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Preparation of High Water Carrying Foam System and Its Dynamic Water Carrying Performance

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ABSTRACT

Since China proposed to achieve carbon peaking in 2030 and carbon neutrality in 2060, the development of geothermal energy in China has attracted much attention. Geothermal energy resources are large, clean, and have a good economy. Aiming at the problem of formation water outlets in geothermal wells, the research of foam systems with high water carrying capacity is put forward. Firstly, the concept of high water carrying foam system was proposed to solve the common water carrying problem in hot spring Wells, and a water-carrying method combining solid-phase water-carrying agent and foam was proposed. Secondly, the foaming agent, stabilizing agent, and solid-phase water-carrying agent in the high water carrying foam system were screened to determine the formula of the high water carrying foam system. Finally, the dynamic water carrying performance of this water carrying method is studied. The results show that (1) the foam system with high water carrying capacity formed by the combination of solid phase water carrying agent and foam has better water carrying capacity; (2) the foam system has the best dynamic water carrying capacity when the liquid holding rate is 18.9%-19.6%, and the dynamic water carrying capacity is as high as 84%.

1. INTRODUCTION

China proposed carbon peak by 2030 and carbon neutral peak by 2060. Vigorously developing clean energy has become a trend. As a new type of renewable energy, geothermal resources mainly include shallow geothermal energy, hydrothermal geothermal resources, and dry hot rock geothermal resources, which are mainly utilized by geothermal Wells.

Hot spring well is also a geothermal well, generally with an air DTH hammer drilling process. In the process of air DTH hammer drilling geothermal well, the problem of formation water is inevitable. [1,2] In this paper, a method of combining solid-phase water-carrying agents with foam water carrying agents is proposed to improve the existing foam water carrying method. The high water carrying foam system is composed of solid-phase water-carrying agents, foaming agents, and stable foam agents.

Super absorbent resin(SAP)[3] is a kind of functional polymer material with a strong hydrophilic group and a certain crosslinking degree developed in recent years. It can absorb water hundreds of times to thousands of times its weight, non-toxic, harmless, and pollution-free. Its water absorption capacity is very strong, water retention capacity is very high, the water absorption can not be a simple physical method of extrusion, and can repeatedly release water, water absorption. In this paper, super absorbent resin (SAP) was selected as the solid phase water carrying agent of high water carrying foam system.

In this paper, a Waring Blender method was used to screen and determine the concentration of foaming agents and stable foam agents in foam system using dynamic water carrying rate and half-life as measurement indexes. [4] Taking water absorption ratio as the measurement index, four types of super absorbent resin (SAP) were selected as the candidate materials of solid-phase water-carrying agent, and their water absorption ratio was tested and compared. Finally, HD711 SAP was selected for the concentration test. After repeated experiments, it was determined that the SAP concentration in the foam system had the best water carrying effect when it was between 0.025% and 0.1%. The final formulation of high water carrying foam system can reach 84% dynamic water carrying rate at room temperature.

2. EXPERIMENTAL PROCESS

2.1 Experimental instruments and materials

The main experimental instruments used in this paper are high-speed mixer for drilling fluid and a foam dynamic water carrying test device.[5] Among them, the dynamic water carrying performance test device is designed and assembled according to the device in standard SY/T5716-1995, as shown in Figure 1. The foam liquid is placed in the foam producing tube on the left, and nitrogen is passed through the bottom of the tube. After nitrogen contacts with the liquid level, foam is generated, and the water content of the foam in the collecting device on the right is the foam carrying water. The dynamic water carrying capacity of foam is generally measured by the water carrying capacity within 15min of ventilation.[6]

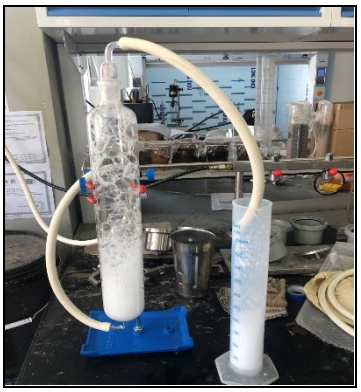

Figure 1: Dynamic water carrying device

The experimental materials in this paper mainly include foaming agents, stable foam agents, and solid-phase water-carrying agents. SDS, ADS, AS, CAB, OP-10, and AES are selected AS foaming agents for an experiment, and XC and CMC are selected AS foam stabilizers for the experiment. Four types of SAP, HD711, HD760, HD128, HD180, were used as research objects.

