Study on hydrocyclone used for natural gas hydrate mining

Wangqiang Ti[1,*], *Yulong* Chang[1], and *Hualin* Wang[1]

[1]National Engineering Laboratory for Industrial Wastewater Treatment, East China University of Science and Technology, Shanghai, 200237, China

Abstract. Nowadays, energy shortages and global environmental pollution problems are becoming increasingly prominent, and the exploration of clean and renewable energy has become an important direction of energy research. Natural gas hydrates have become the most promising alternative energy source in the future due to its advantages of high calorific value, small environmental hazards and abundant mineral deposits. About 99% of natural gas hydrates are stored in the seabed formation. In 2014, China proposed solid-state fluidized mining technology for marine natural gas hydrates. One of its key technologies is to remove sand from hydrates in real time and backfill the sand on the seabed. Therefore, a downhole axial hydrocyclone suitable for the exploitation of marine natural gas hydrates is proposed in this paper. The purpose of this study is to achieve real-time sand removal and backfilling of downhole hydrate mixed slurry, reduce the sand content of produced fluid, protect the seabed stratum structure, and at the same time reduce the energy consumption of pipeline transportation. In this study, the experimental method was used to evaluate the separation performance of the cyclone with a nominal diameter of 100 mm under different working conditions.

1.Introduction

The global reserves of natural gas hydrates contain approximately CH_4 0.82×10^{13} -2.1×10^{15} m^3, equivalent to a carbon content of approximately 1×10^{12} t, the total carbon content is roughly equal to twice the total carbon content of other fossil energy[1]. Natural gas hydrates are known for their rich energy reserves, wide distribution, high energy density and clean combustion, which makes them the most promising alternative energy sources in the future. Therefore, many countries such as the former Soviet Union, Canada, the United States, Japan, China and other countries have launched natural gas hydrate pilot production projects in relevant sea areas. Marine natural gas hydrate extraction methods are shown in the Table 1.1. The mining methods adopted in different countries are different, mainly including the decompression method, thermal stimulation method, inhibitor injection method, CO_2 replacement method and fluidized mining method. The advantages and disadvantages of different methods are shown in the Table 1.1.

Table 1.1 Methods of natural gas hydrate mining

Mining methods	Measures	Advantages	Disadvantages
decompression[2]	Reduce the pressure in the mining pipeline	low cost	Slow mining speed and low efficiency
thermal stimulation[3]	Inject heat into the natural gas hydrate through hot water, microwave, solar energy, electromagnetic heating		Massive energy consumption
inhibitor injection[4]	Inject CH_3OH、CaCl and other substances into the natural gas hydrate	Less equipment investment; Low energy consumption	Great environmental impact; Limited decomposition capacity
CO_2 replacement[5]	Inject CO2 to replace methane in natural gas hydrate	Greenhouse gas consumption; Low environmental impact	high cost

---

[*] Corresponding author: tiwangqiang@163.com

In 2014, the technology of solid-state fluidized mining of marine natural gas hydrates was first proposed. One of its key technologies is to realize real-time separation of hydrate and sand mixed slurry and backfill the sand. Therefore, a downhole axial hydrocyclone suitable for the exploitation of marine natural gas hydrates is proposed in this paper. The purpose of this study is to achieve real-time sand removal and backfilling of downhole hydrate mixed slurry, reduce the sand content of produced fluid, protect the seabed stratum structure, and at the same time reduce the energy consumption of pipeline transportation.

2 Experimental Study

2.1 Hydroyclone structure

2.2 Experiment Process

The experimental process is shown as the figure1.1. First, a certain amount of water and quartz sand particles are added to the tank whose bottom is connected to the pump inlet. The mixed slurry of water and quartz sand particles is pumped to the hydrocyclone inlet. The inlet flow rate ranges from 4 m^3/h to 8 m^3/h. The particles of the mixed slurry are separated from the mixture by centrifugal force. Finally, most of the solid particles are discharged from the sand outlet and returned to the storage tank, and the water from which the solid particles are removed is returned to the storage tank from the water outlet. The whole process is continuously circulated to complete the liquid-solid two-phase separation. Sampling ports, regulating valves, flow meters and pressure gauges are installed at the pump outlet, sand outlet and water outlet to detect the flow and pressure of the inlet and outlet of the hydrocyclone respectively. The particle size and solid content of the sample are tested to further analyze the separation performance of the hydrocyclone.

