Experimental Study on Flow Behavior of Polyethylene Particles in a Rotating Fluidized Bed Reactor

Patsorn Saikam, Pattaraporn Posoknistakul and Pornchai Bumroongsri *

Department of Chemical Engineering, Faculty of Engineering, Mahidol University, Thailand.
*Corresponding author, e-mail: pornchai.bum@mahidol.ac.th

Abstract

Conventional fluidized bed reactor has some advantages including high heat and mass transfer compared to the fixed bed reactor. However, it also has some limitations in practical operation. If the monomer feed rate is too high, the particles will be entrained out of the reactor. Rotating fluidized bed reactor is a new reactor design that is developed to overcome some limitations of the conventional fluidized bed reactor. In this study, the flow behaviors of low density polyethylene particles in the rotating fluidized bed reactor and conventional fluidized bed reactor are experimentally studied by varying the air flow rate. The flow behaviors are recorded using a high-speed camera. The pressure drop and particle loss are measured. At high air flow rate of 0.5 m^3/s, the dense and uniform bed of particles is observed in the rotating fluidized bed reactor while most of the particles are entrained out of the conventional fluidized bed reactor.

***Keywords**: rotating fluidized bed reactor, pressure drop, particle loss, flow behaviors*

1. Introduction

Polymerization is a heterogeneous process. The monomer in the gas phase is reacted with the catalyst particles to form the products. Therefore, an increase in interfacial surface area results in increased heat and mass transfer rate. Conventional fluidized bed reactors provide an excellent way of high contact between gas and solid. Therefore, it is an effective chemical unit for the production of materials and chemicals (Kunii and Levenspiel,1991). The catalyst particles are allowed to act like fluid by flowing gas through the reactor. The basic configurations of the conventional fluidized bed reactor include 4 main parts which are the gas inlet, gas outlet, gas distributor and fluidized bed chamber. The gas is passed upward into the chamber through the particle bed. The flow of gas causes the pressure drop across the bed. When the drag force is sufficient to support the weight of the bed, the particles start to float and behave as a fluid (at minimum fluidization). The product from the process is usually in the gas phase and carried out of the reactor through the gas outlet at a sufficiently high fluid flow rate (Grace,1999).

The conventional fluidized bed has higher heat and mass transfer rate compared to the fixed bed. However, it also has some limitations in practical operation. If the monomer feed rate is too high, the catalyst particles will be entrained out of the reactor by the drag and buoyancy forces. The rotating fluidized bed (RFB) reactor is a new reactor design that is developed to overcome some limitations of the conventional fluidized bed reactor. The monomer is fed in the tangential inlet direction that creates the centrifugal force. The catalyst particles are rotated against the wall of the fluidization chamber by the effect of the centrifugal force so they are retained in the reactor chamber despite high monomer feed rate.

The rotating fluidized bed reactor has many advantages such as high heat and mass transfer rate and temperature homogeneity compared to the conventional fluidized bed reactors (Qian, 1999). In order to induce the rotating motion of the particles in the fluidization chamber static geometry, the fluidization gas is injected tangentially via multiple gas inlet slots at the inner cylindrical wall of the fluidization chamber. The solid particles in the fluidization chamber rotate from the effect of tangential gas-solid force and the particles were fluidized in radial direction by the effect of centrifugal force. The particles tend to from a rotating particle bed against the wall of the reactor chamber. The fluidization gas leaves the reactor chamber via a centrally positioned chimney (Trujillo et al., 2012; Ekatpure et al., 2011).

There are two major types of non-uniform distribution for the fluidization gas and particles in the fluidization chamber which are channeling and slugging. For channeling, the gas and particles rotate preferentially at different longitudinal positions in the fluidization chamber. In case of slugging, the particles accumulate in one or multiples slugs which rotate in the fluidization chamber. Channeling and slugging, the particles have poor gas-particle contact. For high contact area and good gas- particle mixing for heterogeneous, the slugging and channeling should be avoided (Dutta et al., 2010; Wilde and Broqueville, 2008). In this study, the flow behaviors of the Geldart's group D particles in the rotating fluidized bed reactor and conventional fluidized bed reactor are experimentally studied by varying the air flow rate. The flow behavior, pressure drops and particles loss are considered. The novelty is that the flow behaviors of the particles in the rotating fluidized bed reactor and conventional fluidized bed reactor are compared and the optimal air flow rate is experimentally determined.