2.2 Preparation of high water carrying foam system

In the preparation of high water carrying foam system, the liquid holdup, half-life, and dynamic water carrying rate of foaming agent and foam stabilizer were measured by using Waring Blender[7] and dynamic water carrying device to measure the water carrying capacity and stability of foam, and the formulation of foaming agent and foam stabilizer for high water carrying foam system was determined.[8,9] Secondly, the water absorption performance of different kinds of SAP was tested, and the SAP with a higher water absorption ratio was screened out. Finally, different concentrations of SAP were added into the foam to test the dynamic water carrying performance, to screen out the optimal concentration of SAP, and get the final formula of the high water carrying foam system.

2.3 Dynamic water carrying performance test

The solid phase water-carrying agent with good water absorption performance was added to several foaming agent solutions with high dynamic water carrying rate, and the dynamic water carrying device was used to measure the dynamic water carrying performance of the foaming agent solution with solid phase water-carrying agent[10,11], proving that the combination of solid phase water-carrying agent and foam has universal applicability. The dynamic water carrying performance of high water carrying foam system with solid phase water carrying agent was analyzed according to several groups of experiments.[12]

3. RESULTS AND DISCUSSION

3.1 High water carrying foam system

The preparation of high water carrying foam system was carried out according to method 2.2. The evaluation results of the liquid holdup rate of the foaming agent are shown in Table 1. The evaluation results of the dynamic water carrying rate of the foaming agent are shown in Table 2.

Table 1: Foaming volume and liquid holding rate of foaming agent

	SDS		ADS		AS		OP-10		CAB		AES	
Content (%)	Foam Volume (ml)	Liquid holding rate %	Foam Volume (ml)	Liquid holding rate %	Foam Volume (ml)	Liquid holding rate %	Foam Volume (ml)	Liquid holding rate %	Foam Volume (ml)	Liquid holding rate %	Foam Volume (ml)	Liquid holding rate %
0.1	-	-	590	16.9	-	-			410	24.4	550	18.2
0.2	420	23.8	530	18.9	-	-			490	20.4	510	19.6
0.3	520	19.2	430	23.3	440	22.7			510	19.6	550	18.2
0.4	530	18.9	500	20	420	23.8			530	18.9	580	18.2
0.5	550	18.2	540	18.5	430	23.3	440	22.7	560	17.9	590	17.2
0.6	550	18.2	500	20	420	23.8	470	21.3	510	19.6	580	18.2
0.7	540	18.5	540	18.5	300	33.3	510	19.6	530	18.9	550	18.2
0.8	520	19.2	440	22.7	300	33.3	540	18.5	520	19.2	560	18.2
0.9	520	19.2	430	23.3	350	28.6	570	17.5	510	19.6	540	18.5
1.0	520	19.2	550	18.2	400	25	530	18.9	540	18.5	510	19.6

According to the experimental results, 0.2%SDS, 0.3%ADS, 0.3%-1.0%AS, 0.5%-0.6%OP-10 and 0.1%-0.2%CAB all have high liquid retention.

Table 2: Dynamic water carrying rate of foaming agent

Foaming agent	Content（%）	Dynamic water carrying rate（%）
SDS	0.2	80
	0.4	15
	0.6	5
	0.8	4
AS	0.2	65
	0.4	75
	0.6	65
	0.8	57.5
ADS	0.2	60
	0.4	15
	0.6	30
	0.8	4
OP-10	0.2	70
	0.4	64
	0.6	58
	0.8	65
CAB	0.2	60
	0.4	78
	0.6	77.5
	0.8	74
AES	0.2	72.5
	0.4	60
	0.6	39
	0.8	20

According to the dynamic water carrying experiment, 0.2%SDS has the highest dynamic water carrying rate of 80%. Considering liquid holding rate and dynamic water carrying performance, 0.2% SDS was selected as the foaming agent.

The evaluation results of foam stabilizer are shown in Table 3.

Table 3: The half-life of stable foam agent

Stable foam agent	Content(%)	Half-life(min)
XC	0.2	36
	0.4	90
	0.6	＞24h
CMC	0.2	8
	0.4	10
	0.6	23

According to the experimental results, the foam stability of XC is better than CMC. The half-life of 0.2%XC is 36 minutes, which meets the need of stabilization time for high water carrying foam system. Therefore, the foam stabilizer formulation selected in this paper is 0.2%XC.

