Numerical Simulation of Separation of Water Load Magnetic Particles in High Gradient Magnetic Field

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Abstract: Separating radioactive wastewater by using high gradient magnetic separator is one of the new technologies. In this paper, using FLUENT software for simulation, effects of the flow rate, magnetic particle size, intensity of magnetic field, and magnetic media filling rate on adsorption was figured out, and the built mathematical model was effectively verified. In addition, the paper provided theoretical support for developing the prototype for radioactive wastewater magnetic separation.

Introduction

Separating radionuclide in liquid by using high gradient magnetic separator is one of those advanced technologies. High gradient magnetic separation is adding a small amount of coagulant, magnetic particles and so on into the wastewater that flocculate and integrate with the pollutants, then removing the pollutants in the water by efficient sedimentation and magnetic filtering, and the magnetic particles will be recycled and reused by magnetic drum separator, of which the basic working principle is producing high gradient magnetic fields on the surface of magnetic media under an external magnetic field for capturing the magnetic particles nearby[1, 2].

A lot of research on high gradient magnetic separation theory has been undertaken by experts and scholars at home and abroad, through which the high gradient magnetic separation model was divided into empirical model, theoretical model and integrated model, etc. But research for high gradient magnetic separation by fluid mechanics software has not yet been found. The paper, by establishing mathematical physical model, analyses the optimal separation effect of the magnetic particles in high gradient magnetic field, and lays a foundation for the prototype development in the future.

FLUENT Numerical Simulation and Analysis

The purpose of this paper is to study and establish an adsorption model to describe the particles when the magnetic field direction, steel wool, the flow field move vertically, the radius and angle for a single magnetic medium to adsorb magnetic particles, and use FLUENT software for verification.

Set parameters as follows: set the diameter of steel wool as 300μm, the saturation magnetization of steel wool as 871mT, the saturation magnetization of iron oxide particles as 80emu/g, the particle diameter as 1μm, the magnetic field intensity as 1T, and the water flow rate as 1cm/s. The particle density determined by particle measurement is 5g/cm^3 .

In order to figure out effects of factors on the process of high gradient magnetic field capturing magnetic particles, the single factor analysis method is adopted to analyze the adsorption effect of magnetic media and the adsorption radius, and the adsorption radius is r_a obtained by adding particle to the steel wool in the model with a distance of r.

Effect of Flow Rate on Adsorption Radius. Set parameters as follows: set the diameter of steel wool as 300μm, the saturation magnetization of steel wool as 871mT, the saturation magnetization of iron oxide particles as 80emu/g, the particle diameter as 1μm, the magnetic field intensity as 1T, and the flow rate as adjustable. The calculation result is shown in Fig.1.

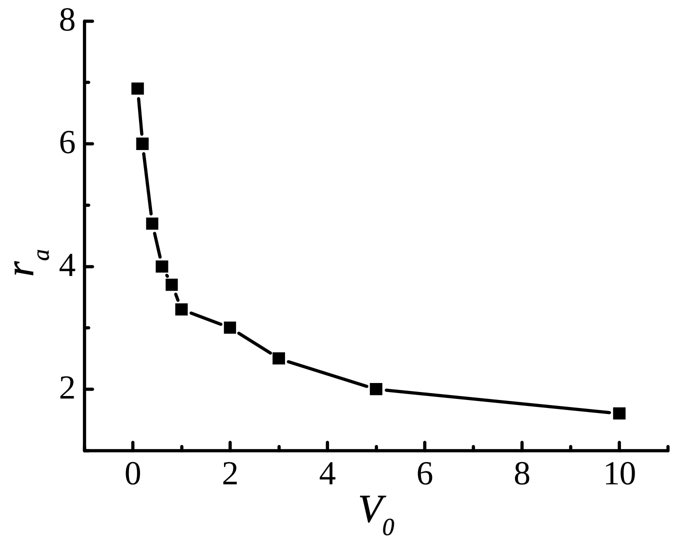

Fig.1 Tendency of r_a as the Flow Rate Changes

From Fig.1, we can get that: when the flow rate is about 10cm/s, there is almost no adsorption by the steel wool and $r_a = r/a = 1.6$, because the fluid force is larger, and it is very short when the water flow through the steel wool, it does against the adsorption and capturing of steel wool. When the flow rate becomes about 0.1cm/s, the adsorption radius of steel wool is $r_a = r/a = 6.7$. It shows that as the flow rate decreases, the adsorption radius of steel wool gradually increases.

