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Vortex Membrane Separation Device Research

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Abstract

The high shear forces generated by dynamic cross-flow filtration are the ideal physical conditions to ensure continuous operation at sustainable high throughputs, and research on dynamic cross-flow filtration equipment has been a hot topic in the direction of membrane contamination. This paper used CFD (Computational Fluid Dynamics) numerical simulation to study the internal flow field distribution and membrane fouling of the vortex membrane separation device. The study found that the vortex membrane module generates a centrifugal shear flow field containing multiple secondary flows when rotating. The secondary flow in the vicinity of a rotating membrane module not only causes flow anomalies in the flow field in the vicinity of the membrane element, but also results in an uneven patchy distribution of shear forces on the membrane surface. In addition, the average shear force at the membrane surface increases with increasing speed, and the difference between the average shear force at the headwater and backwater surfaces is large, and this difference increases with increasing speed.

Keywords

Rotating Speed; Centrifugal Shear Flow Field; CFD; Secondary Flow; Shear Force.

1. Introduction

Improving membrane contamination through hydraulic conditions is an effective and inexpensive method. Changing the hydraulic conditions is usually accomplished by increasing the membrane surface shear to wash away the solid particles and viscous gel layer from the membrane surface [1]. Traditional rotating disc cross-flow filtration [2,3,4] and rotating tubular membrane separation equipment [5,6,7] have a small internal effective membrane area and must provide a higher speed to effectively wash the membrane surface. CFD numerical simulation of cross-flow filtration on rotating discs shows that increasing the rotational speed can increase the shear force on the membrane surface, thus effectively mitigating membrane contamination [8,9]. The same conclusion was reached in the study of rotating disc cross-flow filtration [10] and rotating tubular membrane separation equipment [11]. The vortex membrane separation device is a new type of rotating cross-flow membrane separation device. The principle is mainly that the vortex membrane module generates a centrifugal shear flow field during operation, so that the solid particles on the membrane surface are subjected to the shear and centrifugal force and the secondary flow generated by the flow field around the membrane module, thereby more effective scouring. The membrane surface filter layer. The vortex membrane separation device not only has a larger membrane area inside, but also can generate a larger shear force at a lower speed, so it can more effectively remove the surface filter layer formed in the membrane filtration process, delay membrane pollution, and greatly The service life of the membrane and the chemical cleaning cycle are extended. Therefore, the research on the vortex membrane separation device is particularly important. In this study, computational fluid dynamics numerical simulation and analysis were performed on the membrane filtration process of the vortex membrane separation device under specific equipment operating parameters. Provide certain theoretical guidance for the design and operation of eddy current membrane separation device.

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2. Materials and methods

2.1 Model introduction

The membrane material used in this study is a flat ultrafiltration membrane with a membrane pore size of 0.1μm. It is cut into a rectangle and attached to the flat membrane element. The inside of the membrane is a honeycomb cavity structure. The flat membrane element is equipped with outlet hole, the filtrate enters the hollow cavity of the membrane element from the membrane surface under the suction action of the water pump, converges to the outlet hole, and is collected to the hollow shaft through the conduit and water collection system and then discharged. The vortex membrane separation equipment used in the experiment has a liquid tank length L_1=1.86m, width L_2=1.86m, liquid tank height H_1=1.86m, and the liquid outlet is the upper end of the hollow shaft, as shown in Figure 1. The size of a single vertical diaphragm is 250mm ×1030mm. The 22 vertical diaphragm elements are arranged circularly according to the set installation angle of 45° and fixed on the upper and lower circular mounting plates to form a turbine-type membrane module.

