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Influence of internal grids on particle motion in the fluidized bed reactor

S A Solovev[1,2], O V Soloveva[1] and E G Sheshukov[1]

[1] Kazan Power Engineering University, 51, Krasnoselskaja St., Kazan, 420066, Russia
[2] Kazan Federal University, 18, Kremlevskaja St., Kazan, 420008, Russia

E-mail: serguei_s349@mail.ru

Abstract. A fluidized bed reactor designed for the dehydrogenation of isobutane is considered. The process takes place at high temperature and with heat absorption. A feature of the apparatus is the mechanism of block heating due to the catalyst entering through the pipe located in the center. The analysis of the effect of the grids located in the apparatus on the reactor heating is carried out.

1. Introduction

Fluidized bed reactors are used for many processes of the petrochemical and refining industries and energy [1-3]. The Eulerian-Eulerian approach is widely used for fluidized bed apparatus modeling when both the carrier (gas, liquid) phase and the discrete (solid granular) phase are considered as continuous. For the discrete phase, the equation of the granule temperature variation is added due to the change in their kinetic energy due to collisions (for example, [4]).

The ability to control the particle movement in the fluidized bed with internal elements such as grids and deflectors is widely studied. Experimental and numerical studies of devices with installed perforated plates and grids are presented in [5,6]. Grids were considered in [7] to improve the quality of dense bed fluidization. The influence of the heated particle feeder on the fluidized bed reactor heating is considered in [8,9]. The effect of grids on the fluidized bed porosity and the particle residence time in a bed were experimentally and numerically studied in [10].

This paper describes an industrial large-scale fluidized bed reactor used to dehydrogenate isobutane to isobutylene. The reaction takes place with the heat absorption. The pipe for supplying heated catalyst particles from the regenerator is located in the center of the apparatus. The focus is on grids located in the reactor. Grids can be installed at different distances from the walls. Three variants of the gap between the grids and walls and their influence on the particle motion and heating of the reactor are considered.

2. Problem formulation

We consider an industrial fluidized bed reactor with a catalyst particle diameter of 20-200 μm (Figure 1). The reactor has a cylindrical shape with a diameter of 5.2 m and a working area height of 11 m. At the bottom of the reactor there is a feeder for a gas with temperature of 550°C. Gas consumption is about 24 t/h. A feature of the apparatus is a centrally located vertical supply pipe from the regenerator of a heated catalyst at a temperature of 650°C. The grids with a free cross-section area of 30% are located in reactor.

An analysis of the reactor design showed that there is a gap between the grids and the block walls.

The size of the gap may differ due to errors in the manufacture and installation of grids, as well as due to thermal metal expansion. In this paper, we consider three options for the gap size, there are 9 cm, 5 cm and 3.6 cm. The gap is considered to be the same from the side of the reactor wall and from the side of the central pipe. It is required to determine the influence of the gap size on the hydrodynamic and heat exchange processes in the reactor.

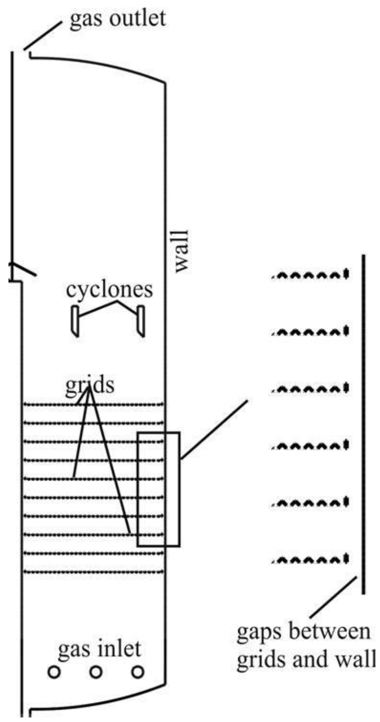


Figure 1. Reactor model and explored gaps.

3. Mathematical models

In the present work, the continuous Eulerian–Eulerian multiphase model is used, supplemented by the kinetic theory of gases to take into account collisions of solid particles. For each phase, we write the laws of conservation of mass, momentum and energy.

