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Research Article

Jet breaking tools for natural gas hydrate exploitation and their support technologies☆,☆☆

Wang Guorong[a], Zhong Lin[a,*], Zhou Shouwei[b,e], Liu Qingyou[d,e], Li Qingping[c], Fu Qiang[c], Wang Leizhen[a], Huang Rong[a], Wang Guangshen[a] & Li Xuefeng[a]

[a] College of Mechatronic Engineering, Southwest Petroleum University, Chengdu, Sichuan 610500, China
[b] China National Offshore Oil Corporation, Beijing 100010, China
[c] CNOOC Research Institute, Beijing, 100027, China
[d] MOE Key Laboratory for Fluid Machinery and Power Machinery, Xi Hua University, Chengdu, Sichuan 610039, China
[e] State Key Laboratory of Oil & Gas Reservoir Geology and Development Engineering, Southwest Petroleum University, Chengdu, Sichuan 610039, China

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Abstract

Marine natural gas hydrate (NGH) reservoirs in China are characterized by shallow burial depth and weak cementing. In view of these characteristics, it is in an urgent need to develop a series of technologies and support tools to ensure safe, economical, green and efficient NGH exploitation. In this paper, a new technical idea of NGH jet breaking and fluidization exploitation without changing the temperature and pressure conditions of NGH reservoirs was proposed, and the support nozzle tools for NGH jet breaking was designed, experimentally tested and optimized. Then, the relationships between the jet breaking parameters of nozzles (e.g. working pressure drop, flow rate, and lifting and lowering velocity and frequency) and the borehole diameters and breaking rates of broken NGH were investigated based on laboratory tests, and the field construction engineering charts of NGH jet breaking and fluidization exploitation were established. Finally, this method was practically verified at Well Liwan 3 in the South China Sea. And following research results were obtained. First, the NGH jet breaking and fluidization exploitation technology can increase the production efficiency of NGH exploitation, protect the safety of reservoir bottom and reduce the energy consumption of NGH exploitation. Second, by using the nozzle tools of NGH jet breaking, the generated borehole diameters are regular, broken particles can flow back well, and the lowering velocity of jet breaking without pilot holes is less than 7.1 m/h. Third, the engineering charts of NGH jet breaking and fluidization exploitation interpret the influential laws of jet breaking behaviors and construction parameters on the borehole diameters and breaking rates of NGH so as to provide a reference for the selection of NGH production test technology parameters. And fourth, the successful implementation of the NGH jet breaking and fluidization technology in the production tests of Well Liwan 3 verifies the feasibility of NGH jet breaking and fluidization exploitation process, and exhibits its promising application prospects in NGH future commercial exploitation.

Keywords: Natural gas hydrate (NGH); Jet breaking; Fluidization exploitation; Multi-functional nozzle; Breaking effect; Technological parameter; Construction chart; Production test; South China sea; Well Liwan 3

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* Corresponding author.
E-mail address: zhonglin858296@163.com (Zhong L.).
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Natural gas hydrate (NGH), especially marine hydrate, is a kind of new energy resource undeveloped with the most reserves twice the known reserves of coal, oil and gas around the world [1,2]. Its effective and controllable industrial exploitation is still a worldwide challenge [3,4]. The traditional techniques for NGH exploitation, like pressure drop, hot compress, chemical inhibitor and CO_2 flow rate, are only suitable for marine non-diagenetic NGH reservoirs, in view of their characteristics and disadvantages [5–10]. Based on the commercial exploitation standard, i.e. 12 x 10^4 m^3/d, given the NGH reservoir thickness of 60 m and the hydrate proportion in the reservoir of 30%–40%, the daily NGH exploitation will cover a radius ranging from 2.84 m to 3.28 m. The goaf may induce geological disasters like formation collapses and subsea landslides [11,12]. Therefore, it is in an urgent need to develop a series of technologies and support tools to ensure safe, economical, green and efficient NGH exploitation [13]. Wu Kaisong designed a new drill bit for recovering marine NGH through solid fluidization [14]. Zhou Shouwei proposed and developed a three-dimensional visual NGH exploitation simulation experiment system to support the hydrate production testing and deepwater engineering research [15]. In this paper, a new technology of jet breaking and fluidization exploitation is proposed. Meanwhile, the jet breaking nozzle is designed and optimized. An on-site operation engineering chart is provided for NGH jet breaking and fluidization exploitation. The success of NGH exploitation testing demonstrates the feasibility and application prospects of the jet breaking and fluidization exploitation technology.