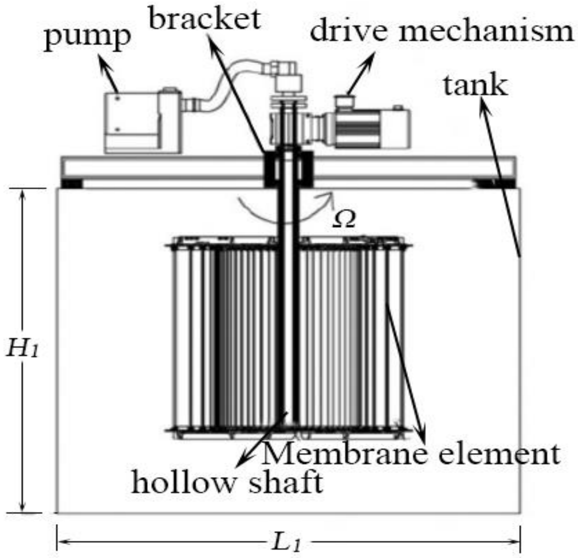

Fig.1 Schematic diagram of vortex membrane separation device

2.2 Numerical simulation

Since the actual equipment is installed at a 45° vertical membrane element, reverse rotation (according to the right-hand screw rule, the speed is positive during forward rotation, and negative during reverse rotation) and 20r/min, 30r/min and 40r/min .There are three kinds of rotation speed, so it is necessary to carry out numerical simulation for these three situations. First, use SolidWorks (version 2019) to establish a three-dimensional geometric model, and then import DesignModeler to process the geometric model. According to the structure of the equipment, the basin is meshed, and the tetrahedral mesh is used as a whole. Select 14 million grids for calculation. According to the used MRF (Multiple reference frame model) model and the rotating characteristics of the rotating membrane module, while satisfying accuracy and minimizing computing resources, the Mixture multiphase flow model (basic phase is water, the second phase is air) and MRF model are used for simulation calculation. The discrete equation adopts the second-order upwind style; the pressure-velocity coupling method adopts the SIMPLEC(Semi-Implicit Method for Pressure Linked Equations Consistent) algorithm; the turbulence model chooses the RNG k-ε(Re- normalization group) model, which adopts the standard wall function near the wall, and the residual convergence standard of all terms adopts 10^{-5}.

Through simulation calculation and analysis, the distribution characteristics of the fluid flow when the membrane module rotation speed Ω is 20r/min, 30r/min and 40r/min when the installation angle

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α is 45° and when the membrane module rotates in reverse. Fig. 2 shows the speed contours at the section z=0.6 when the installation angle is 45°, the speed Ω=-30r/min.

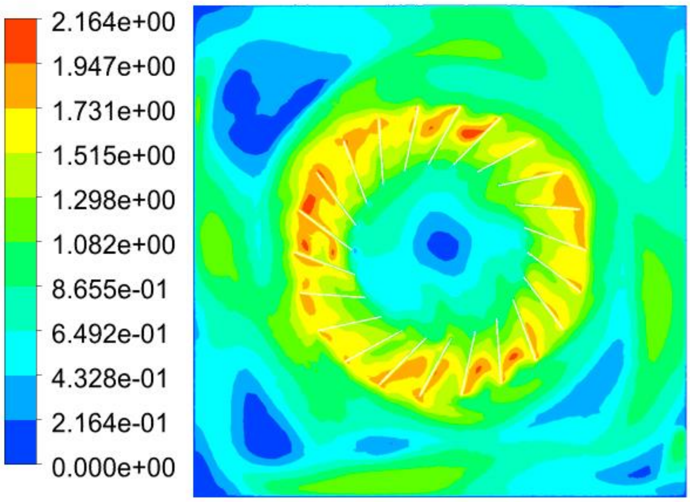

Fig.2. α=45o,Ω=-30/min ,the diagram of the velocity distribution at cross section z=0.6m

3. Result and Discussion

3.1 Flow field analysis

When the membrane module rotates, there is a typical centrifugal shear secondary flow field in the liquid tank. The distribution of tangential velocity is divided into two areas, the solid revolving area (the ring-shaped cylinder formed when the membrane module rotates) and the free vortex area (the area inside and outside the ring-shaped cylinder). In the free revolving area, the liquid near the rotating membrane module and the membrane element Revolve at approximately the same speed to form a solid revolving part; on the outside of the solid revolving part, as the distance from the center of rotation increases, the flow velocity decreases, forming a free vortex part. The secondary flow distributed around the membrane module can be seen in the flow velocity vector diagram in Fig. 3.

