Research on Fluid Dynamics Behavior Monitoring System based on Slurry Bed Reactor

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Abstract. In this paper, a behavior monitoring system is developed based on the fluid mechanics in the slurry bed reactor. In using this system, the researchers studied the hydrodynamic behavior of the slurry bed, and this paper proposed the theoretical basis and hypothesis for monitoring the fluid dynamic behavior of the slurry bed. Therefore, this paper designs a fluid mechanics model that summarizes the fluid mechanics' behavior monitoring technology and analyzes the role of vertical tube bundles in the fluid mechanics' behavior monitoring of slurry beds. At the same time, this paper also discusses the problems faced by the fluid dynamics behavior monitoring system and the future development trend.

Keywords: Slurry Bed Reactor; Fluid Mechanics; Monitoring.

1. Introduction

Due to its high dimension, strong nonlinearity, and large amount of data, fluid mechanics is an important field that behavior monitoring is good at and can bring about innovations in research paradigms. Behavior monitoring has been initially applied in fluid mechanics, and its application potential has been gradually confirmed. Based on the background of fluid mechanics in slurry bed reactor, combined with the recent research results of the research group in this paper, the fluid mechanics' behavior monitoring modeling technology and its latest progress are discussed.

2. Research on the Industrial Application of Slurry Bed Reactor

2.1 Application of Large-Scale Chemical Slurry Bed Reactor

In the large-scale chemical industry field, the most typical application of slurry bed is Fischer-Tropsch synthesis. Fischer-Tropsch reactors go from fixed bed to fluidized bed to slurry bed. Compared with a fixed and fluidized bed, a slurry bed reactor has the advantages of simple structure and convenient operation.

The violent turbulence of bubbles and slurry significantly enhances the mass transfer and heat transfer effects. The reaction temperature is easy to control, the processing capacity of a single unit is improved, the energy consumption is low, and the conversion rate and the product selectivity are high. The Chinese Academy of Sciences has also profoundly studied the slurry bed reactor and realized industrial production. Slurry bed reactors are used in the production of dimethyl ether and methanol.

2.2 Slurry Bed Reactors for Fine Chemicals

Fine chemicals generally refer to high value-added chemicals produced in small batches, such as medicines, dyes, pesticides, coatings, etc. The traditional exemplary chemical production process mainly adopts the stirred tank reactor for batch operation, which has a low production capacity, poor heat and mass transfer effect, low yield, high cost, and severe pollution. In recent years, with the continuous improvement of environmental requirements, the competition in fine chemicals has become increasingly fierce. The development and application of new processes and reactors have attracted more attention [1]. Compared with the traditional stirred tank reactor, the slurry bed reactor has the advantages of low energy consumption, uniform catalyst distribution, good mass transfer and heat transfer performance, etc., and can realize continuous and large-scale production.

2.3 Application Research of Slurry Bed Reactor in the Field of Petroleum Hydrogenation

Hydrorefining and cracking utilize catalysts to react heavy oil with hydrogen to produce light oil. In recent years, the market demand for light oil products has been increasing, and the trend for heavy crude oil has become increasingly severe. Countries have become increasingly strict with environmental protection requirements, and the importance of oil hydrogenation has become increasingly prominent. During the fixed bed hydrogenation process, the catalyst is prone to coking, which leads to the deactivation of the catalyst, blockage of the bed, and reduction of production efficiency.

3. Research on the Hydrodynamic Properties of the Bed

3.1 Flow Pattern

There are apparent differences between slurry bed reactors' flow, mass transfer, mixing, and bubble behavior in different flow pattern regions. Generally speaking, the flow pattern of the slurry bed can be divided into three types: uniform bubbling zone, non-uniform bubbling zone, and transition zone. The uniform bubbling zone exists when the superficial gas velocity and the distributor's good performance are low [2]. It is characterized by a uniform radial distribution of gas holdup, weak bubble coalescence, small bubble size, and narrow distribution; a non-uniform bubbling zone appears. The region with high gas velocity is characterized by the apparent enhancement of bubble aggregation, the increase of the volume fraction of vacuoles, the widening of the size distribution of bubbles, and the uneven radial distribution of gas holdup. There is a typical transition zone in the uniform and non-uniform bubbling zones when the gas distributor has good distribution performance and low liquid viscosity.

