RESEARCH NOTE

EXPERIMENT AND APPLICATION OF AN ANNULAR FOAM BREAKER FOR FOAM DRILLING FLUID

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Abstract The annular foam breaker is one which uses the vacuum and shear force generated by the Coanda effect to break foam. Its effectiveness in destroying drilling foam has been tested in wellbore flow simulation loop experimental stand. Experimental results showed that the operating pressure of the annular foam breaker should be larger than 0.6MPa and the stabilizers concentration of the foam drilling fluid should be as low as possible so as to obtain higher foam-breaking efficiency. Moreover, the annular foam breaker was more effective to destroy wet foam system. When the gas to liquid ratio of the foam was lower than 100, the foam-breaking efficiency was up to 85%. From the results obtained in Yuanba-10 well located in Sichuan province of China, it can be drawn that the annular foam breaker had a high efficiency that only 400 m^3 foaming solutions was consumed with total 672m of foam drilling footage in 26 in. section. The consumption of ingredient additives and water were decreased drastically with using the annular foam breaker, which reduced the foam drilling cost sharply.

Keywords Foam fluid; Foam drilling; Mechanical foam breaker; Annular foam breaker.

چکیده کف شکن حلقوی وسیله ای است که از نیروی خلاء و برشی تولید شده توسط اثر کواندا برای شکستن کف استفاده میکند. اثربخشی آن در از بین بردن کف ناشی از حفاری در شبیه سازی جریان در چاه و چرخه تجربی مورد آزمایش قرار گرفته است. نتایج تجربی نشان می دهد که فشارعملیاتی کف شکن حلقوی باید بزرگتر از ٠/٦ MPa و غلظت تثبیت کننده‌های سیال کف حفاری باید تا حد ممکن پایین باشد تا بازدهی بالا از شکستن کف بدست آید.علاوه بر این، کف شکن حلقوی برای از بین بردن سیستم کف مرطوب موثر است. هنگامی که نسبت گاز به مایع کف پایین‌تر از ١٠٠ باشد، بازده شکستن کف تا بالاتر از ٨٥ ٪ خواهد بود. از نتایج به دست آمده درچاه Yuanba-١٠ واقع در سیچوان چین می‌توان نتیجه گرفت که کف شکن حلقوی بازده بالایی دارد که تنها ٤٠٠m^3 از حلال های کف ساز با تنها ٦٧ m از کل طول کف حفاری در ٢٦ in مصرف می‌شود. مصرف افزودنی‌ها و آب با استفاده از کف شکن حلقوی به شدت کاهش می‌یابد که در نتیجه هزینه کف حفاری را به مقدار زیاد کاهش می‌دهد.

1. INTRODUCTION

Drilling foams have the greatest benefits during underbalanced drilling due to their ability to lift large quantities of produced liquids and drilled cuttings [1]. Drilling with foam is not only normally faster than conventional mud drilling but is indispensable in areas where the supply of water is limited or when drilling through cavernous formations into which the drilling mud flows and becomes lost [2, 3]. Moreover, foam has a high carrying capacity and a relatively small volume of air is required for foam drilling and the expense of the equipment for a given size well is greatly reduced over that of using air alone. Compared with air, foam can also handle large volumes of produced fluids. However, foam remains stable and requires a long period of time to dissipate back to the volume of the original liquid after returning to the surface [4, 5]. So an extremely large pit is required to contain the foam to allow sufficient room for cuttings and for the foam to dissipate. Amount of foams accumulated in this large pit deteriorate the difficulties of disposal and will be blown out with the wind, carrying various chemicals which results in environment pollution. Moreover, the foam fluid can not be reutilized so that it needs enormous volume prepared, consumes abundance of water and ingredient additives, which made the foam drilling cost increase greatly. According to the statistical dates obtained in TBK-2 well, drilled by Great Wall Drilling Company in Iranian TBK gas field, the foam fluid was consumed about 1799 m^3 with 378 m of the drilling footage in the 26 in. section, which cost about 75070.75 US dollars [6].