2. Objectives

1. To study the flow behaviors of the Geldart's group D particles for fluidization in the rotating fluidized bed reactor and the conventional fluidized bed reactor.

2. To compare the particle behaviors in the rotating fluidized bed reactor and the conventional fluidized bed reactor such as flow pattern, pressure drop and particle loss.

3. Materials and Methods

3.1 Experiments in a conventional fluidized bed reactor.

The schematic diagram of the experimental apparatus in the conventional fluidized bed reactor is shown in Figure 1. The experimental setup consists of a compressor for supplying air, the distributor, the reactor chamber, the cyclone, the solids recuperator, the computer, and the high speed digital camera.

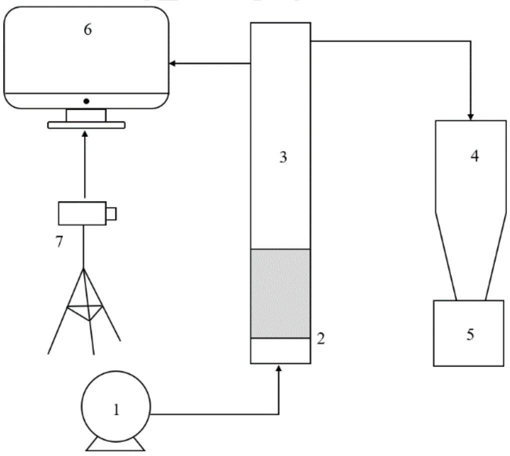


Figure 1 Schematic diagram of experimental setup in conventional fluidized bed reactor: (1) Compressor (2) Distributor (3) Reactor chamber (4) Cyclone (5) Solids recuperator (6) Computer (7) High speed digital camera

The main body of the conventional fluidized bed reactor as shown in Figure 2 consists of 4 main parts including the top part, the acrylic column, the bottom part and the stainless distributor plate.

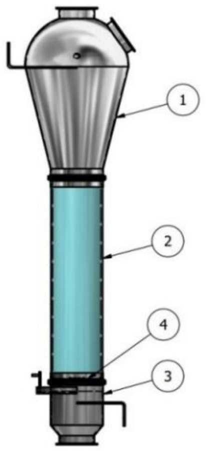


Figure 2 Conventional fluidized bed reactor: (1) Top part (2) Acrylic column (3) Bottom part (4) Distributor plate

The geometrical specifications of the conventional fluidized bed reactor are listed in Table 1.

Table 1 Geometrical specifications of conventional fluidized bed reactor

Number	Geometrical variable	Value	Unit
1	Top part diameter	30	cm
	Height	35	cm
2	Acrylic column diameter	15	cm
	Acrylic column height	60	cm
3	Bottom part diameter	15	cm
	Bottom part height	18	cm
4	Diameter	14	cm

The experiments are performed in the batch mode of operation. The operating conditions are listed in Table 2. The particles flow behavior is observed by a high-speed video camera. The recording frame rate at 120 frames per second with global shutter is used. Furthermore, the pressure drop is measured at different positions.

Table 2 Experimental Conditions in the conventional fluidized bed reactor

Operating parameter	Value	Unit
Air flow rate	0.025-0.5	m^3/s
Solid material	Low density polyethylene	-
Bed temperature	298	K
Particle density	821.43	kg/m^3
Particle diameter	2.089	mm
Mass of solid particles	1	kg

3.2 Experiments in rotating fluidized bed reactor

The schematic diagram of the experimental setup with all components in the rotating fluidized bed reactor is shown in Figure 3.

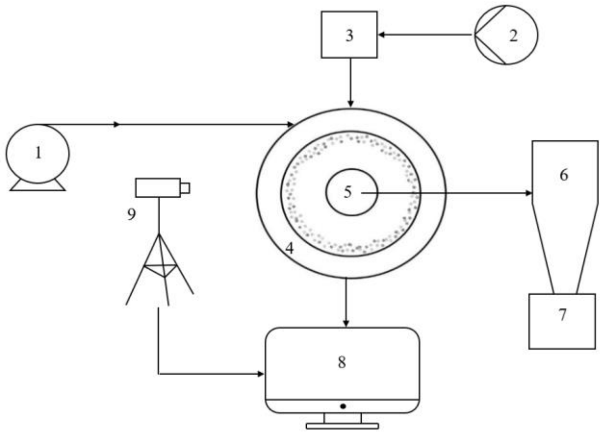


Figure 3 Schematic diagram of the experimental setup in the rotating fluidized bed reactor: (1) Compressor (2) Blower (3) Solid feed container (4) Reactor chamber (5) Chimney (6) Cyclone (7) Solids recuperator (8) Computer (9) High speed digital camera

The experimental setup consists of the compressor, the blower, the solid feed container, the reactor chamber, the chimney, the cyclone, the solid recuperator, the computer and the high speed digital camera. The main body of the rotating fluidized bed reactor, as shown in Figure 4 consists of two concentric cylinders that are the air inlet jacket and the inner cylindrical reactor body with the central gas outlet.

