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Experimental Investigation of Minimum Fluidization Velocity in Three Phase Inverse Fluidized Bed System

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ABSTRACT

Minimum fluidization velocity is one of the most important parameters when characterizing the hydrodynamics of a fluidized bed. Experiment studies on the effects of bed height and material density on the minimum fluidization velocity for inverse fluidization beds. Were carried out using a 10 cm diameter cylinder fluidized bed. Two types of particles were tested polyethylene (PE) and polypropylene (PP) bead, each with a density of 966.6, 877.3, 896.4, or 846.2 kg/m^3, respectively, Results show that minimum fluidization velocity for tow tested materials was insensitive to bed height and increased with increasing the material density. The minimum fluidization velocity was correlated with dimensionless groups and independent parameters with correlation coefficient is 0.9389.

Keywords: Three Phase, Fluidization beds, Minimum Fluidization velocity and Bed High.

دراسة تاثير ادنى سرعة للسوائل في الطبقة المتميعة للانظمة المتعددة الاطوار

الخلاصة

الحد الأدنى لسرعة الطبقة المتميعة هي أهم المعالم التي تميز عند الدراسة الهيدروناميكا للطبقة المتميعة. الدراسات تجربة على آثار ارتفاع كثافة المواد المدروسة وعلى سرعة تسييل الحد الأدنى للطبقة المتميعة عكسية. نفذت باستخدام ١٠ سم قطر اسطوانة. وكان تم اختبار نوعين من الجزيئات البولي إثيلين (PE) والبولي بروبلين (PP) ، ولكل منها كثافة ٩٦٦،٦، ٨٧٧،٣، ٨٩٦،٤، ٨٤٦،٢

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kg/m3 وعلى التوالي، وتبين النتائج أن سرعة تسييل الحد الأدنى لسحب المواد اختبار الحساسية ارتفعت بزيادة مع زيادة كثافة المواد. وايجاد موديل للسرعة الطبقة المتميعة بالاعتماد على النتائج العملية وبنسبة خطأ ٠،٠٩٣٨٩.

NOMENCLATURE

D_h	Holes diameter in distributor	m
g	Gravitational acceleration	m/s^2
H_o	Height of fixed bed	m
Re	Reynolds number, $U_{sg}d_p\rho_L/\mu_L$	-
U_{sg}	Superficial gas velocity	m/s
U_l	Minimum fluidization velocity	m/s
U_{lmf}	Minimum fluidization velocity	m/s
We	Weber number, $\rho_L dp U_{sg}^2/\sigma_L$	-
	Greek Symbols	
μ_{eff}	Effective viscosity of continuous	mPa.s
ρ_g	Gas density	Kg/m^3
ρ_l	Liquid density	Kg/m^3
ρ_s , ρ_p	Particle density	Kg/m^3
σ	Liquid surface tension	N/m
ΔP	Pressure drop	Pa

INTRODUCTION

Fluidization is a technique through which fine solid particles behaves like a fluid through contact with liquid or gas or both. Under the fluidized state, gravitational pull force on solid particles is offset by the fluid drag force. In fluidized condition particles remain in a semi-suspended condition.

The term 'fluidization' is usually associated with two or three phase systems, in which solid particles are fluidized by a liquid or gas stream flowing in the direction opposite to that of gravity. In these classical fluidized bed systems, the solid particles have a higher density than the fluid. Fluidization where the liquid is a continuous phase is commonly conducted with an upward flow of the liquid in liquid-solid systems or with an upward co-current flow of the gas and the liquid in gas-liquid-solid systems. Under these fluidization conditions, a bed of particles with a density higher than that of the liquid is fluidized with an upward flow of the liquid counter to the net gravitational Force of the particles.

Fluidized bed hydrodynamic behavior is very complex and must be understood to improve fluidized bed operations. One of the most important parameters to characterize fluidized bed conditions is the minimum fluidization velocity (U_{mf}) (Ramos et al.2002).