Various types of equipment and techniques have been employed to break foam including both chemical and mechanical methods [7- 9]. Chemical methods employ various chemical antifoaming agents to break foam including silicone oils, non-ionic surfactants, etc [10, 11]. It is an effective method which has been used widely in foam drilling projects. Nevertheless, antifoaming agents are detrimental to the foam fluid reutilization and waste dispose. They are also being quite expensive. In this perspective, mechanical foam breakers are becoming more and more attractive. A number of mechanical foam breakers have been proposed over the years such as high rotate centrifugal foam breaker, foam–breaking cyclones, and air jet breaker, etc [12- 15]. However, mechanical devices heretofore developed for breaking foam have not been effective, particularly for tenacious foams, and even where reasonably effective, have been expensive to build and to operate. Therefore, a definite need exits, for improvement in ways and means for breaking foam.

In the present paper, an annular foam breaker, which is designed mainly based on Coanda effect, is being developed for use in foam drilling [16]. Its effectiveness in destroying high-rate gas bubbling systems of foam drilling fluid is investigated. The effect of the operating conditions on its performance is also examined. It turns out to be one of the most effective ways since it combines two effects of vacuum and shear force to break foam.

2. THE ANNULAR FOAM BREAKER

Schematic diagram of a typical annular foam breaker is shown in Fig. 1. Compressed air is supplied via the air channel to the slots between the foam receive chamber and the jet body. The air-stream flows through these slots at high speed and thanks to the Coanda effect, adheres to the convergent slots wall (Coanda surface). Then, it enters the narrowest section called the throat and continues along the walls of the diffuser. Such a high speed flow causes the pressure nearby decrease. When the foam drilling fluid flow through this low pressure region, the bubble will be burst as a result of the quick changed in pressure. Moreover, because of the compressible mixing effects, the high speed air flow interacts with the relatively low speed foam fluid in the jet body chamber, and then mix all along the length of the jet body and the diffuser. The difference in velocity between the air-stream and the foam drilling fluid makes the momentum transfer from the high velocity air to foam fluid, which sets up a strong shear force to collapse the bubbles.

It can be seen from Fig. 1 that the structure of the annular foam breaker is very simple, and there is no moving parts or small openings that could plug during service.

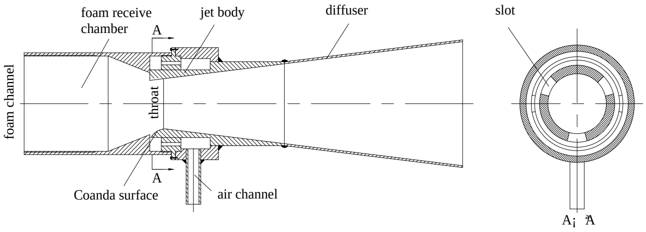


Figure 1. Schematic of annular foam breaker

3. LABORATORIES EXPERIMENT

3.1. Experiment Stand The test rig used for the annular foam breaker experiments represented schematically in Fig. 2 [17]. A air compressor station, with working capacity up to $4m^3$/min at a delivery pressure of 1.0Mpa is used to supply compressed air for generating foam drilling fluid and for operating the annular foam breaker. The air flow rates can be controlled and measured by ball valves and gas flow meters mounted on the air lines, respectively. Surfactant solution is supplied by a plunger displacement pump from storage tank to the foam generator. The pump model is 3DP-40, with a 15 kW motor and a capacity up to 30L/min. The liquid flow rate can be controlled by adjusting the transducer to change the motor speed. The surfactant solution and compressed air are combined in a foam generator to promote foam formation and to ensure homogeneity of the flow. After flowing through the simulated wellbore, the foam fluid carrying cuttings enters into the annular foam breaker where air is vented to atmosphere and the surfactant solution is drained into the measuring container.

