The Characteristics Evaluation of CO_2-foam System

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Abstract—This paper researches on the characteristics of the foam system chosen for CO_2 foam flooding in the low permeable oil fields. In view of the actual situation of the oilfield high temperature, high salinity and water injection difficulty, the selected agents must also meet the requirements of stability and foaming property. Through the specific half-life and foam volume under different temperature conditions, found: FP388, FP246 and FP275 three kinds of foaming agent have good foaming properties; the half-life of bubble down quickly as the temperature from 45 °C to 100 °C; the half-life of FP275 is the largest of the three when they at the same temperature; The difference of FP388 and FP275 stability decreases with temperature increasing; all of the three kinds of foam system can meet the needs of the refinery, and the property of the foam system of FP388 is the best among them through the comprehensive consideration.

Keywords-low permeability; CO2 foam flooding; study of characteristics; half-life; high temperature

I. INTRODUCTION

The capture and storage about CO_2 become very important with the attention of the CO_2 emissions of national governments. It also provides unprecedented opportunities and challenges for enhancing oil recovery by CO_2 injection technology [1]. At the same time, our country has made great progress in the CO_2 resources exploration. A lot of CO_2 gas reservoirs have been found in the Songliao basin, Bohai bay basin, and many other basins [2]. And it provides material conditions for enhancing oil recovery by large-scale CO_2 flooding and CO_2 foam flooding in our country. Due to CO_2 foam flooding taking advantages of CO_2 flooding and foam flooding, it has great application prospect in improving oil recovery and CO_2 underground storage [3]. In order to select suitable foam system formula for field application, this paper has studied on the characteristics of the foaming property and stability of several foam systems through the indoor experiments.

II. BASIC SITUATION OF TEST AREA

The experimental zone is Jilin oilfield H block, The block average reservoir pressure is 23.11MPa, the average reservoir temperature is 97.3°C. Formation water salinity is 11737.7mg/l, Content of Cl^- is 4481.6 mg/L, Water type is $NaHCO_3$ type, pH value is 7 or so. The water flooded wells Increased, the use efficiency of Injected water is low, part of the oil well formation pressure is low, the production of fluid and oil showed a trend of decline. Developing a single layer of low permeability reservoir is faced with difficulty to control the large area of water flood, and need to take effective measures to improve the development effect and Enhance oil and gas recovery of the block.

Considering the above situation synthetically, the selected CO_2-foam system must satisfy the characteristics of high temperature resistance, salt resistance and good stability [4].

III. EXPERIMENTAL CONDITIONS

Composition of CO_2 foam system: high purity CO_2 gas; Fluorocarbon Yin non sexual foaming agent FP388 (0.4 wt %); Yin non sexual foaming agent FP246 and FP275; Stable foam agent WP125 (0.4 wt %).

The experimental water: Simulated formation water, $NaHCO_3$ type, Total salinity 11737.7 mg/L.

The experimental temperature: 45°C, 75°C, 100°C.

IV. STABILITY EVALUATION

Foam stability is the most important property of foam [5]. Study the foam decay mechanism and enhance foam stability.

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A. *Stability Representation of the CO_2-foam System*

Assess with the half-life. Through high-speed stirring apparatus, the gases and liquids mixed as certain proportion form a large number of foam in a short period of time. Move foam to the test tube with a calibration fast, and record the foam volume and start the time. Stop timing when a foam volume into half of the original volume, and record the time which is called a half-life as the measurement of foam stability [6]. The greater half-life value is, the better foam stability is.

Improve foam stability mainly adopt two ways at present [7]. One is adding active substances into the foaming agent solution, which enhance interaction between adsorbed molecules and increase surface strength of liquid membrane through the synergy. Another way is adding the tackifier into foaming agent solution, which can improve the viscosity of liquid, increase the elasticity of the liquid film, extend the half-life of foam [8].

B. *Affecting Factors of the Foam Stability*

Foam is the bubble dispersion system which is composed of gas, and it is a thermodynamic instability system with very high surface free energy. Now generally believed the decay mechanism of foam is that: the loss of liquid in the foam and the diffuse of gas through the liquid film. The stability of foam is mainly controlled by following factors:

1) The surface tension of foaming agent solution

The liquid surface area and the surface energy increases as the bubble generated. Foam system always tends to the lower surface energy state. Low surface tension can reduce the energy of the foam system, and it is conducive to the stability of foam.