3.2 Gas Content

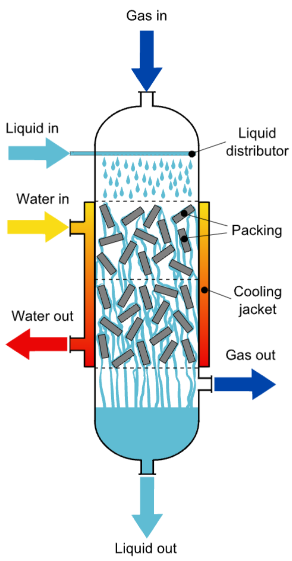

Fig 1. Structure of large-scale chemical slurry bed reactor

The gas holdup directly affects the interphase force, gas-liquid mass transfer, and flow pattern of the reactor and is one of the essential parameters for designing the reactor. The gas holdup is related to operating conditions and physical parameters, including apparent gas velocity, liquid circulation velocity, physical properties of gas and liquid, solids holdup, reactor geometry, and distribution. In general, the gas holdup increases with the increase of the gas velocity, while the uniform bubbling area has a linear relationship with the gas velocity; in the non-uniform bubbling area, the bubble aggregation increases, the proportion of significant bubbles increases, and the gas holdup increase with the gas velocity. Increased and slowed down. See Figure 1.

3.3 Characteristics of Bubbles

After the distributor is formed, the bubbles rise in the liquid phase. Polymerization and crushing finally achieve the equilibrium bubble size distribution and rising speed. System pressure, solid holdup, liquid properties, and other factors greatly influence bubble behavior. When the gas velocity is constant, the bubble diameter decreases as the system pressure increases. Gas density increases, bubble diameter increases [3].

When the pressure increases, the bubble breaking effect is enhanced, and the bubble size is further reduced. In general, with the increase of solid holdup, the average diameter and rising rate of bubbles increase, and the gas holdup decrease. In this paper, it is found through experiments that the hydrodynamic behavior of the slurry bed with high solid holdup shows that with the increase of solid holdup, the polymerization speed of bubbles accelerates, and the size of bubbles increases.

The flow field in the bubble column is a turbulent motion driven by bubble buoyancy, and its gas holdup distribution and flow velocity distribution are similar and have strong positive and negative coupling effects [4]. On the one hand, when the gas holdup is radially installed with different numbers of tubes, the distribution of the average gas holdup in the tower is uneven, which will cause a difference in buoyancy, resulting in the rapid rise of bubbles in the central area, forming a steep liquid phase velocity gradient; It is also affected by the centripetal lateral lift, and its magnitude is proportional to the liquid phase velocity gradient, and the gas holdup tends to be steeper as the velocity gradient increases. In the empty tower, the large bubbles rise in a spiral shape, and the bubbles move centripetally under the action of lateral lift. The radial turbulence disperses the bubble group. The two factors of uniform distribution balance each other and form a gas holdup that is stably distributed along the radial direction. After adding the tubes, the lateral turbulence of the bubbles and the liquid is hindered by the tubes, resulting in two effects: first, the bubbles rise from a spiral to a straight line, but the centripetal force is less affected by the tubes, so that the bubbles gather in the central area, The distribution of gas holdup in the central area is steep, which accelerates the floating speed of the central area, drives the liquid to rise rapidly, and forms a "chimney effect." The apparent turbulent viscosity decreases, and the liquid velocity distribution tends to be steep [5]. Generally speaking, the longitudinal tube bundle surface resistance to fluid is divided into two categories: axial friction resistance and radial turbulent pulsation resistance. The test results show that the axial frictional resistance has little effect on the velocity distribution; the tubes play a significant role in the shape resistance of the radial turbulent pulsation, which forms a steeper velocity distribution and gas-containing gas by restricting the radial diffusion of bubbles and the exchange of liquid momentum rate distribution. However, according to the experimental results in this paper, this configuration is just the opposite, making the flow velocity distribution steeper and repeatedly intensified. The researchers performed three-dimensional calculations using a two-phase turbulence model. The no-slip boundary conditions were used to calculate the time-averaged flow velocity, and there was a considerable rise and fall change between the tubes. Therefore, considering the effect of tube bundles under the turbulent constitutive relation and its boundary conditions is inconclusive. The research results can provide an essential basis for establishing a proper monitoring and calculation model of hydrodynamic behavior and the development of an industrial slurry bed reactor with tube bundles.

