Numerical Calculation of Dynamic Hydrocyclone Separation

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Abstract

Aiming at the solid-fluidized green mining technology of deep-sea shallow gas hydrate in seafloor, a comprehensive analysis of domestic and foreign separation equipment is proposed. The dynamic hydrocyclone is used to separate the hydrate slurry.The finite element model of dynamic hydrocyclone is established and verified by numerical calculation.Based on the Reynolds stress model, a simulation analysis method suitable for the liquid-solid-solid two-phase flow is studied and analyzed. The distribution of the corresponding parameters of the flow field in the dynamic hydrocyclone is obtained by numerical calculation. The numerical results show that the separation efficiency of the hydrocyclone is up to 2m3/h, the split ratio is 30%, the rotating speed is 1050r/min,the sediment volume fraction is 0.02 and the natural gas hydrate volume fraction is 0.04, the separation efficiency is 98.47%.

Keywords

Nature gas hydrate,separation,multiphase flow,dynamic hydrocyclone,CFD.

1. Introduction

Gas hydrates serve as potential sources of energy for the future,large amount of resources,clean and so on.The amount of methane in natural gas hydrate is about 2.0×1016m³,which is double the total amount of fossil fuel minerals currently proven, and the maximum geological reserves of natural gas hydrate distributed on land are about 5.3×1011t.The maximum geological reserve distributed in the ocean is about 1.61×1015t.Only the reserves of natural gas hydrate in the ocean are enough to meet human needs for more than 1,000 years.Natural gas hydrate,after being decomposed and released,is mainly composed of methane,which contains less impurities compared with conventional natural gas and produces little environmental pollutants after burning.It is an ideal clean energy source in the future[1].

For the development of the weakly cemented gas hydrates in the deepwater shallow layers in the oceans,Shouwei Zhou et al.Put forward the deepwater shallow gas hydrate solid-state fluidized mining technology,which is a new development idea with little pollution and secondary disasters Small advantage[2-3].According to this technology,the slurry mixture of natural gas hydrate,silt and seawater pulverized by "submarine in-situ solid-state mining" and "seabed free-sand separation system" before being pumped to the offshore platform propose the use of a dynamic hydrocyclone for mixing the mixture for separation of sand,the numerical calculation made a very good separation effect.

2. The introduction to dynamic hydrocyclones

Dynamic hydrocyclones and static hydrocyclones also use the centrifugal force to achieve the separation between different phases.The static hydrocyclone can be converted into kinetic energy by the inlet pressure to form a centrifugal force field,while the dynamic hydrocyclone is through the application of electric energy,the drum rotates at high speed to form the centrifugal force field[4].

Compared with the static hydrocyclone,the dynamic hydrocyclone has the characteristics of small particle size,short residence time,small weight and small volume,great adaptability to the treatment volume and pressure changes and little pressure loss,high separation efficiency[5-6]. Based on these advantages,a dynamic hydrocyclone is proposed to separate the seabed gas hydrate slurry.

The main structure of the dynamic hydrocyclone includes rotating drum,rotating gate,exit section and other parts.The basic geometric structure is shown in Fig. 1.

Motor driven swirler rotating parts to do high-speed rotary motion,the two-phase or multi-phase mixed slurry pressure from the entrance into the rotating gate,the rotating gate to the diversion and pre-rotation to accelerate the flow to get high-speed rotation flow,by the flow and the inner wall of the drum between the friction force to form a larger and stronger vortex velocity field.Due to the density difference of the sand,seawater and gas hydrate in the mixed slurry,the gas hydrate and part of the seawater are pressed toward the center of the tumbler due to the centrifugal acceleration of the mixed slurry obtained by 1000 times of the gravitational acceleration,and finally discharged from the overflow port,mud mixed with the remaining seawater to the drum wall migration,by the axial force along the same direction,from the bottom outlet.

Fig. 1 Three-dimensional structure of dynamic hydrocyclone

3. Numerical simulation experiment of dynamic hydrocyclone

3.1 Basic assumptions

The internal flow of a dynamic hydrocyclone containing silt,gas hydrate and seawater is a complex solid-liquid two-phase flow.To achieve the numerical simulation of the internal turbulent flow field,the following assumptions are made.

(1)The liquid phase(seawater) is an incompressible fluid and the particulate phase(silt and gas hydrate)is a continuous medium with constant physical properties.

(2)The solid particle phase is spherical,with uniform particle size,regardless of the phase change.

(3)The flow in the rotating drum is steady flow.The single motion reference frame (SRF) model is adopted.The reference frame is fixed on the dynamic hydrocyclone model.The moving area is the gas hydrate slurry in the rotating drum.