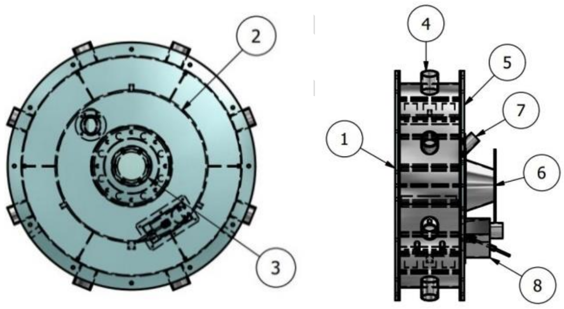


Figure 4 Rotating fluidized bed reactor: (1) Acrylic Front Plate (2) Chamber (3) Chimney (4) Jacket (5) Acrylic Back Plate (6) Air Outlet (7) Feed inlet (8) Particle Outlet

Table 3 lists the geometrical specifications of the rotating fluidized bed reactor. The air from the reactor jacket is allowed to enter the inner cylindrical reactor chamber through 16 tangential slots equally spaced over the entire periphery of the reactor. The plane end walls in front and back of the reactor are made of clear acrylic allowing the visual observation of the two-phase flow. The particles flow behavior is observed by a high-speed video camera. The recording frame rate at 120 frames per second with a global shutter is used. Furthermore, the pressure drop is measured at different positions.

Table 3 Geometrical specifications of rotating fluidized bed reactor

Number	Geometrical variable	Value	Unit
1	Acrylic front plate diameter	73	cm
2	Chamber diameter	45	cm
	Number of slot	16	-
3	Chimney diameter	12	cm
4	Jacket diameter	65	cm
	No. of air inlet	8	-
	Diameter of air inlet	3.81	cm
5	Acrylic back plate diameter	73	cm

Number	Geometrical variable	Value	Unit
6	Air outlet diameter	10.16	cm
7	Feed inlet diameter	3.81	cm
8	Particle outlet diameter	3.81	cm

The experiments are performed in a batch operation. The operating conditions are listed in Table 4. Initially, only gas continuously enters the main reactor body through the jacket inlets and exits through the chimney located at the central position of the reactor chamber in order to obtain a steady rotating gas flow. The gas removed from the fluidization chamber via chimney is sent to the cyclone. The cyclone is connected to the downstream of the gas outlet. The solid particles in the gas stream are separated from the gas in the cyclone. The clean gas is released into the atmosphere. Next, the particles are fed to the rotating fluidized bed reactor resulting in an annular rotating bed of solid particles.

Table 4 Experimental conditions in the rotating fluidized bed reactor

Operating parameter	Value	Unit
Air flow rate	0.025-0.5	m^3/s
Solid material	Low density polyethylene	-
Bed temperature	298	K
Particle density	821.43	kg/m^3
Particle size diameter	2.089	mm
Mass of solid particles	1	kg

4. Results and Discussion

4.1 Effect of air flow rate in a conventional fluidized bed reactor

Figure 5 showed the effect of air flow rate on the flow pattern of particles recorded using the high speed camera. The reactor was divided into 10 sections. As the gas flow rate increased, higher value of bed height is obtained. At the gas flow rate higher than 0.3 m^3/s, almost all particles were entrained out of the reactor.

