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The Numerical Simulation on Pressure Field of Decanter Centrifuge at Various Revolving Speeds

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Abstract: ***The separation effect of centrifuge is influenced by its revolving speed. The higher revolving speed it gains, the faster solid particles sediment it can realize, which means the better separation effect will be achieved. The paper is finished upon the basis of high-speed decanter centrifuge LW355-1235. Taking the speed discrepancy of 25r/min between spiral and drum into consideration, we use Fluent, thefluid computation software, to obtain the distribution of pressure field by simulating the internal flow field with the use of RNGk-ε turbulence model under different circumstances. The result shows that under the circumstance of a certain speed discrepancy, The difference between simulated hydraulic pressure and theoretical pressure is getting bigger with the increase of revolving speed and decrease of hysteresis of liquid layer. Besides, static pressure increases in accordance with the revolving speed, but it decreases at the overflow. Dynamic pressure increases along the radial direction with its peak at depiler hole, and it decreases at dregs discharge exit and overflow. This paper is designed to provide a reference for the structural design and theoretical research for decanter centrifuge.***

Keywords: Decanter centrifuge; Numerical simulation; Revolving speed; Pressure field

1. Preface

Horizontal screw discharging centrifuge (called decanter centrifuge for short) is a fast-revolving centrifuge which is able to absorb materials continuously, separate materials and classify them, as well as unload finished products with spiral pusher[1-2]. It is generally used in solid-liquid separation, for its continuous operation, large handling capacity, and good adaptability[3-4]. The solid-liquid separation is realized by the centrifugal force through high-speed revolution of drum. The solid-liquid mixture in the drum forms a cylindrical liquid-ring layer, with solid particles of high density accumulated in internal wall. The spiral pusher which does relative motion against drum scratches solid particles and pushes them out of dregs discharge exit. During the whole process, drum, spiral pusher, solid particles squeeze each other, so the analysis of internal pressure field of decanter centrifuge will optimize its structure so as to improve separation efficiency.

To further explore the influence of centrifuge internal speed and pressure on its separation efficiency, scholars have conducted many theoretical and experimental researches both at home and abroad. Dong Liandong and Fu Shuangcheng[5] analyzed the velocity field and internal pressure field of decanter centrifuge with model RNG K- of Fluent. Zhou Cuihong and Ling Ying[6]analyzed the structural parameters of centrifuge and its dehydration efficiency by using Fluent. Zheng Shengfei and Huang Zhixin[7] used the model RSM and DPM of Fluent to analyze the distribution of both pressure and velocity of decanter centrifuge's three-dimensional flow field. Yu Ping and Lin Wei[8] analyzed the relation between the speed of centrifuge separation field and structural property parameters with Model DPM of Fluent. Guorui Zhu[9] simulated the centrifuge flow field M-2301 with Fluent and obtained its solid phase distribution. Dong Liandong[10] conducted numerical simulation for 7 types of typical turbulence models with the use of Fluent under the same gridding circumstance. GRACE[11]put forward the backflow of centrifuge during separation.

The paper believes the researches mentioned didn't deal with the influence of revolving speed discrepancy and revolving speed on the internal pressure field of decanter centrifuge.Fluent and multiphase flow model Euler are used in this study. The author uses the turbulence model RNG K- in the multi-reference frame(MRF) to analyze how the precipitation of solid particles is influenced by the internal pressure field of decanter centrifuge with the premise of existence of revolving speed discrepancy between drum and spiral pusher, thus providing important reference for improving the structural design of decanter centrifuge and increasing the separation efficiency.