The evaluation results of the water absorption performance of SAP are shown in Table 4.

Table 4: Water absorption ratio of SAP

SAP	Water absorption ratio in 1 min(g/g)	Water absorption ratio in 3 min(g/g)	Water absorption ratio in 5 min(g/g)	Water absorption ratio in 10 min(g/g)	Water absorption ratio in 20 min(g/g)
HD711	139	153	175	186	199
HD760	83	128	146	155	172
HD128	144	147	148	146	143
HD180	102	154	166	182	186

According to the experimental results, SAP of HD711 model and HD180 model has high water absorption ratio. The HD711 does better, with nearly 200 in 20 minutes. HD711 SAP was selected as the solid-phase water-carrying agent in the high water carrying foam system. Different concentrations of SAP were added into 0.2%SDS foaming agent solution to test dynamic water carrying performance, and the results were shown in Table 5.

Table 5: Dynamic water carrying capacity of SAP

SAP content（%）	Dynamic water carrying rate（%）
0.025	81
0.05	84
0.075	76
0.1	72

According to the experimental results, both 0.025% SAP and 0.05%SAP can promote the dynamic water carrying rate of the foam system, and 0.05%SAP can increase the dynamic water carrying rate of the foam system by 4%. Therefore, 0.05%SAP (HD711) was selected as a solid-phase water-carrying agent to be added to the foam system.

According to the above evaluation results, the formula of high water carrying foam system was finally determined as 0.2%SDS+0.2%XC+0.05%SAP(HD711), and the dynamic water carrying rate of the system was 84%.

3.2 Water content and dynamic water carrying rate of foam

In the evaluation and screening of foaming agents, the water content and dynamic water carrying rate of several different foaming agents were measured respectively. Through the experiments in Table 1 and Table 2 and the observation and study of the foam morphology in the foam dynamic water carrying device, the relationship between the foam water content and dynamic water carrying rate was obtained: When the foam carries water with different water content, if the water content is too high, the foam volume is small, the foam quality is poor, and the suspension capacity is poor, resulting in poor water carrying effect (as shown in Figure 2).

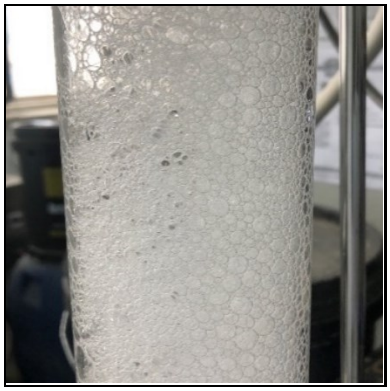

Figure 2: Foam with high water content

If the water content is too low, the foam quality is good, the structure is uniform and stable, but the water carrying speed is slow at the same time. Poor efficiency and poor water carrying effect (as shown in Figure 3).

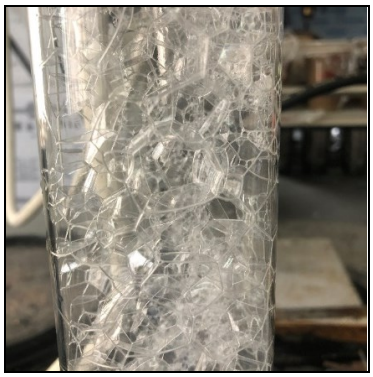

Figure 3: Foam with low water content

When the liquid holding rate of foam is 18.9%-19.6%, some foam volumes are large and some are small (as shown in Figure. 4). One part of the small foam has high water content and is responsible for ensuring water carrying efficiency; the other part of the large foam has good foam quality and is responsible for lifting and suspending the foam with high water content and carrying it up. Such foam system has strong water carrying capacity and high efficiency.

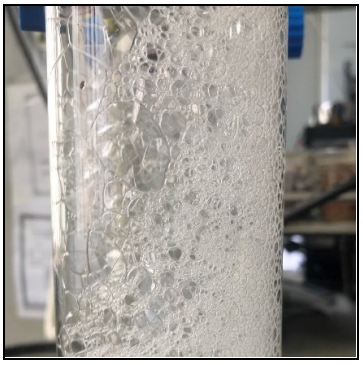

Figure 4: Foam with liquid holding rate of 18.9%

3.3 Dynamic water carrying rate of high water carrying foam system

Dynamic water carrying performance test of high water carrying foam system was carried out according to method 2.3. The results are shown in Table 6.

