

Research Article

Energy efficiency simulation of the process of gas hydrate exploitation from flue gas in an electric power plant

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Abstract

It is a safe and environmentally-friendly method to exploit natural gas hydrates (“hydrate”) by using flue gas (mainly including CO₂ and N₂) from electric power plants. So far, however, its energy consumption and energy efficiency has not been investigated thoroughly. In this paper, the process to exploit hydrates from flue gas was established. Firstly, flue gas is injected into hydrate reservoirs after it is pressurized. The hydrates in reservoirs partially experience thermal decomposition while the rest is replaced with flue gas, so CH₄–CO₂–N₂ mixture is formed. Secondly, the concentrated CH₄–CO₂ mixture is got after N₂ is separated and removed by using membrane component. And thirdly, the CH₄–CO₂ mixture is delivered to the original electric power plant. This process was simulated by using the software Aspen Plus to analyze the production/injection ratio in the process of flue gas replacement under different injection pressures, the methane replacement ratio, and the energy consumption and energy efficiency in the whole process. It is indicated that the energy in the process of hydrate exploitation from flue gas is mainly consumed at the pressurized injection stage, and the injection pressure increase correspondingly results in the increase of energy consumption at pressurization and membrane separation stages, and to some extent improves the recovery ratio of pressure energy. Besides, when the injection pressure is 5–16 MPa, the production/injection ratio in the process of flue gas replacement is 0.03–0.26, the methane replacement ratio is 19.9–56.2%, the unit energy consumption in the whole process is 2.15–1.05 (kW·h)/kg_{CH₄}, and the energy return on investment (*EROI*) is 7.2–14.7. It is concluded that the energy efficiency of hydrate exploitation from flue gas can be effectively improved by increasing the injection pressure in the range of 5–10 MPa. © 2017 Sichuan Petroleum Administration. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Keywords: Flue gas; Electric power plant; Natural gas hydrate; Exploitation; Energy efficiency; Simulation; Energy return on investment (*EROI*); Replacement; Carbon dioxide

Natural gas hydrate (hydrate) is a promising kind of energy resource [1–6]. Hydrate exploitation through CO₂ replacement is currently considered as a valuable technology, by which clean energy can not only be exploited but greenhouse gas can be stored in the form of solid hydrate [7–10]. However, the exploitation by directly using pure CO₂ replacement may result in low replacement rate and accumulative gas production. The replacement exploitation by directly injecting flue gas from electric power plant can reduce the cost for

obtaining CO₂ and also greatly improve replacement rate and accumulative gas production [11,12].

Although the efficiency of exploitation by flue gas replacement is high, the injection of a large amount of flue gas (in which the CO₂ content is less than 20%) into the reservoir will increase the energy consumption of compressors and thus reduce the energy efficiency of the exploitation process. So, it is necessary to calculate such energy consumption and efficiency quantitatively. In this study, the process to exploit hydrate from flue gas was established, and it was simulated by using the software Aspen Plus to analyze the production/injection ratio in the process of flue gas replacement, the methane replacement ratio,

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and the energy consumption and energy efficiency under different injection pressures in the whole process.

1. Process of natural gas hydrate exploitation from flue gas

1.1. Establishment of the exploitation process

Hydrate is a kind of energy resource. In its development and utilization overall consideration should be given to the exploitation methods, transportation ways and utilization modes, for more efficient resource utilization. The authors established the process of hydrate development and utilization from flue gas (mainly including CO₂ and N₂), as shown in Fig. 1. Firstly, the flue gas was injected into a hydrate reservoir after it was pressurized to get CH₄-bearing gas (N₂, CO₂ and CH₄). Secondly, the CH₄-rich mixture (CO₂ and CH₄) was got after N₂ was separated and removed by using membrane component. And thirdly, the CH₄-rich mixture was delivered to the original electric power plant.