2. Turbulence Model and Governing Equation

The internal flow field of decanter centrifuge, as a turbulence model, is an irregular 3-dimensional revolving flow of complexity and volatility. Speed, pressure, temperature, time and other physical parameters in turbulence model vary randomly in accordance to time and space. Standard modelk-εis a kind of high Reynolds Number Model, which lacks simulation accuracy for pressure gradient, strong separation flow, and big curvature flow. ModelRNG k-ε[12]comes from strict statistic technology, with corrected parameters added, which makes it react better against the influence from transient interflow and curvature flexure, and able to compute low Reynolds Number turbulence flow as well. To make it accord with real turbulence, we use model RNG k-ε, for our focus on internal pressure field of decanter centrifuge. The equation 1 and 2 are turbulence energy equation and dissipation rate equation respectively.

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_k}(\rho \mu_k k)=\frac{\partial}{\partial x_k}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \quad (1)$$

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_k}(\rho\mu_k\varepsilon)=\frac{\partial}{\partial x_k}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+$$

C3εGb−C2ερε2k+Sε（2）

In the two equations above, G_k represents the generation item of turbulence energy k caused by average velocity gradient; G_b represents the generation item of turbulence item caused by buoyancy lift; Y_M represents the expansion item of impulsive motion in compressible flow; α_k and $\alpha_\varepsilon$are corresponding Prandtl numbers of turbulence energy and turbulence dissipation rate respectively. $C_{1\varepsilon}$、$C_{2\varepsilon}$、$C_{3\varepsilon}$are empirical constants. According to the recommended values of Launder and later experiments, for incompressible fluid, the constants in software simulation are as follows: $C_{1\varepsilon}=1.45$、$C_{2\varepsilon}=1.92$、$C_{3\varepsilon}=0.09C$、$\sigma_k=1.0$、$\sigma_s=1.3$。

3. Numerical Simulation Method

3.1 Geometrical model and mesh generation

The drum and spiral pusher in decanter centrifuge operate at a certain revolving speed discrepancy, to realize the separation of suspension liquid and discharge of dregs. The main dimensions of the high-speed decanter centrifuge LW355-1235 we used for simulation are shown in table 1, and the cutaway view of centrifuge's runner is shown in diagram 1 and diagram 2. We used non-structural mesh generation for the fluid domain of decanter centrifuge. Volume meshes are mainly tetra and mixed, which are generated automatically. There are altogether 903807 grids and 161145 nodes.

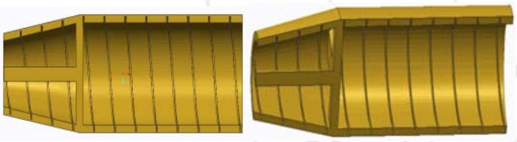


Diagram 1: Model structure

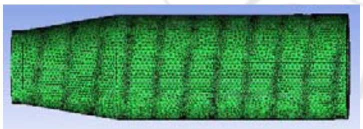
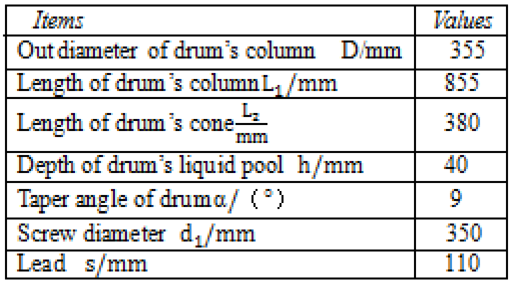


Diagram 2: Decanter centrifuge unstructured mesh

Table 1: The main structural dimensions of decanter centrifuge

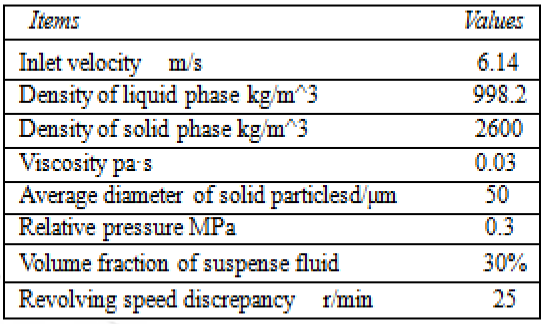


Items	*Values*
Out diameter of drum's column D/mm	355
Length of drum's column L_1/mm	855
Length of drum's cone $\frac{L_2}{mm}$	380
Depth of drum's liquid pool h/mm	40
Taper angle of drum α/（°）	9
Screw diameter d_1/mm	350
Lead s/mm	110