The mass conservation equation for gas or solid phase:

$$\frac{\partial \alpha_i \rho_i}{\partial t} + \nabla \cdot \left(\alpha_i \rho_i \vec{v}_i \right) = 0, \tag{1}$$

where α_i is volume fraction, ρ_i is density, $\vec{v}_i$ is velocity.

The momentum conservation equation for the gas phase:

$$\frac{\partial \alpha_g \rho_g \vec{v}_g}{\partial t} + \nabla \cdot \left(\alpha_g \rho_g \vec{v}_g \vec{v}_g \right) = -\alpha_g \nabla p + \nabla \cdot \overline{\overline{\tau}}_g + \alpha_g \rho_g \vec{g} + \sum_j \vec{R}_{gj}, \tag{2}$$

where p is pressure, $\overline{\overline{\tau}}_g$ is stress tensor for gas phase, $\vec{R}_{gj}$ is interfacial interaction force between the gas and j-th discrete solid phases. In equation (2), the stress tensor is:

$$\overline{\overline{\tau}}_g = \alpha_g \mu_g \left(\nabla \vec{v}_g + \nabla \vec{v}_g^{\,T} \right) + \alpha_g \frac{2}{3} \mu_g \nabla \cdot \vec{v}_g \overline{\overline{I}}, \tag{3}$$

where μ_g is shear viscosity, $\overline{\overline{I}}$ is unit tensor. The interfacial interaction force is written as:

$$\vec{R}_{gj} = K_{gj} \left(\vec{v}_g - \vec{v}_j \right), \tag{4}$$

where K_{gj} is interfacial interaction coefficient.

The momentum conservation equation for the solid phase:

$$\frac{\partial \alpha_s \rho_s \vec{v}_s}{\partial t} + \nabla \cdot \left(\alpha_s \rho_s \vec{v}_s \vec{v}_s \right) = -\alpha_s \nabla p - \nabla p_s + \nabla \cdot \bar{\bar{\tau}}_s + \alpha_s \rho_s \vec{g} + \sum_j \vec{R}_{sj}, \quad (5)$$

where p_s is solid granule pressure; $\bar{\bar{\tau}}_s$ is stress tensor for solid phase; $\vec{R}_{sj}$ is interfacial interaction force between the solid and j-th gas or solid phases. In equation (5), the stress tensor is:

$$\bar{\bar{\tau}}_s = \alpha_s \mu_s \left(\nabla \vec{v}_s + \nabla \vec{v}_s^{\,T} \right) + \alpha_s \left(\lambda_s - \frac{2}{3} \mu_s \right) \nabla \cdot \vec{v}_s \bar{\bar{I}}, \quad (6)$$

where μ_s, λ_s is shear and bulk viscosity. The interfacial interaction force is written as:

$$\vec{R}_{sj} = K_{sj} \left(\vec{v}_s - \vec{v}_j \right). \quad (7)$$

Let us note that for the interaction of gas and solid phases $K_{gs} = K_{sg}$.

The energy conservation equation for the gas or solid phase:

$$\frac{\partial \alpha_i \rho_i h_i}{\partial t} + \nabla \cdot \left(\alpha_i \rho_i \vec{v}_i h_i \right) = \alpha_i \frac{\partial p_i}{\partial t} + \bar{\bar{\tau}}_i : \vec{v}_i + \sum_j Q_{ij}, \quad (8)$$

where h_i is enthalpy; Q_{ij} is heat transfer intensity between the *i*-th and *j*-th phases. Let us note that $Q_{ij} = Q_{ji}$.

