Powder Technology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Distributions of solids holdup and particle velocity in the FCC riser with downward pointed feed injection scheme

Zihan Yan [1], Sheng Chen [1], Zhao Wang, Chen Li, Yiping Fan *, Chunxi Lu *

State Key Laboratory of Heavy Oil, China University of Petroleum (Beijing), Beijing 102249, China

ARTICLE INFO

Article history:
Received 13 November 2015
Received in revised form 22 March 2016
Accepted 25 March 2016
Available online xxxx

Keywords:
FCC
Riser
Feed injection scheme
Solids holdup
Particle velocity

ABSTRACT

A downward pointed feed injection scheme in which the feed jets contact with the catalysts countercurrently is put forward to improve the nonuniform distribution of solids in the feed injection zone of FCC riser. The radial nonuniformity index (*RNI*) is used to quantify the nonuniformity in radial distributions of catalyst particles in the new and traditional feed injection scheme. Comparison between the two types of schemes is made. Experimental results show that the particles distribute more uniformly in the initial contact region of oil with catalysts in the downward pointed feed injection scheme. The influence region of feed spray above the nozzles shortens considerably. Based on the axial profile of *RNI*, the proposed scheme is divided into three subzones. The proper operating conditions and setting angle of nozzles are also given. In addition, the correlations for calculating the distributions of solids holdup and particle velocity are established through which an industrial example are predicted.

1. Introduction

Fluid catalytic cracking (FCC) is an important primary conversion process in the oil refining industry, which produces olefins, gasoline, and some other low-molecular weight products of higher value [1]. Riser reactor is one of the most important units in the FCC process. In general, a riser reactor can be divided into four parts according to the different functions, i. e. the prelift zone, the feed injection zone, the full reaction zone, and the quenching zone. In the feed injection zone, the contact between feed oil and catalyst particles will directly influence the FCC reactions [2]. In a traditional feed injection scheme, the feed nozzles are usually installed upwards towards the riser axis with an angle of 30–40° [3]. The flow patterns and hydrodynamics of gas–solid two-phase in the traditional feed injection zone have been investigated by some researchers, including both experimental and numerical simulation methods.

Fan et al. [4,5] studied the flow of the catalyst particles as well as the dispersion of the feed spray in the traditional riser feed injection zone via cold model experiments. The results illustrated that a secondary flow appears near the riser wall, which will cause the quite nonuniform distribution of catalyst particles in the feed injection zone. E et al. [6,7] explored the effect of operating conditions on the solids holdup profiles in the feed injection zone in detail. It was found that the non-uniform distribution of solids holdup could be reduced by optimizing the operating parameters. However, the flow patterns of catalysts and feed spray will not change significantly. Gao et al. [8,9] incorporated lumped kinetic models into 3D computational fluid dynamics to simulate the complex flow and reaction in FCC riser. It was shown that the concentration distributions of both solid and gas phases have big gradients in the radial, axial and tangential directions. Patel et al. [10] found that the pre-cracking in the feed injection zone plays an important role in steering the overall performance of the FCC reaction by using the Lagrangian and Eulerian model, which indicated that improving the contact of oil with catalysts in the feed injection zone is quite important. The above results have indicated that the catalyst particles distribute quite nonuniformly in the traditional feed injection zone, which is believed to be harmful for the contact and reaction of feed oil with catalyst particles.

In order to enhance the mixing of catalysts with feed spray in the feed injection zone, some kinds of improvements have been presented. Several spiral internals were introduced to create a rotate flow pattern in the riser in Maroy's patent [11]. Zhong et al. [12] proposed a reducing-diameter feed injection scheme along with a tangential secondary air injection to eliminate the axial down-slipping of catalyst particles. Two types of feed injection schemes covering inner louver conduits or baffles were put forward by Fan et al. [5] to control and utilize the secondary flow. Moreover, some new kinds of FCC feed nozzles with adjustable setting angles have been invented [13–16]. However, these inventions are essentially tentative works. The internals in the riser can provide places for coke deposition, which brings about new problems. Mauleon et al. [17] disclosed a process for the catalytic cracking in a fluidized bed wherein the feed jets are injected countercurrently to the prelift flow in the US patent 4,883,583. Chen et al. [18] found that the direction of secondary flow is towards the riser center when the

---

* Corresponding authors.
E-mail addresses: fanyipin2002@yahoo.com (Y. Fan), lcx725@sina.com (C. Lu).

[1] These authors contributed equally to this work.

http://dx.doi.org/10.1016/j.powtec.2016.03.048
0032-5910/© 2016 Elsevier B.V. All rights reserved.

Please cite this article as: Z. Yan, et al., Distributions of solids holdup and particle velocity in the FCC riser with downward pointed feed injection scheme, Powder Technol. (2016), http://dx.doi.org/10.1016/j.powtec.2016.03.048

feed spray contact with the catalyst particles countercurrently by using the Kutta–Joukowski lift theorem. The secondary flow of feed spay will mix with the main flow soon. The disadvantages of secondary flow can be controlled to some extent in this way. However, the gas–solid two phase flow behaviors in this new kind of feed injection scheme still need to be further explored.

In this paper, the hydrodynamics of catalyst particles in the new type of feed injection scheme wherein the feed jets contact with the catalysts countercurrently were investigated in a large scale cold model FCC riser. The correlations for estimating the distributions of solids holdup and particle velocity in the proposed feed injection scheme were established based on the experimental data.

