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Colloidal Gas Aphron (CGA) Drilling Fluid: A Drilling Technique to Protect EGS Geothermal Reservior

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ABSTRACT

Hot dry rock (HDR) has a high-temperature reservoir and huge resources and is considered to be clean and renewable energy that can undertake the new energy revolution. There are many technical bottlenecks in the industrial development of HDR by using the enhanced geothermal system (EGS) technology. By analyzing EGS cases and drilling fluid technology, this paper proposes that colloidal gas aphron (CGA) drilling fluid can effectively solve the serious leakage problem in low-pressure blocks, and has a geothermal reservoir protection effect. This paper summarizes the research progress of high-temperature resistant CGA drilling fluid in the past 10 years, as well as the application status in the engineering site. The applicability of CGA drilling fluid in EGS was comprehensively analyzed and discussed, and the future research direction of CGA drilling technology was proposed.

1. HOT DRY ROCK (HDR) AND ENHANCED GEOTHERMAL SYSTEM (EGS) TECHNOLOGY

Geothermal resources are divided into hydrothermal geothermal and hot dry rock (HDR) geothermal according to their occurrence state, and can be divided into low-temperature (<90℃), medium-temperature (90~150℃), and high-temperature (≥150℃) resources according to the reservoir temperature. HDR refers to the high-temperature rock mass with no or only a small amount of fluid and a temperature higher than 180℃, whose heat energy can be utilized under the current technical and economic conditions[1]. According to the 2006 Geothermal Energy Research report of MIT, HDRs developed by the Enhanced Geothermal System (EGS) is the key to the country's energy transformation[2].

Drilling is the only means to explore and develop HDR. However, the high-temperature conditions of geothermal drilling are complicated and the drilling cost is high, which seriously restricts the economic development of geothermal. According to statistics, the drilling cost of HDR accounts for about 60% of the total development cost[3]. In addition, the pores, cracks, or even caves are highly developed in the reservoir formation, and the formation pressure coefficient is low. In some areas, the equivalent density of formation pressure is lower than that of hot water[4], and the use of conventional water-based drilling fluid will inevitably cause losses. As shown in Table 1, many HDR projects are facing a serious problem of lost circulation. It not only brings the well instability, sticking, and the waste of drilling fluid and materials, but also caused reservoir damage. A small amount of reservoir damage can lead to significant loss of productivity, economic losses, and even wellbore abandonment. During production, additional costs are needed to restore the geothermal reservoir permeability. Therefore, developing a drilling fluid system with a reservoir protection effect for HDR is necessary and urgent.

Table 1: International typical HDR geothermal projects.

Project	The problem of loss circulation	Reservoir temperature (℃)
Qinghai Gonghe Project, China[5]	High temperature drilling causes serious increase of the filtration of drilling fluids.	236
Soultz Project, France[6]	The leakage almost accompanies the whole drilling process, and the maximum leakage rate is 20m^3/h.	200
Fenton Hill Project, USA[7]	The drilling cost was increased by 10-20% due to the leakage and other problems.	>200
Cooper Project, Australia[8]	About 60% of the drilling time of Well Habanero 1 was spent on handling lost circulation	>250

2. CHARACTERISTICS AND ADVANTAGES OF COLLOIDAL GAS APHRON (CGA) DRILLING FLUID

2.1 Underbalanced drilling fluid

In view of the serious lost circulation problem of geothermal drilling, and the need to reduce drilling costs and protect reservoirs, New Zealand Geothermal Energy Company took the lead in using the underbalanced drilling technology in Okari, Kenya, and Honshu

Island, Japan during the 1970s~1980s. By creating a bottom hole pressure lower than or close to the formation pressure in the annulus, the leakage problem under the effect of pressure difference was effectively avoided, Subsequently, it was successfully applied in geothermal drilling around the world[9-12].

In 2009, China Great Wall Drilling co., LTD successfully applied the foam drilling technology when conducting high-temperature geothermal drilling in the OLKARIA area of Kenya. By reducing the pressure on the bottom hole, CGA drilling fluid effectively prevented leakage and sealed the fractures, which maximized protected the reservoirs. It also improved the drilling speed and created a new record of Chinese drilling companies in Kenya's drilling history (the drilling cycle is 40 days). However, the project team also pointed out that the special equipment used in air foam drilling significantly increased the cost[13].

