Flow Analysis of Two-Phase Flow in Curved Pipe of Polar Cruise Seawater Pipeline

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Abstract. In order to study the flow characteristics of seawater-ice crystals two-phase flow in the polar cruise seawater pipeline system, the curved pipe in the pipeline system is taken as the research object. Through numerical simulation, the effects of different initial conditions on the flow of seawater-ice crystal two-phase flow in curved pipe are analyzed, and the flow analysis results are obtained. The results show that in the curved pipe, the fluid is separated at the bend, and the pressure loss at the corner of the curved pipe is the most serious; the increase of the flow rate and the IPF (ice packing factor) will cause the ice crystals to gather toward the center; when the fluid has a high IPF, the ice crystals can be converted into a symmetric distribution state by being concentrated on the inner wall surface of the pipe at a relatively low flow rate; in the range of 0.5 m/s-2 m/s, the increase in fluid velocity has a significant effect on the distribution of ice crystals, and when the fluid velocity exceeds 2 m/s, the increase in flow rate has no significant effect on the distribution of ice crystals.

1. Introduction
As the trend of economic globalization continues to deepen, people's demands for life and values have changed greatly. Eco-tourism has emerged as the times require. The most fascinating snow and ice scenery are the most fascinating for tourists [1]. As the demand for the global adventure tourism market continues to increase, small-scale expedition cruises will enter the market in the next few years. To date, at least 11 cruise lines around the world have announced plans to build new cruise ships. By the end of 2021, a total of 22 new expedition cruise ships will enter the market [2]. When the polar cruise is sailing in the polar region, due to the extremely low ambient temperature, there are ice floes in many navigation areas [3]. Some small ice crystals may flow into the seawater pipeline system. The presence of ice crystals will inevitably affect the seawater pipeline system [4]. Will lead to the failure of the ship's power system [5]. Therefore, it is necessary to carry out the analysis of the flow of seawater-ice crystals two-phase flow in the polar cruise seawater pipeline system.

2. Mathematical model
In the seawater-ice crystals two-phase flow, the Euler-Euler two-phase flow model based on particle dynamics theory is used. The Euler-Euler model uses the liquid phase and the solid phase as the continuous phases of interaction to establish their corresponding N-S equations. In numerical simulation, the flow of two-phase flow is regarded as turbulent flow and incompressible flow. The
governing equations have continuity equation, momentum conservation equation, energy conservation equation. The RNG turbulence model takes the solid-liquid mixed phase as the research object, and comprehensively considers the influence of the liquid phase and the particle phase on the flow process.

3. Numerical procedures

3.1. Thermal properties of seawater and ice crystals
In the range of 0-20m in depth, the salinity of seawater is about 11‰. For the convenience of calculation, the salinity of seawater is 10‰. The temperature of the seawater-ice crystals two-phase flow in the seawater system pipe is about 0 °C. When the salinity is 10 % and the temperature is around 0 °C, the density and specific heat of seawater do not change significantly with temperature, which can be regarded as a fixed value. The thermal conductivity and viscosity of seawater vary significantly with temperature and cannot be considered as a fixed value [6].

| Phase name      | Density (kg⋅m\(^{-3}\)) | Specific heat (J⋅kg\(^{-1}\)⋅K\(^{-1}\)) | Thermal conductivity (W⋅m\(^{-1}\)⋅K\(^{-1}\)) | Viscosity (Pa⋅s) |
|-----------------|--------------------------|------------------------------------------|-----------------------------------------------|-----------------|
| Seawater        | 1003                     | 4140                                     | 0.56                                          | 1.82×10\(^{-3}\) |
| Ice crystals    | 900                      | 2080                                     | 2.21                                          | -               |

3.2. Model building and meshing
A spatial 3D model of the 90° curved pipe was built in Solidworks software, and then imported into the ICEM software for meshing. Due to the simple structure of the curved pipe, the structure grid which is suitable for simple geometric structure and high quality is selected, determine the number of meshes is 89100 and the quality is above 0.65. Figure 1 shows the meshing of the 90° curved pipe.

3.3. Flow analysis in curved pipe
The fluid velocity is set to 0.5m/s-3m/s, the IPF is set to 5%-30%, the ice crystals diameter are set to 5×10\(^{-4}\) m and the diameter of the curved pipes are 0.04 m. The two-phase flow model uses the Euler-Euler model to set the boundary condition and solution methods in the software. Considering gravity, the direction of gravity coincides with the negative direction of the Y-axis. The pipe flow simulation does not consider the influence of phase change on the flow. The convergence accuracy is set to 10\(^{-4}\), and the wall surface adopts the fixed wall temperature condition.

In Figure 2, it can be clearly observed from the figure that the pressure loss at the corner is the most serious, and the main reason for this phenomenon is the energy loss caused by the secondary flow phenomenon. The secondary flow means that the lateral pressure exerts a certain effect on the flow along a certain boundary, so that it has a force parallel to the boundary, so the fluid velocity near the boundary is lower, and the fluid is more offset than the fluid farther from the boundary, this caused a secondary flow.