When the density of the particles is smaller than that of the liquid and the liquid is the continuous phase, Fluidization can be achieved by down flow of liquid, it called Inverse Fluidization. Considering a bed of solid particles floating on a fluid surface, when a liquid or a gas is passed at a very low velocity down through the bed of particles, the particles start to move and there is a pressure drop. Increasing the fluid velocity steadily, the pressure drop and the drag on the individual particles increases and eventually the particles move more vigorously and get suspended in the fluid. The particles float or sink depending on their density relative to the fluid/suspension. If the density of solid particles and continuous liquid phase is almost same then fluidization is only achieved by counter-current flow of gas and this type of fluidization is called solid-liquid-gas inverse fluidized bed.

If we only take into consideration the processes where the liquid is the continuous phase, two configurations are possible. The first case generally involves particles with a density higher than that of the liquid. It is known as mode E-I-a in Fan's (1989) classification. This kind of a reactor is widely used at the industrial scale, and well described in the literature (Wild et al.,1984; Muroyama and Fan, 1985). In the second case, solid particles may have a density lower than the liquid: this kind of reactor is commonly named inverse three-phase fluidized bed (referred as mode E-II-a by Fan), or inverse three-phase turbulent bed where the fluidization is only ensured by the gas flow (Comte et al., 1997).

The influence of bed height on minimum fluidization velocity has been studied using different types of fluidized beds. Zhong et al. (2006) completed minimum fluidization experiments in spouted fluidized beds. In a spouted fluidized bed, the bed chamber is tapered like a funnel, which creates different hydrodynamics, and the fluidization air is typical injected through a single orifice.

EXPERIMENTAL FACILITY

A schematic diagram of the experiment setup is shown in fig.(1).The column is transparent and made up of acrylic material with an outer diameter 10 cm and the wall thickness of 2mm. Height of column is 1.25m, with an inlet at the top and an outlet at the bottom. The flow of the fluid (water and solutions of carboxymethyl cellulose (CMC)) through this opening was controlled by use of valves. Water pumped through rotameters by 0.5HP motor pump to the top of the column.

Six pressure taps were mounted flush with the wall of the column at 0.125-m height intervals from the liquid distributor. Bed porosity was determined from the knowledge of pressure drop, bed height, and properties of liquid and solid. The extended bed height was taken as the point at which a change in the slope of the pressure drop plot was observed.

Throughout this study, aqueous solutions of carboxy methyl cellulose (CMC), whose apparent viscosity was varied from 1.0 to 38.0 3 1023 Pa s, was used as the continuous liquid phase; compressed filtered air as the gas phase; and either polyethylene (PE) or polypropylene (PP) bead, each with a density of 966.6, 877.3, 896.4 and 846.2 kg/m3, respectively, as the solid phase.

The apparent viscosity of liquid phase was determined with a Brookfield Synchrolectric Rotational Viscometer.

The properties of solid materials (PE) and (PP) and liquid phase with fluid flow rate range are summarized in Tables (1 and 2), respectively.

RESULTS AND DISCUSSION

The minimum fluidization velocity does not depend on the initial bed height.Umf depends upon the density of particles, for higher density particles Umf will be low than the lower density particles. As the particle density decreases, the upward buoyancy force increases and a higher downward force (that is liquid flow rate) is required to reach the condition of onset of fluidization.

Bed expansion characteristics in liquid-solid fluidization are an important parameter which helps in the design and scale-up of fluidized bed.The bed expands only if the flow rate is above the minimum fluidization velocity.The bed with larger initial bed height expands faster than the less initial bed height.It is observed from the figures (2, 3, 4, and 5) that the bed height remains unaffected (fixed) up to a certain liquid flow rates and there-after varies linearly with flow rates. Flow by existed showed literature that bed height variation depend on solid densities. This is due to the fact that at a low flow rate the force due to the downward flow of liquids is less than the net buoyancy force of the particles acting in the opposite direction. Hence the particles remain as a packed bed attached to the bottom distributor plate. With further increase in flow rate, a condition (net upward force just equals to net downward force) is reached where the lowest layer of the particles just starts to get detached from the bed. The velocity corresponding to this flow rate is termed as minimum fluidization velocity and the condition is referred as on-set of fluidization. With further increase in flow rate, more and more particles get detached from the packed bed, bed height increases linearly as the downward force due to the liquid overcomes the upward buoyancy forces due to the low density particles.The observed trend is similar to that of classical fluidization.