2.2 Colloidal gas aphron (CGA) drilling fluid

With the development and innovation of underbalanced drilling technology, the Colloidal Gas Aphron Drilling Fluids (CGA drilling fluid) technology can be used for reference and promotion from oil and gas drilling wells. CGA drilling fluid system is developed by American MI Drilling Fluid Company and Acti Systems Company for near/underbalanced drilling. It has the advantages of underbalanced drilling (good cuttings carrying, fast penetration rate, obvious reservoir protection effect, and long bit service life). It also effectively solves the problem of low stability of conventional foam drilling fluid and the need for booster equipment. CGA technology has been successfully applied in thousands of wells drilled in the depleted oil and gas reservoirs and low-pressure areas, and has achieved good economic benefits, which is applicable in geothermal drilling for the following reasons:

1) The aphrons in CGA drilling fluid are generated by mechanical agitation or pipeline shearing of surfactants and biopolymers at a speed of higher than the critical speed (>5000rpm). Compared with traditional underbalanced drilling fluid, CGA does not require additional pressurizing equipment, which reduces the cost of equipment leasing;

2) CGA drilling fluid can adjust the bottom hole pressure by controlling the density of drilling fluid, so as to minimize the leakage effect under the effect of differential pressure and its damage to the formation.

3) As shown in Figure 1, a large number of independent rigid microbubbles with the diameter of ~100μm are in the CGA system. The aphron has a structure of "one core and three membranes". This unique multi membrane structure makes aphrons have extremely high stability and compression resistance. The stable existence of the aphrons under HTHP environment is of great significance for its successful application in the drilling field. More importantly, aphrons will accumulate in the formation pores/fractures ahead of the liquid to achieve temporary sealing. There is almost no affinity between aphrons and the formation rock surface, so it can be easily removed through the reverse drainage during the production stage[14,15].

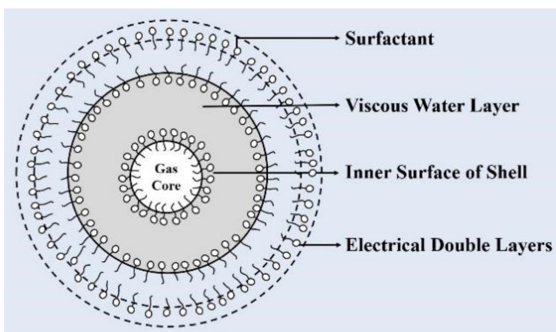

Figure 1: Structure of aphrons.

3. RESEARCH AND APPLICATION STATUS OF CGA DRILLING FLUID

3.1 Field application

CGA drilling fluid was first used in Fusselman Oilfield in western Texas in 1998. In this area, there was leakage in the deflection section of horizontal wells. After the xanthan gum drilling fluid was converted into CGA drilling fluid, the pump pressure quickly recovered, and the rest of the well was successfully drilled. Later, the CGA drilling fluid system successfully solved the problem in the dolomite vein zone with large underground cracks and severe well leakage in northern Texas[16,17]. CGA drilling fluid has been successfully applied in depleted oil and gas reservoirs and leaky and collapse-prone formations in the TBK gas field in Iran, old oil fields in northwest Venezuela, Netherlands block in the North Sea, Poza Rica oil field in Mexico, Alberta in Canada and other regions. By 2007, about 300 wells in North and South America had been successfully constructed using CGA drilling fluid. However, in recent years, the global drilling business has been greatly impacted by the fluctuation of international crude oil prices, and there are few reports on the field application of CGA drilling fluid.

As shown in Table 2, with the increase of field application experience, the CGA drilling fluid system has been continuously optimized based on the geological conditions, and a series of CGA systems with controllable density, temperature resistance, pollution resistance (calcium/salt/oil/cuttings) and anti-collapse performance have been developed, which has successfully solved the problems of seriously lost circulation, reservoir damage, and other drilling difficulties that are often faced in the depleted reservoirs and low-pressure areas.

CGA technology meets the production requirements of green, safe and fast drilling, and has achieved good economic benefits. It can also be concluded that CGA technology has been applied in drilling oil, gas, and coalbed methane, but it has not been practiced in geothermal drilling, especially HDR drilling.

Table 2: Application of CGA drilling fluid in the drilling field.