3.2Boundary conditions and solution strategy

Velocity inlet is adopted at inlet boundary, with the inlet turbulence intensity 5% (Computed according to empirical equation $I=\mu'/\bar{\mu}=0.16(Re_{D_H})^{1/8}$). Pressure outlet is adopted at outlet boundary, with all flows on wall meeting the requirement of velocity no-slipping. The detailed parameters are shown in table 2.

Table 2: Parameters selection of decanter centrifuge



Items	*Values*
Inlet velocity m/s	6.14
Density of liquid phase kg/m^3	998.2
Density of solid phase kg/m^3	2600
Viscosity pa·s	0.03
Average diameter of solid particlesd/μm	50
Relative pressure MPa	0.3
Volume fraction of suspense fluid	30%
Revolving speed discrepancy r/min	25

The internal flow field of decanter centrifuge belongs to rotational flow, which is complex. To obtain accurate result, separation and display computing method is used, and SIMPLE algorithm is adopted in pressure-velocity coupling. Second order upwind discretization is adopted in turbulence dissipation items, turbulence energy, and momentum equation.

4. Result and Analysis of the Simulation

4.1 The existence of hysteresis coefficient

Let's take the centrifuge with revolving speed of 3200r/min as an example. The relation between tangential velocity and radius is computed according to equation and shown as diagram 3. The diagram 4 shows the relative error between simulated value of tangential velocity and theoretical value with the increase of revolving speed.

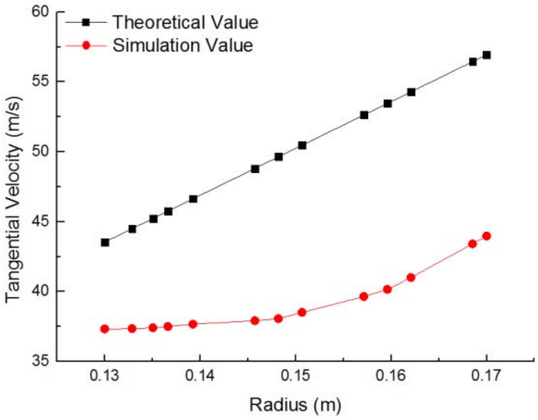


Diagram 3: Tangential velocity and Radius

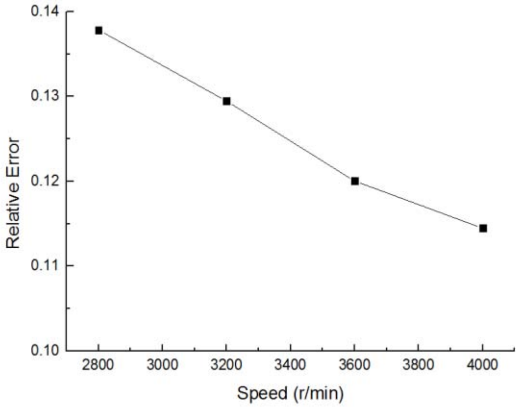


Diagram 4: Relative error and Speed

From diagram 3, it is obvious that tangential velocity increases along the radius direction, and simulated value is less than theoretical value. That's because during the operation of decanter centrifuge, drum and spiral push the surrounding liquid layer to rotate together, but the relative sliding among liquid layers is not consistent with the revolving speed of drum, with the existence of a certain degree of speed lag. From diagram 4, we know that the increase of revolving speed and the decrease of the discrepancy between simulated value and theoretical value (the decrease of absolute relative error) play an important role in mitigating liquid layer lag. By dimensional analysis and retrogression treatment of experimental data, Sun Qicai[13]solved the N-S equations and deduced the computational formula of angular velocity field in swirling flow field. Besides, he measured the maximum relative error between computed value and measured value was less than 15%, which also confirmed the simulation was successful.

