The Experimental Simulation Technology and System of Solid Fluidization Exploitation of Marine Non-Diagenetic Natural Gas Hydrate

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With huge reserves, marine natural gas hydrate is one of the most potential unconventional alternative energy sources after shale gas, coalbed methane and tight gas. The research and pilot engineering of natural gas hydrate exploitation technology mainly adopts the depressurization method at home and abroad, all of which refer to the exploitation technology of conventional oil and gas.

While using the depressurization method to exploit the non-diagenetic gas hydrate, the undersea hydrate decomposes in situ, partly flows to the bottom of the well, and escapes into the seawater in large quantities, and the hydrate will face the following six risks if it decomposes disorderly and could be lost in control. (1) Plugging and shutting down caused by mud and sand entering well. (2) A large amount of decomposed gas is dissipated into the seawater, resulting in waste of resources, low gas recovery rate and low production. (3) During long term exploitation, hydrate ore body collapses, resulting in stratum instability and submarine landslide, etc. (4) The deformation of seabed structure leads to the instability and loss of control of production equipment, resulting in the risk of production safety. (5) Large quantities of loose natural gas inflated freely, causing disaster to ships at sea and damaging marine ecology. (6) Large quantities of natural gas entering the atmosphere produce greenhouse effect. If the marine non-diagenetic natural gas hydrate is not reasonably exploited, it will cause catastrophic accidents, and the six risks it faces have always been the focus of attention in the development of marine non-diagenetic natural gas hydrate. It is necessary to adopt safe and effective scientific and technological innovation methods for green exploitation of this kind of hydrate resources.

Therefore, the project team led by Zhou, Academician of Chinese Academy of Engineering, divided the hydrate into the kind of diagenetic and non-diagenetic, proposed the technological strategy of 6 “utilize”, firstly created the technological principle of solid fluidization exploitation of non-diagenetic natural gas hydrate and the technological process of hydrate mining, crushing, ejection and fluidization of seawater, separation and backfill of sand, slurry lift and deep separation and re-backfill in the platform, and achieved the safe and green exploitation which let nature take its course, turned the harm into a benefit, and turned the uncontrollable into controllable.

Based on this principle, Southwest Petroleum University invented the experimental simulation method and technology, cooperating with China National Offshore Oil Corporation and Sichuan Honghua Petroleum Equipment Co. Ltd. The overall process simulation of solid fluidization exploitation with water depth of 1500 m and pipeline length of 4500 m is achieved. The world’s first large physical experimental simulation system of solid fluidization exploitation of marine natural gas hydrate is researched and developed, which

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has full independent intellectual property rights and includes 3 modules and 12 subsystems of sample preparation of hydrate, crushing and slurry modulation, high-efficient pipeline transportation and separation of slurry, image capture in real-time, data collection and automation of security control and so on.

On April 28, 2015, the world's first marine non-diagenetic gas hydrate solid fluidization exploitation laboratory was inaugurated in Southwest Petroleum University. The world's first large-scale physical simulation experiment system of marine non-diagenetic natural gas hydrate solid fluidization exploitation with completely independent intellectual property rights has been successfully invented and developed. The system consists of 3 modules of rapid preparation, fragmentation and slurry modulation of large samples, high-efficient pipeline transportation and separation of slurry, and real-time image capture, data collection and safety control and 12 subsystems of preparation, fragmentation, slurry modulation, screw pump conveying, horizontal pipeline transportation and decomposition, vertical pipeline transportation and decomposition, multistage depressurization, multistage heating, sample analysis of on-line automatic preservation of heat and pressure, three-phase separation, operation monitoring, and image capture and data test and analysis. Based on the formation physical properties of natural gas hydrate reservoir in the target area of test production with water depth of 1310 m, and buried depth of 117-192 m, such as argillaceous silty sand, loose argillaceous cementation, non-diagenesis, average porosity of 43%, and average saturation of 40%, the simulation experiment of solid fluidization exploitation of marine non-diagenetic gas hydrate is carried out supported by the large-scale physical simulation experiment system.