The equation for the solid phase granule temperature [11]:

$$\frac{3}{2} \left[\frac{\partial}{\partial t} \left(\alpha_s \rho_s \Theta_s \right) + \nabla \cdot \left(\alpha_s \rho_s \vec{v}_s \Theta_s \right) \right] = \left(-p_s \bar{\bar{I}} + \bar{\bar{\tau}}_s \right) : \nabla \vec{v}_s + \nabla \cdot \left(k_{\Theta s} \nabla \Theta_s \right) - \gamma_{\Theta s} + \phi_{sg}, \quad (9)$$

where $k_{\Theta s}$ is the granule energy diffusion coefficient; Θ_s is solid phase granule temperature; $\gamma_{\Theta s}$ is energy dissipation from particle collisions; ϕ_{sg} is energy exchange between solid and gas phases.

The coefficient of interfacial interaction can be written in the form [4] in the case of the two phases interaction of type as gaseous and solid granular. In the case of the interaction of two solid granular phases, we use [12]. The shear viscosity of the solid phase is taken into account as the sum of the viscosity of the collisions and the kinetic viscosity [4]. The bulk viscosity in the solid phase is responsible for the resistance of granules of particles to compression [13]. The pressure in the solid granular phase is considered to be independent and takes into account the pressure change due to the collision of particles [4]. The expression $k_{\Theta s} \nabla \Theta_s$ describes the diffusion energy flow of granules from [4]. The term $\gamma_{\Theta s}$ in the equation for the granule temperature characterizes the rate of energy dissipation in the s-th solid phase caused by collisions between the particles of the phase [13]. Transfer of kinetic energy from fluctuations of particle velocities from the s-th solid phase to the g-th gaseous phase is considered from [4]. In the case of the presence of a granular solid phase, the calculation of the Nusselt number in the heat exchange between the s-th solid phase and the g-th gaseous phase is applied from [14].

The flow considered in the apparatus under the accepted loads is turbulent. In the solution model used for the calculations, a dispersion $k-\varepsilon$ model of turbulence was used, in which the motions of the “secondary” solid granular phases are generated against the background of the motion of the “primary” gas phase. The written system of differential equations is solved in the ANSYS Fluent software package. The computational domain was divided into quadrilateral elements. In the present work in the calculations carried out, the typical number of finite elements was 500 thousand. The boundary conditions were prescribed for all elements of the constructed model of the apparatus.

4. Results

The polydisperse catalyst is located in the reactor. For the calculations, we choose the average fraction with a diameter of 100 μm. However, the average gas velocity over the cross section of the apparatus is not enough for entrainment of such particles. In turn, the fine fractions can have a significant impact on the bed movement and the heating of gas and particles. At the same time, the system of cyclones and filters of an industrial reactor returns particles with a diameter of more than 40 μm to the block. Therefore, we choose an additional average fraction of fine particles with a diameter of 50 μm and a volume content of 20% of the total number of particles in the reactor.

At a given gas flow rate, catalyst particles circulate throughout the reactor volume. The fields of granule concentration are similar for all variants of the considered values of the gaps. However, the analysis of temperature fields shows significant differences. Fig. 2 presents the temperature fields for calculations after one minute of reactor operation. The temperature scale is from 550°C (blue areas) to 570°C (red areas). In figure 2 (a) the heated region above the central tube is visible. Thus, the incoming heat is quickly removed from the reactor. In figure 2 (b) the heated regions are above the central tube. On the contrary, the regions in the lower and middle parts of the reactor are more heated. In this case, for the case with a gap of 3.6 cm, a well-heated area is observed near the outer wall of the apparatus.