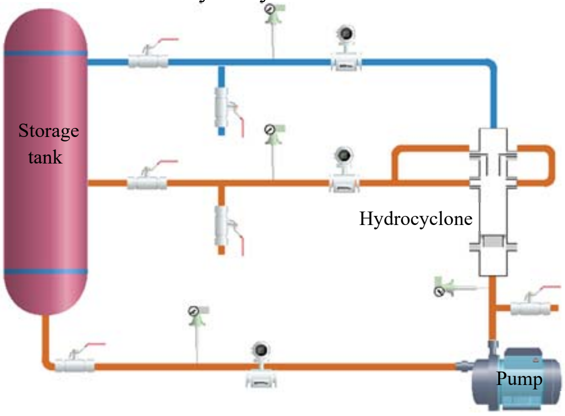

Fig.1.1 experiment process

2.3 Analytical method

During the experiment, the fluid at the inlet and outlet of the hydrocyclone is sampled and analyzed. The solid content measurement of the sample is calculated by the gravimetric method. First the sample volume is recorded, then the sample is vacuum filtered. The solid particles obtained by suction filtration are dried and weighed. The calculation formula of solid content is:

$$C=\frac{m}{V} \qquad (2\text{-}1)$$

Where C is the solid content, m is the mass of the solid particles after suction filtration, drying, and V is the total volume of the sample

So the separation efficiency is:

$$E=\frac{C_1\times Q_1}{C\times Q} \qquad (2\text{-}2)$$

Where E is the separation efficiency, C_1 is the solids content of the sand outlet, Q_1 is the flow of the sand outlet, C is the inlet solid content, and Q is the inlet flow.

3 Results and discussion

3.1 Material analysis

Water and three kinds of quartz sand particles were used in this experiment. The density of water is 998 kg/m3 and the viscosity is 0.018 mPa·s. The density of the quartz sand particles is 2600 kg/m^3, three kinds of quartz sand particles with different particle sizes are used, and the particle size distribution of the three particle sizes is tested using a Malvern laser particle size analyzer. The particle size test results are shown in the figure1.2. The particle size distributions of the three types of particles shows a single peak shape, and the average particles sizes are 30μm, 80μm, 200μm.

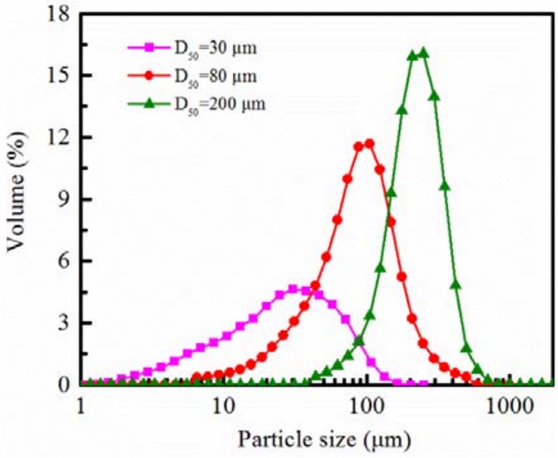

Fig.1.2 Inlet particles sizes distributions

3.2 Effect of inlet flow rate on separation efficiency

Figure 1.3-5 are the efficiency curves of three different particle sizes D_{50}=200 μm, D_{50}=80 μm, D_{50}=27 μm respectively. The inlet solid content of the hydrocyclone is 1000 mg/L, but the imported sampling test results fluctuate slightly. For particles with an average particle size of 200 μm, in the range of inlet flow rate of 4-8 m^3/h, as the inlet flow rate continues to increase, the overall separation efficiency increases rapidly and then remains stable. When the inlet flow rate is greater than 6 m^3/h, the solid content of the mixture can be reduced from 1000 mg/L to about 180 mg/L, and the separation efficiency is about 83%. When quartz sand particles with an average particle size of 80 μm were used in the experiment, the separation efficiency increased with the increase of flow rate in the range of inlet flow rate of 4-8 m^3/h. the solid content can be reduced from 1000 mg/L to about 450 mg/L, and the separation efficiency is about 58% at an inlet flow rate of 8 m^3/h. For particles with an average particle size of 30 μm, the overall separation efficiency increases as the flow rate increases in the range of inlet flow rate 4-8 m^3/h. After treatment by the hydrocyclone, the solid content decrease from 1000 mg/L to less than 800 mg/L, and the separation efficiency is about 33%.

For the experiments with three particle sizes and five inlet flow rates of 4 m^3/h、5 m^3/h、6 m^3/h、7 m^3/h、8 m^3/h, the separation efficiency increases rapidly with the increase of the flow rate, and, and the growth rate obviously slows after the flow rate reaches 7 m^3/h. As the flow rate increases, the centrifugal force on the fluid and particles also increases, which makes the particles can be driven to move to the side wall faster. But as the flow rate continues to increase, the turbulence intensity in the hydrocyclone also continues to increase, and the collision force between the particles cannot be ignored. The collision between particles will have a significant impact on the migration of particles. Therefore, as the inlet flow rate continues to increase, the separation efficiency tends to increase first and then decrease.