Moreover, the experiment of solid fluidization exploitation is carried out systematically for the first time, which provided an important basis for the formulation of the test scheme, the optimization design of the process and the research and development of downhole tools, supported the world's first successful test exploitation of solid fluidization method, and proved the scientific feasibility of the principle and the technology of solid fluidization exploitation.

Large samples of non-diagenetic natural gas hydrate were prepared experimentally, the variations of resistivity, acoustic velocity and hydrate saturation with different particle size, compaction degree, shale content and other parameters of the samples were tested and analyzed. The effects of different mechanical crushing parameters on the breakage of non-diagenetic natural gas hydrate are simulated and evaluated experimentally, and the mechanical crushing engineering plate of marine non-diagenetic gas hydrate sample is established. The phenomena of vertical pipeline transportation and the variation of rock carrying capacity before and after hydrate decomposition were obtained by experiments. Meanwhile experiments were conducted to obtain the phenomena of horizontal pipeline transportation experiments before and after hydrate decomposition and the variation regularity of rock carrying capacity. In order to analyze the gas-liquid-solid multiphase non-equilibrium flow in solid fluidization exploitation of marine non-diagenetic natural gas hydrate, a mathematical model has been developed.

Through the high-efficient pipeline transportation and separation experiments of marine non-diagenetic natural gas hydrate slurry, and the comparison of experimental and theoretical calculation data, it is found that the variation trend is consistent and the error is small, which verifies the accuracy of the mathematical model and lays a foundation for the development of the technology scheme of solid fluidization test exploitation of marine non-diagenetic natural gas hydrate.

We have formulated the technical scheme of solid fluidization test exploitation of marine non-diagenetic natural gas hydrate. Based on the formed experimental technology, theory and wellbore structure of solid fluidization exploitation of marine non-diagenetic natural gas hydrate, the annular phase state and

multiphase flow of the target well for solid fluidization exploitation of marine non-diagenetic natural gas hydrate are analyzed. The multiphase flow parameters in annulus with different liquid discharge, liquid density, wellhead backpressure, gas production and jet diameter have been obtained, and the prediction of characteristic parameters has been formed.

The idea of high-pressure jet crushing technology for solid fluidization test exploitation of marine non-diagenetic natural gas hydrate is researched and put forward. At the same time, the high-pressure jet crushing nozzle tool for natural gas hydrate is researched and developed completely by ourselves, and the range of construction parameters under different crushing aperture and breaking rate is revealed by experiments in the construction of hydrate test exploitation engineering. The process parameters of fluidization test exploitation of target well were optimized, and the parametric plate of fluidization test exploitation of marine natural gas hydrate was established. Based on the analysis of annular phase and multiphase flow in the target well and the development and experimental analysis of the high pressure jet crushing tool, the optimization of the key parameters in the operation of the target well for the solid fluidization test exploitation of natural gas hydrate is carried out. Based on the analysis of annular phase state and multiphase flow in the target well, the development and experimental analysis of the high pressure jet crushing tool, and the optimization of the key parameters in the operation of the target well for solid fluidization test exploitation, a scheme for the solid fluidization test exploitation of marine non-diagenetic natural gas hydrate is designed.

The experimental simulation technology and system, as well as the first testing results, were reported in the Journal Science. The invention and development of the large-scale physical simulation experiment system, and the conduction of simulation experiment provides the key parameters for the formulation of the technical scheme and the design of the operation flow of the first successful solid fluidization test exploitation of marine natural gas hydrate. It is proved that the principle of solid fluidization exploitation is scientific and feasible, and the exploitation technology is feasible and promising. The successful research and development and further upgrade of the system are expected to promote the solid fluidization exploitation technology of marine non-diagenetic gas hydrate to become a leading edge of a subversive technology in the world. It is expected to accelerate the commercial development process of natural gas hydrate in China and even in the world.

Keywords: Marine non-diagenetic natural gas hydrate; solid fluidization; exploitation; physical simulation; experimental system; test scheme