Experimental study on pore forming characteristics of simulated hydrate broken by high pressure water jet

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Abstract—Natural gas hydrate is a research hotspot at present. However, the current exploitation technology can’t meet the demand of commercial exploitation of natural gas hydrate. In order to improve the efficiency of hydrate production, this paper believes that the idea of using high-pressure water jets for sandblasting perforation is expected to constitute an effective way to extract natural gas hydrates. The experimental study on sandblasting perforation and hydraulic slitting of simulated reservoirs was carried out by using large-scale ground fracturing equipment and full-scale hydraulic blasting perforating equipment. The driving pressure is analysed under the action of high-pressure water jet. The influence of diameter on the effect of simulated reservoir fracture. The results show that the diameter of the perforation increases with the increase of pressure; This experimental study can provide an experimental basis for the use of abrasive jet blasting perforating technology to improve the efficiency of natural gas hydrate production.

1. Introduction
Natural gas hydrate, also known as combustible ice, is scattered in seabed sediments and land frozen soil areas. It has a series of advantages such as low pollution, high energy, shallow reservoir depth and large reserves. It has huge resource potential and high efficiency. It is considered to be the most ideal energy in the 21st century. In May 2017, China’s first trial production of natural gas hydrate in Shenhu Haijiang, the South China Sea proved that China has made a breakthrough in the field of hydrate production and provided technical support for China to occupy the commanding height of global energy development strategy in the future\textsuperscript{[1]}. Therefore, this paper holds that the idea of sandblasting perforation with high-pressure water jet is expected to constitute an effective way to exploit natural gas hydrate. Through this experimental study, the feasibility of natural gas hydrate exploitation by high-pressure water jet is verified, which can provide an experimental basis for using sand blasting perforation technology to improve the exploitation efficiency of natural gas hydrate\textsuperscript{[2]}.

2. Experimental scheme and device
The working principle of the simulated reservoir injection experimental device is as follows: firstly, the target is installed with a crane, and the jet tool is assembled and the experimental device is built according to the diameter of the nozzle required for each experiment\textsuperscript{[3]}. The jet pump pressure and sand ratio are set through the console. The high-pressure jet output by the jet pump flows through the high-pressure pipeline to the nozzle and then shoots out to break the simulated reservoir. With the progress of the experiment, the water volume in the cavity increases, and the excess water carries the broken
simulated reservoir and sediment particles and is discharged through the drainage hole \cite{4}. After the completion of fracturing, after the jet pump is turned off through the console, the experimental device is disassembled manually, and the target is disassembled by the crane. Then, the simulated reservoir crushing effect is observed and recorded, and the experimental data are measured \cite{5}.

![Experimental device](image)

3. Analysis of experimental results of sand blasting perforation

3.1. Analysis of the influence of pump pressure on the fracture effect of simulated reservoir

In order to study the influence of pressure on the simulated reservoir crushing effect under the action of high-pressure water jet, four groups of experiments were carried out, the pressure was 15, 20, 25 and 30 MPa, the sand ratio was 6\%, and the nozzle diameter was 6mm. Table 3-1 shows the jet operating parameters and test results.

| No. | pressure /MPa | ratio /% | Nozzle diameter/mm | depth /cm | max/cm | min/cm |
|-----|---------------|----------|---------------------|-----------|--------|--------|
| 1   | 15            | 6        | 6                   | 40.5      | -      | -      |
| 2   | 20            | 6        | 6                   | 77.7      | 20.3   | 12.2   |
| 3   | 25            | 6        | 6                   | 96        | 22     | 20     |
| 4   | 30            | 6        | 6                   | 148       | 23.5   | 15     |
According to Fig.2, by analysing the crushing effect under different jet pressures, it can be seen that the jet pressure has a significant impact on the crushing effect when the high-pressure water jet breaks the simulated reservoir. As the pressure increases, the fracture depth of the simulated reservoir becomes larger and the size of the broken hole becomes larger.

3.2. Analysis of the influence of nozzle diameter on the fracture effect of simulated reservoir

In order to study the influence of nozzle diameter on the simulated reservoir crushing effect under the action of high-pressure water jet, the sand ratio is 6%, the pump pressure is 25MPa, and the nozzle diameter is 4mm, 5mm, 6mm and 7mm. Table 3-2 shows the jet operating parameters and experimental results.

Table 2 Fracture test results of simulated reservoir under different nozzle diameter conditions

| No. | Pressure (MPa) | Ratio (%) | Nozzle Diameter (mm) | Depth (cm) max/cm | Depth (cm) min/cm |
|-----|----------------|-----------|----------------------|-------------------|-------------------|
| 7   | 25             | 6%        | 4                    | 115.8             | 11                |
| 3   | 25             | 6%        | 5                    | 148               | 20.4              |
| 3   | 25             | 6%        | 6                    | 96                | 22                |
| 7   | 25             | 6%        | 7                    | 54                | 30                |
Fig. 3 Effect of nozzle diameter on crushing depth

It can be seen from Fig. 3 that when the high-pressure water jet breaks the simulated reservoir, the breaking depth first increases and then decreases with the increase of nozzle diameter, while the breaking size always increases. By analysing the crushing effect under the condition of different nozzle diameter, it can be seen that the nozzle diameter has an important influence on the crushing depth and size when the high-pressure water jet is used to simulate reservoir crushing. When the nozzle diameter is 5mm, it has a better crushing depth after perforation. The crushing size increases with the increase of nozzle diameter, because when the nozzle diameter increases, the jet flow will increase, and then the jet scouring effect will be stronger, and the flow rate of upward fluid will be faster, which will cause greater tensile stress on the contact surface of simulated reservoir, and finally lead to the increase of crushing size.\[2\]

4. Analysis of simulated reservoir fracture process under the action of high pressure water jet

When the high-pressure water jet breaks the simulated reservoir, the breaking process is roughly divided into three stages:

Step1: The upper part is broken.