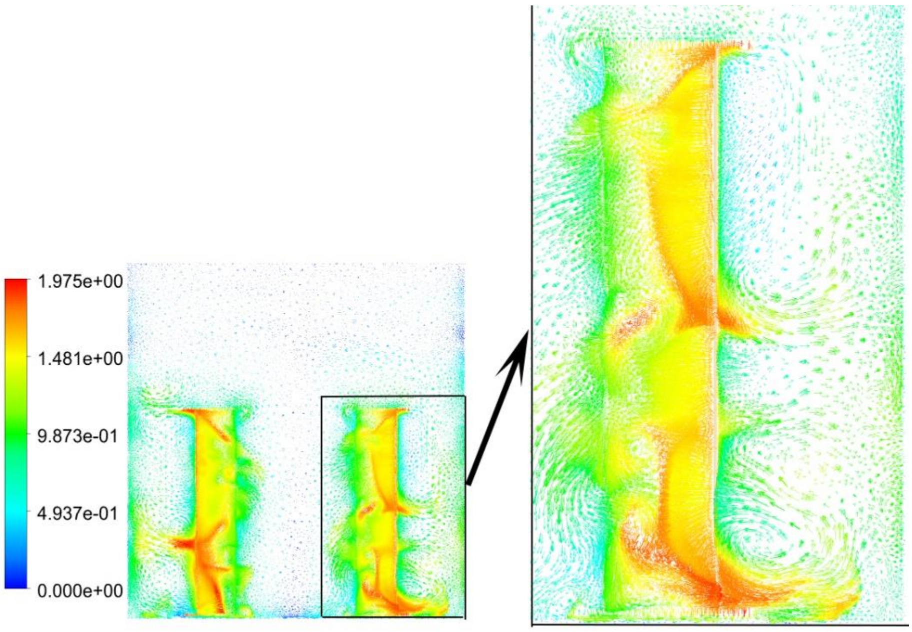

Fig.3. Flow rate vector diagram

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Through the CFD simulation, the speed change graphs in the radial flow zone from R1 to R2 along the X direction with the rotation center of the membrane module as the origin are obtained at three speeds. The result is shown in Fig. 4.

Through the overall change of the curve in Fig. 4 above, it is found that the flow velocity curve has a peak, and the flow velocity decreases near the right end of the studied radius interval. This is due to the presence of a concomitant flow containing multiple secondary flows around the membrane module field, the complicated accompanying flow field makes the direction of flow velocity in this area unstable, causing abnormal flow velocity.