3.2 Geometric model and grid

Total Dynamic Hydrocyclone[7] is adopted.The main geometric parameters are as follows,drum diameter D=50mm and length L=760mm.The rotating grid is of a four-leaf bar structure with blade length l=100mm and blade thickness h=4mm,central axis diameter d=30mm,overflow orifice diameter d1=10mm,deep drum distance s=20mm.

A dynamic hydrocyclone model was established by using AutoCAD software and meshed in ICEM CFD.The velocity gradient near the rotating grid and the overflow was larger,corresponding to the grids at the rotating grid and the overflow,and the other regions were adopted.More sparse grid to speed up the calculation.The total number of final hexahedron cells is about 100,000. Fig. 2 is a schematic diagram of the grid.

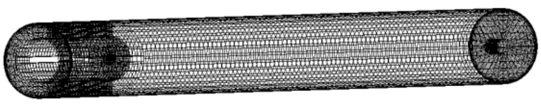

Fig.2 Model meshing

3.3 Gas hydrate slurry setting method

Simplify the media model of the seabed gas hydrate slurry.The gas hydrate slurry extracted by the solid-state fluidization simplifies the three-media two-phase flow into three media,seawater,sand and gas hydrate,it is also assumed that the volume fractions of seawater,silt and gas hydrate are 70%,10% and 20%,respectively.Medium parameter setting,the density of seawater is 1025kg/m3,the viscosity is 0.0017kg/m·s,the density of sediment is 2600kg/m3,the viscosity is 1.72×10-5kg/m·s,the density of natural gas hydrate is 600kg/m3,1.20×10-5 kg/m·s.Based on the fractured natural gas hydrate slurry during solids fluidization,a preliminary study was conducted on the particle size of solid particles 10-90μm.

3.4 Boundary conditions

Assuming that all three media are axial inlets and have the same velocity,the throughput is Q=3m³/h,the inlet pressure is 0.15MPa,turbulence is given by hydraulic diameter and turbulence intensity(5%),Shunt ratio is 30%.The wall is made of non-sliding solid wall,and the standard wall function is used to determine the flow near the wall.The wall condition of the drum is selected as Moving Wall.The rotation speed is 700r/min,1500r/min,2500r/min and 3000r/min.The PRESTO pressure-velocity coupling scheme and SIMPLEC are used as the coupling algorithm between pressure velocities.The discretization scheme of control equation is QUICK differential format.

3.5 Separation efficiency calculation formulation

Separation efficiency is one of the important technical indexes to evaluate the degree of perfection of the cyclone separation process.The separation of natural gas hydrate mixed slurry is carried out by using Hancock's integrated efficiency formula.This formula is used for separation according to the particle size difference, for example,Grading,mud removal,clarification and separation of the technical evaluation of separation[8].

$$E=\frac{(\alpha-\vartheta)(\beta-\alpha)}{\alpha(\beta-\vartheta)(100-\alpha)}\times 10000\% \quad (1)$$

In the formula,α is the volume fraction of the calculated material in the inlet,β is the volume fraction of the calculated material in the overflow port, ϑ is the volume fraction of the calculated material in the underflow outlet.Seawater as one of the separated media,there is no clear requirement for the discharge from the bottom or overflow.Therefore,the volume occupied by seawater is not taken into consideration when calculating the separation efficiency.

4. Numerical calculation and analysis

4.1 Tangential velocity distribution at different rotational speed

Take the solid phase particle size of 60μm,the remaining boundary conditions set unchanged. Among the three main velocities of the dynamic hydrocyclone flow field,the tangential velocity determines the centrifugal force suffered by the internal medium,which is one of the most important parameters that affect the separation performance[9].

As shown in Fig. 3 and Fig. 4,the tangential velocity distributions of dynamic hydrocyclones and static hydrocyclones are similar,and they are both forced vortex areas and outcrops that increase with increasing radius of the tangential velocity in the inner swirling zone.The tangential velocity of the flow zone is composed of the free vortex zone decreasing with increasing radius.It can be found that the trend of the tangential velocity distribution at the two cross sections is basically the same,indicating that unlike the static hydrocyclone,the phenomenon that the tangential velocity of the dynamic hydrocyclone attenuates in the axial direction does not occur,which is also a dynamic hydrocyclone One of the reasons why it is better than static hydrocyclones.