Time	Formula	Properties of drilling fluid	Field application
2016[18]	Self-synthesized foaming agent LF-2, foam stabilizer HMC-1, viscosity increaser HT-XC, fluid loss agent KH-931 and SMP-II	The density of drilling fluid is 0.85~0.95g/cm^3, the filtration is lower than 7.4mL. The system has strong shale inhibition and sealing ability, and its temperature resistance is 150°C.	This system is used in 21 wells of Cicai, Shencai and Lengjia Oilfield, with the maximum well depth of 4005m and the maximum bottom hole temperature of 141.5°C. Compared with the adjacent wells, the penetration rate of the same formation is increased by 70% after using CGA drilling fluid. The ignition is successful for many times, which significantly improves the success rate of exploration and development.
2017[19]	Self-synthesized foaming agent GWFOM-LS, foam stabilizer xanthan gum and PAC-LV	The density of drilling fluid is between 0.70 and 0.96 g/cm^3. The system has resistance to 10%NaCl, 0.5%$CaCl_2$ and high-temperature(130°C).	The problem of serious leakage, unsafe production and geological data acquisition caused by high fracture development in Chad buried hill reservoir has been solved by using CGA technology. Compared with adjacent wells using water-based drilling fluid, the average diameter expansion rate has decreased by 2.93%.
2021[20]	Gemini anionic foaming agent (LHPF-1) and the foam stabilizer xanthan gum	The density of drilling fluid is 0.93~0.95 g/cm^3. The sealing rate and permeability recovery are higher than 90%, and it can resist 7% cuttings/coal dust pollution.	CGA system was successfully applied to coal measure formation without any complicated downhole accidents. The gas coincidence rate is high and the wellbore maintained stabile. The filtration volume is less than 5mL. Compared with the adjacent wells using water-based drilling fluid, the average well diameter expansion rate is reduced by 4.1%.

3.2 Experimental research

At present, researchers mainly focus on the stability and diameter distribution of microbubbles, rheological properties, sealing performances of microbubbles in porous media. Besides, some scholars developed new treatment agents and explored the application in CGA systems, which has made breakthroughs in temperature resistance.

The research team represented by Xiuhua Zheng and Wenxi Zhu is committed to developing a high-temperature resistant CGA system. In 2020, the characteristics of CGA drilling fluids prepared with attapulgite at 25~180°C were investigated. Results show that the addition of attapulgite significantly reduces the average diameter of aphrons and improves the bubble size distribution of CGA fluids, which is conducive to the stability of CGA fluids. The study also pointed out that the temperature resistance of the system was not more than 120°C due to the viscosity reduction of xanthan gum, and the development of a new tackifier was the key to improving the temperature resistance[21]. Then, the team synthesized the modified polymers XG-g-AAA and EST based on xanthan gum or starch in 2021. The temperature resistance of the CGA system prepared with XG-g-AAA or EST as the tackifier is not less than 180°C[22,23]. Sodium dodecyl sulfate (SDS) is commonly used as a foaming agent in CGA systems, which has poor thermal stability and salt resistance. It has been reported that SDS fails due to precipitation under high salinity, and the thermal weight loss at 177°C is up to 30-40%. Then, the foaming ability of a novel zwitterionic surfactant (AGS-8) was studied. AGS-8 was found to be a promising foaming agent in the drilling of high-temperature salt-gypsum formations. Results show that AGS-8 generated stable foams after aging at 180°C for 16 h or in saturated salt solution (36%wt NaCl) after 150°C aged[24]. The development of new treatment agent effectively improved the high-temperature performance of CGA system.

4. CONCLUSION AND EXPECTATION

4.1 Technical difficulties of applying CGA drilling fluid in the HDR drilling

1) The long-term high-temperature environment makes the drilling fluid and treatment agents easy to be degraded and ineffective, and it is difficult for the drilling fluid to balance the formation pressure, carry cuttings, protect wells, and other functions. According to the application and research status of the CGA system, the field application temperature of CGA drilling fluid is no more than 150°C, and the temperature resistance of relevant treatment agents has reached 180°C. However, the conversion from experiment to practical application still needs further work. In a word, the high-temperature resistance of CGA drilling fluid used in HDR geothermal wells is the first breakthrough.

2) With increasingly strict environmental regulations, drilling fluids need to be biodegradable, green, and non-toxic. The traditional drilling fluid system often releases formaldehyde and other toxic substances under a high-temperature environment. The discharge of drilling fluid also has bad effects on the ecological environment and formation. Therefore, the development of drilling fluids tends to be environmental-friendly.

4.2 Expectation

Researchers and engineers at home and abroad have been working on the design and development of HT/ultra-HT drilling fluid treatment agents and have made progress in laboratory experiments. The author believes that, with the development of environment-friendly high-temperature resistant surfactants and tackifiers, the CGA system for HDR drilling will be developed. The popularization and application of CGA technology are helpful to protect geothermal reservoirs and reduce drilling costs, thus promoting the economic exploration and development of geothermal resources.

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