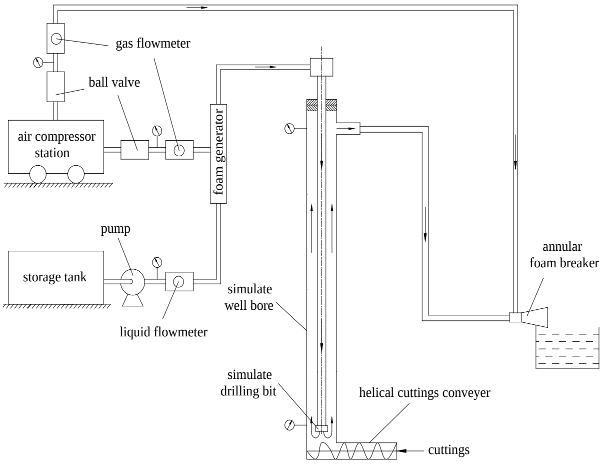


Figure 2. Schematic of wellbore flow simulation loop experimental stand

The foam-breaking efficiency of the annular foam breaker can be calculated by Equation (1):

$$h_0 = \frac{V_b - (V_a - l_a)}{V_b} \times 100\% \tag{1}$$

where, η_0 is the foam-breaking efficiency, V_b is the volume of foam produced before foam breaking, V_a is the volume of the mixed fluid after foam breaking, and l_a is the net liquid volume in V_a.

If there is no foam-breaking, that is $l_a = 0$, so $V_a = V_b$ and $\eta_0 = 0$; if all of the bubbles burst, then $V_a = l_a$, $\eta_0 = 100\%$. Therefore, the efficiency of the annular foam breaker can be accurately calculated by the Equation (1). However, l_a is not easy to measure because it is mixed together with the residual foam. Since the experimental results are recorded at intervals of 30s , the liquid volume is very small compared with the foam volume. So the Equation (1) can be simplified as follows:

$$h = \frac{V_b - V_a}{V_b} \times 100\% \tag{2}$$

From Equations (1) and (2), the error value ζ is represented as:

$$\zeta = \eta_0 - \eta = \frac{l_a}{V_b} \times 100\% > 0 \tag{3}$$

The actual efficiency is higher than the computational one.

The foaming fluid used in experiment is same with the one used in the field, which is the polymer-surfactant-based aqueous solution. The surfactant used to generate the foam is Sodium Dodecyl Sulfonate (SDS: $C_{12}H_{25}$-OSO_3Na, made from Shanghai WhiteCat Shareholding Co., Ltd, China) at concentrations of 0.3 ~ 0.5 wt% in distilled water. Xantan Gum(($C_{35}H_{49}O_{29}$)$_n$, made from Shandong Zhongxuan Company, China) and aqueous polymer solution of Anion Polyacrylamide (APAM: made from Shenyang Jiufang Co., Ltd, China) are used as the viscosity increase agent and foam stabilizer, and the concentration are 0.05% ~ 0.15 wt%, 0.02 ~ 0.07 wt%, respectively. The half-life of the foam system is about 30 to 90 min, which is relevant to the concentration of the foam stabilizer. The experimental results are recorded at intervals of 30s.

3.2. Results and Discussion

3.2.1. Effect of the Annular Slot Width Keeping the flow rate of the surfactant solution liquid as 0.01m^3/min , the gas to liquid ratio of the foam system as 100:1 which generally used in foam drilling project. The air flow rate to drive the annular foam breaker was 2m^3/min and the operating pressure was about 0.6MPa. The effect of the annular slot width (termed as *d*) on the foam-breaking efficiency has been studied by varying the value of *d* as shown in Fig. 3.

It is found that the η value changes little when the value d increases from 0.2mm to 0.6mm. But, further increases the value of d, the η value decreases sharply. Therefore, the value of the annular slot width should not exceed 0.6mm. The d value adopted in the following study is 0.4mm.