4.2 Result and analysis of pressure field simulation

To better show the feature of flow field practically, the simulation is conducted under the revolving speed of 2800r/min, 3200r/min, 3600m/min, and 4000r/min. Meanwhile, there exists a revolving speed discrepancy of 25r/min between drum and spiral pusher.

4.2.1 The simulation of centrifugal hydraulic pressure

During the operation of decanter centrifuge, the solid-liquid material layer in drum, which is under the action of centrifuge, will impose a certain pressure on the internal wall of drum. That is called centrifugal hydraulic pressure. Its computational formula is shown in equation (3)[2].

$$p_c = \rho\omega^2 \int_{r_1}^{R} r dr = \frac{1}{2}\rho\omega^2(R^2 - r_1{}^2) \qquad (3)$$

In the formula, p_c represents centrifugal hydraulic pressure, ρ represents the density of material, ω representsangular velocity of drum, R represents the radius of drum, and r represents the radius of material-ring surface in drum. With the increase of revolving speed, the relation of revolving speed and hydraulic pressure is shown in diagram 5. The analysis of simulated hydraulic pressure and theoretical hydraulic pressure at axial position z=100mm is shown in table 3.

Table 3: Simulated hydraulic pressure and theoretical hydraulic pressure at axial position z=100mm

Revolving speed of drum (r/min)	simulated hydraulic pressure (kpa)	Theoretical hydraulic pressure (kpa)	Discrepancy (kpa)
2800	1.40	1.41	0.01
3200	1.79	1.84	0.05
3600	2.13	2.33	0.2
4000	2.43	2.87	0.44

From table 3, we know hydraulic pressure discrepancy accountsfor 0.7% of theoretical hydraulic pressure at the drum revolving speed of 2800r/min. The percentage is 2.7%, 8%, 15% at revolving speed of 3200r/min, 3600r/min, and 4000r/min respectively. The reason for the inconsistency of simulated and theoretic hydraulic pressure is speed lag. Form diagram 5, we know that the hydraulic pressure increases as the revolving speed of drum increases, thus their discrepancy increases as well. Simulated hydraulic pressure is larger than the theoretical hydraulic pressure as it gets close to cone of centrifuge (z=700mm), because spiral material layout gets faster at the constant revolving speed of 25r/min, which means solid phase squeezes the internal wall of drum harder.

4.2.2 The simulation of static pressure

The internal pressure field of decanter centrifuge is analyzed with the revolving speed of 3200r/min as a reference. The cloud pictures of static pressure at different cross sections are shown in diagram 6. The relation between static pressure at column section and revolving speed at z=300mm and z=800mm are shown in diagram7. The relation between static pressure at column section and revolving speed at z=1080mm and z=1180mm are shown in diagram 8.

From diagram 6, we know that static pressure increases along the radius direction, meanwhile it has obvious pressure gradient, symmetry, and reaches its peak at internal wall in drum, which accords with vortex theory[14]. From diagram 7, we know static pressure increases gradually when the revolving speed of cone section of centrifuge increases, and it reaches the maximum at internal wall of drum. From diagram 8, we know that static pressure increases as the revolving speed increases at cone section. The value of static pressure is larger than cone section without the same change law. That is because the cone section of drum and spiral pusher squeeze the solid sedimentation layer of drum from both sides, which drives solid particles squeeze each other, and brings about solid-liquid separation and backflow of liquid.