Under the action of water jet, the contact surface of simulated reservoir is affected by tensile shear. When the tensile shear strength is greater than the tensile shear strength of sediment, broken holes appear on the contact surface\[6\]. When the jet continuously breaks the simulated reservoir, the fracture near the broken hole expands rapidly, and the high-pressure jet enters the fracture, reducing the tensile strength of the reservoir. At the same time, the upper part of the reservoir will also be subjected to the tensile shear action caused by jet\[7\]. When the tensile shear action reaches the maximum, the upper area of the reservoir will expand downward.

Step2: The middle part is broken.

Under the high-speed crushing of water jet, the crushing hole expands rapidly, and the crushing depth increases\[8\]. At the same time, the action distance of jet will also increase. Because of the resistance, the jet is dispersed and the section expands, resulting in water flow in the direction other than the vertical action surface, shearing and scouring the inner wall of the reservoir, resulting in the increase of fracture size\[9\].

Step3: The lower part is broken.

When the crushing depth increases to a certain extent, the strength of the jet decreases and the flow velocity in the tangential direction decreases, resulting in the reduction of the crushing size, the expansion speed of the hole slows down, and the upward return fluid carries more debris, the resistance increases and the energy decreases\[10\].
5. Conclusion
Based on the results and discussions presented above, the conclusions are obtained as below:

(1) Through the experiments conducted by the large-scale surface fracturing equipment and full-scale hydraulic sand blasting perforation experimental device, it is found that when the pressure is 30MPa, the sand ratio is 6% and the nozzle diameter is 6mm, the simulated hydrate reservoir is expected to be perforated 150cm deep and the maximum diameter of the hole is 25cm. The feasibility of natural gas hydrate production by high-pressure water jet is verified, which provides an experimental basis for using sand blasting perforation technology to improve the production efficiency of natural gas hydrate.

(2) Characteristics of simulated reservoir pores: there are abrasive particles and simulated reservoir debris in the pores; The inside of the hole is smooth, and there are obvious erosion characteristics around the hole under the action of abrasive jet. The surface shape of the eyelet is mostly oval or regular circle; The middle and upper parts of the eyelets are mostly near circular or cylindrical cylinders; The end of the eyelet is a conical cylinder.

(3) In the next step, it is necessary to carry out experimental research on the crushing of simulated hydrate sediments with different reservoir characteristics by high-pressure water jet under different working conditions, and deeply study the crushing mechanism of seabed hydrate sediments.

References
[1] Van der Geer, J., Hanraads, J.A.J., Lupton, R.A. (2010) The art of writing a scientific article. J. Sci. Commun., 163: 51–59.
[2] Chermenski F P, Davidyants G F. Pulsed water jet pressures in rock breaking[C]//Proceeding of the Fifth International Symposium on Jet Cutting Technology. Cranfield, BHRA, 1980: 155-163.
[3] Moridis G J, Collett T S, Dallimore S R, et al. Analysis and interpretation of the thermal test of gas hydrate dissociation in the JAPEX/JNOC/GSC et al. Mallik 5L-38 gas hydrate production research well[J]. Bulletin-Geological Survey of Canada, 2005, 585: 140.
[4] Osadetz K G, Chen Z. A re-evaluation of Beaufort Sea-Mackenzie Delta basin gas hydrate resource potential: petroleum system approaches to non-conventional gas resource appraisal and geologically-sourced methane flux[J]. Bulletin of Canadian Petroleum Geology, 2010, 58(1): 56-71.
[5] Yamamoto K, Terao Y, Fujii T, et al. Operational overview of the first offshore production test of methane hydrates in the Eastern Nankai Trough[C]//Offshore Technology Conference. Offshore Technology Conference, 2014.
[6] Annoni, M., Cristaldi, L., Lazzaroni, M., Ferrari, S.. Nozzles Classification in a High Pressure Water Jet Systems[P]. Instrumentation and Measurement Technology Conference Proceedings, 2007. IMTC 2007. IEEE,2007.
[7] V. V. Koryakina,I. K. Ivanova,M. E. Semenov,I. I. Rozhin,A. F. Fedorova,E. Yu. Shits. Specific features of the growth, composition, and content of natural gas hydrates synthesized in inverted oil emulsions[J]. Russian Journal of Applied Chemistry,2017,90(8).
[8] Wang Sheng,Zhang Chuan,Yuan Chaopeng,Chen Liyi. Rheological Properties of Polymer Drilling Fluid Developed for Permafrost Natural Gas Hydrate Drilling[J]. Chemistry and Technology of Fuels and Oils,2017,53(2).
[9] Azad Jarrahian,Ehsan Heidaryan. Natural gas hydrate promotion capabilities of toluene sulfonic acid isomers[J]. Polish Journal of Chemical Technology,2014,16(1).
[10] Boswell R. Japan completes first offshore methane hydrate production test—Methane successfully produced from deepwater hydrate layers[J]. Center for Natural Gas and Oil, 2013, 412: 386-7614