system wasn’t so economic. In the beginning of 2005, one PCP well (Well#0) was put into production with 1400m lift. The system operated stably and was pulled out till the mid of 2006 due to the new development requirement of the block. According to the good performance of this case, PCP lifting technology was recommended to be applied in higher lift wells (above 1800m) in Hailar basin.

Pilot Test of PCP Lifting System
In 2006, a pilot test was implemented including 4 PCP wells in Hailar Oilfield from August to November. The pump efficiency was very high up to 90% in the beginning of the operation. But several weeks later, high fluctuate of operating loads were found in all the wells. See Fig. 2. Obvious oscillation could be observed from the surface polished rod and abnormal sound could be heard clearly, which indicated the pumps weren’t operated in the constant speed. Under this abnormal operating condition, rod and pump failures were frequent in the following several months. Up to April, 2007, Well#1 has a rod failure after one month operation. Well#2 has three rod failures in five months. Well#3 has two rod failures in two months. Except that Well#3 operated normally, all the other three wells’ average running life was around two months.
The Mechanism Study of PCP Failure in Hailar Oilfield

Study indicated that, the drastic oscillation of PCP rod string in Hailar Oilfield was the same as “Stick-Slip” effect in tribology theory. Stick-slip points to the unstable movement of a friction pair in case of constant driving speed and load. The friction force of stick-slip decreases with the increment of speed. It is an alternating friction force whose self-oscillation was maintained by the relations of oscillation speed and moving speed. “Stick-slip” was usually led by the following factors: 1) Friction factor was changed; 2) Rotating or moving speed was too low; 3) Rigidity of system was decreased.

According to the special characteristics of PCP failures in Hailar basin, a project was commenced which focused on three respects: 1) pump’s compatibility; 2) operating parameter’s influence, 3) rod string design.

-Pump’s Compatibility.
The traditional PCP products of company were designed for the central block of Daqing Oilfield where the lift was around 1000m and operating temperature was under 70°C. When PCP was applied in Hailar basin, a new developed elastomer was used with higher rated temperature of 90°C. Although it showed good results in the initial experiment in laboratory, the elastomer’s performance was still in doubt due to the big difference of operating conditions between laboratory and the oilfield.

And the lift of Well#0 was about 1400m. The operating temperature was around 70°C, while the latter 4 PCP pilot test wells were operated in 85°C. In addition, the operating temperature might be higher than 80°C due to the lower displacement. As the result, the temperature effect of elastomer might be underestimated. In order to verify the above ideas, more simulation experiments were carried out.

-Medium’s Influence on Elastomer.
Elastomer swelling experiments were implemented under the temperature simulating conditions in situ. See Fig. 3. Experiments showed that elastomer swelling process could be divided into three stages. In the first stage, elastomer swelled very quickly and the swelling ratio had a linear relationship with time. In the second stage, elastomer swelling ratio increased much slowly. And in the third stage, swelling ratio kept on a constant level. When the temperature was changed back to the original, a remaining swelling ratio could be observed.

Analysis indicated that, the elastomer swelling in the first stage was mainly caused by temperature effect while medium effect worked dominantly in the second stage. And the remaining swelling ratio was caused by medium effect.

Experiments indicated that temperature has a considerable influence on elastomer swelling ratio in more than 1800m lift wells which wasn’t understood exactly in the past. Under the influence of temperature, the interference fit of the pump increased considerably which led to the increment of operating torque, and the decrement of elastomer rigidity as well. These influence enhanced elastomer’s elastic lag effect which resulted in the oscillation of operating load.

-Medium Type’ Influence on Pump Performance.
Another PCP performance test was implemented by different mediums. Pump’s operating load was stable when lifting machine oil while it was unstable and oscillated periodically in case of lifting water. See Fig. 4. Analysis indicated that, the friction factor between rotor and stator in case of lifting water was much higher than lifting machine oil. Different friction factor resulted in stronger elastic lag effect of elastomer and then led to the oscillation of operating torque. In application, load fluctuate was more severe in the first few days due to high water cut of producing liquid. And after oil was produced, load fluctuate would be decreased obviously.