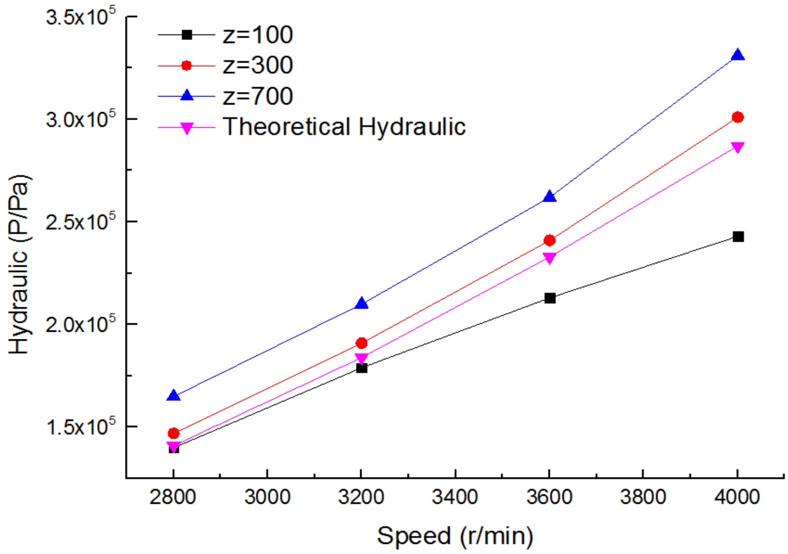


Diagram 5: The relation of revolving speed and hydraulic pressure

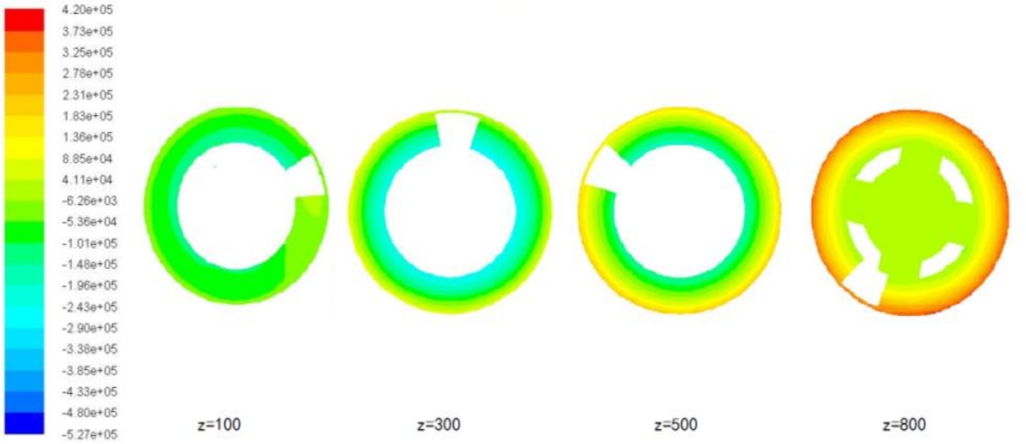
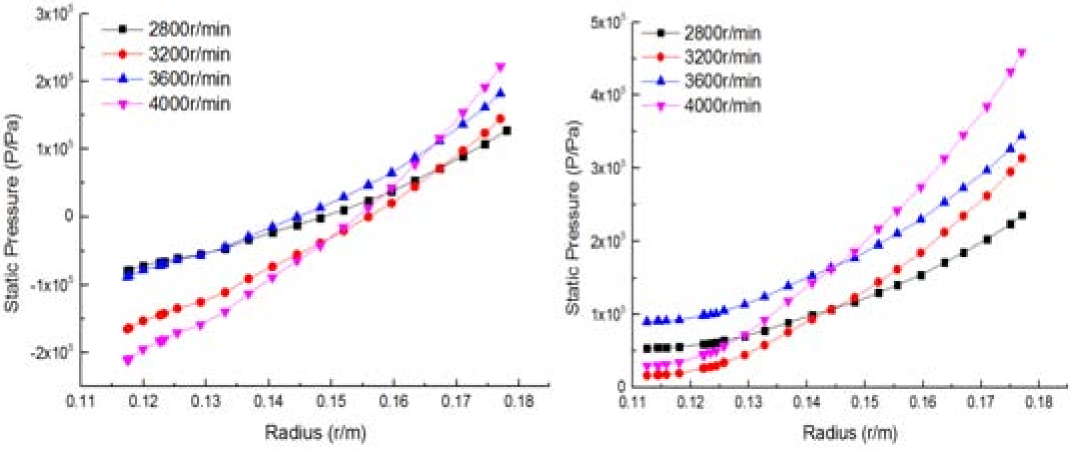
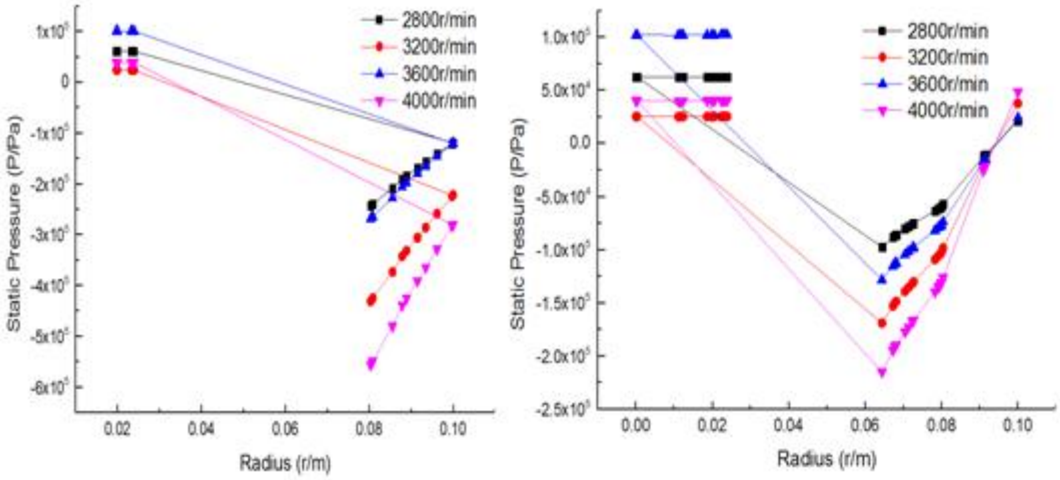


