Design of a New Type of Dense Loading Distributor

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***Abstract*—With the progress of oil refining technology, the catalytic reactor equipment is developing towards large scale. Meanwhile, the catalyst loading technology and loading equipment have a great influence on the catalyst distribution and pressure drop in the hydrogenation fixed bed reactor. So we need automatic loading technology and equipment to improve loading efficiency and uniformity. A distributor of new structure mentioned in this paper is dsigned by means of massive investigations of existing dense loading technology and equipment, combining with discrete element method(DEM). The results of numerical simulation shows that catalyst loading speed increases with the increase of the rotation speed of the distributor and the size of the hole, and decreases with increase of the diameter of the distributor. The uniformity of catalyst bed layer increases with the incease of the diameter of the distributor and decreases with the increase of rotation speed of the distributor,and the size of the hole has remarkable impact on its uniformity. The DEM simulations also reveal that when using these devices of this structure to load cylindrical particles, there will be ups and downs like a hump in the center of the catalyst bed.**

***Index Terms*—Catalyst, dense loading, distributor, numerical simulation**

I. INTRODUCTION

Because catalysts can accelerate the rate of chemical reaction and do not enter the chemical reaction itself, catalysts are widely applied in modern chemical industry. More than 80% of modern chemical processes need catalysts. The key characteristic of accelerating the reaction rate is the activity of the catalyst. Therefore, maintaining the activity of the catalyst and prolonging the service life in the process of catalyst application is of great economic significance. If the catalyst loading quality is not high, it will cause the catalyst "bridging", the reactant "short circuit", the pressure drop of the catalyst bed layer not uniform and part of the it "hot spots" or even it collapsing, which affects not only the service life of the catalyst, but also the quality of products[1-3]. At present, the transformation from sock loading to dense loading is mostly realized all around the world[4].

II. CATALYST DENSE LOADING

The catalyst dense loading started in 1970s[5]. It uses a special dense loading device, through which the catalyst particles is scattered along the radial direction of the reactor. Then, the catalyst particles fall evenly at a certain speed under the action of gravity after throwing out the device. When the catalyst particles fall to the surface of the bed layer, they still have some kinetic energy, which can not only consolidate the catalyst bed layer, but also place themselves horizontally [6].

Compared with the sock loading, dense loading has many advantages: (1) Dense loading can increase the loading density of the catalyst bed layer from 10% to 25%[7], and decrease the porosity about 15%. That is to say, the unit volume can fill more solid catalysts[8], so as to improve the processing capacity of the reactor; (2) Due to the catalysts fall evenly and show a horizontal state at the surface of the catalyst bed layer, the loading is more uniform and dense, which reduce the possibility of bed layer collapsing and channeling, and improve the distribution of the fluid, the contact efficiency of liquid and the temperature distribution of the catalyst bed layer, which reduce the occurrence of hot spots, making operation more safe; (3) As the automation of dense loading is higher than that of sock loading, the efficiency of catalyst loading is greatly improved.

Nowadays, the main dense loading equipments are the single-layer rotary disk of UOP[9], the circular plate distributor consist of three disks of different diameter of Chevron[10], the warp distributor designed by Tian Pengand[11] , etc.

III. MODEL SET-UP

Since the catalyst particle motion has the characteristics of high speed, discreteness and randomness, the traditional method of simulation can not be used on particle motion process. DEM , a analysis method for discrete particles, has been widely used in the research of complex dynamic behavior of particles in the complex physical field, and plays an irreplaceable role [12].

In this paper, a cone distributor is studied, as shown in Figure 1. The ratio of its diameter(D) to height(h) is 10:1,and its center remains a non hole area with a diameter of 30mm for the connection of transmission. It has a series of interleaved annular holes(width=L). A model of cylindrical particle with a diameter of 3mm and a height of 9mm, as shown in Figure 2, is used in the following numerical simulations. Figure 3 shows the model of catalyst dense loading established in EDEM. There is a storage bin in the center of the reactor and close to its upper surface. The upper part of the storage bin sets a particle factory, and a distributor is setted beneath the storage bin.The reactor is setted as a cylinder with a diameter of 8m and a height of 2m. The exit of the storage bin is originally setted as "physical",and then "virtual" when the particles are generated completely(t=0.5s). The related parameters involved in the DEM simulations are shown in Table 1.