Effect of Particle Size on Adsorption Radius. Set parameters as follows: set the diameter of steel wool as 300μm, the saturation magnetization of steel wool as 871mT, the saturation magnetization of iron oxide particles as 80emu/g, the particle diameter as adjustable, the magnetic field intensity as 1T, and the flow rate as 0.1cm/s. The calculation result is shown in Fig.2.

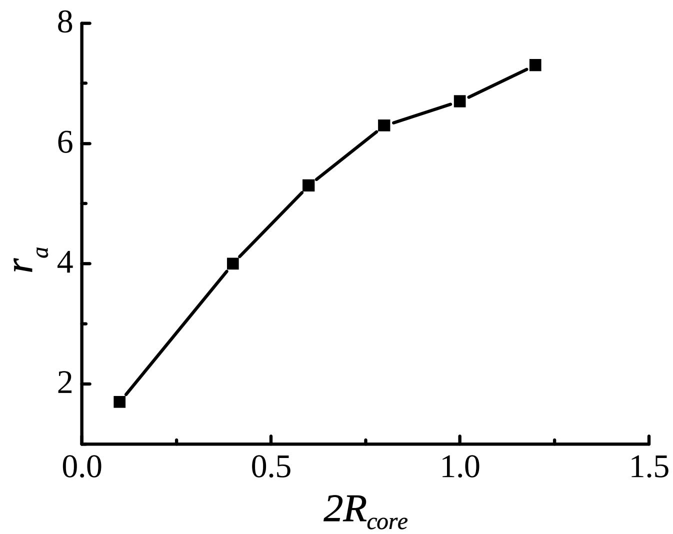

Fig.2 Tendency of r_a as the Particle Size Changes

From Fig.2, we can get that when the particle diameter is 0.1μm, the adsorption radius of steel wool is $r_a = r/a = 1.7$, and it is difficult for the steel wool to capture particles of small sizes. When the particle diameter is1μm, the adsorption radius of steel wool is $r_a = r/a = 6.7$, and it is easy for the steel wool to attract and capture particles of larger sizes, the bigger is the particle size of particle. As the magnetic particle size increases, the adsorption radius of steel wool gradually increases, but when the particle diameter is above 1μm, the increasing rate of adsorption radius decreases.

Effect of Magnetic Field Intensity on Adsorption Radius. Set parameters as follows: set the diameter of steel wool as 300μm, the saturation magnetization of steel wool as 871mT, the saturation magnetization of iron oxide particles as 80emu/g, the particle diameter as 0.5μm, the magnetic field intensity as adjustable, and the flow rate as 0.1cm/s. The calculation result is shown in Fig.3.

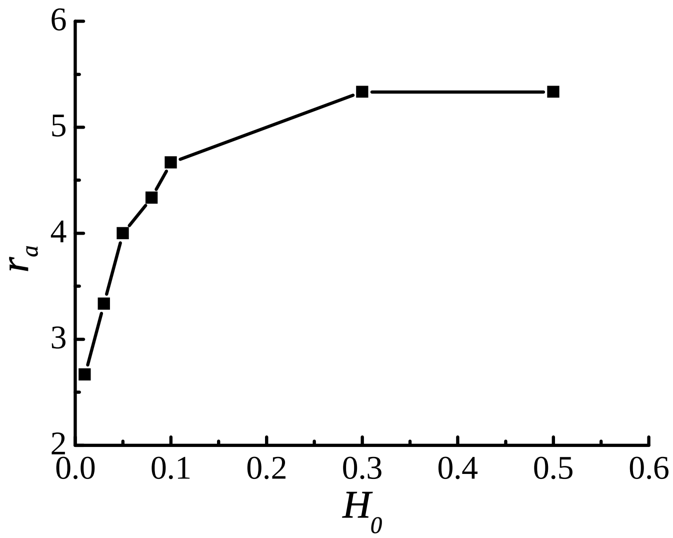

Fig.3 Tendency of r_a as the Magnetic Field Intensity Changes

From Fig.3, we can get that: as the magnetic induction intensity of external magnetic field increases, the capturing effect of steel wool on particles increases gradually. This is mainly because as the magnetic induction intensity of magnetic field increases, the magnetization of steel wool will be saturated soon, but the magnetization of magnetic particle will be slowly saturated, so before the magnetic particles become saturated, as the magnetic field intensity increases, the magnetic field force also increases. It is shown in the Figure that when the magnetic field force increases to about 0.1T, the increasing rate of the adsorption radius of steel wool decreases, the adsorption radius will almost keep constant. This is because the particle is close to magnetic saturation. After particles being magnetized to saturation because of the magnetic field intensity in engineering practice, the influence of magnetic field on the adsorption decreases, so improving the magnetic field force is mainly achieved by changing other parameters of the steel wool and the magnetic field gradient.