1. NGH jet breaking and fluidization exploitation technology and jet breaking scheme

The advantage of this technology is that the temperature and pressure conditions of the NGH reservoir are not actively changed, so it can significantly improve the safety of the NGH reservoir during exploitation. Risers and packers are combined to connect the surface treatment & decomposition platform to the subsea overlying strata buried pipeline. Coiled tubing is adopted to connect the blowback device, jet breaking and exploitation tool, downhole separator, mud backfill device and mechanical breaking device to perform NGH jet breaking and fluidization exploitation [16]. As to the working principle of this technology, a front exploitation and breaking tool is applied to drill a pilot hole. Then, a conical transition section is formed between the pilot hole and the jet breaking wellbore to facilitate the cuttings return to the surface. The nozzle is landed via the coiled tubing to break and fluidize the hydrate. After downhole separation, the hydrate fluid lifted via risers; mud is backfilled and reservoir is consolidated. Thus, the jet breaking and fluidization exploitation process is completed. This technology uses nozzles to break hydrate by jetting and extract hydrates, without actively breaking the pressure and temperature balance of NGH reservoirs. In this way, the efficiency of NGH exploitation is improved, the bottom safety of the reservoir is ensured, and the energy consumption in exploitation is reduced.

1.1. NGH jet breaking scheme

The jet breaking nozzle is directly connected to the coiled tubing to avoid flow limitation by the flow rate of PDM. The design of the nozzle structure is shown in Fig. 1. The structure of a single nozzle is firstly designed. Then, based on the optimal design of nozzle, the influences of nozzle hole arrangement under different flow rates, pressure drops, and lifting/lowering velocities and frequencies on the cutting backflow capacity, regularity of borehole diameters and size of borehole diameter are identified. Finally, the engineering chart of NGH jet breaking and fluidization exploitation is generated.

1.1.1. Design of nozzle structure

Fig. 2-a and b show the two-dimensional cross-sections of two nozzle structures with and without chamfer at the holes. Given the inlet pressure of 4.36 MPa and the outlet pressure of atmospheric pressure, the velocity distribution of the two nozzle structures are shown in Fig. 2-c and d. The nozzle L/d influences the jet breaking, and the chamfer parameter ($l\times\beta$) determines whether the jet is divergent or not. The flow field at the outlet of the nozzle without chamfer is concentrated, which can facilitate the wellbore creation by jet breaking through adjusting the jet breaking radius. When the chamfer is designed at the outlet of the nozzle, the flow field distribution area at the outlet is divergent, which can help carry cuttings up to the surface.

1.1.2. Design of nozzle hole arrangement

In order to make the nozzle structure preferable for engineering application, it is necessary to design the nozzle hole arrangement based on the optimized nozzle structure, as is shown in Fig. 3. A row of 6 flowback holes are designed at the uppermost of the nozzle, with an angle of 15° from the axis. One hole is arranged along the axial direction at the front end of the nozzle. A row of 6 holes are arranged at the front end of the nozzle, with an angle of 45° from the axis. A total of 18 holes in three rows (3 × 6) are evenly distributed at the nozzle side normal direction (the circumferential angle between every two is 20°, and the axial distance of every adjacent two holes is 10 mm), which have no chamfers and are used for evenly breaking the circumferential hydrate. The diameter of each hole is 2 mm. The front jet holes with 45° from the axis and the holes for backflow are chamfered by 1 × 1 mm.

1.2. Experimental test of NGH jet breaking

An experimental test was conducted on the NGH jet breaking to determine the breaking efficiency, develop the engineering chart as a reference for on-site operation parameters selection, and verify the effect of broken particles backflow performance as well as the nozzle performance to determine a reasonable nozzle structure.