Figure 6 showed the effect of air flow rate on the pressure drop and particle loss. At the air flow rate of 0.06 m^3/s, the pressure drop was almost constant and no particle loss was observed. However, the particle loss increased as the air flow rate was increased beyond 0.06 m^3/s. The minimum fluidization velocity is 0.41 m/s corresponding to the air flow rate 0.02 m^3/s

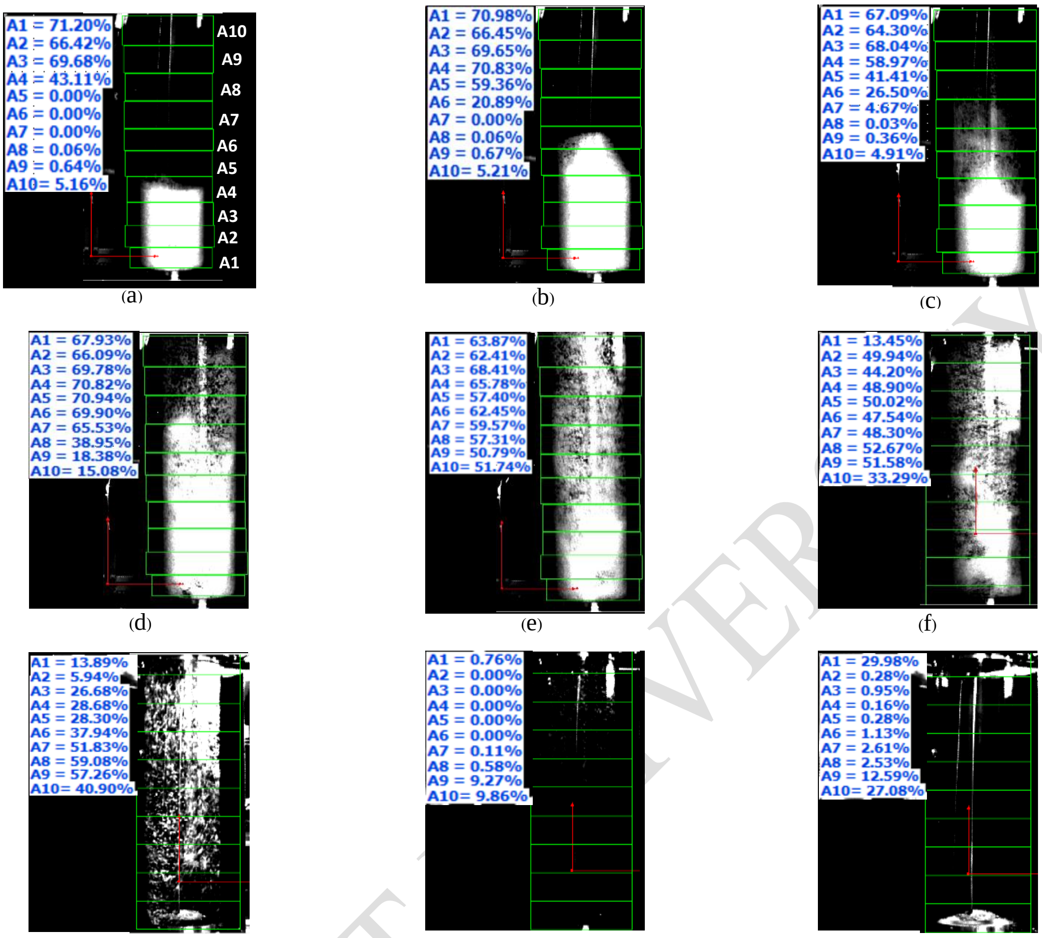
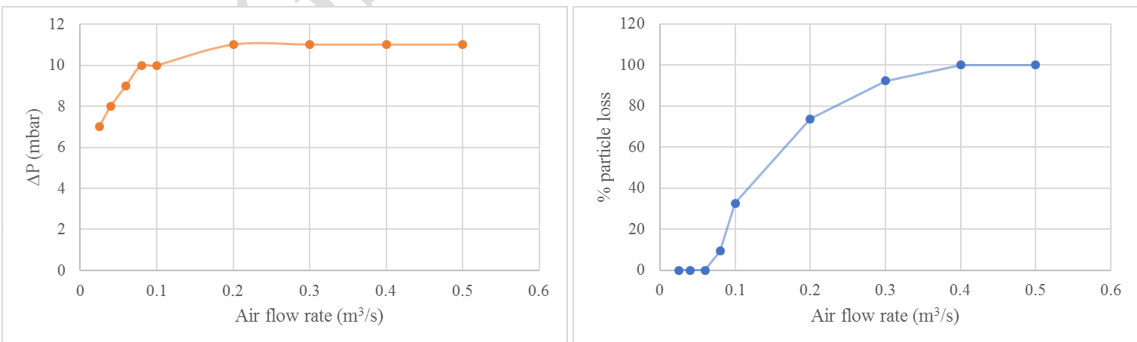