Diagram 6: Static pressure at different cross sections



z=300mm z=800mm

Diagram 7: Static pressure at column section and revolving speedat z=300mm and z=800mm



z=1080mm z=1180mm

Diagram 8: Static pressure at column section and revolving speed at z=1080mm and z=1180mm

4.2.3The simulation of dynamic pressure

Dynamic pressure is an additional force in the process of decanter centrifuge high-speed operation. There are 3 features to measure the size of liquid dynamic energy, namely, the constant positive dynamic pressure, opposite direction of flow motion, and influence from barometric pressure. The cloud pictures of different dynamic pressure are shown in diagram 9. The relation of dynamic pressure of column section and revolving speed at z=300mm and z=800 is shown in diagram 10. The relation of dynamic pressure of column section and revolving speed at z=1080mm and z=1180mm is shown in diagram 11.

From diagram 9, we know that dynamic pressure increases along the radius direction, and reaches its peak at the internal wall of drum. From diagram 10, we know that the dynamic pressure of column section increases as the revolving speed increases. The dynamic pressures along radius direction at different cross sections vary due to different liquid speed. From diagram 11, we know that dynamic pressures at both cone and column section increase as the revolving speed increases. From the value of dynamic pressure, we can find that it is getting declined. According toPlandtl boundary-layer theory[15], we know there exists speed gradient zone at wall of spiral pusher, so the dynamic pressure at boundary is on a decline curve.

