Numerical simulation of flow field and the study of the uniform distribution of fluid in uranium hydrometallurgy fixed bed based on CFD

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Abstract. Uranium hydrometallurgy fixed bed is used to separate and extracting uranium compounds from the leaching of uranium ore. It is a very important equipment in the process of uranium purification. The distribution of the internal flow field of uranium hydrometallurgy fixed bed has great effect on the running efficiency of fixed bed. In this paper, on the basis of fluid mechanics, computational fluid dynamics software Fluent is used to numerical simulation for resin adsorption process in axial flow uranium hydrometallurgy, fixed bed that the diameter is 1600 mm and the height is 6800 mm and to research internal flow field distribution of the fixed bed. The results shows that the fluid distribution in the fixed bed is uneven in the process of adsorbent resin adsorption. The groove shunt filter plate at the exit is a powerful measure to realize the uniform distribution of fluid in the resin layer of fixed bed.

1. Introduction
Uranium hydrometallurgy fixed bed is a very important equipment used to separate and extracting uranium compounds from the leaching of uranium ore. And mainly used to complete the process of resin adsorption and leaching [1-2]. Because its structure is simple and easy to operate, it is widely used in our country’s uranium mines [3]. In the process of resin adsorption, uranium leaching in the uranium ore enters the fixed bed from the top of the fixed bed, and the uranium compounds are adsorbed in the adsorbent resin through the ion exchange process of the resin bed. Then the adsorption tail is discharged from the bottom of the fixed bed, after the resin is saturated, the saturated resin is transported to the leaching fixed bed for uranium purification. During the adsorption of fixed bed, the fluid distribution in the bed directly affects the ion exchange process and the adsorption efficiency.

At present, the axial flow of fixed bed is mainly used in uranium hydrometallurgy resin adsorption process. The study of adsorption efficiency mainly concentrated in the resin and adsorption process. However, the study of fixed bed design and internal flow field is mainly dependent on experience and cold simulation [4-9].

In recent years, with the rapid development of computer technology and simulation methods, Computational Fluid Dynamics (CFD) provides a strong condition for the study of flow field in fixed bed. Through the calculation of fluid flow characteristics in the fixed bed to obtain the information of internal flow field, By which it can provides an important reference for the optimization of fixed bed. Zhong Siqing et c.[10] used CFX software to finish numerical simulation and experimental study of flow field in axial flow fixed bed with gas distributor and collector; Guo Xiangbo etc. [11]finished
numerical calculation of flow field in the large fixed-bed reactor that the liquid entered from the bottom of the inlet distributor and went through the porous media; Calis etc. [12] finished the numerical simulation and experimental verification for the distributing of the velocity and pressure drop in the catalytic reactor.

In this paper, CFD Software is used to establish the hydrodynamic model of resin adsorption process and finish the numerical simulation of flow field in fixed-bed to get the distribution of fluid field in the process of resin adsorption. Then, the uniform distribution of internal flow field is studied, which is aimed at optimizing the structure of fixed-bed and improving the efficiency of uranium extraction.

2. Modeling

2.1. Physical modeling

Physical modeling of φ1600 Uranium hydrometallurgy fixed bed is shown in figure 1:

![Figure 1. φ1600 uranium hydrometallurgy fixed bed](image)

1. base 2. liquid outlet 3. filter 4. manhole 5. resin layer 6. tower body 7. pressure gauge 8. liquid inlet 9. spare port

The process of resin adsorption: The leaching of uranium ore enters the tower body (6) from the inlet (8), then go through the resin layer (5). The uranium compounds is adsorbed by the resin, and the tail liquid is discharge through the filter (3) and the liquid outlet (2).
Change the way of packing of resin in φ1600 uranium hydrometallurgy fixed bed. Instead of filter at the bottom of fixed bed, a grooved liquid shunt filter plate which can filter and prevent resin leakage is installed at junction between cylinder and bottom head. Shunt filter plate evenly open a diameter of 0.5 mm small round hole, the opening rate of entire shunt filter is 40%. As shown in figure 2.