Figure 5 Flow behaviors of particles at different air flow rates (m^3/s): (a) 0.025 (b) 0.04 (c) 0.06 (d) 0.08 (e) 0.1 (f) 0.2 (g) 0.3 (h) 0.4 (i) 0.5



*ΔP = Pressure drop across the reactor

(a) (b)

Figure 6 Effect of air flow rate on (a) pressure drop (b) particle loss for the conventional fluidized bed reactor

4.2 Effect of air flow rate in rotating fluidized bed reactor

Figure 7 showed the effect of air flow rate on the flow pattern of particles. It was observed from the high speed camera that the distribution of particles along the wall was better as the air flow rate increased. At a low air flow rate, the particles accumulated in one of the slugs in the fluidization chamber. These phenomena disappeared at a sufficiently high air flow rate. At the air flow rate of 0.5 m^3/s, the dense and uniform bed of particles was observed.

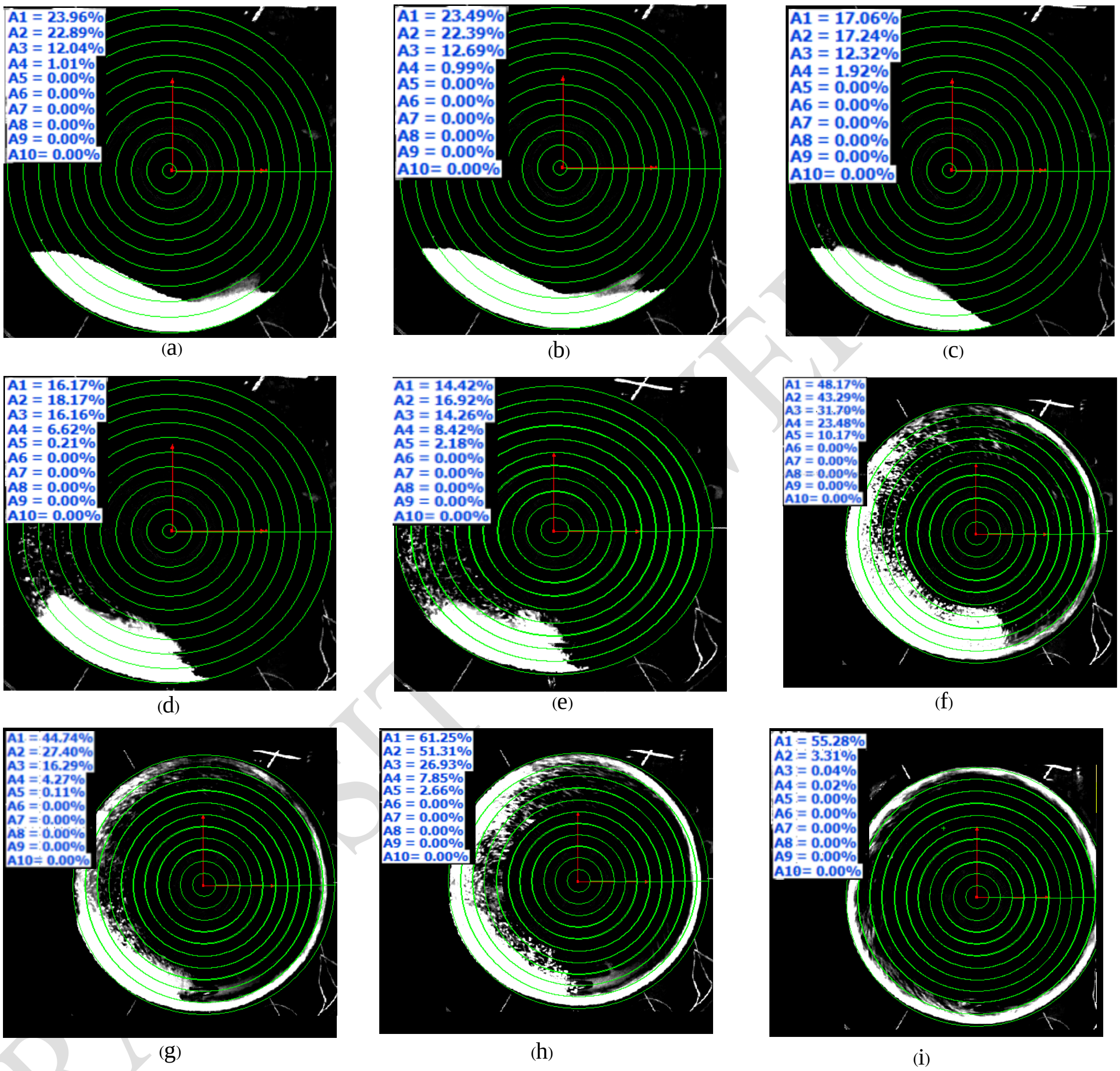
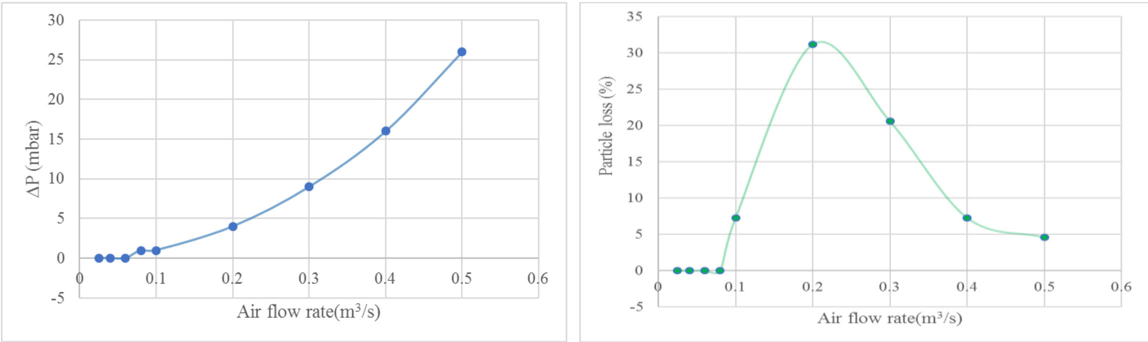