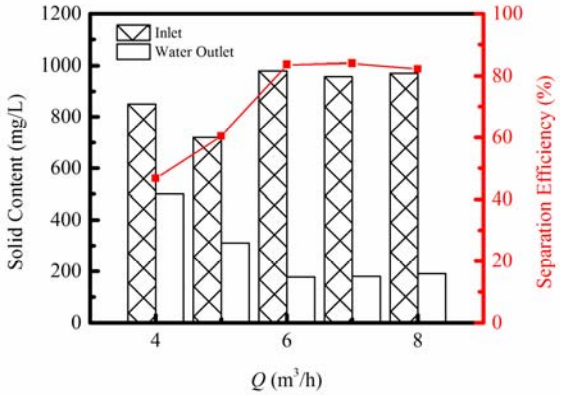

Fig.1.3 Hydrocyclone separation efficiency of particles with D$_{50}$=200 μm

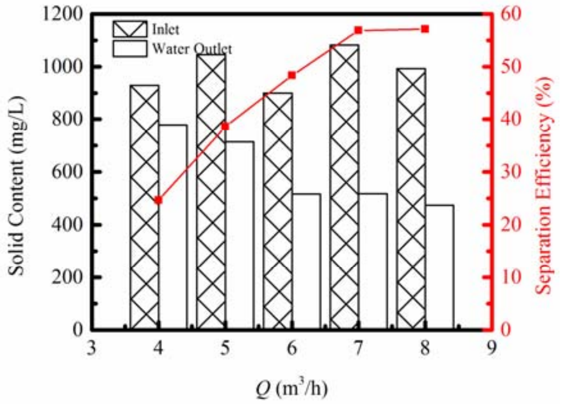

Fig.1.4 Hydrocyclone separation efficiency of particles with D$_{50}$=80 μm

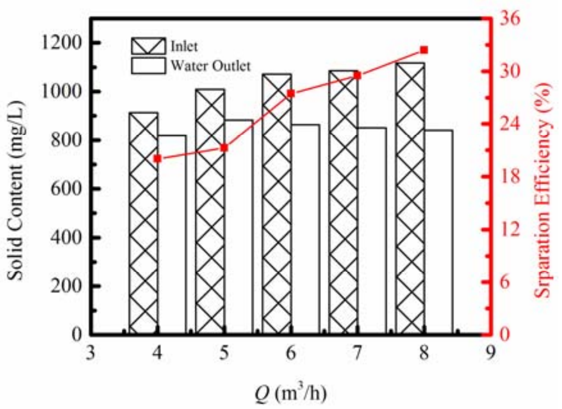

Fig.1.5 Hydrocyclone separation efficiency of particles with D$_{50}$=30 μm

3.3 Effect of particles size on separation efficiency

For different particles, the relationship between hydrocyclone efficiency and flow rate is similar. However, the optimal flow rate for small particles is slightly larger. The reason is that the particle size has a great influence on the centrifugal force and resistance of the particle movement. At the same flow rate, the large-diameter particles are subject to greater centrifugal force, so it will be easier to migrate to the side wall of the hydrocyclone. For small-sized particles, resistance occupies a more important position in the migration process and hinders separation, so a stronger centrifugal force is required. So under the same conditions, the efficiency of different particles being separated is quite different. When the inlet solid content is 1000 mg/L and the inlet flow rate is 8 m3/h, the average particle size of 27 μm particles are separated with an efficiency of 31%, the average particle size of 80 μm particles is separated with an efficiency of 59%, the average particle size of 200μm particles is separated with an efficiency of 81%.

4 Conclusion

The hydrocyclone proposed in this paper has good separation ability which can effectively achieve real-time sand removal and backfilling during subsea gas hydrate mining. This study can provide a reference for the exploitation of marine natural gas hydrates.

References

1. Z. R. Chong, S. H. B. Yang, P. Babu, et al. APPL ENERG, **162**(2016).
2. X. F. Liu, C. H. Liu, J. J. Wu. GEOFLUIDS, **2019**(2019)
3. M. Roostaie, Y. Leonenko. J PETROL SCI ENG, **184**(2020).
4. M. Aminnaji, B. Tohidi, R. Burgass, et al. J NAT GAS SCI ENG, **45**(2017)
5. Y. Chen, Y. H. Gao, L. T. Chen, et al. J NAT GAS SCI ENG, **61**(2019)