2.2. Mathematical modeling

The fluid flow at the entrance of the fixed bed is calculated as turbulence. Taking into account the accuracy of fluid flow calculation and the computing capacity of the computer, the standard κ-ε turbulence model is used.

2.3. Governing equations

(1) Mass conservation equation

$$\frac{\partial (\rho u)}{\partial t} + \text{div}(\rho u) = 0$$

(2) Momentum conservation equation

$$\frac{\partial (\rho u_i)}{\partial t} + \text{div}(\rho u_i u_j) = \text{div}(\mu \text{grad}u_i) - \frac{\partial p}{\partial x_j} + S_i$$

(3) Energy conservation equation

$$\frac{\partial (\rho T)}{\partial t} + \text{div}(\rho u T) = \text{div}\left(\frac{k}{c_p} \text{grad}T\right) + S_T$$

(4) Turbulence control equation

$$k = \frac{\overline{u_i u_i}}{2} = \frac{1}{2}(\overline{u^2} + \overline{v^2} + \overline{w^2})$$

$$\varepsilon = \frac{\mu_t}{\rho} \frac{\partial u_i}{\partial x_k} \frac{\partial u_i}{\partial x_k}$$

2.4. Mesh generation

The two-dimensional geometric model is built and meshing of fixed bed is divided by GAMBIT software. Since the structure of fixed-bed is relatively complex, a quadrilateral unstructured grid is used, the grid nodes are 17980, and the grid cells are 35380. After the grid is divided, the grid model is imported into FLUNET for grid check and the result of check is qualified.

2.5. Boundary conditions

(1) Inlet boundary condition includes inlets of liquid, and the liquid inlet boundary condition is

$$V = 0.56 \text{ m/s}$$

(2) The outlet is outflow boundaries.

(3) The no-slip boundary conditions is used on the wall and there is no velocity.
3. Results and analysis

3.1. The distribution of fluid field in the process of resin adsorption

Fluent software is used to numerical simulation for resin adsorption process in uranium hydrometallurgy, fixed bed. The diameter of inlet and outlet are 160 mm, and the leaching of uranium ore enters the tower body from the top inlet of the fixed bed. The velocity is 0.56 m/s. Adsorbent resin is filled in the fixed bed, and the height of resin layer is 4300 mm, the height of quartz sand filter layer is 200 mm. The experiment shows that the porosity of the resin layer and the quartz sand filter layer is 0.4, and the simulation results are shown as follows:

1) Velocity distribution

Figure 3 shows the internal velocity distribution of the resin adsorption process in φ 1600 uranium hydrometallurgy fixed bed. It can be seen from the figure that the leaching of uranium ore jet into the fixed bed at a high speed, after reaching the resin layer, due to the resistance of the resin layer, the liquid flow to both sides of the upper part of the bed to form the phenomenon of backmixing. At the same time the velocity distribution of liquid in the resin layer is not uniform, especially in the vicinity of the outlet, the flow velocity at the central axis and the flow velocity near the wall are quite different. In order to understand the distribution of velocity in the resin layer for more clarity, a radial velocity distribution curve of 300 mm, 1800 mm and 3800 mm from the top of the resin bed is built, as shown in figure 4.

![Figure 3. Nephogram of velocity distribution](image)

![Figure 4. Curve diagram of the radial velocity](image)

It can be seen from figure 4, after the liquid enters the resin layer from the inlet, the velocity of the liquid in the resin bed is greatly reduced due to the resistance of the resin. In addition, the velocity distribution in the resin layer is inverted V- From the central axis to both sides of the decline, near the outlet, the speed difference between the central axis and the near wall is greater, which will lead to resin adsorption process, resin is not full saturation, so the adsorption efficiency will be reduced.

