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Gas–solids flow patterns in a novel dual-loop FCC riser

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Abstract

A novel FCC process for maximizing iso-paraffins (MIP) has been developed by Research Institute of Petroleum Processing, SINOPEC. The MIP process is capable of reducing olefin content and increasing iso-paraffin content of gasoline to meet the new specification of gasoline of olefin content less than 35 vol.%. The MIP reactor is a combination of a conventional FCC riser (section I) and a dense circulating fluidized bed (section II), acting as two different reaction zones, respectively. This paper is devoted to improving the understanding of gas-solids flow patterns in the MIP riser. Experiments were conducted in a 10.2 m high two-stage riser with diameters of 45 mm in lower section and 90 mm in upper section. FCC catalysts were carried by atmospheric air in the experiments. The overall and local flow patterns were determined by using the axial pressure profiles measurements and radial local optic fiber probe measurements of particles velocity and voidage at different riser height. The measurements revealed that a much complex axial and radial profiles of voidage and particle velocity existed in the riser. Significant velocity fluctuations and a much lower voidage existed at the inlet of section II due to the influences of diffuser and particles feeding above the diffuser. The influences of gas velocity and additional particles feeding on the pressure drop and solids circulating rate were different in section I and in section II. In section II, these influences weakened with the height increased.

Keywords: CFB; Dual solids circulating loops; Pressure drop; Voidage; Particle velocity; FCC process

1. Introduction

Circulating fluidized beds have been used in a variety of industrial processes due to their distinct advantages of uniform temperature distribution, high gas-to-particle mass and heat transfer rates and flexible operation. For instance, the oil refining industry considers the circulating fluidized bed to be one of the most promising technologies, with high efficiency and high solids throughput. However, many disadvantages exist in the oil products produced by fluid catalytic cracking (FCC) riser, such as high olefin content, high sulfur content, etc. In China, over 80% of gasoline is produced by FCC riser, which contains over 40–65 vol.% of olefins. The new specification of gasoline requires that the content of olefin be less than 35 vol.%.

According to the reaction mechanism of catalytic cracking, a novel FCC process for maximizing iso-paraffins (MIP) was developed by Xu et al. [1–3], which consists of two reaction zones in one reactor. The catalytic cracking reaction is conducted in the first reaction zone located at the lower part of the riser, and the olefins formed in the first reaction zone are transformed to iso-paraffins and aromatics by alkene isomerization and hydrogen transfer reactions in the second reaction zone located at the upper part of the riser. In order to meet the favourable reaction conditions of high catalyst concentration in the second reaction zone, a novel FCC riser with a diffuser in the middle of the riser was designed, and additional FCC particles were fed into the riser above the diffuser. Two solids circulating loops exist in the novel riser and the relationship of the pressure drops between them is very important to process design. The axial and radial

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distributions of voidage, particle velocity and gas velocity in the novel riser are different from that in the conventional riser. For proper design and economic operation of the novel riser, studies on the pressure drop between different axial locations, the axial and radial profiles of voidage and particle velocity as a function of superficial gas velocity, solids circulating rate, etc., are very important. In this paper, experiments were conducted in a cold model constructed according to the principle of the MIP process. Relationships between the solids circulating rates and the pressure drop in two sections, the variations of local voidage and particle velocity with operation conditions were investigated.

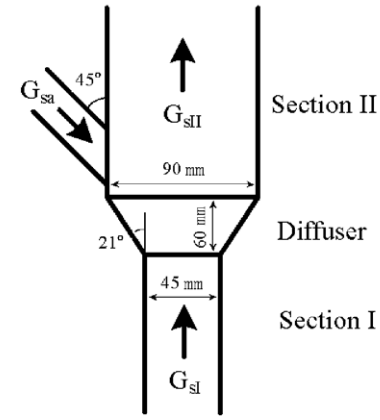

Fig. 2. Relationship between solids circulating rates.