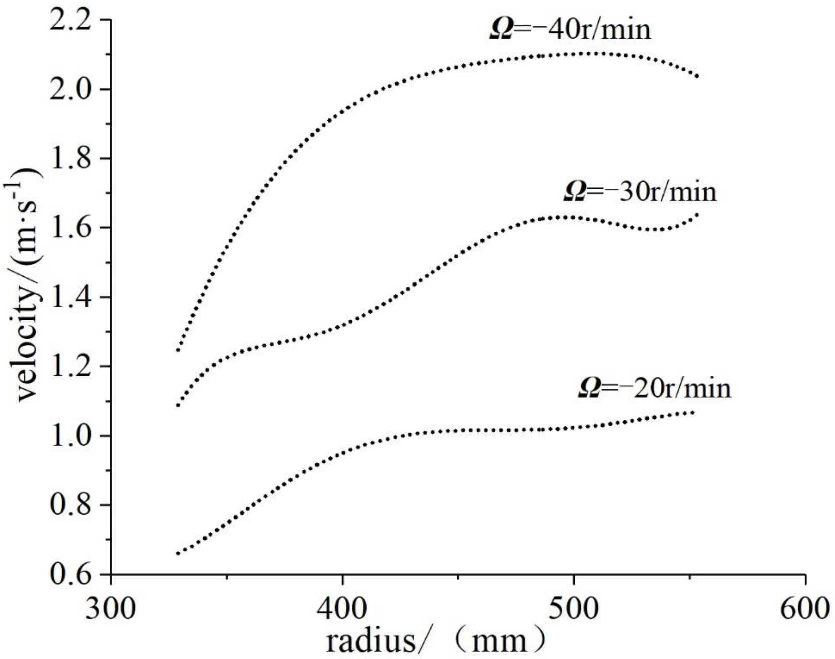

Fig.4. α=45o,distribution of the flow velocity along the radial dirction at different speeds

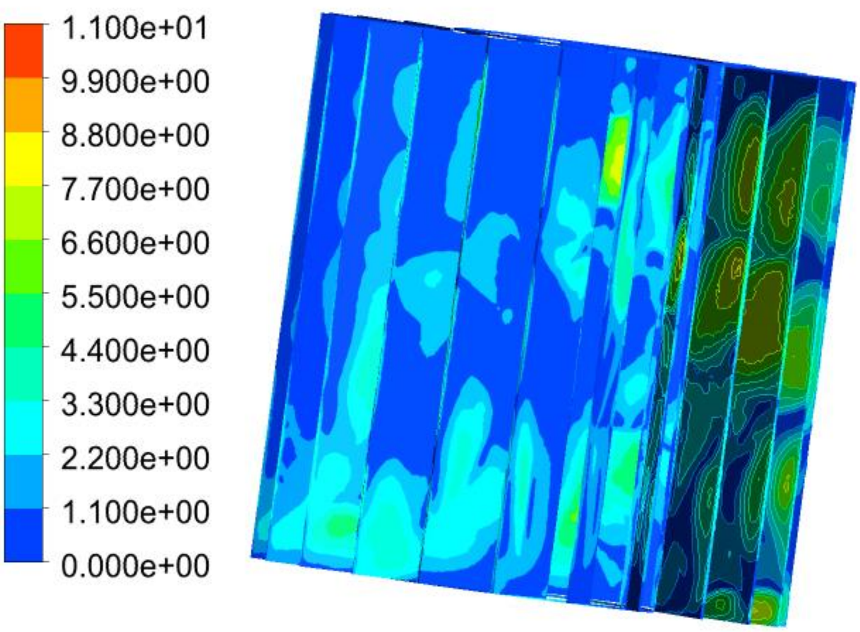

Fig.5. α=45o, Ω=-30r/min,the distribution of shear force of rotating membrane module

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3.2 Analysis of Shear Force

It can be seen from Fig. 5 of the surface shear force distribution of the rotating membrane module that the shear force distribution on the surface of the membrane element is present in patches. The uneven distribution of fluid shear force on the membrane surface is inevitable, mainly because the configuration of the membrane pool is diverse, and the presentation of the shear force is also very complicated[12]. We can use the average shear force to quantitatively study it. The average fluid shear force on the surface of the membrane element is calculated using the area integral average method.

The average shear force value of the surface of the rotating membrane module obtained by CFD-Post post-processing, and the variation law of the average shear force of the two membrane surfaces with the three rotational speeds is shown in Figure 6. From the figure, we can see that the average shear force on the surface of the front water surface and the back water surface increases with the rotation speed. The value of the shear force on the front water surface is greater than that of the back surface, and the difference of average shear force between the two surfaces getting bigger with the rotating speed increases.