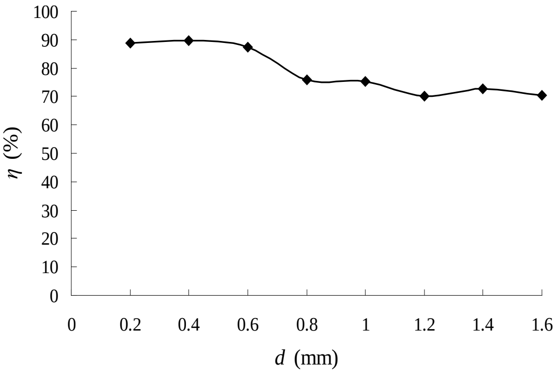


Figure 3. Relationship between the slot width and the foam-breaking efficiency

3.2.2. Effect of the Operating Pressure P_o The effect of the operating pressure on the foam-breaking efficiency has been carried out with an annular slot width of 0.4mm and other conditions unchanged. The test results are given in Fig. 4. It can be seen that the foam-breaking efficiency increases with an increase of the value P_o until P=0.6MPa, and after that it changes little with increasing P_o value. Therefore, the operating pressure of the annular foam breaker should be larger than 0.6MPa.

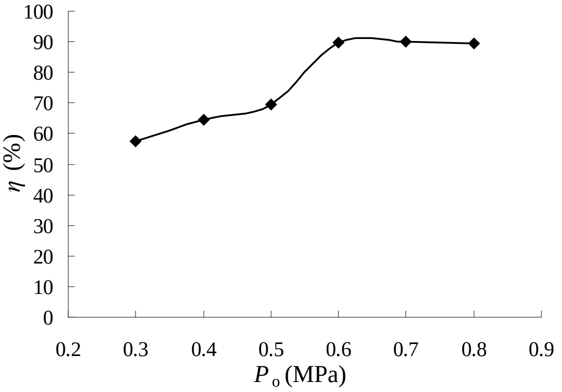


Figure 4. Relationship between the slot width and the foam-breaking efficiency

3.2.3. Effect of the Gas to Liquid Ratio α. The best foam drilling practice requires effective transport of cuttings while keeping the circulating bottom hole pressure at minimum. Controlling the foam quality or, similarly, the ratio of the gas to liquid α, is an essential task to achieve these goals. A critical value of α needs to be specified at the top of the well to be able to continue drilling without allowing the foam breaking into a mist. So, the value of α is different under the different drilling conditions. For foam drilling, α is usually between 50 and 300.

Keeping the annular slot width as 0.5mm, the operating pressure of the annular foam breaker as 0.6MPa and other parameters unchanged, the effect of the gas to liquid ratio on the foam-breaking efficiency has been tested as given in Table 1. It can be seen that the lower the ratio of the gas to liquid is, the higher the foam-breaking efficiency is. When the ratio of the gas to liquid decreases from 300 to 50, the foam-breaking efficiency increases from 75.76% to 86.58%. So, it is more effective in destroying the wet foam system for the annular foam breaker. Therefore, in order to obtain a higher foam-breaking efficiency of the annular foam breaker, the gas to liquid ratio of the foam drilling fluid should be as low as possible in the drilling field.

TABLE 1. Relationship between the gas to liquid ratio and foam-breaking efficiency (30s)

Gas to liquid ratio α	300	150	100	75	50
Liquid flow rate (L/min)	0.20	0.40	0.60	0.80	1.00
Foam volumes before breaking V_b (L)	19.6	36	46.70	52.30	56.10
Foam volumes after breaking V_a (L)	4.75	8.16	6.20	6.67	7.53
Foam-breaking efficiencyη (%)	75.76	77.33	86.72	87.25	86.58

3.2.4. Effect of the Base Liquid Viscosity. One of the primary advantages of foam is the capacity for cuttings transport. Its structure does not allow the fallback of solids, even under no circulation conditions in contrast to air, mist, or aerated fluids, in which the velocity is the primary parameter affecting cuttings lifting. It is well known that the foam stability is one of the important parameters affecting foam carrying capacity. Since foam should always be stable during circulation process, polymers are often added to increase the viscosity of the aqueous phase to enhance its stability. However, it is very difficult to break such stable foam. Fig. 5 shows the foam-breaking efficiency of the foam systems with different stability. Composition of these foam systems are as follows:

Foam system No.1: 0.3%SDS + water;

Foam system No.2: 0.3% SDS+0.03% Xantan Gum + 0.01% Polyacrylamide + water;

Foam system No.3: 0.3% SDS+0.15% Xantan Gum + 0.05% Polyacrylamide + water.

