Study on leakage plugging agent for steam well casing of heavy oil injection

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Abstract. This paper analyses the causes of the casing leaks of heavy oil thermal recovery wells, and analyses the trapping and sealing methods used in the current oil fields and their existing problems. Aiming at the problems of poor temperature resistance, insufficient strength, short plugging period and high cost for traditional cement and polymer plugging agents, a high temperature resistant plugging agent suitable for plugging in steam injection wells has been developed. The performance of the plugging agent was analysed and evaluated. The research shows that the high temperature-blocking agent has high strength, high temperature resistance, and high salinity and easily injected. It can withstand temperatures up to 300 °C and strength above 90 MPa. The plugging agent can meet the application requirements of the steam injection well.

1. The introduction
In the process of heavy oil extraction by steam injection, the casing and cement ring are easy to be damaged due to the influence of high temperature and high pressure, thus causing casing leakage. The leakage of casing will seriously affect the normal production of oil well, and bring trouble to the later construction process. Aiming at the problems of poor temperature resistance and insufficient strength of the commonly used chemical-plugging agents, a high-temperature and high-strength high-temperature gel-plugging agent was developed in this paper. Experiments show that the new plugging agent has good temperature resistance and high strength and is suitable for use in heavy oil thermal recovery wells.

2. The cause of casing leakage
2.1. Electrochemical corrosion
When hydrogen sulfide gas, oxygen and carbon dioxide gas from an oil well dissolve in the liquid, an electrochemical reaction takes place in the casing, which in the long run can cause corrosion and damage to the casing. Hydrogen sulfide gas dissolved in the liquid will cause hydrogen embrittlement phenomenon in the casing, and high-strength steel will crack and damage due to embrittlement. Dissolved oxygen will also cause a certain degree of corrosion to the casing, even low concentration of oxygen will also cause a certain degree of corrosion to the casing, under the combined action of dissolved oxygen and water will cause iron corrosion.
2.2. Casing damage caused by geological factors
Before oilfield development, the stratum is in the original stress balance state. With the development of the oilfield, the stress in the stratum and wellbore is released, the original stress balance in the stratum is broken, the stress around the wellbore is re-distributed, and the casing is subjected to the concentrated stress from the rock. In addition, when the oil well starts to produce, under the condition of high temperature and pressure, the rock in the formation will expand or creep and the pressure on the casing will further increase. When the stress reaches or exceeds the yield strength of the casing material, the casing will be damaged.

2.3. Engineering factors
During steam injection, high temperature will affect the casing to some extent. There are two main aspects to this effect: first, continuous high temperature will reduce the yield strength of the casing; second, due to the alternations of steam injection and stop injection, the casing will constantly expand and contract. The continuous action of such alternating load will further reduce the yield strength of the casing. When the effective stress received by the casing reaches or exceeds the minimum yield limit at the corresponding temperature, fatigue cracks and compression deformation may occur in the casing, which will eventually lead to damage and leakage of the casing. Under the condition of continuous high temperature, the strength of cement will be reduced to some extent. The high pressure generated by steam injection is likely to crush the cement ring, resulting in uneven stress outside the casing and channelling.

3. Leakage sealing technology and existing problems of steam injection well casing
At present, physical and chemical methods are mainly used to seal the leakage point in order to restore the normal production of oil Wells. This includes the use of small casing reinforcement, casing subsidies, cement plugging, packer isolation and other technologies.

3.1. Mechanical plugging technology
The technology of small casing reinforcement and casing subsidy is one of mechanical plugging technology. The engineer will seal the special casing to the place where the leakage occurs. Under the action of cement cementing force or mechanical force, the subsidy casing and the leakage casing are closely bonded together to plug the leakage point. However, these two methods will cause casing diameter change in the process of use, which will bring inconvenience to the later construction. However, the sealing period of the packer is short and the setting failure is easy to occur, which leads to the increase of the cost.

3.2. Cement plugging technology
Cement plugging agent is a kind of plugging agent, which is widely used at present. Engineers inject specific cement plugging system into the formation, and after the cement particles consolidate, they form a hard cement ring around the casing and seal the leakage point. However, cement-plugging agent has many problems, such as large brittleness of solidified body, high filtration loss, poor temperature resistance, insufficient chemical shrinkage and tensile resistance, and low bonding strength with casing and formation. It is easy to fail under high temperature and cause secondary leakage.

3.3. Polymer plugging agent
At present, the polymer-plugging agents commonly used in oilfield mainly include gel-plugging agent, resin-plugging agent and modified vegetable tannin extract plugging agent. This kind of blocking agent is mainly composed of main agent, crosslinking agent and initiator. When the plugging agent system is injected into the formation, under certain pressure and temperature conditions, it will gradually form a three-dimensional space network structure, and eventually form a high-strength polymer, which will be cemented with the casing cement ring to plug the leakage point. However, polymer-plugging agent cost higher, poor temperature resistance, in high temperature conditions easy to fail.
4. High temperature blocking agent

In order to solve the problem of poor temperature resistance and low strength of granular cement plugging agent in the sealing of high temperature steam injection leakage well, it is necessary to use high temperature plugging agent in the high temperature thermal production well. The commonly used high-temperature plugging agent in oilfield mainly includes solid particle high-temperature plugging agent, high-temperature foam gel system plugging agent, high-temperature resin plugging agent and high-temperature gel plugging agent [3].