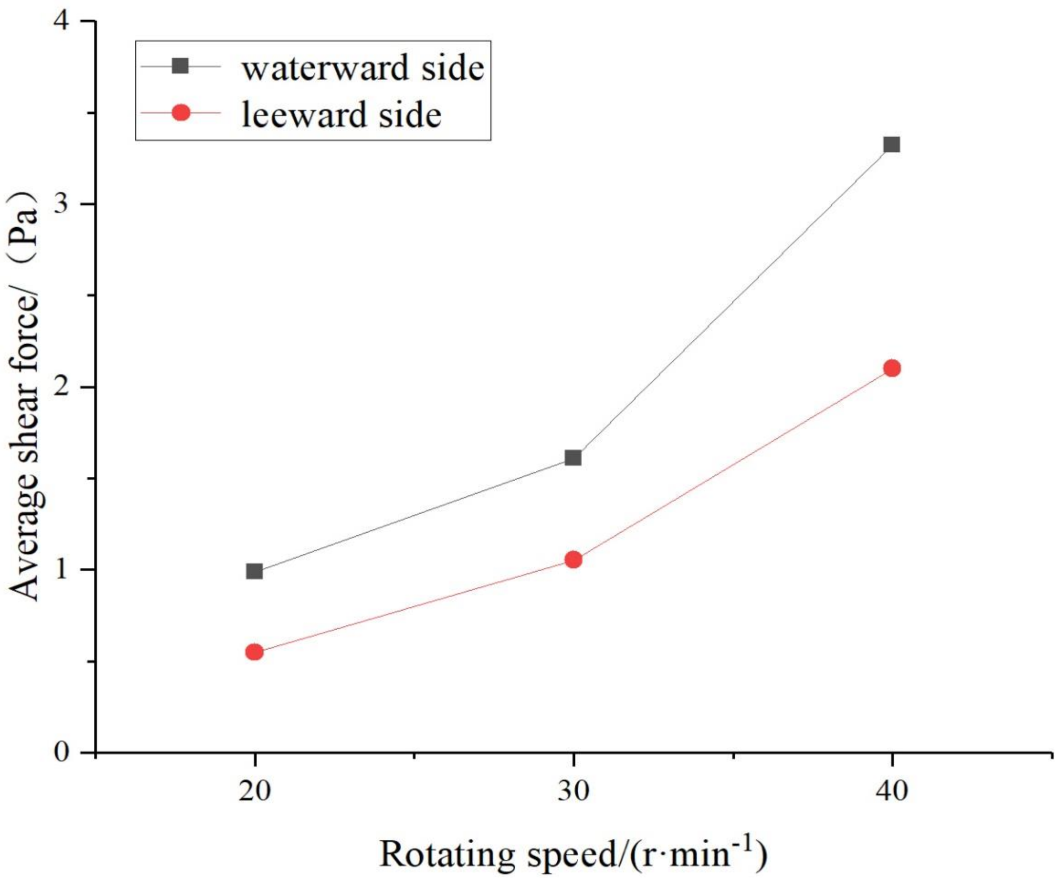

Fig.6. The average shear force of the two surfaces varies with the rotating speed

4. Conclusion

The numerical simulation analysis of the votex membrane separation equipment under three different speed conditions by CFD draws the following conclusions:

1) The rotation of the membrane module generates a centrifugal shear flow field, and there is an accompanying flow field containing multiple secondary flows around the membrane element. The secondary flow will affect the flow velocity in the area around the membrane module, resulting in an abnormal flow velocity, which is specifically manifested as an increase in the inner flow velocity and

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a decrease in the outer flow velocity. At three different speeds, the flow velocity curve has a peak value.

2) The angular force distribution caused by the secondary flow near the membrane module increases the rotational shear force, and at the same time, it also causes the membrane surface to appear unevenly patchy. The average shear force on the membrane surface increases with the increase of the rotation speed, and the average shear force on the front and back water surfaces has a large difference, and this difference will continue to increase as the rotation speed increases.

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