2. Experiment

2.1. Experimental apparatus and the feed injection scheme

The experimental setup is shown in Fig. 1. The system basically consists of a riser section, a gas–solid separation section and a recirculation section. The riser section is 0.186 m in inner diameter and 11 m in height. Four nozzles corresponding to the feed nozzles are equipped downward relative to the riser axis at a height of 4.5 m above the gas distributor. The feed jets contact with the catalyst particles countercurrently in the feed injection zone. The angle of the nozzle axis relative to the riser axis is α. Three different setting angles of nozzles ($\alpha = 30^o$, 45^o and 60^o) are investigated, respectively. The schematic diagram of the proposed feed injection scheme is shown in Fig. 2.

2.2. Experimental materials

In this paper, both the prelift gas and the feed spray were instead of atmospheric air, which was supplied by a Roots blower. The flow rates were controlled by several rotor flowmeters. It is reasonable to use the atmospheric air as the feed injection because the evaporation time of feed oil is very short (usually less than 0.2 s) in the industrial riser. Besides, in order to make the experimental condition closer to the real case, the velocities at the exit of feed nozzles are nearly the same with that of the vaporized feed oil in the industrial riser. The solids used were typical FCC catalyst particles whose particle density ρ_p is 1200 kg/m^3, bulk density ρ_b is 930 kg/m^3 and mean diameter d_p is 65 μm.

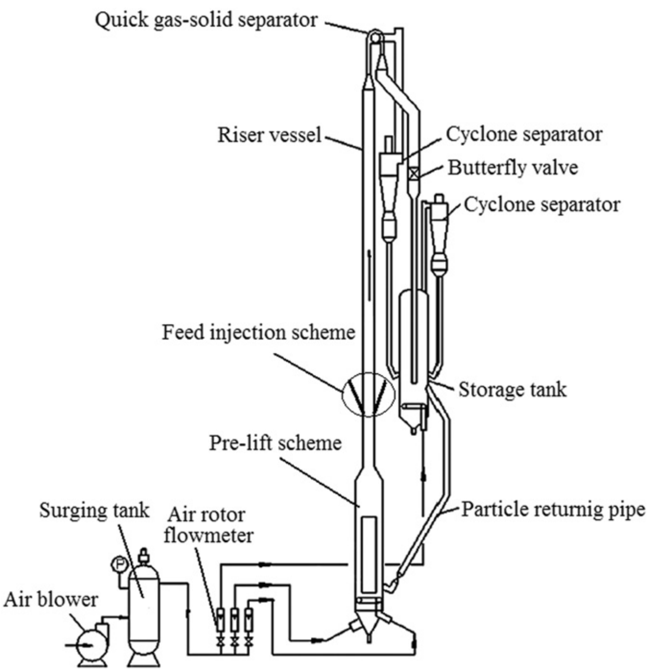

Fig. 1. Experimental setup.

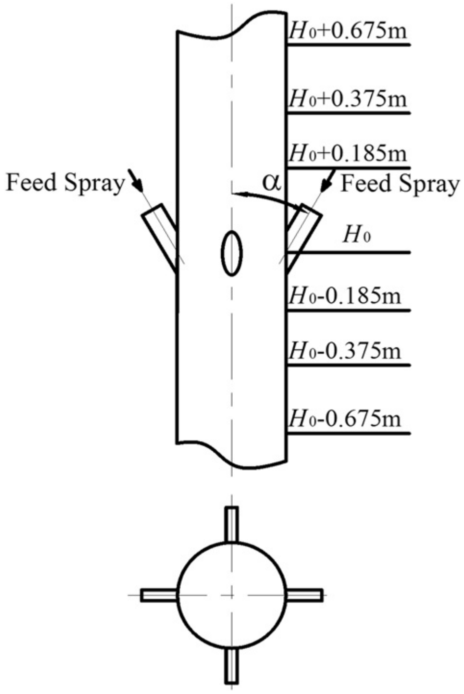

Fig. 2. The feed injection scheme.

2.3. Experimental methods

The axial profile of solids holdup $\overline{\varepsilon_p}$ was determined by measuring the pressure differences Δp along the riser axial.

The local solids holdup and particle velocity were simultaneously measured by a PV-6D Particle Velocity Analyzer [19,20] (produced by the Institute of Process Engineering, Chinese Academy of Science), which is similar to Fan's research [4]. When a beam of light irradiates a cluster of particles, part of the light is reflected while the other part is absorbed. The intensity of reflected light depends on the concentration of the particle cluster irradiated. Then the local solids holdup was obtained by analyzing the reflected light signal. The probe of the analyzer consists of two optical fiber sensors with a vertical distance of *l*. The delay time of particles passing through the tip of these two sensors was measured via the sampled signal. Therefore, the local particle velocity moving in front of the probe tip can be obtained by dividing the distance *l* by the delay time. By this way, the local solids holdup and particle velocity were obtained at the same time.

The solid flux was measured in the recirculation section by measuring the time (t) and the volume (V) of particles that accumulated in the storage tank. When the inner diameter (D) of the riser was known, the solid mass flux in the riser can be calculated by:

$$G_S = \rho_b V / \left(t \frac{\pi}{4} D^2 \right).$$

2.4. Operating conditions and measuring points

To cover the operating conditions in the industrial riser, the superficial velocity of the prelift gas ranged from 2.4 m/s to 4.1 m/s and the gas velocities at the exit of each nozzle ranged from 41.8 m/s to 78.5 m/s. The solid flux in the riser was controlled in a range from 64.2 to 98.5 kg/(m^2 s).

Please cite this article as: Z. Yan, et al., Distributions of solids holdup and particle velocity in the FCC riser with downward pointed feed injection scheme, Powder Technol. (2016), http://dx.doi.org/10.1016/j.powtec.2016.03.048