4.1. High temperature gel plugging agent

The plugging agent studied in this paper is a kind of high temperature resistant gel plugging agent. High temperature gel plugging agent is made of polymer and crosslinking agent under certain conditions. At present, the commonly used macromolecular substances include HPAM, the commonly used crosslinking agents include high metal cation (aluminium ion, chromium ion, etc.), phenolic prepolymer, polyethylenimine, etc. However, when the temperature is higher than 100℃, the molecular chain of the conventional polymer will break seriously and the strength of the polymer will be greatly reduced. In order to enhance the temperature resistance of polymer gels, the following methods can be adopted: introducing the heat-resistant group into the polymer or adding the thermal stabilizer component into the gel-forming solution [4, 5].

4.2. A new type of high temperature resistant gel blocking agent

4.2.1. Plugging mechanism of plugging agent. Silicone polymer is a kind of compound with silicon-oxygen bond as main chain and other organic groups as branch chain. The polymer has excellent properties of high temperature resistance, insulation and physiological inertia [6].

HT400 blocking agent is a kind of high temperature-blocking agent. Organic silicon molecules are added into the gel system to make it have the excellent performance of organic silicon, thus forming a new kind of gel high temperature blocking agent. The blocking agent is a pale yellow liquid at room temperature (Figure 1.).

Figure 1. HT400 high temperature plugging agent.

When the modified silicone gel high-temperature blocking agent enters the formation, a large number of active groups in the organic structure main agent in the blocking agent will react quickly with the active groups on the rock surface and the surface of the casing, and the blocking agent will adsorb on the rock and the surface of the casing. The organic groups form a three-dimensional space network structure through mutual adsorption and bridging, and agglomerate other components in the plugging agent. With the continuous increase of network structure, the structure density and strength gradually increase. At the same time, the gel material in the plugging agent solidifies under stratigraphic conditions and crosslinks with organic structural agents, to form a polymer with high strength and cementing interface. In this way, the plugging agent can stay firmly in the leakage layer, to form a good seepage resistance in the leakage layer and prevent the further occurrence of leakage.
4.2.2. **Performance test of plugging agent.** HT400 plugging agent is an organosilicon modified gel-plugging agent, which has the following characteristics:

- **Good right Angle thickening performance (Figure 2.).** By adjusting the amount of curing agent to adjust the curing time, to adapt to different well conditions. The curing process of plugging agent is divided into two steps. The first part is the adhesive forming time of plugging agent. During this period, the plugging agent has a violent thermal polymerization reaction and the temperature of the system rises rapidly, but the plugging agent still has a certain fluidity; the second part is the curing time. The thermal polymerization reaction temperature of the plugging agent system reaches the highest, the fluidity of the system gradually decreases, the hardness gradually increases, the temperature of the system gradually decreases until the temperature drops to the temperature of the reaction environment, and the plugging agent is completely cured.

- **Good fluidity performance.** HT400 is a pale yellow, transparent and odourless liquid at room temperature, with a viscosity of 60 mP∙s and a density of 1.05 g/cm³. When the plugging agent enters the stratum, it will preferentially enter the highly permeable layer and block the big hole.

- **HT400 plugging agent has good resistance to high and low temperature.** It can maintain a high strength under the condition of -20℃~400℃, and the interface cementing strength can also maintain stability under the continuous action of high temperature and high pressure, and the strength is kept above 90MPa.

- **It has good salt resistance and alkali resistance, and can maintain the stability of structure and strength in high salinity or high alkaline environment.**

![Figure 2. Curing process of HT400 high-temperature blocking agent.](image)

**Experimental process:**

The salinity of simulated water used in the experiment is similar to that of formation water in ShengLi oilfield. The plugging agent samples were placed at 80℃ to form glue and solidify. Then, the samples were immersed in simulated water with different concentrations and put into a high-temperature and high-pressure reactor to maintain a temperature of 180 ℃and a pressure of 8MPa for 24h. Finally, take out the sample and measure the strength of the sample.

According to the experimental results in table 1, although the strength of plugging agent gradually decreases with the increase of salinity, when the salinity is greater than 12000mg/L, the strength of plugging agent can still remain above 90MPa, which fully meets the requirements of the oil field.

| Salinity (mg L⁻¹) | 8000   | 10000  | 12000  | 14000  |
|------------------|--------|--------|--------|--------|
| Strength of plugging agent (MPa) | 98.7   | 94.3   | 90.4   | 88.9   |

Table 1. Influence of salinity on the strength of plugging agent system.
According to the data in Table 2, the strength of the plugging system gradually decreases with the increase of alkalinity. However, the strength of plugging agent can still remain within the safe range (above 90MPa).

Table 2. Influence of alkalinity on compressive strength of plugging agent system.

| Alkalinity (gL⁻¹) | 0.02  | 0.04  | 0.06  | 0.08  | 0.1  |
|------------------|-------|-------|-------|-------|------|
| Strength of plugging agent (MPa) | 98.9  | 97.3  | 96    | 93.4  | 93.3 |

5. Conclusion
According to the research content of the article, we can get the following conclusions.
- Aiming at the problem of casing leakage in steam injection well, the advantages and disadvantages of several kinds of commonly used plugging agents are analysed. A high temperature resistant and high strength plugging agent was developed.
- A series of experiments were conducted to evaluate the performance of HT400. The effects of various factors on the properties of plugging agent were tested. The temperature resistance of plugging agent exceeds 300°C and the strength exceeds 90MPa.
- Compared with the traditional plugging agent, HT400 has the characteristics of good temperature resistance, easy to be injected into the formation, high plugging strength and salinity resistance, which fully meets the environmental requirements of the steam injection well.

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