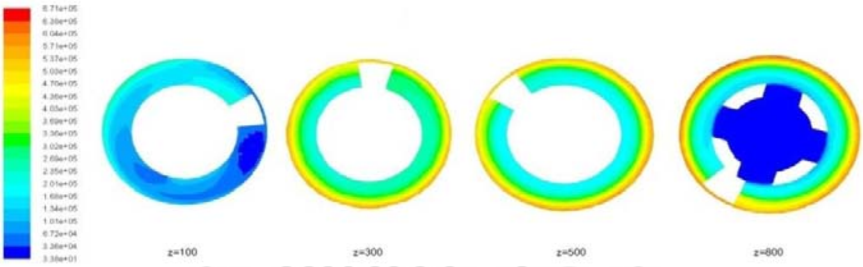
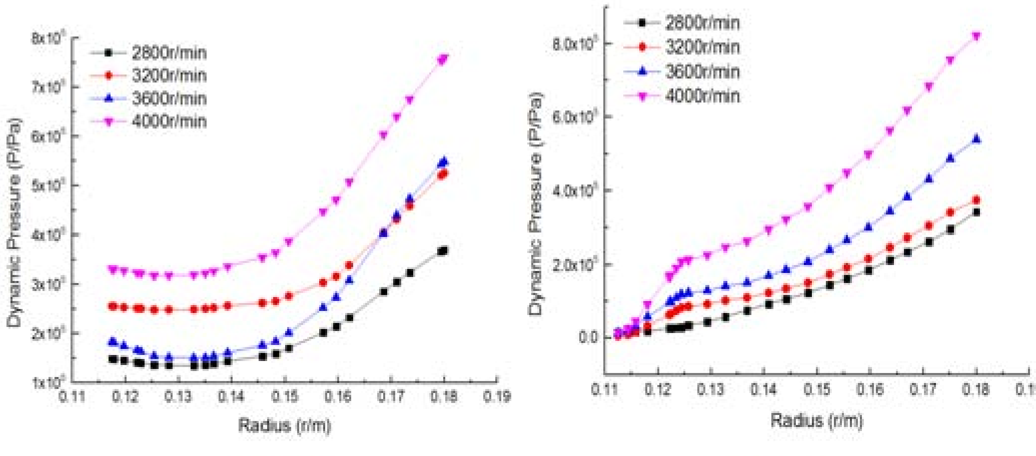
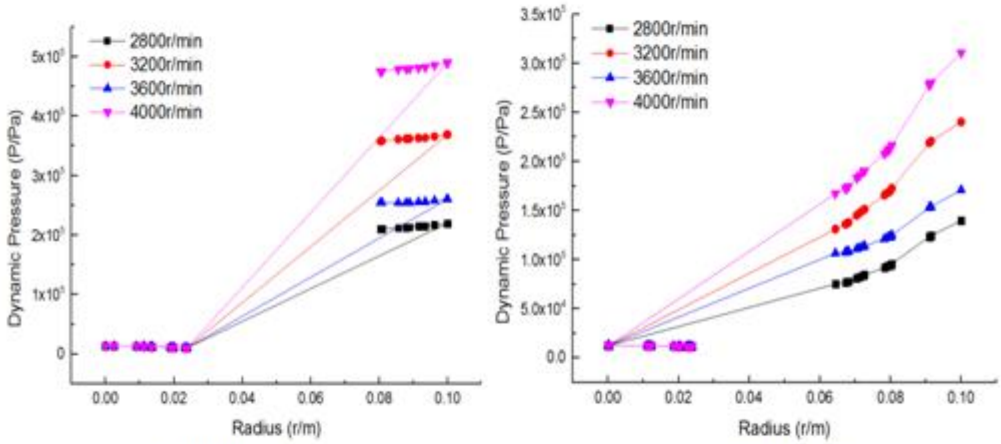


Diagram 9: Dynamic pressure at different cross section



z=300mm z=800mm

Diagram10: Dynamic pressure at column section and revolving speed at z=300mm and z=800mm



z=1080mm z=1180mm

Diagram 11: Dynamic pressure at column section and revolving speed at z=1080mm and z=1180mm

5. Conclusion

Liquid computation software FLUENT, multiphase flow model Euler, and turbulence model RNG k-ε are used in this study under the MRF to compute pressure field of centrifuge. The study analyze how the change law of pressure field distribution of decanter centrifuge is influenced by the change of revolving speed under the circumstance of existence of revolving speed discrepancy between drum and spiral.