EMPIRICAL CORRELATION OF GAS HOLDUP

Dimensional analysis is used to correlate diameter of holes in the distributor , superficial gas velocity , superficial liquid velocity , height of bed , diameter of particle , density of particle and physical properties gas phase and liquid phase which affect the gas hold-up in three-phase fluidized beds.

U_{mf} is assumed to be a function of the Following parameters.

$$U_{mf} = f\ (U_g, U_l, \rho_g, \rho_l, g, \Delta\rho\ (\rho_s-\rho_l), \Delta p,\ \mu_{eff},\ dp,\ D_h, Ho,\ \rho_p,\ \sigma,\ Cw) \qquad \ldots(1)$$

Applying Buckingham's π theorem for
dimensional analysis, the following correlation is obtained.

$$U_{mf} = \frac{5.6*10^{-4}\ Re^{1.05} We^{-0.25} dp^{2.01} [(\rho_s - \rho_g)g]^{1.02}}{\rho_g^{0.1} \mu^{0.88}} \qquad \ldots(2)$$

A comparison between the observed and predicted results of minimum fluidization velocity is shown in Figure (6).

The bed remains fixed until the minimum fluidization velocity is reached. At the minimum fluidization velocity the lower particles just starts to move, the movement is like waves, particles goes up and comes down, net movement is zero.

As the further increase in flow rate the movements of particles increases, the lower particles moves downward the vacant space is filled by upper particles and so on, in doing so particles leaves their position and they interact with neighbour particles, this phenomena leads to mass transfer and also heat transfer.On further increasing in flow rates, particles start rotational motion with wavy motion. This phenomena leads to turbulence and the better mixing. The minimum fluidization velocity doesn't depend on the bed height.

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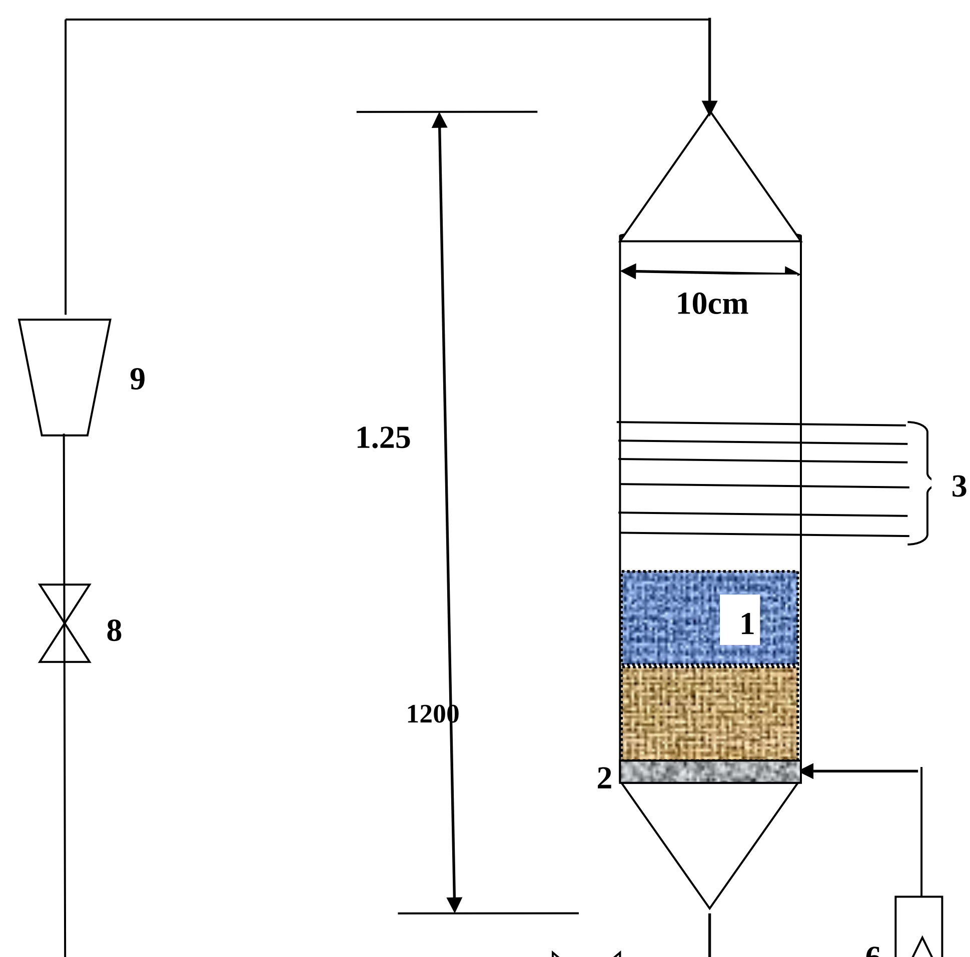
Particle	**Average Diameter**	**Density (Kg/m^3)**
polyethylene	4 mm ID	877.3
polypropylene	4 mm ID	966.6