2. Experimental

2.1. Apparatus

The experimental apparatus is shown in Fig. 1. The riser (A) is 10.2 m high and consists of three sections. Section I, the lower part, is 3.94 m in height with 45 mm ID; section II, the upper part, is 6.20 m in height with 90 mm ID; a diffuser, whose cross-section area increases with distance above its base, is located between section I and section II. The diffuser is of conical shape, its details shown in Fig. 2. The downcomer (B) is 10.5 m in height with 120 mm ID, at 5.25 m high of which exists an eccentric tube (C) of 2.0 m in height with 70 mm ID. Perforated-plate valves (D) covered by wire mesh are equipped, respectively, at 8.3 m high of downcomer and in top inclined standpipe for measuring solids circulating rates G_{sII} and G_{sa}. Twenty pressure taps are mounted around solids circulating loops to enable the pressure drop to be accurately determined. Four measuring holes for optical fiber probes are opened in the riser on elevations of 2.34, 4.30 , 5.63 and 7.77 m, respectively. The array of measuring points on each elevation is also shown in Fig. 1. Many of the measuring points are arranged near the wall because solids flux and particle velocity vary sharply with position near the wall.

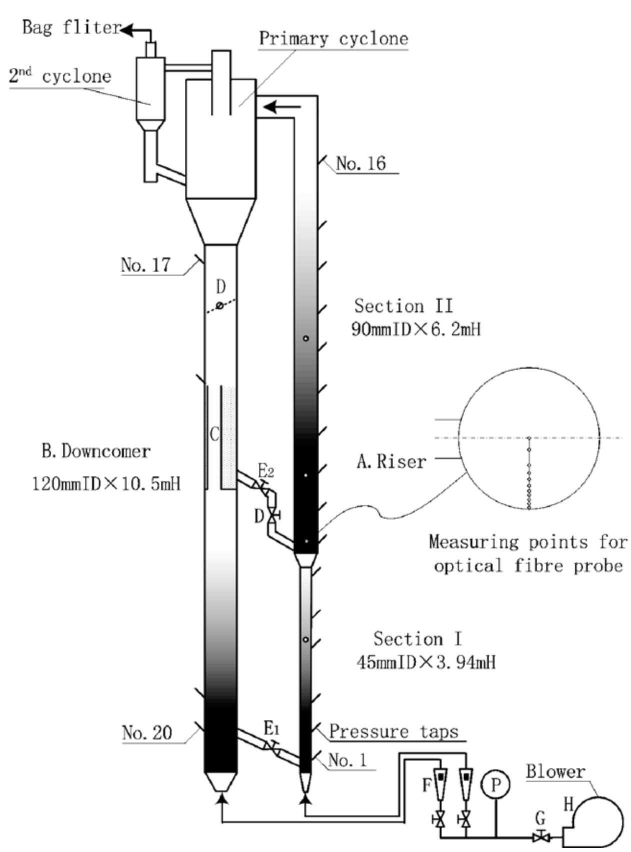

Fig. 1. Schematic diagram of experimental apparatus.

Air, provided by a blower (H) and its flow rate regulated by a control valve (G) and measured with a rotameter (F), entered riser through a perforated distributor. Particles were supplied to the riser from downcomer through two 45°-inclined standpipes, respectively, on elevations of 0.5 and 4.25 m of riser, in which two solid-rate control valves (E_1, E_2) were equipped to regulate the solids circulating rate (G_{sI}, G_{sa}). After leaving the downcomer, particles were transported to riser via the inclined standpipes and then up the riser by airflow. Particles carried over from the top of the riser were fed to the primary and secondary cyclones in which most of the particles were removed from the air stream and returned to the downcomer. The exhausted air exited the apparatus through a bag filter.

Fluid catalytic cracking (FCC) catalysts used in this study has a mean diameter of 82 μm and a particle density of 1450 kg/m^3. The size distribution of FCC catalysts is shown in Fig. 3, measured by using the Coulter-LS230 laser granularity analyzer.

2.2. Measurement

Manometers, connected to pressure taps by plastic tubes, were used to measure pressure drops of the system.