2) The surface viscosity

The surface viscosity refers to the viscosity in the surface monolayer of the liquid. This kind of viscosity is mainly produced by the interaction action between the hydrophilic group in the surface monolayer of the surfactant molecules and the hydration. The greater the Surface viscosity is, the liquid film drainage speed and the liquid membrane permeability are smaller.

3) The solution viscosity

As the foaming agent solution viscosity turns greater, the discharge of the liquid in the foam turns not easy, the drainage rate of liquid membrane reduce, the thinning speed of the liquid membrane turns slow, the rupture time of the liquid membrane delay, the stability of foam increases.

4) The surface charge of the liquid membrane

When the ionic surfactant as foaming agent, its molecule is arranged directly in the bubble film, and forms electric double layer surface diffusion. When the two liquid membranes close to a certain extent, the ions with the same charge repels each other. So it can prevent the liquid film thinning, which is conducive to the stability of foam.

5) Gibbs surface elasticity and Marangoni effect

When the foam is hit, foam thin locally, surface area increases, surfactant molecules density decreases, and surface tension increases. The local immediate increase makes the surface shrinkage immediately and makes the liquid flow to the thin place, i.e. the flow of the liquid from the low surface tension zone to high surface tension zone makes the thickness of the local thinning liquid film restore to the original when the surface tension recoveries, and this phenomenon is called surface elastic or Gibbs surface elasticity. This phenomenon of the spread of the bulk phase liquid which is caused by the surface tension gradient called the Marangoni effect, and it block the liquid film thinning. The more significant the Marangoni effect is, the repair effect of the foam is stronger, and the foam is not easy to break. In addition, the stability of the foam is influenced by external factors. Under the static condition, the greater the pressure, the stability of the foam is greater; as the temperature increases, the stability of the foam reduces.

C. *The Evaluation of Stability for Three Kinds of Foaming Agent*

The three kinds of foaming agent used in the experiment are FP388, FP246 and FP275, and the Stable foam agent is WP125. The foaming agent formula and the density of formation water are all need determined according to the requirement of oil field [9]. So the experiments measure the stability of CO_2-foam system within the specified scope of density only.

In the process of experiment, form CO_2 foam system as the quality of gas liquid ratio is 5%. The mass ratio was converted to volume ratio around 30:1 by the density of CO_2 and foaming agent solution, and eventually the volume ratio between gas and liquid determined as 30:1 by considering the compressibility and the volume thermal expansion of the gas in the constant temperature cabinet with 45°C.

Firstly, put the CO_2 gas and the foaming agent solution which has been prepared into the pistons container. Then connect piston container to the core holder and pump through the pipelines. Inject the CO_2 gas and foaming agent solution at the same time as the gas liquid volume ratio is 30:1 at one end of the core holder. After a period of mixing action, the formed foam flows out at the other end. Which is placed in the core holder is a high permeability core of $1200\times10^{-3}\mu m^2$. Gas and solution form foam with a certain size through the role of core pore when gas and solution flow through the core, and the main role is "stir" foaming.

Experimental methods and steps: Firstly, Receive the formed foam by the measuring cylinder with the range of 50 ml through the foaming device. And then place the measuring cylinder with foam in the constant temperature cabinet at room temperature 45°C, 75°C, 75°C respectively (the choice of temperature is based on the actual conditions of the laboratory) which under atmospheric pressure. Measure the half-life of CO_2-foam system. Data records are shown in TABLE I.

TABLE I. THE HALF-LIFE OF 3 KINDS OF FOAMING AGENT

Types of foaming agent	**Half-life(s)**					
	Room temperature	***45°C***		***75°C***		***100°C***
FP388	1141	964		483		167
FP246	1156	923		409		113
FP275	1371	1055		566		221

As can be seen from the half-life data in table1, under atmospheric pressure, the half-life of three kinds of foam system appeared the same change trend when the temperature is higher than the room temperature, i.e. as the temperature increases, the half-life of the system decreases. The specific relation curve as shown in Fig. 1.