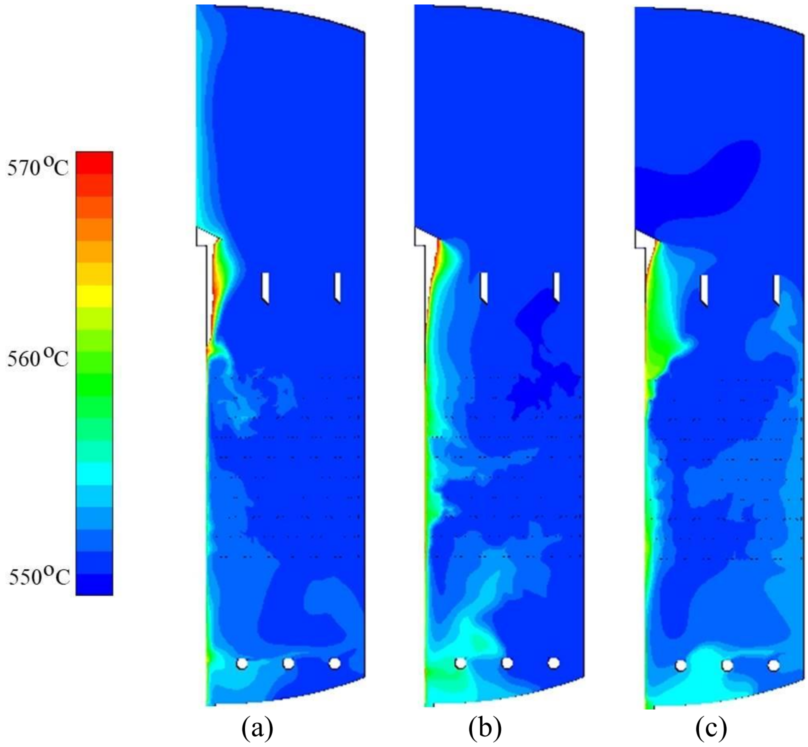
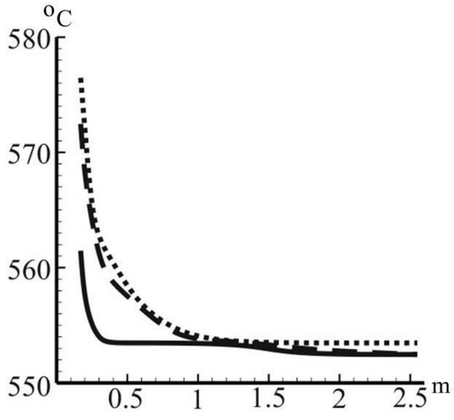
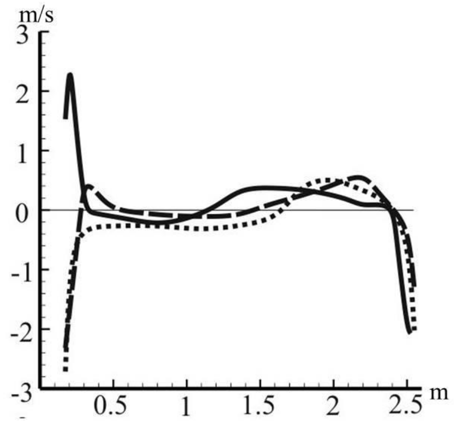


Figure 2. The temperature distribution (°C) in the reactor for three values of the investigated gap: (a) 9 cm, (b) 5 cm, (c) 3.6 cm.

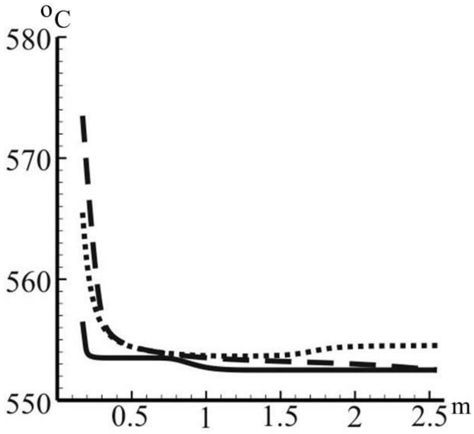
To analyze the results of calculations, averaged parameters were constructed in the reactor sections: (a) – the upper grid, (b) – the lower grid. The graphs are built for the time interval of the blocks from 40 s to 70 s. Figure 3 shows the average temperature values. For the 9 cm gap option, there is a slight temperature increase in all sections. An exception is the area around the central pipe. Options with gaps of 5 cm and 3.6 cm show significantly better heating in all areas. We also note that in all sections for the case with a gap of 5 cm, the region around the symmetry axis of the reactor is better heated, and for the case with a gap of 3.6 cm, the region near the outer wall of the unit is better heated. An analysis of the results of the reactor heating indicates that, as a result of a change in the gap, the directions of the main circulation flows of gas and catalyst particles also change. We calculated the averaged values of the velocity for axial particle motion in the reactor cross sections for the values of the investigated gap. The results are presented in figure 4.