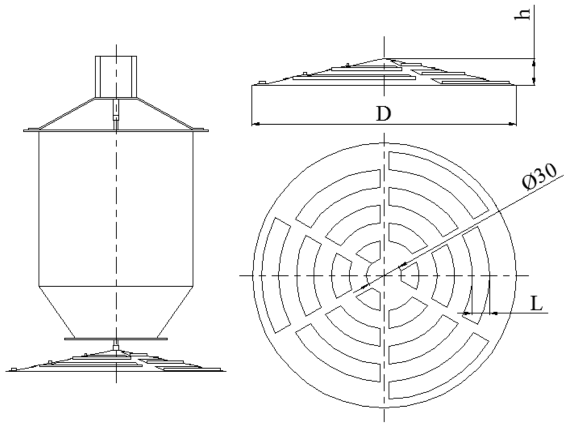

Figure 1. The structure view of the distributor

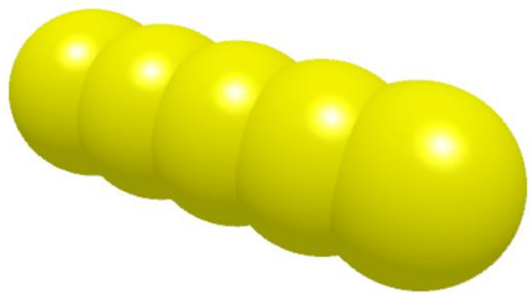

Figure 2. Model of the cylinder catalyst paticle

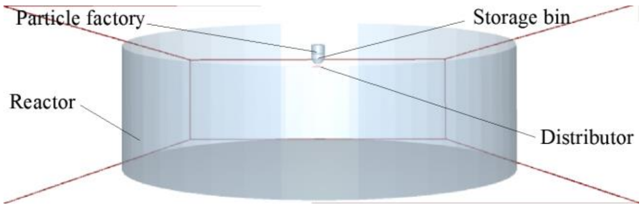

Figure 3. Model of catalyst dense loading

TABLE 1.
RELATED PARAMETERS IN DEM SIMULATIONS

Properties	Value
Particles	
Poisson's ratio	0.25
Shear modulus(Pa)	1e+10
Density(kg/m^3)	3200
Coefficient of restitution	0.1
Coefficient of static restitution	0.8
Coefficient of rolling restitution	0.6
Particle generating total mass(kg)	1
Wall & Distributor	
Poisson's ratio	0.3
Shear modulus(Pa)	7e+08
Density(kg/m^3)	7800
Coefficient of restitution	0.1
Coefficient of static restitution	0.625
Coefficient of rolling restitution	0.55
Time step(s)	2e-06

IV. RESULTS AND DISCUSSION

A. Factors affecting the catalyst loading speed

The study of the factors affecting the catalyst loading speed has a guiding significance for the selection of catalyst feeding speed.

1) Effects of diameter of the distributor on catalyst loading speed

Select an area with the hight of 100mm and the diameter of 8m at the bottom of the reactor for research. Figure 4 shows variation of total particle mass with time in the very selection with different diameter of the distributor. The former 0.5s is used to generate particles as mentioned above. Then, most of the particles pass through the distributor and continue to fall down in the next 1s, and reach the bottom of the reactor in the next 0.5s. The rest a few particles will arrive gradually in the next 0.5s. That is to say, the time interval that can reflect the loading speed is from 1.5s to 2.0s. Compared the gradients, it can be found that catalyst loading speed increases with decrease of the diameter of the distributor wich are respectively 1.85kg/s, 1.78kg/s and 1.58kg/s.

