Investigation of the gas feeder design for a fluidized bed chemical reactor or combustor

S A Solovev
Kazan State Power Engineering University, Krasnoselskaja st. 51, Kazan, 420066, Russia
E-mail: solovev.sa@kgeu.ru

Abstract. In the present work, a model of a gas feeder for the industrial apparatus of the petrochemical or energy industry is constructed. Using the methods of computational fluid dynamics, we calculated the gas motion in the constructed models. Various options for the size and arrangement of the gas feeder elements in the system are considered. The analysis of the calculation results is carried out and the best design options are determined to ensure uniform distribution of the gas velocity to the nozzle of the gas supply system.

1. Introduction
In industrial reactors of the petrochemical and oil refining industries, it is often necessary to use large gas distributors, for example, for the fluidization process [1-3]. Moreover, the same fluidization process is used for coal and biomass combustion [4-8].

An important problem in the design of a fluidized bed apparatus is the uniform movement of gas along the height of the block. In this case, it is possible to provide the calculated indicators of the process under consideration uniformly in all sections. Thus, choosing the right gas distributor plays an important role. For example, in [9] it was shown how two different gas distributors can significantly affect the efficiency of a fluidized bed reactor.

In the present work, using numerical simulation, several variants of gas feeder for a large-scale apparatus are calculated. The options are determined that provide the most uniform distribution of gas velocity for the entire supply system.

2. Problem formulation and methods
2.1. Gas feeder construction
Consider a gas distributor for a large-scale industrial reactor. Let the reactor be in the form of a cylindrical column. Then we will consider the gas feeder in the form of five rings with a diameter of 0.3 m. The diameter of the largest ring is 4.9 m, the diameter of the smallest ring is 1.8 m. Let this device consist of two sets of half rings (figure 1, a) or four sets of quarter rings (figure 1, b). Such a separation into parts is associated with the conditions of reliability and the possibility of installation.
On each ring there are nozzles for the exit of gas with a diameter of 3.2 cm. The nozzles are located at an angle of 45°. The distance between the nozzles is 8 cm. The sections of the rings are interconnected by a pipe through which gas flows into them. To this pipe, another supply pipe fits from below. The location of this pipe is not initially determined. It can be either closer to the outer edge of the distributor, or closer to the inner edge of the distributor. In this paper, we consider several options for the location of the supply pipe. We determine how the location of the supply pipe affects the movement of gas through the distributor system.

2.2. Gas flow model
The following differential equations are considered for computational fluid dynamics model.

The mass conservation equation

\[ \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0, \]  

(1)

where \( \rho \) is the density, \( \mathbf{v} \) is the gas velocity.

The momentum conservation equation

\[ \frac{\partial \rho \mathbf{v}}{\partial t} + \nabla \cdot (\rho \mathbf{v} \mathbf{v}) = -\nabla p + \nabla \cdot \left[ \mu \left( \nabla \mathbf{v} + \nabla \mathbf{v}^T \right) \right] + \mathbf{f}, \]  

(2)

where \( p \) is the pressure, \( \mu \) is the dynamic viscosity.

The presented mathematical problem is solved by the finite volume method. The entire computational domain is divided into finite volumes of a triangular shape. In the calculations carried out in this work, the average number of finite elements was about 16,000,000 elements (figure 2). The numerical scheme is steady.

The boundary conditions were established in accordance with the operating mechanisms of the calculated gas feeder. The impermeable wall condition has been established on all impermeable surfaces. At the gas flow supply section, the conditions for the gas mass flow rate were set in gas feeder model: 4 kg/s for half ring, 2 kg/s for quarter ring. On the site in the reactor model for the gas outlet, the conditions of external pressure outside the considered region were set.
3. Results

Consider four cases of the location of the supply pipe: between the first and second ring, between the second and third ring, between the third and fourth ring, and between the fourth and fifth ring. All cases were investigated both for half rings and for quarter rings. The final results are presented in figures 3 and 4.

![Figure 2. Mesh for gas feeder numerical simulation.](image)

![Figure 3. The average gas velocity at the nozzles for half rings.](image)

An analysis of the calculations showed that the gas velocity at the nozzles is close on each individual branch, but can vary significantly on different pipes. As a result of the calculation, we estimate the average gas velocity at the nozzles on a separate branch. Figure 3 shows the calculation results for each of 4 cases. It can be seen that the highest velocities are achieved on the pipe with the smallest diameter. However, there is no uniform distribution of gas velocity on different pipes for all cases. The best result is achieved for cases 3 and 4, when the supply pipe is located closer to the outer edge of the gas distributor. There, the largest differences in gas velocity are 36%.
Then we consider the calculation results for a gas distributor consisting of four quarters of a circle. The result is shown in figure 4. For all cases of the location of the supply pipe, the distribution of gas velocity on the nozzles is more uniform. The best result is also achieved for cases 3 and 4, when the supply pipe is located closer to the outer edge of the gas distributor. There, the greatest differences in gas velocity are 17%.

![Figure 4. The average gas velocity on the nozzles for quarter rings.](image)

Thus, the most uniform distribution of gas velocity at the nozzles of the distributor is achieved for the shape of a quarter rings. The location of the supply pipe should be closer to the outer edge of the gas distributor.

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