The trends in velocity near the wall of the dynamic hydrocyclone in two figure are similar, but the tangential velocity at the z=150mm section (from the rotating grating) is different from the tangential velocity at the z=450mm section,which is due to the z=150mm cross-section affected by the rotating grid,the velocity gradient is very large and the turbulence in the flow field is strong.Under different speed conditions,the tangential velocity distribution trends are basically the same.When the speed is 700r/min,the two cross-sections show that a double-vortex structure has been formed.At this time,the centrifugal force is not enough because the speed is small,so the forced vortex area is smaller.With the continuous increase of rotational speed,the range of forced vortex increases gradually and the location of maximum tangential velocity also increases.Tangential velocity was double vortex structure,in line with the center of the compulsory vortex and external free vortex law.The tangential velocity generated by the flow field inside a dynamic hydrocyclone at this speed is consistent with the measured tangential velocity measured by LDA technique by Dabir[10].Explain the correctness of the established model and numerical simulation method.

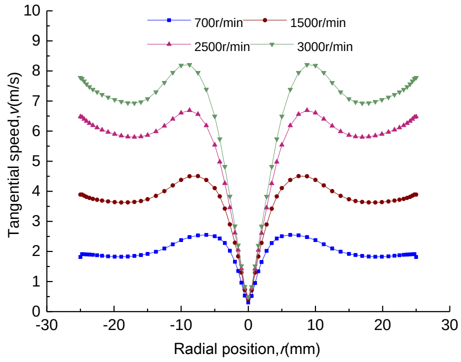

Fig.3 z=150mm tangential speed

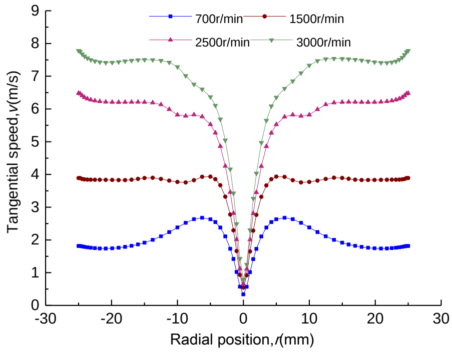

Fig.4 z=450mm tangential speed

4.2 Density distribution

As shown in Fig. 5,it can be seen from the figure that due to the strong swirling flow field inside the dynamic hydrocyclone,the gas with the lowest density in the three media is distributed at the axial center and discharged from the overflow port.Most the high-density,silt-seawater mixture is distributed near the wall of the dynamic hydrocyclone and eventually exits through the underflow.The density distribution of natural gas hydrate slurry increases along the radial direction from the axis to the wall and reaches the maximum at the wall[11].

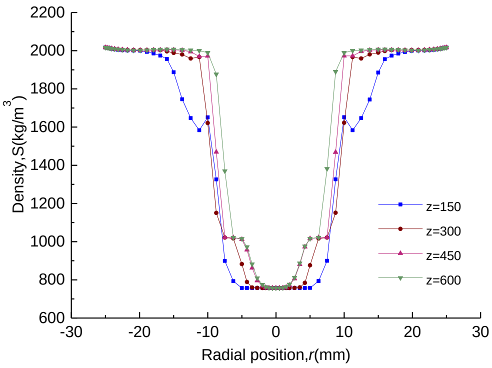

Fig.5 Density distribution

4.3 Effect of different rotational speed and particle size on separation efficiency

The numerical calculation is made at the speed of 700r/min,1500r/min,2500r/min and 3000r/min,and the gas hydrate particles are 10 -60μm.The corresponding parameters are extracted from the numerical simulation post-processing,and substituted into the formula(1),the result is shown in Fig. 6.

As can be seen from the figure,the overall separation efficiency of gas hydrate at seafloor increases with the increase of rotating speed.When the rotating speed increases from 700r/min to 1500r/min,the separation efficiency increases obviously.With the continuous increase of rotating speed,separation efficiency continues to increase,this is because the greater the tangential velocity,the greater the centrifugal force field,the better the cyclone separation.Separation efficiency of natural gas hydrate increased gradually with the increase of seafloor particle size.The separation efficiency increased gradually from 10 to 70μm,and the separation efficiency was above 90% at 60 -70μm,stable at about 98%.And particle size has little effect on the separation efficiency[12].

The separation efficiency of natural gas hydrate increases with the increase of the rotational speed of the hydrocyclone,and the particle size of natural gas hydrate is also one of the most influential factors.