4. Theoretical Basis and Assumptions of Fluid Dynamics Behavior Monitoring

The system concept introduces the behavior monitoring model. The concept of a system has different concepts in different research systems. The research object of engineering thermodynamics is a collection of invariable substances called an open system or a closed system. A system refers to a set of defined fluid particles in fluid mechanics. The system boundary isolates the fluid from the outside world. The system moves with the movement of the fluid, and the shape of its boundary and the size of the enclosed space also change with the movement. This definition uses Lagrangian methods to describe fluid motion, similar to behavioral monitoring motion in enclosed spaces. In relatively closed spaces (such as airport lounges and moving passenger cars), the movement of behavior monitoring can be regarded as a closed system. Entry and exit of a closed system are rare, and when it occurs on a large scale, it is considered an anomalous event. People usually focus on the role and effects of fluids in physics or space. For example, when the plane is flying, considering the pressure distribution on the wing, it is more convenient to use the Euler method. The control volume refers to the space area determined in the flow field, and the boundary surface of the control volume is called the control surface. There can be fluid flow on the control surface. See Figure 2.

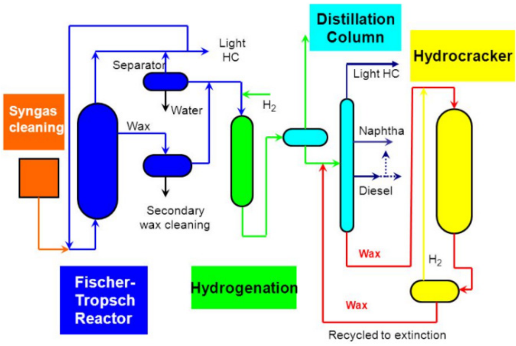

Fig 2. Slurry Bed Reactor in Petroleum Hydrogenation Process

Similarly, behavior monitoring is not in a closed space but a visible area. If the camera's field of view is used as the control surface, behavior monitoring will continuously enter and exit the camera interface. The surrounding buildings and other environments usually constrain behavior monitoring, and the boundary of environmental constraints can be regarded as a control surface. This system can communicate with the outside world. We call it an open system. After introducing the concept of the system, the thesis puts forward the following hypothesis: the behavior monitoring system always tends to keep the energy constant without external disturbance. That is to say, in the absence of emergencies as an external force, the change range of the behavior monitoring exercise intensity remains unchanged. The energy tends to be stable; if the system's total energy changes, it will be affected by the external force. An external force is an abnormal event that monitors and interferes with behavior.

5. Fluid Mechanics Behavior Monitoring Technology

5.1 Data Acquisition System

Due to the particularity of the fluid mechanics' behavior monitoring equipment, it is necessary to collect multiple data types and data collection ranges, so the data acquisition equipment for the fluid mechanics' behavior monitoring usually adopts the multi-channel control method. For example, a control-level monitoring host and a ground-level control unit are set up in the equipment to ensure the safe operation of crucial parts of the equipment; a liquid level monitor is placed outside the equipment to collect data in real-time and determine whether the alert state needs to be turned on according to the movement direction of the monitoring behavior. In addition, data collection points should be set up on low-voltage electrical equipment and control equipment so that managers can visually confirm whether this equipment is within the normal range. Once an accident occurs, monitoring personnel can judge the problem based on the data and take corresponding measures.

5.2 Internet Communication

Domestic behavior monitoring equipment generally uses DSTH and 323 MCS communication protocols to form a network monitoring system using TCP and IP protocols. It can directly access local area networks and wide area networks. The system can support a variety of communication methods, enabling data acquisition equipment to access signals at different distances. It has substantial flexibility and can upload the collected data signals to the central control system through VPN, microwave, etc., according to the actual situation to realize the operation of remote monitoring equipment.

5.3 Central Control System

The central control system processes the collected data so that managers can intuitively understand the functional status of the equipment and can also provide managers with real-time monitoring images. Therefore, the central control system should have the functions of signal reception, data storage, graphics processing, video processing, etc., and fully integrate the monitoring data of fluid dynamics behavior. The control center will affect the decision-making of the fluid mechanics' behavior monitor. Its role is crucial. It can monitor the temperature through thermal elements to ensure that the equipment operates within a reasonable temperature range. In exceptional cases, such as non-personnel intrusion, or improper operation of the operator, the control center can control the equipment through real-time dialogue with the on-site personnel, which is convenient for repair and maintenance.