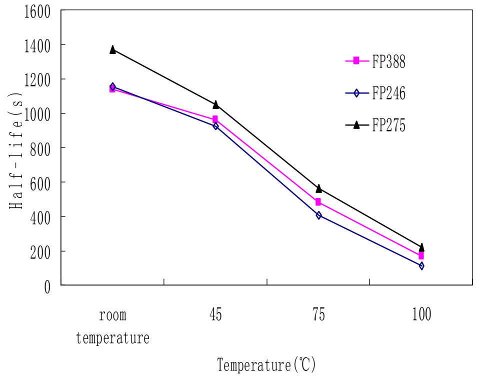

Figure 1. The relation curve of the half-life of foaming agent and temperature

As can be seen from Fig.1: Under atmospheric pressure, the stability of the CO_2-foam system as the temperature increases, the half-life decreases rapidly, and stability deteriorates; And at the temperature scope from 45°C to 100°C, the half-life of foam falls fast, the stability changes greatly; At the same temperature, the half-life of FP275 is the largest among the three kinds of foaming agent solution whose density is the same. I.e. that the stability of foam is best; Only under the condition of room temperature the stability of FP246 and FP388 fairly, but when temperature increases, the stability of FP246 change quickly, in the three kinds of foaming agent, the stability of foam formed by FP246 is the worst. As the temperature increases, the difference of the stability between FP388 and FP275 decreases.

V. The Property Evaluation of the Foaming

A. The Property Measurement of the Foaming

Evaluating the foaming property of the foaming agent is always measured by the maximum foam volume of the foaming agent in general. The greater the largest foam volume is, the better the foaming property of the foaming agent has. The maximum foam volume refers to the largest foam volume generated by foam system under the certain conditions.

1. Experimental apparatus: piston containers, foam generator.

2. Experimental conditions: room temperature.

3. Experimental methods and steps

1) Calculate the CO_2 gas volume (600ml) needed for 20ml foaming agent solution according to the gas liquid volume ratio as 30:1;

2) Pour 20ml surfactant solution into the device of measuring the foam volume, and the device is a thin tube with scale line. And then flood CO_2 gas at the rate of 3 ml/min from the bottom of the device by the displacement function of advection pump [10];

3) End of the experiment, the volume of the formed foam generated in the foam generator, which is the largest foam volume of the foam system.

B. The Experimental Results

In this experiment, only measured the maximum foam volume of three foaming agent at room temperature and atmospheric pressure. The recorded data as shown in TABLE II.

TABLE II. THE MAXIMUM FOAM VOLUME OF 3 KIND OF FOAMING AGENT UNDER ROOM TEMPERATURE

Foam formula	**FP388**	**FP246**	**FP275**
V_F(ml)	780	772	761

Plotting according to the data in Table 2, as shown in fig .2.

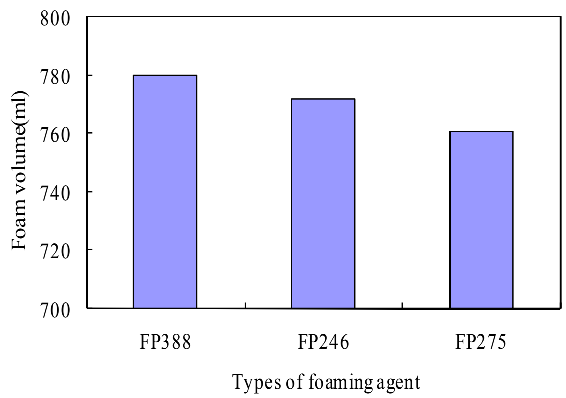

Figure 2. The maximum foam volume of three kinds of foaming agent

As can be seen from fig .2: At room temperature, among the three kinds of foaming agent as FP388, FP246 and FP275, the maximum foam volume of FP388 is 780ml, It is the largest foaming volume; but the gap between the three is not great, the differential of the maximum foaming volume is only 19ml, i.e., three kinds of foaming agents all have good foaming properties, but the foaming properties of FP388 is the best.

VI. Conclusions

Experimental results show that: Under atmospheric pressure, the stability of the CO_2-foam system as the temperature increases, the half-life decreases rapidly, and stability deteriorates; And at the temperature scope from 45°C to 100°C, the half-life of foam falls fast, the stability changes greatly; at the same temperature, the half-life of FP275 is the largest among the three kinds of foaming agent solution whose density is the same.

Add tackifier into foaming agent solution, which can improve the viscosity of liquid, increase the elasticity of the liquid film, extend the half-life of foam.

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