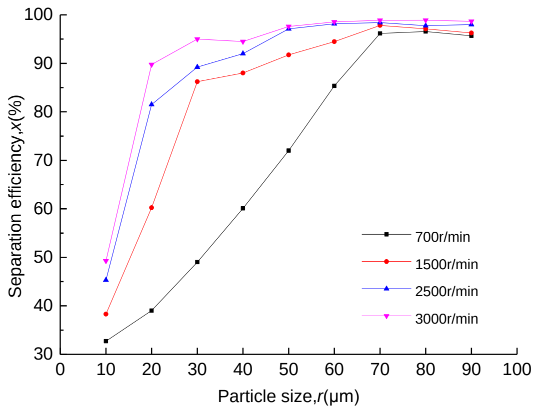

Fig.6 Separation efficiency at different speeds

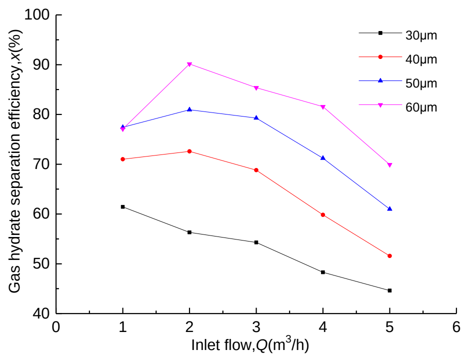

Fig.7 The separation efficiency of different entrance traffic

4.4 Effect of different inlet flow rate and particle size on separation efficiency

Take the particle size of 30-60μm,the split ratio of 30%,speed of 1050r/min,the inlet flow rate of 1-5m3/h.The separation efficiency is shown in Fig. 7.As can be seen from figure,for gas hydrates with particle sizes of 40-60μm,there is a slight increase in separation efficiency at inlet flow rates of 1-2m3/h.When the particle size is 60μm and the inlet flow rate is 2m3/h,the separation efficiency reaches 90.14%.Then the inlet flow rate continued to increase,the separation efficiency began to decline,this is because the inlet flow rate increases,the gas hydrate slurry in the dynamic hydrocyclone drum residence time shorter,making the separation time decreases.Separation efficiency is reduced.At the same time too large flow will destroy the stability of the flow field inside the cyclone,so that the separation efficiency is reduced.So for a specific structure of the dynamic hydrocyclone,the inlet flow has an optimal value.

4.5 Effect of inlet media volume fraction on separation efficiency

The gas hydrate mixed slurry extracted from the seabed contains three kinds of media,namely, sand,gas hydrate and seawater.The content of each of the sand and gas hydrate has a great influence on the separation efficiency.Based on the above results, the numerical simulation of gas hydrate with particle size of 30-60μm was carried out, see Table 1.

As shown in Fig. 8,as the volume fraction of inlet gas hydrate and silt increases,the separation efficiency decreases.The separation efficiency is only 30%-40% when the inlet sediment volume fraction is 0.2 and the natural gas hydrate volume fraction is 0.4,while the separation efficiency is 90% when the inlet mud volume fraction is 0.02 and the gas hydrate volume fraction is 0.04 %, The highest separation efficiency of 98.47%.This is because, as a unit volume of gas hydrate slurry increases,the overall concentration,density and viscosity of the slurry increase as the volume fraction of silt and gas hydrate increases,resulting in a decrease in separation efficiency.The particle size of natural gas hydrate also has a greater impact on the separation efficiency.

Table.1 The volume fraction of each medium

Numble	Silt	Gas hydrate	Seawater
1	0.02	0.04	0.94
2	0.05	0.10	0.85
3	0.10	0.20	0.70
4	0.15	0.30	0.55
5	0.20	0.40	0.40

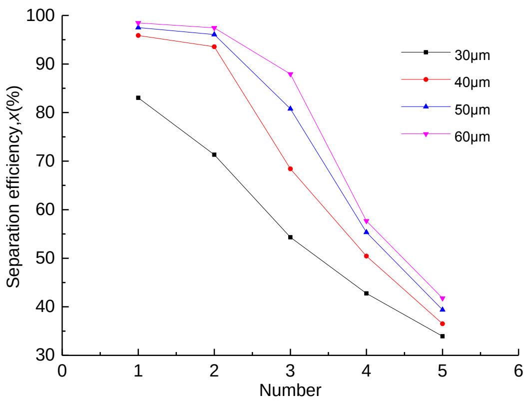

Fig.8 Each medium volume fraction of the separation efficiency

5. Conclusion

(1)By verifying the relevant literature data,the tangential velocity of the internal flow field is compared and analyzed,and the correctness and reliability of the numerical simulation method for the dynamic hydrocyclone in this paper are validated.

(2)Based on the Reynolds stress model and the multi-phase mixture model,thegas hydrate slurry is numerically studied to obtain the distribution regularity of the tangential velocity and density of gas hydrate slurry in the dynamic hydrocyclone.

(3)The effects of different operating parameters on the separation efficiency of natural gas hydrate slurry were studied.The results showed that the inlet flow of dynamic hydrocyclone was 2m3/h,the split ratio was 30%,the rotating speed was 1050r/min,the volume fraction of mud was 0.02,when the gas hydrate is 0.04,the separation efficiency reaches 98.47%.

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