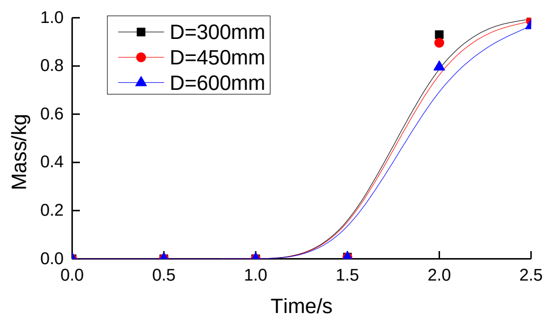

Figure 4. variation of mass with time in the selected region with different diameter of the distributor

2) Effects of rotation speed of the distributor on catalyst loading speed

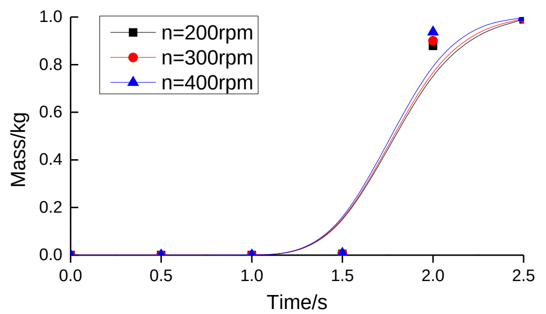

Figure 5. variation of mass with time in the selected region at different rotation speed of the distributor.

Figure 5 shows variation of total particle mass with time in the very selection mentioned above at different rotation speed of the distributor. It is found that the trend of gradients and the time interval are similar with that mentioned above. And catalyst loading speed increases with the increase of the rotation speed of the distributor. The loading speed is respectively 1.75kg/s, 1.79kg/s and 1.86kg/s.

3) Effects of size of the hole on catalyst loading speed

Figure 6 shows variation of total particle mass with time in the very selection mentioned above with different size of the hole. It can be seen that the trend of gradients and the time interval are similar with that mentioned above. And catalyst loading speed increases with the increase of the size of the hole. The loading speed is respectively 1.45kg/s, 1.55kg/s and 1.58kg/s.

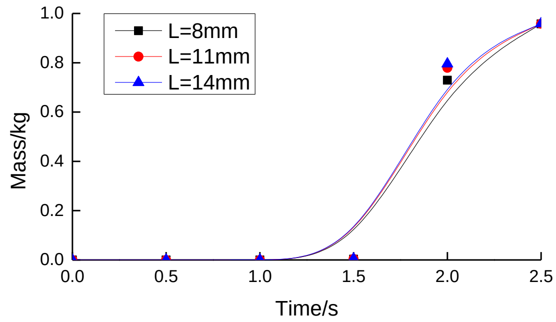

Figure 6. variation of mass with time in the selected region with different size of the hole

B. Factors affecting the catalyst distribution in the reactor

1) Effects of diameter of the distributor on the catalyst distribution in the reactor

Select a rectangular region(width 100mm, hight100mm) in the bottom of the reactor at radial direction, divide the selection into 20 equal parts and count the number of catalyst particles of each small region. Figure 7 shows 2.5s later variation of total number of particles with distribution radius in each selected rectangular region with different diameter of the distributor. It is found from that the uniformity of the catalyst bed layer and the distribution radius increase with the increase of the diameter of the distributor. The distribution radius is respectively 2.2m, 2.6m, 3.0m. That means 600mm is the best diameter of the distributor in the case of same rotation speed and same size of hole to load this kind of catalyst particles mentioned above into the reactor at the hight of 2m. What's more, there will be ups and downs like a hump in the center of the catalyst bed when using these devices of this structure to load cylindrical particles, no mater what diameter.