The half-life of three foam systems are 6, 25, 60min, respectively.

It can be seen from Fig. 5 that the foam-breaking efficiency decreases with increasing foam stability. When the liquid flow rate is 0.8 L/min (the ratio of gas to liquid is 50), the efficiency of the annular foam breaker will be only 76.71% for the foam system No. 3, while it is 87.25% and 83.02% for the foam system No.1 and No.2, respectively. Therefore, the concentration of the foam stabilizers should be as low as possible.

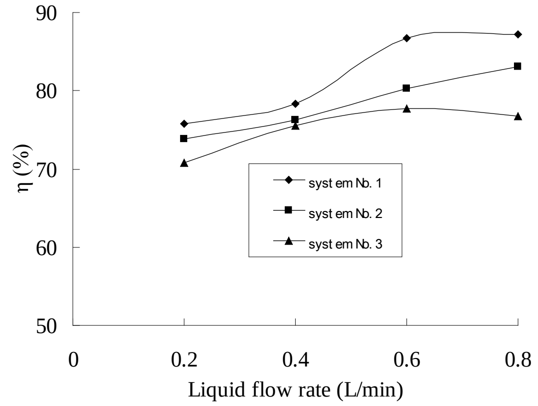
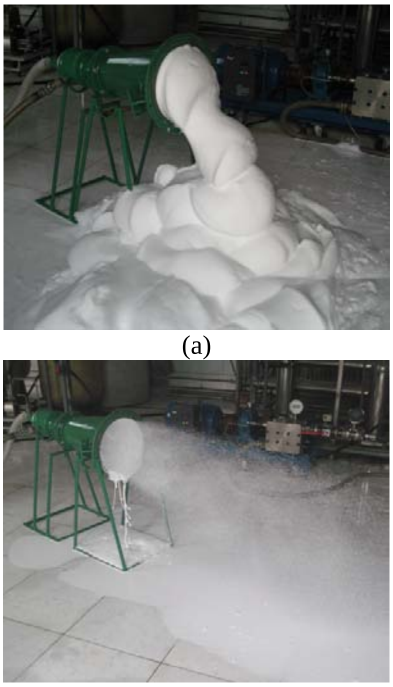


Figure 5. Comparison of different foam systems

Fig. 6 shows the experimental pictures of the annular foam breaker before and after foam-breaking for the foam system No. 3. It can be seen that the foam system has a large volume before foam-breaking, occupying a vast space. When the annular foam breaker is operating, the foam volume reduces to such an extent that the fluid mixture outflowing from the foam breaker can be pumped easily. Therefore, the liquid extracted from the degraded foam can be reutilized in timely, which will significantly reduce the cost of the foam drilling.



(a)

(b)

Figure 6. Comparison of different foam systems: (a) The state of the foam fluid before breaking, (b) The state of the foam fluid after breaking.

4. FIELD APPLICATION

The performance of the annular foam breaker has been tested in Yuanba-10 well in Cangxi county of Sichuan province, China. This well was equipped with Φ720 mm ID casing set at a depth of 30m. A 26 in. section would be drilled with aqueous foam fluid from this point to a depth of approximately 700 m. Six compressors with total working capacity up to 210 m^3/min and two boosters with 160 m^3/min of processing capability were used to generate foam. Another compressor with working pressures of 0 to 1.0 Mpa and a maximum 35 m^3/min was used to operate the annular foam breaker, which was located at the end of the blooie line. Foaming solution used in this well was composed of 0.3% SDS, 0.03-0.05% Xantan Gum and 0.01 to 0.03% Polyacrylamide, and total 300 m^3 were prepared. The half-life of the foam was controlled about 30 min. The foaming solution and air were conducted through a foam generator to form the foam. Then, the foam was sent to the standpipe to be injected into the hole as drilling fluid. The total return stream from the borehole entered into the annular foam breaker, where the foam was breaking down and the solid cuttings with the liquid phase were discharged into a mud pit. After that, the liquids separated from cuttings in the mud pit were pumped into a tank for its analysis, conditioning and reutilization.