5.4 Model Building

The driving force and flow resistance caused by the difference in a gas holdup in the riser and downcomer are balanced in a stripped circulating bed. Due to the slurry system

The particle size of the medium solid particles is minimal, so the liquid-solid phase is generally treated as a liquid-solid quasi-homogeneous phase. The pressure difference between the riser and the downcomer caused by the gas holdup in the riser is:

$$\Delta \mathrm{P} = \mathrm{P_{sus}} \mathrm{g} \mathrm{H} \alpha_{\mathrm{g}}, \mathrm{R}. \tag{1}$$

$\Delta \mathrm{P}$ is the pressure difference due to gas holdup, g is the acceleration of gravity, the subscript g is the gas phase.

This paper has two types of correlations about gas holdup: semi-theoretical and semi-empirical correlations based on drift flux models and exponential empirical correlations. In this paper, the exponential correlation is used to correlate the gas holdup:

$$\alpha_g, R = \alpha U_g^b \tag{2}$$

The subscript b is the bubble.U_g is the apparent gas velocityThe parameters a and b were regressed using the experimental data, and a and b were determined to be 1 and 0.8, respectively. The resistance drop in different areas is calculated according to the following methods. See Figure 3.

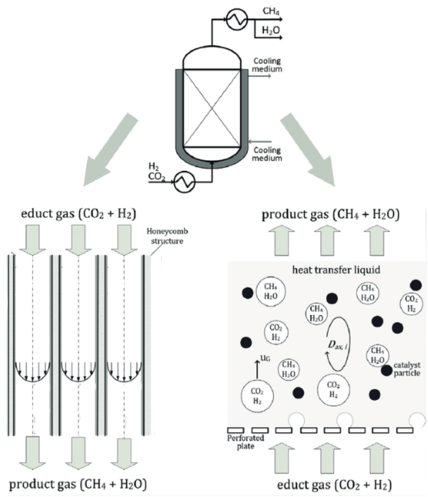

Fig 3. Chemical process of slurry bed reactor for chemical industry

Pressure drops in riser:

$$\Delta P_{f,R} = \frac{1}{2} P_{sus} K_{f,R} U_{sus}^2, R, \tag{3}$$

The drag coefficient $K_{f,R}$ is calculated using the Fanning formula, and the friction factor f_R can be calculated using the formula in single-phase flow:

$$K_{f,R} = 4 f_R \frac{H}{D} \tag{4}$$

$$f_R = 0.7 Re_{sus,R}^{-0.3} \tag{5}$$

$$\Delta P_{f,D} = \frac{1}{2} p_{sus} K_{f,D} U_{sus,D}^2 \tag{6}$$

where $Re_{sus,R}$ is the Reynolds number calculated based on the physical properties of the slurry and the circulating liquid velocity in the riser.$K_{f,D}$ is the coefficient of friction in the downpipe. See Figure 4.