(a)

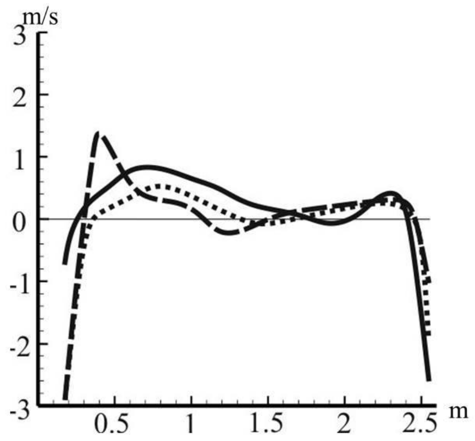


(a)



(b)

Figure 3. The averaged values of the temperature in the sections of the reactor for the three values of the gap being investigated: solid lines – 9 cm, dashed lines – 5 cm, dashed lines – 3.6 cm.



(b)

Figure 4. The averaged values of the velocity of axial motion of particles in the sections of the reactor for three values of the gap being investigated: solid lines – 9 cm, dashed lines – 5 cm, dashed lines – 3.6 cm.

The essence of the reactor under consideration is that gas and catalyst particles must move in the vicinity of the heated granule feeder. So, in the first case with a gap of 9 cm, it can be seen that the incoming heat is quickly carried upwards by the upward flow. In the case of a gap of 3.6 cm, the incoming heat is transferred by descending flows to the lower part of the reactor and to the zones near the outer wall, which allows heating a large number of large catalyst grains.

5. Conclusion

Grids installed in the fluidized bed reactor can have a significant impact on the hydrodynamics of the phases and the thermodynamics of the apparatus. In this case, not only the transparency and the shape of the grids, but also the distance between the grids and the walls of the apparatus is important. For a reactor in the presence of a central vertical pipe designed to supply heated particles, an increase in the efficiency of heating the apparatus by reducing gaps for the movement of free gas and catalyst particles along vertical surfaces is shown.

Acknowledgments
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References
[1] Yang W C 2003 *Handbook of Fluidization and Fluid-Particle System* (Taylor and Francis Group)
[2] Basu P 2006 *Combustion and Gasification in Fluidized Beds* (CRC Press.)
[3] Sadeghbeigi R 2012 *Fluid Catalytic Cracking Handbook* (Butterworth-Heinemann)
[4] Gidaspow D 1994 *Multiphase Flow and Fluidization* (Academic Press.)
[5] Yang S, Li H and Zhu Q 2015 *Chem. Eng. J*. **259** 338-347
[6] Yang S, Peng L, Liua W, Zhao H, Lv X, Li H and Zhu Q 2016 *Powder Technol.* **296** 37-44
[7] Zhou E, Zhao Y, Duan C, Yang X, Yu X, Li G, Liufeng Y, Fan X and Zhang Y 2016 *Fuel*. **185** 555-564
[8] Soloveva O V and Solovyev S A 2016 *IOP Conf. Ser.: Materials Sci. Eng.* **158(1)** 012086
[9] Soloveva O V, Solovev S A, Egorova S R, Lamberov A A, Antipin A V and Shamsutdinov E V 2018 *Chem. Eng. Res. Des.* **138** 212-228
[10] Klenov O P, Noskov A S and Parahin O A 2017 *Chem. Eng. J*. **329** 66-76
[11] Ding J and Gidaspow D 1990 *AICHE J*. **36(4)** 523-538
[12] Syamlal M 1987 *The Particle-Particle Drag Term in a Multiparticle Model of Fluidization* (Morgantown WV EG & G Washington: Analytical Service Center)
[13] Lun C K K, Savage S B and Jeffrey D J 1984 *J. Fluid Mech*. **140** 223-256
[14] Gunn D J 1978 *Int. J. Heat Mass Transfer*. **21** 467-476