-Operating Parameter’s Influence.
The production rates of 4 PCP wells were all under 10m³/day. The highest production rate of Well#3 was 8.5m³/day. And Well#1 and Well#2 were only 3.2m³/day. Well #4 was 4.5m³/day.

Except Well#3, the dynamic liquid level of all the other three wells was near the pump due to low production rate. Hence the rotor and stator friction pair operated in non-liquid lubrication status in most cases, which would result in the change of friction factor. As the above introduced, that would enhance the tendency of “slip-stick” of the pump. As for Well #3, having a higher production, the pump operated in liquid-lubrication status which contributed a lot in its stable operation for a long time.

Moreover, all the wells operated under 50rpm. At this low rotating speed, “slip-stick” was easier to be found for PCP pump.

-Rod String Design’s Influence.
In Hailar Oilfield, the average lift was above 2000m, much higher than the average of Daqing Oilfield (around 1000m). In that case, rod rigidity would be lower which would enhance the tendency of pump’s “slip-stick” effect.

Having not understood all the above influence clearly, severe load fluctuate (”slip-stick”) was found in PCP pilot test in Hailar Oilfield. In that case, the frictional process of downhole system was the same as an adjusting system with feedback characteristics. The alternating oscillation speed led to an alternating friction force to maintain its self-oscillation by frictional effect, which resulted in the periodic load fluctuate of the system. That was the resource of frequent rod broken failures in the PCP pilot test in Hailar Oilfield.
PCP Personalized Design Methodology
Based on the above analysis, a set of PCP personalized design methodology was created.

-Personalized Design of Elastomer Formula.
According to simulation test results, it was believed that the previous high temperature resistance elastomer couldn’t meet the requirement of Hailar Oilfield. Thus, elastomer formula was improved which decreased the swelling ration considerably in operating conditions.

-Personalized Design of Pump Structure Parameters.
In order to improve the pump’s overall compatibility in Hailar Oilfield, structure parameters have to be changed with the improvement of elastomer properties as well. The goal of design was to decrease the friction force between rotor and stator as well as the influence of rotor’s oscillation without negative effect on pump’s lifting performance. FEM was implemented to describe the physical characteristics of PCP in application. According the simulating results, a series of personalized optimal design methods were created for pump structure parameters, such as interference fit and eccentricity. See Fig. 5.

-Rod String Optimal Selection.
After an overall estimation for the different sucker rod string, a type of special PCP rod string was determined to be used in Hailar Oilfield. This type of rod string has special design on improving the rigidity and anti-broken performance which could help to decrease rod failures effectively.

Application
From the end of 2006 to the mid of 2007, the PCP personalized design methodology was implemented in 4 wells (three wells were new). Apart from the small load oscillation in the first few days due to high water cut, all the PCP wells operated stably with high efficiency in the following operation. No periodic sound was heard from the surface again and small load oscillation could only be measured by sensor. See Fig. 6. Take the three wells in B block for example, the dynamic liquid levels were all near 1600m. The pump efficiency was around 85%. And the operating current amplitude ranged from 0.3 to 0.8A. All the systems had no oscillation on the surface.

Conclusions
1. In the stage of PCP pilot test in Hailar Oilfield, severe load oscillation was found which resulted in frequent rod fatigue failures. According to the mechanism study of “slip-stick” issue, three main factors were determined including: 1) Pump’s incompatibility; 2) operating parameter; 3) rod string design.
2. Through personalized design in adjusting elastomer formula and pump’s structure parameters, PCP’s performance was improved considerably. In addition, operating parameters design and rod string design were improved as well. And a set of personalized PCP design methodology was created for Hailar Oilfield.
3. Although the new PCP systems operated stably with high efficiency in application, the personalized design PCP methodology still needs to be improved and completed in the future.

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Reference
Appendix

Fig. 1-Map of Hailar Basin

Fig. 2-Well#1’s load curve in pilot test

Fig. 3-An example of medium’s effect on elastomer test
Fig. 4-An example of medium type’s effect on pump’s operating load test

Fig. 5-PCP’s FEM analysis result

Fig. 6-Operating Torque of Well#2