(1) With the increase of drum revolving speed, the discrepancy between simulated value of tangential velocity and theoretical value decreased, which has a dramatic impact on mitigating liquid layer lag. The relative error between theoretical value and simulated value of tangential velocity is 13.78% at the revolving speed of 2800r/min. The percentage is 11.44% at the revolving speed of 4000r/min.

(2) With the increase of drum revolving speed, the centrifugal hydraulic pressure imposed on it increases, and the discrepancy between the simulated and theoretical hydraulic pressure. The discrepancy is 0.01kpa and 0.44kpa at the revolving speed of 2800r/min and 4000r/min respectively.

(3) Static pressure increases along the radius direction, meanwhile it has obvious pressure gradient, symmetry, and reaches its peak at internal wall in drum, which accords with vortex theory. The static pressures at both column section and cone section increase as the revolving speed increases, and the varying gradient of static pressure at cone section is larger than that at column section. The static pressure is on a decline curve from z=800 to z=300, but with the increase of radius, static pressure increases rapidly to discharge liquid.

(4) Dynamic pressure increases gradually along radius direction, and it reaches its peak at the internal wall of drum. Dynamic pressures at both column section and cone section increase as the revolving speed increases. It reaches the peak value at depiler hole, and decreases at dregs discharge exit and overflow, which accords with the Plandtl boundary-layer theory.

References

[1] Yuan Huixin. Separation process and equipment [M]. Beijing: Chemical Industry Press, 2008.
[2] Sun Qicai, Jin Dingwu. The principle structure and design calculation of centrifuge [M]. Beijing: China

Machine Press, 1987.

[3] Yu Leilin, Xi Lifeng, Yu Ruyou. The domestic status quo, foreign development and large-scale custom design of centrifugal separation technique [J]. World of Chemistry, 2006, 47 (11): 696-699.

[4] Wang Hanbing, Ma Chunhe, Li Xia. Analysis of the factors influencing centrifuge separation effect and the dealing strategies [J]. Refining and Chemical Industry, 2004, 15 (2):43-43.

[5] Dong Liandong, Fu Shuangcheng, Yuan Huixin. The numerical simulation of decanter centrifuge internal pressure field [J]. Chemical Industry and Engineering Progress, 2014, 33(2):309-313,336.

[6] Zhou Cuihong, Ling Ying, Shen Wenjun. The simulation study of sludge dehydration of decanter centrifuge [J]. Chinese Journal of Mechanical Engineering, 2014(16):206-212.

[7] Zheng Shengfei, Ren Xin, Xie Linjun. 3-dimensionaly numerical simulation of decanter centrifuge flow field [J]. Light Industry Machinery, 2009,27(6):26-29.

[8] Yuping, Lin Wei, Wang Xiaobin. Simulation analysis of decanter centrifuge separation field [J]. Chinese Journal of Mechanical Engineering, 201,47(24):151-157.

[9] Dong Liandong, Yuan Huixin, Fu Shuangcheng. Application analysis of turbulence model in numerical simulation of decanter centrifuge [J]. Chemical Industry and Engineering Progress, 2013, 1 (1):36-41.

[10] Sun Qicai, Zeng Fanjun. Research of fluid angular velocity field in drum of centrifuge [J]. Journal of Fluids Engineering, 1990 (11):1-5.

[11] Liu Jixiang. Theory and application of rotational flow separation [M]. Beijing: Coal Industry Press, 1985.

[12] Chen Yupu, Wang Huimin. Fluid Dynamics [M]. Beijing: Tsinghua University Press, 2013.