In order to keep a good cutting transport capacity, the average flow rate of gas and liquid varied as the well got deeper from 70 m^3/min of air and 220 L/min of foaming solution at 30m, to 140 m^3/min of air and 340 L/min of foaming solution at 702 m. The gas to liquid ratio was controlled between 150 and 450. Large, angular cuttings are lifted to the surface quickly rather than being ground into the smaller. The maximum diameter of cuttings removed from the bottom hole is up to 15mm, which proved that the foam system has superior cuttings entrainment and transport properties. The average penetration rate was 4.88 m/h, which was at least four times greater than the ones achieved with conventional drilling in the same area.

Though there was still remain small amount of foam cannot be broke up, the annular foam breaker could effectively separate a majority of the air from the foam fluid. It can be seen from Fig. 7 that the foam volume was greatly reduced when the annular foam breaker was working, and there was no phenomenon of lots of foam accumulated in the mud pit. The liquid phase of the foam can be recycled and reutilized in timely. After foam drilling finished, there were only about 400 m^3 of waste disposals, which include 300 m^3 of the foaming solution pre-prepared and 100 m^3 of water used to adjust the performance of the recycled foam liquid.

In a word, the foam drilling footage in 26 in. section of Yuanba-10 well was 672 m, and total 400 m^3 of foaming solutions were consumed, While the foam drilling footage in TBK-2 well was 378 m with 1799 m^3 of foaming solutions consumed. Therefore, the consumption of ingredient additives and water are decreased drastically with using the annular foam breaker, which reduce the foam drilling cost sharply.

The field experience has shown that the reutilized foam fluid produces foam with higher viscosity with improved lifting capacity [18]. Reusing the fluid reduces the surfactant usage saving on both chemical and disposal costs. However, the half-life of the reused foam is reduced by the natural solids in the system though the system viscosity increases. Moreover, there are large difference between field actual values and laboratory test ones for half-life since the formation condition and cuttings have significant effect to it. It is inadequate to use the half-life to measure the stability of the reused foam. How to evaluate the performance of the reutilized foam solution is a key problem need to further study.

(a)

(b)

Figure 7. Pictures of the annular foam breaker applied in Yuanba-10 well: (a) Foam fluid state before reaking, (b) Foam fluid after breaking.

5. CONCLUSIONS

An annular mechanical foam breaker has been developed in this study, which is designed mainly based on Coanda effect. It is a very effective device to break the drilling foam that can make the foaming liquid recycled, thereby save foaming agents and reduce the drilling cost, at the same time make unnecessary or at least minimize the necessity for the setting pits used previously to dispose of the foam and foaming agents.

Based on the field case and experimental test, the following conclusions can be drawn:

1. Operating pressure of the annular foam breaker has a great influence on its performance. The higher the operating pressure is, the better the foam-breaking efficiency is. So the operating pressure of the annular foam break should be larger than 0.6MPa.
2. The annular foam breaker is more effective to destroy wet foam system. When the gas to liquid ratio of the foam is lower than 100, the foam-breaking efficiency is up to 85%.
3. The foam-breaking efficiency of the annular foam breaker decreases with increasing foam stability. So the concentration of the foam stabilizers should be as low as possible.
4. The annular foam breaker has been successful applied to foam drilling, and the foam solution can be recycled and reutilized. Not only the foaming agents but also the volumes of the water disposal are reduced greatly.

6. ACKNOWLEDGEMENT

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