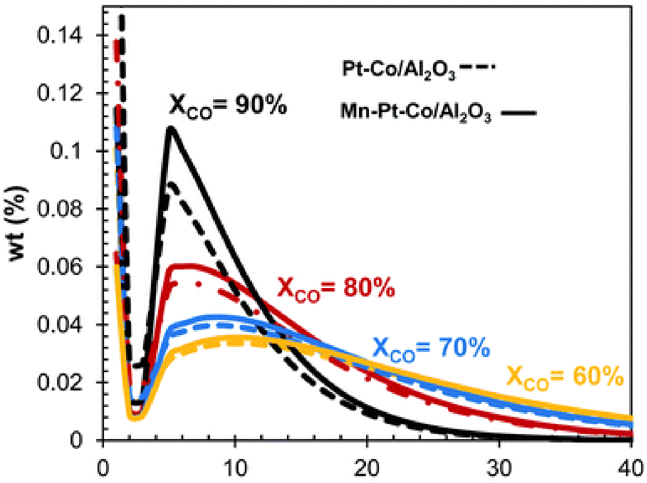

Fig 4. Effect Analysis of Slurry Bed Reactor for Chemical Industry

6. Vertical Tube Bundles Monitor the Effect of Slurry Bed Hydrodynamic Behavior

Since Fischer-Tropsch synthesis is a strongly exothermic reaction, vertical heat exchange tube bundles to maintain reactor temperature balance has become a research hotspot. At present, there are two different benchmarks for the comparative study of empty towers and tubular towers with vertical tube bundles, one is based on the apparent gas velocity based on the total cross-sectional area, and the other is based on the effective cross-sectional area minus the area occupied by the vertical tube bundle is the benchmark. In this paper, the fiber optic probe is used to measure the bubble chord length distribution, and it is found that in the tube column, the corresponding size of the Bubble Chord Length Distribution Peak moves in the direction of tiny bubbles, and the number of large bubbles is significantly reduced. That may be because the vertical tube bundle greatly influences the turbulent dissipation rate, and bubbles' aggregation and breakup behavior is very sensitive to the turbulent dissipation rate parameter. However, the research on the simulation of bubble size distribution in the tubular column using the CFD-PBM simulation scheme is still blank. Influence of solid particles and internal components on fluid mechanics and reaction behavior in slurry bed reactors Large-scale circulation of the liquid phase is beneficial to reducing gas holdup, while reducing bubble size is helpful to increasing gas holdup. The combined effect of the two makes the slurry bed. The average gas holdup varies little, while the vertical tube bundle significantly affects the radial gas holdup distribution. Compared with the empty tower, the gas holdup in the central area of the tube tower is similar, and the gas holdup in the middle ring area is reduced due to the drive away from the vertical tube wall; in addition, the vertical tube bundle spacing affects the reaction by confining bubbles and turbulent eddy structures. Therefore, the arrangement and spacing of vertical tube bundles focus on the impact study. The research on vertical tube bundles mainly focuses on the hydrodynamic behavior in cold mode reactors. There are few literature reports on the effects of vertical tube bundles on mass transfer and reaction behavior in hot mode reactors.

7. Challenges and Future Trends

The research on fluid mechanics and behavior monitoring has excellent prospects for development. Judging from the current extensive attention and preliminary applications in the application field of fluid mechanics, behavior monitoring technologies such as behavior monitoring and reinforcement learning will promote the development of a new paradigm of data-driven fluid mechanics' research. Establish. According to the author's recent relevant research experience and preliminary understanding, the challenges and urgent scientific problems to be solved in the monitoring of hydrodynamic behavior in slurry bed reactors are put forward as follows:

7.1 Data Structures and Learning Patterns

Behavior monitoring relies on massive amounts of data, and only massive amounts of data can enable deep networks to learn thoroughly. High-precision calculations of fluid mechanics require a lot of computational resources; and, in some cases, the cost of acquiring data, such as flight test data. Therefore, how constructing data and training the network on a small sample set is an urgent problem to be solved in the application of behavior monitoring. In addition, the way of data extraction and expression is directly related to the effect of behavior monitoring modeling. Therefore, exploring reasonable and effective feature extraction methods is also an important research direction.

7.2 Integrate Fluid Mechanics with Behavioral Monitoring

The behavior monitoring technology is based on the governing equations of fluid mechanics. These methods are only suitable for some exceptional cases and cannot combine specific characteristics of specific problems. The integration of behavior monitoring and various disciplines provides new methods for solving practical problems and has essential significance for the development of various disciplines.

7.3 Establish a Standard Fluid Mechanics Dataset

In order to make the research and inspection of behavior monitoring more convenient, there are a large number of datasets in the field of image processing. The current research on fluid dynamics behavior monitoring requires many resources to construct a data set each time. Due to different data sources, there are significant obstacles to the test and improvement of the method. Therefore, the proposal of a standard dataset for fluid mechanics is of great significance for the further development of behavior monitoring.

7.4 Construction of a New Data-driven Research Paradigm of Fluid Mechanics

As a representative of behavior monitoring technology, behavior monitoring itself is still in the development stage. However, in the past few years, it has achieved good results in various fields, showing the great potential of traffic monitoring technology. The fluid mechanics' behavior monitoring technology is in the ascendant, showing a good situation in which a hundred flowers are blooming, but it is still in its infancy and exploration stage, and there is still a big gap with the expectations of the industry for the fluid mechanics' behavior monitoring capability. Combining behavioral monitoring and establishing a data-driven fluid mechanics research paradigm requires the joint efforts of academia and industry.

8. Conclusion

In a word, the application of modern Fluid Dynamics Behavior Monitoring Technology to the construction of slurry bed reactor can comprehensively analyze and study the work management of slurry bed reactor, especially from the actual situation, its function is explained in-depth, and it is used as an It solves various problems in the fluid mechanics monitoring system under the slurry bed reactor, and uses modern Fluid Dynamics Behavior Monitoring Technology such as CDMA and 3G to simplify and improve the efficiency of the construction of slurry bed reactors. Especially the safety and convenience of the fluid mechanics' behavior monitoring technology can make a detailed understanding of the slurry bed reactor in all directions and store the information comprehensively, and further use advanced technology for slurry bed reaction. The work of the reactor has been improved to lay a theoretical foundation for improving the quality of the slurry bed reactor.

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