Table 6: Dynamic water carrying performance of high water carrying foam system

Foaming agent	SAP content(%)	Dynamic water carrying rate(%)
0.2%SDS	Control	80
	0.025	81
	0.05	84
	0.075	76
	0.1	72
0.4%AS	Control	75
	0.025	76
	0.05	78
	0.075	70
	0.1	65
0.4%CAB	Control	78
	0.025	76
	0.05	80
	0.075	71
	0.1	67

It can be concluded from the experiment that SAP of different concentrations can improve the dynamic water carrying performance of different foams. SAP will turn into crystal particles after absorbing water. When the SAP concentration is too high, too many crystal particles will sink at the bottom of the tube and be difficult to carry out (as shown in Figure 5).

Figure 5: SAP crystal particles settling at the bottom of the tube

SAP with a concentration of 0.05% can not only help water carrying, but also be easily carried out by foam, which has the best dynamic water carrying effect (as shown in Figure 6).

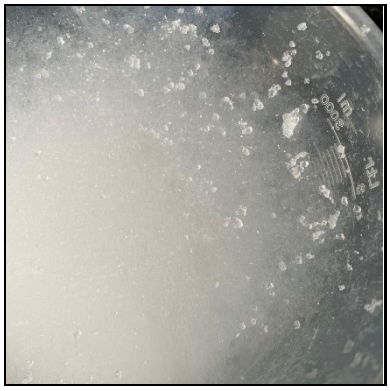

Figure 6: SAP crystal particles are carried out

4. CONCLUSION

Based on the above studies, the following conclusions can be drawn:

(1) Combining SAP with foam, the formulation of high water carrying foam system is 0.2%SDS+0.2%XC+0.05%SAP(HD711).

(2) The traditional evaluation method of foaming agent foaming ability is not suitable for the screening of water-carrying foaming agents, it is not the case that the foaming agent with stronger foaming ability will produce stronger water-carrying capacity. The foam carrying capacity of high water content is poor, and the foam carrying efficiency of low water content is poor. Generally, the foam system with a liquid holding rate of 18.9%-19.6% has better dynamic water carrying capacity.

(3) High water carrying foam system is a solution obtained by combining solid-phase water-carrying agent with foam. Adding SAP into different foaming agent solutions can enhance the dynamic water carrying performance of the foam system, so it can be seen that the combination of SAP and foam water carrying method has certain feasibility.

ACKNOWLEDGMENTS

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REFERENCES

[1] Wang Zhe, Zhang Yong, Jiang Rongqing. Research status of foam DTH drilling technology at home and abroad [J]. West China Exploration Engineering,2001,(06):95-96.

[2] Chen Etiquette. Theory and Practice of Foam and Foam Drilling Technology [D]. Chengdu University of Technology,2004.

[3] Wu Yifan. Research progress and development trend of super absorbent resin [J]. New chemical materials,2019,47(05):23-26+31.

[4] Li Bing, Du Jie, Gao Yufeng, Ma Wenhao. Journal of southeast university (natural science edition),2020,50(04):651-657.

[5] Yijun Yang, Jinchang Wang, Ruili Zhou, Ping Wang, Xiaojun Fang, Weiran Wu, Weifeng Xu, Xuzhu Luo, Xueqi Cen. Performance evaluation and field test of a new efficient foaming agent [J]. Sino-foreign energy,2019,24(05):53-57.

[6] Zhang Teng, Gao Wangbin, Liu Yang, Lin Jincheng, Yang Qin, Zhao Hongliang. Petrochemical application,2018,37(12):52-56.

[7] Yarbane El Houssein. Experimental study on foam stability and defoaming method [D]. Jilin University,2007.

[8] ZHANG Hui. Study on properties of betaine water-based foam and its application in foam drilling [D]. Shandong University,2009.

[9] Zhao Xiaoli, SU Changshou, TAN Xiaoli, Song Weijun. Development of a new foam agent [J]. West China Exploration Engineering,2004,(06):119-121.

[10] liu hui. Evaluation method of foaming agent under high temperature and high pressure [J]. Laboratory research and exploration,2020,39(07):24-27.

[11] Tian Yulu, WANG Jiwei, Li Jiayu. Application Chemical Industry, 201,50(01):183-188.

[12] Chen Xiangui. Development of microfoam drilling fluid [D]. Northeast Petroleum University,2013.