Fig. 2 is an exploitation way of hydrate development and utilization process. The flue gas (CO₂ and N₂) from the electric power plant was injected into the hydrate reservoir after it was pressurized. Due to the high gas temperature, the hydrate reservoir experienced thermal decomposition, and then experienced replacement process after the temperature got lower. The mixture exploited from the hydrate reservoir is of low methane concentration and high pressure, the pressure energy of which was partially recovered through turbine expansion and then entered the membrane separation device for separation, and finally the methane-rich product was got and delivered to the electric power plant.

1.2. Process simulation

Aspen Plus is a large-scale and universal process simulation software, which is highly praised by staff in chemical industry

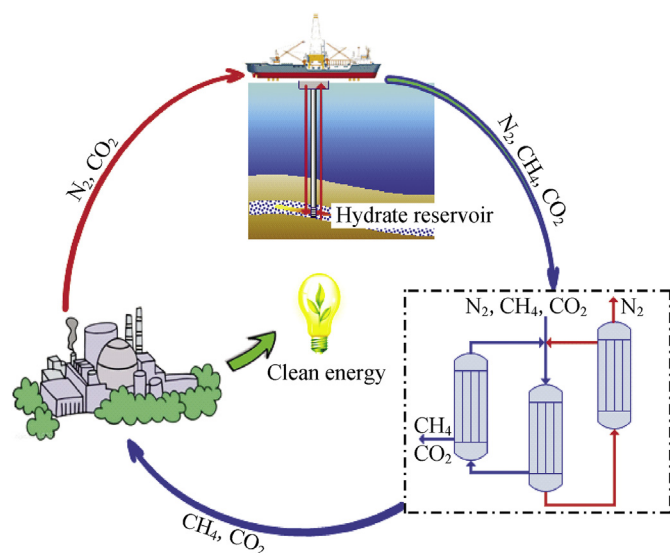


Fig. 1. Process of hydrate development and utilization from flue gas.

for its wide applications and computation reliability. The exploitation process (Fig. 3) was simulated, according to Fig. 2 by using Aspen Plus 11.1. The process includes three stages: pressurized injection stage, exploitation stage and membrane separation stage.

1.2.1. Pressurized injection stage

This flue gas (CO₂ and N₂) was pressurized from 0.1 MPa to the needed injection pressure through three-level pressurization, the process of which was simulated by COMPER 1 module. The isentropic efficiencies of compressors are all 0.85 and the mechanical efficiencies are all 0.95.

1.2.2. Exploitation stage

This stage includes hydrate decomposition and replacement. Due to the high temperature of material flow after pressurization, the hydrate entering the hydrate reservoir was first partially decomposed, which was described by FLASH 1 module. Then the hydrate experienced replacement after the temperature got lower, which was described by HYDRATE module.

1.2.3. Membrane separation stage

This stage includes pressure energy recovery and three-level membrane separation. In the pressure energy recovery stage, the high-pressure gas exploited from the reservoir was depressurized to the inlet pressure needed by membrane separation through turbine expansion, during which the pressure energy was transformed into electric energy and cold energy. The isentropic efficiency and mechanical efficiency of turbine is the same as that of the compressor. Styrene-butadiene-styrene (SBS) triblock copolymer was used in the membrane separation stage [13]. In this stage, the membrane-front inlet pressure is 2.0 MPa, permeation-side pressure is 0.15 MPa and retentate-side pressure is 2.0 MPa.

1.3. Methane content in the output gas

Methane content in the output gas is composed of two parts: methane exploited from thermal decomposition and methane exploited from replacement. The former was produced from partial hydrate decomposition, which can be calculated according to the decompound enthalpy (ΔH_{diss}) of methane hydrate and the quantity of heat (Q) in injected gas, as is shown in Formula (1).

$$n = \frac{Q}{\Delta H_{\text{diss}}} \quad (1)$$

In the formula, Q represents the heat released when the temperature of thermal fluid decreases to the temperature of the hydrate reservoir, kJ; ΔH_{diss} represents the decompound enthalpy of methane hydrate, kJ/mol.

The methane exploited from replacement can be determined according to the variation in molar weight of CO₂ and N₂ before and after injection, and the molar weight was determined according to the gas composition before and after injection and the molar when CO₂ and N₂ entered the hydrate

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