In Figure 3, when the seawater and ice crystals mixture flows turbulently in the curved pipe, the fluid movement is hindered by the deformation at the bend, and the velocity of the flow layer near the wall
is lower at the outer side of the pipe, resulting in less centrifugal force. However, the flow rate in the main flow area is large, and the centrifugal force exerted by the fluid is also larger, so that the main flow area flows toward the near wall surface, and additional flow is added to the fluid. At the same time, in order to maintain the mass conservation in the pipeline, the fluid also forms a flow of the wall area to the main flow zone.

In Figure 4, the flow rate of the ice crystals continues to increase as the fluid does not reach the bend. The ice crystals near the inner wall accelerate significantly when they are closer to the bend. When passing through the bend, the flow rate of the ice crystals exceeds the speed of the nearby seawater. Due to the centrifugal force, the ice crystals flow toward the wall surface of the pipeline, and finally pile up on the outside of the pipeline. In Figure 5, when the flow rate of the ice crystals is sufficiently large, the centrifugal force is also large, the fluid will have a tendency to move toward the wall area, and the boundary layer is separated at about 45° of the curved section. As the ice crystals continue to flow downstream along the curved section, the separated boundary layer will reattach to the tube wall, thus reattaching points appear on the tube wall. In the vicinity of the upstream and downstream of the reattachment point, ice crystals near the inner wall flow in opposite directions.
3.4. Distribution of ice crystals in curved pipe

3.4.1. Effect of different import speeds on the distribution of ice crystals. The numerical simulation shows the distribution of ice crystals and seawater in the cross section of the straight pipe section of the curved pipe which is 200mm away from the inlet. The simulation results are imported into the TECPLOT software for processing, as shown in Figure 6. (a) to (f) show that in the case of IPF=10%, the ice crystals volume distribution cloud map inside the pipeline when the fluid velocity are 0.5m/s, 1m/s, 1.5m/s, 2m/s, 2.5m/s, 3m/s.

It can be concluded from Figure 6 that when the fluid flow velocity is small, since the density of the seawater is greater than the density of the ice crystals, the ice crystals will flow toward the wall area of the pipe under the action of the floating force. As the flow rate increases, the turbulent flow energy of the fluid also increases. Under the action of turbulence, the ice crystals will obtain a large buoyancy, which is weakened by the influence of gravity, and the ice crystals are evenly distributed in the fluid.

Figure 6. Volume distribution of ice crystals in a straight pipe section at a distance of 200 mm from the inlet of the curved at different seawater flow rates.
When the flow rate is 2m/s, the fluid in the pipeline exhibits a symmetric suspension flow regime, and the ice crystals near the wall region are less than the mainstream zone; When the fluid velocity exceeds 2 m/s, the outer volume of the central portion of the pipe is more uneven than the inner ice crystals volume. In the outer area of the center of the pipeline, fluid turbulence does not affect the particles, the suspension of ice crystals is mainly affected by the collision between the particles and the lift of the particles, the ice crystals appear unevenly distributed; The volume of ice crystals near the wall of the pipe. The fraction is relatively small, because the ice crystals will collide with the inner wall of the pipe near the inner wall, and then the ice crystals will flow toward the central zone. With the increasing flow rate, the degree of collision of ice crystals with each other will increase and increase, and its effect on the suspension of ice crystals is also increasing. At this time, the volume fraction distribution of ice crystals does not change significantly.

3.4.2. Effect of different ice content on ice crystals distribution. In Figure 7, (a) IPF=30%, fluid velocity V=1 m/s; (b) IPF=10%, V=1 m/s. As can be seen from the figure, when the ice content of the fluid increases, the ice crystals in the pipe tend to be symmetrically distributed. This is because the increase of the ice-containing rate exacerbates the collision between the ice crystals, which generates a suspension force for the ice crystals to provide lift, and weakens the ice crystals by gravity. (a) is more symmetrical than (b), because the collision of the particles with each other is more severe in the case where the volume fraction of the ice crystals is higher. (c) For IPF=10%, V=3m/s, it can be seen that at higher flow speeds, more ice crystals flow to the outer wall surface of the curved section, because the centrifugal force is stronger, twice the effect of the flow at higher flow rates is more pronounced.

![Figure 7. Volume distribution of ice crystals in different ice rates and flow rates at the curved.](image)

4. Conclusions
The flow characteristics of two-phase flow in the curved pipe of the Polar Cruise Seawater Pipeline System are discussed. Concluded as follows:

1. In the curved pipe, the fluid is separated at the curved, and the fluid in the near wall area will flow toward the inner wall surface of the pipe, causing a secondary flow phenomenon.
2. The pressure loss at the corner of the curved pipe is the most serious.
3. The increase in flow rate and ice rate will cause ice crystals to aggregate toward the central.
4. In the 0.5m/s-2m/s, the increase of fluid velocity has obvious influence on ice crystals distribution. When the fluid velocity exceeds 2m/s, the increase of flow velocity has no obvious effect on ice crystals distribution.
5. when the IPF increases, the ice crystals in the pipe tend to be symmetrically distributed.

5. References
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