Effect of Steel Wool Filling Rates on Adsorption Efficiency. By establishing the physical model of adsorption of steel wool with different spacing, and then calculate the adsorption percentage of discrete particles by the FLUENT simulation, the relationship between filling rate and adsorption efficiency obtained is shown in Fig.4.

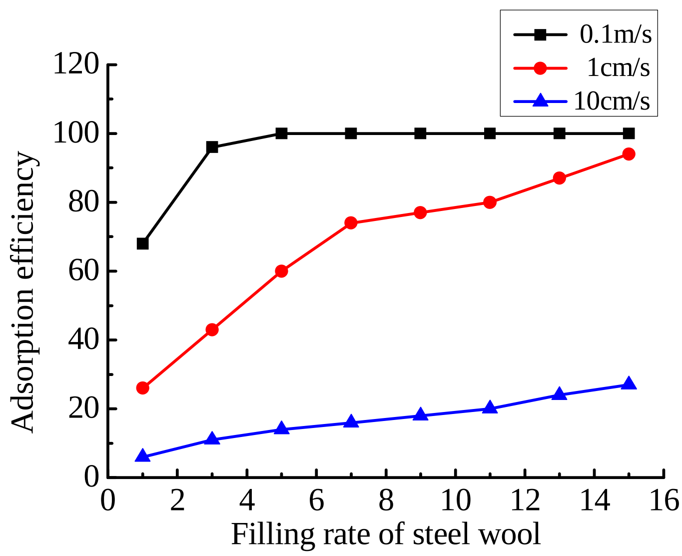

Fig.4 Curves of Adsorption Efficiency VS. Filling Rate at Different Flow Rates

From Fig.4 we can see that as the filling rate of steel wool increases, the adsorption efficiency increases, because if the filling rate of magnetic media increases, the spacing of steel wool decreases, the high gradient area formed also increases, so the area of effective adsorption of particles will increase accordingly. Besides, as the magnetic medium filling rate increases, the chances of collision between the magnetized particles and the ferromagnetism steel wool increases when the magnetized particles passing through the separation interval, and the possibility for the particles to be captured by the magnetic steel wool increases. But in actual engineering situations, it is necessary to consider the interaction among steel wools, if the distance between two pieces of steel wool is too close, it might interfere with the local magnetic field, leading to decrease magnetic field gradient and magnetic field force, moreover, the filling rate which is too high will impact the flow rate as well[3]. Therefore, when treating waste water, the filling rate is generally selected as 5%-10%.

Conclusions

By using the DPM model of the FLUENT software, the paper achieve numerical simulation on adsorption process of water load magnetic particles in 2D high gradient magnetic field, the simulation results show that:

(1) As the flow velocity increases, the adsorption radius of steel wool gradually decreases. When the flowing rate is over 10cm/s, there is almost no adsorption effect of the steel wool, so it does against the capturing of the magnetic particles at high flow rate.

(2) It is difficult for the steel wool to capture particles of small sizes, when the particle diameter is less than 0.1μm, it is hard to capture. It is easy to for the steel wool to capture particles of larger sizes. As the magnetic particle size increases, the adsorption radius of steel wool gradually increases, but when the particle diameter is above 1μm, the increasing rate of adsorption radius decreases

(3) As the magnetic induction intensity of external magnetic field increases, the capturing effect of steel wool on particles increases gradually. When the magnetic field force increases to about 0.1T, the increasing rate of the adsorption radius of steel wool decreases, the adsorption radius will almost keep constant. This is because the particle is close to magnetic saturation. After particles being magnetized to saturation because of the magnetic field intensity in actual experiments, the influence of magnetic field on the adsorption decreases, so improving the magnetic field force is mainly achieved by changing other parameters of the steel wool and the magnetic field gradient.

(4) As the filling rate of steel wool increases, the adsorption efficiency increases. But in actual engineering situations, it is necessary to consider the interaction among steel wools, if the distance between two pieces of steel wool is too close, it might interfere with the local magnetic field, leading to decrease magnetic field gradient and magnetic field force, moreover, the filling rate which is too high will impact the flow rate as well. Therefore, when treating waste water, the filling rate is generally selected as 5-10%.

In this paper, using FLUENT simulation calculation, effects of the flow rate, magnetic particle size, intensity of magnetic field, and magnetic media filling rate on adsorption was figured out, providing theoretical basis for the prototype for radioactive wastewater high gradient magnetic separation.

References

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