Figure 7 Flow behaviors of particles at different air flow rates (m3/s): (a) 0.025 (b) 0.04 (c) 0.06 (d) 0.08 (e) 0.1 (f) 0.2 (g) 0.3 (h) 0.4 (i) 0.5

The pressure drop and particle loss were shown in Figure 8. The pressure drop increased as the air flow rate increased. The particle loss was highest at the air flow rate of 0.2 m^3/s due to non-uniform particle distribution. As the air flow rate was further increased, the particle loss was reduced. Small amount of particle loss was observed at the air flow rate of 0.5 m^3/s.



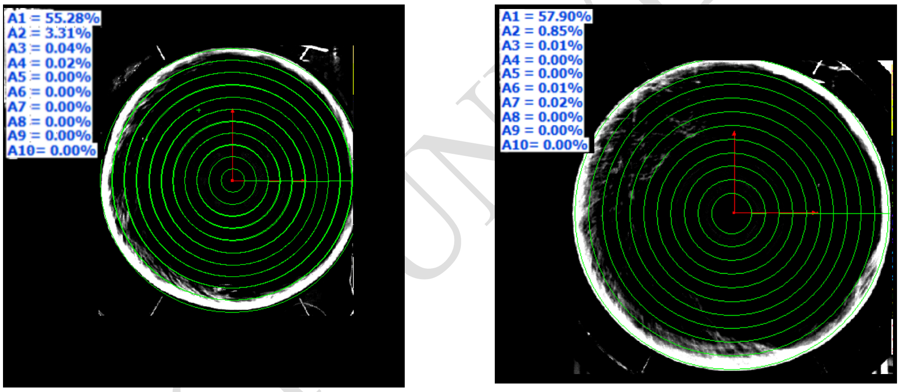
*ΔP = Pressure drop across the reactor

(a) (b)

Figure 8 Effect of air flow rate on (a) pressure drop (b) particle loss for the rotating fluidized bed reactor

4.3 Effect of chamber diameter

Figure 9 showed the effect of the chamber diameter on the flow pattern of particles. As the chamber diameter is bigger, the fall-out of particles can be observed due to lower effect of the centrifugal force.



(a) (b)

Figure 9 Flow behaviors of particles at different chamber diameters (m): (a) 0.45 (b) 0.54 at the same air flow rate 0.5 m^3/s

5. Conclusion

In this work, the flow behaviors of low density polyethylene in the rotating fluidized bed reactor and conventional fluidized bed reactor were experimentally studied. The pressure drop and particles loss were measured and recorded. As the air flow increased, the rotating fluidized bed reactor gave less amounts of particle loss than the conventional fluidized bed reactor. In the design of the fluidized bed reactor, higher gas flow rate resulted in a larger heat and mass transfer between the gas and solid phases.

6. Acknowledgements

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