Table (1) The Properties of Solid materials Used in This Study.

	μ_l*10^3(Pa.s)	σ_l*10^3(N.s)	$\rho_l(Kg/m^3)$	U_G*10^2(m/s)	U_l*10^2(m/s)
Pure water	0.96	72.9	1000	0.2-0.8	1-6
Aqueous solution of CMC	11	73.2	1001	0.2-0.8	1-6

Table (2) Liquid Physical Properties and Fluids Flow Rate Range.

0.1 wt %					
Aqueous solution of CMC 0.2 wt %	24	73.3	1002	0.2-0.8	1-6
Aqueous solution of CMC 0.3 wt %	38	73.6	1003	0.2-0.8	1-6



1-Solid materials. 2-Gas distributer, 3-Preesure tap, 4-Liquid tank, 5-Liquid pump 6-Gas rotameter, 7-Air Compressor, 8-Control valve, 9-Liquid flow meter.

Figure (1) Schematic diagram of the Experimental Setup

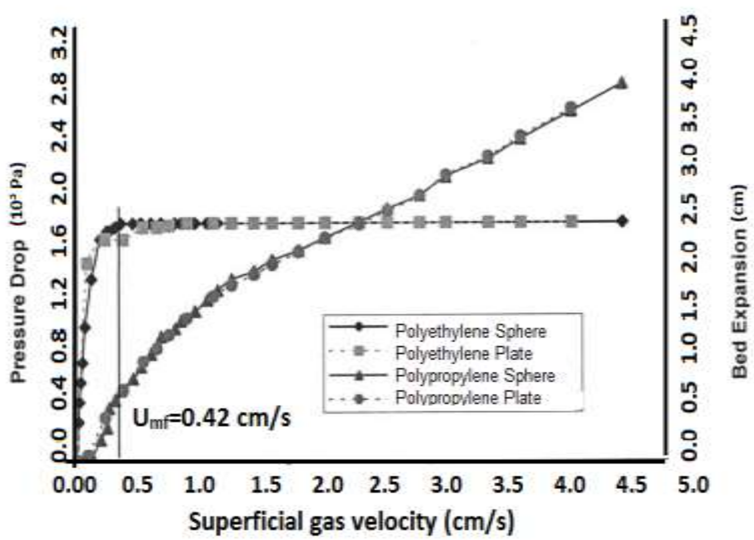


Figure (2) Effect of Superficial velocity on Bed expansion and Pressure drop for purewater at U_{mf}=0.42cm/s.

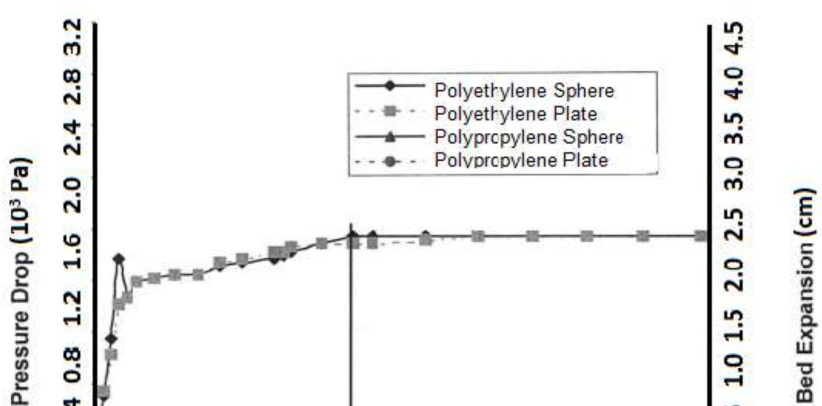


Figure (3) Effect of Superficial velocity on Bed expansion and Pressure drop for CMC 0.1 % at U_{mf}=0.415cm/s