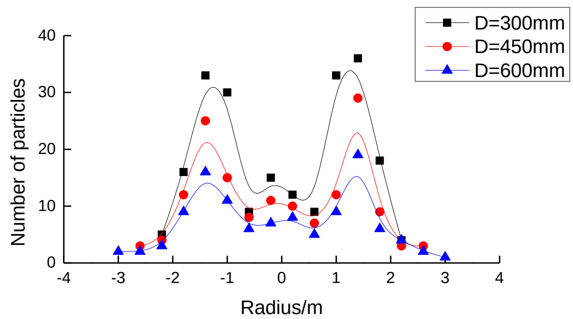

Figure 7. variation of number of particles with distribution radius in each selected rectangular region with different diameter of the distributor

2) Effects of rotation speed of the distributor on catalyst distribution in the reactor

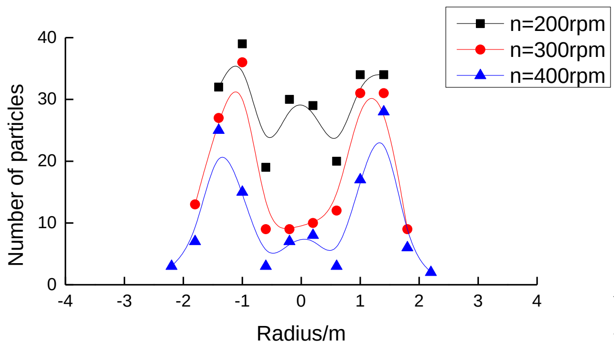

Figure 8. variation of number of particles with distribution radius in each selected rectangular region at different rotation speed of the distributor

Select a rectangular region and divide it into 20 equal parts like above. Figure 8 shows 2.5s later variation of total number of particles with distribution radius in each selected rectangular region at different rotation speed of the distributor. It is obvious from figure 8 that the distribution radius increases with the increase of the rotation speed of the distributor. The distribution radius is respectively 1.4m, 1.8m, 2.2m. However, the uniformity of the catalyst bed layer decreases with the increase of the rotation speed of the distributor. And the "hump" is still existence whatever rotation speed.

3) Effects of size of the hole on the catalyst distribution in the reactor

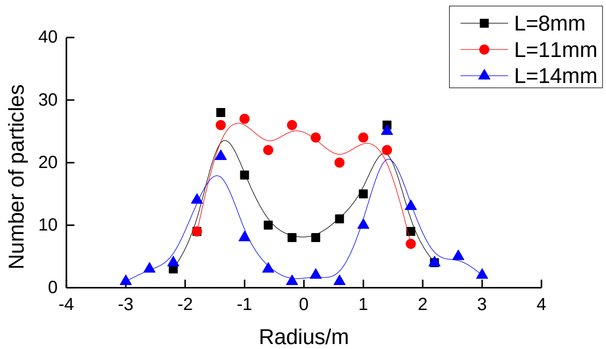

Figure 9. variation of number of particles with distribution radius in each selected rectangular region with different size of the hole

Select a rectangular region and divide it into 20 equal parts like above. Figure 9 shows 2.5s later variation of total number of particles with distribution radius in each selected rectangular region with different size of the hole. It can be found from figure 9 that the distribution radius and the uniformity of the catalyst bed layer cannot compose linear relationship with the size of the hole. The distribution radius is respectively 2.2m, 1.8m, 3.0m, and the uniformity is the best when the size of the hole is 11mm. However, the ups and downs is still existence when loading the cylindrical particles into the reactor whatever size of the hole. The "hump" is due to the unreasonable structure of the distributor because of the uncontinuity of the hole of the distributor. During loading process, there are fewer particles distributed from the hole in the center and on the edge of the distributor which contributes to the "hump".

V. CONCLUSIONS

Catalyst loading process is simulated with the DEM. It is found that catalyst loading speed increases with the increase of the rotation speed of the distributor and the size of the hole,and decreases with increase of the diameter of the distributor. The uniformity of catalyst bed layer increases with the incease of the diameter of the distributor and decreases with the increase of rotation speed of the distributor,and the size of the hole has remarkable impact on its uniformity. The distribution radius increases with the increase of the diameter of the distributor and the rotation speed of it, but cannot compose linear relationship with the size of the hole. It also reveal that when using these devices of this structure to load cylindrical particles, there will be ups and downs like a hump in the center of the catalyst bed. Therefore, the structure of the distributor should be improved then.

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