2) Axial pressure distribution

Figure 5 shows the axial pressure distribution of the resin adsorption process in φ 1600 uranium hydrometallurgy fixed bed. It can be seen from the figure that the pressure distribution in the fixed bed is not uniform and the distribution of the pressure drop from top to bottom is close to 0.4 MPa, which is basically consistent with the field test data. In order to quantify the axial pressure, the axial pressure distribution curve in the resin bed is made from the top of the resin bed to the bottom about 4300 mm. It can be seen from the figure 6, The pressure in the resin bed is parabolic along the axis and the pressure loss is about 0.25 MPa.
3.2. Influence of grooved liquid shunt filter plate on flow field distribution in fixed bed

(1) Velocity distribution

Figure 7 shows the internal velocity distribution of the resin adsorption process in φ1600 uranium hydrometallurgy fixed bed with a grooved liquid shunt filter plate. It can be seen from the Figure that the leaching of uranium ore jet into the fixed bed at a high speed, after reaching the resin layer, due to the resistance of the resin layer, the liquid flow to both sides of the upper part of the bed to form the phenomenon of backmixing. Due to the addition of filter plate at the bottom fixed bed, the flow rate in the resin is evenly distributed and only a local convergence flow is formed at the outlet. The design of the outlet shunt filter plate provides a good improvement to the fluid distribution in the fixed bed. For a clearer understanding of the improved effect, a contrast curve of radial velocity is shown in figure 8.

It can be seen from figure 7 that after installing a grooved liquid shunt filter plate at junction between cylinder and bottom head instead of filter at the bottom of fixed bed, the flow rate in the fixed bed resin is substantially linearly distributed in the radial direction. Consequently, the uniform distribution of the fluid in the fixed bed was realized.
(2) Pressure distribution

Figure 9 shows the axial pressure distribution of the resin adsorption process in φ1600 uranium hydrometallurgy fixed bed with a grooved liquid shunt filter plate. It can be seen from the figure, after changing the structure of filter, pressure changes have been improved in the fixed bed, and the pressure is hierarchical along the axial direction. We can see that the maximum pressure is about 0.09MPa which appears at the top of the fixed bed, and the pressure loss is 0.04 MPa, which is much better than before. The pressure distribution curve in the resin bed was made along the central axis at 4300 mm from the top of the resin bed, as shown in figure 10.

![Figure 9. Nephogram of pressure distribution](image1)

![Figure 10. Curve diagram of the axial pressure](image2)

It can be seen from the figure, the axial pressure in the resin bed is linearly distributed after changing, and the pressure loss in the resin layer is almost one order of magnitude smaller than before.

From the comparative analysis, we can know that the application of the grooved filter plate has a great influence on the distribution of the flow field in uranium hydrometallurgy fixed bed, and it is an important means and effective measure to realize the uniform distribution of the flow field in the fixed bed.

4. Conclusion

In this paper, computational fluid dynamics software is used to numerical simulate for resin adsorption process in uranium hydrometallurgy, fixed bed that the diameter is 1600 mm. Based on the analysis of velocity distribution and pressure distribution, the following conclusions are drawn:

(1) During the resin adsorption process in axial flow uranium hydrometallurgy, fixed bed, the fluid distribution of the resin bed in fixed bed is not uniform, resulting that adsorption resin can not be fully saturated, and there is a "false saturation", so adsorption efficiency is reduced. At the same time, the pressure distribution in the fixed bed is decreasing from top to bottom, and the pressure loss is close to 0.4 MPa. The pressure in the resin bed is distributed along the axis to the parabola and the pressure loss is about 0.25 MPa.

(2) The design of grooved liquid shunt filter plate of uranium hydrometallurgy fixed bed joints between cylinder and bottom head is a powerful method to realize the uniform distribution of liquid velocity in the resin bed. At the same time, the design of grooved liquid shunt filter plate reduces the pressure loss in the fixed bed.

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