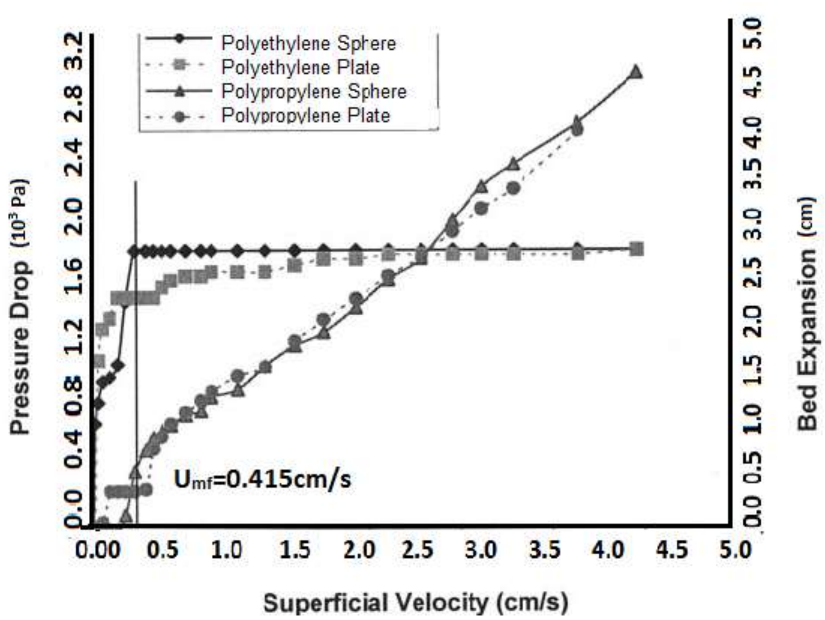


Figure (4) Effect of Superficial velocity on Bed expansion and Pressure drop for CMC 0.2 % at U_{mf}=3.2cm/s.

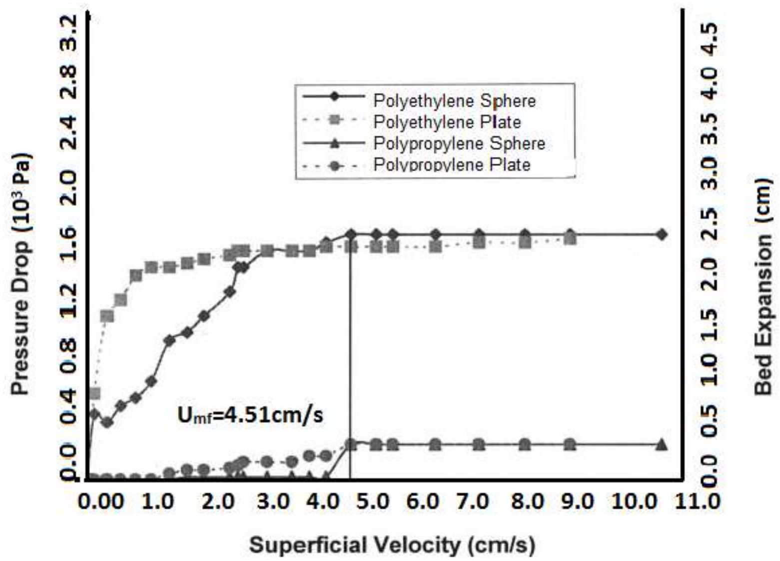


Figure (5) Effect of Superficial velocity on Bed expansion.and Pressure drop for CMC 0.3 % at U_{mf}=4.51cm/s.

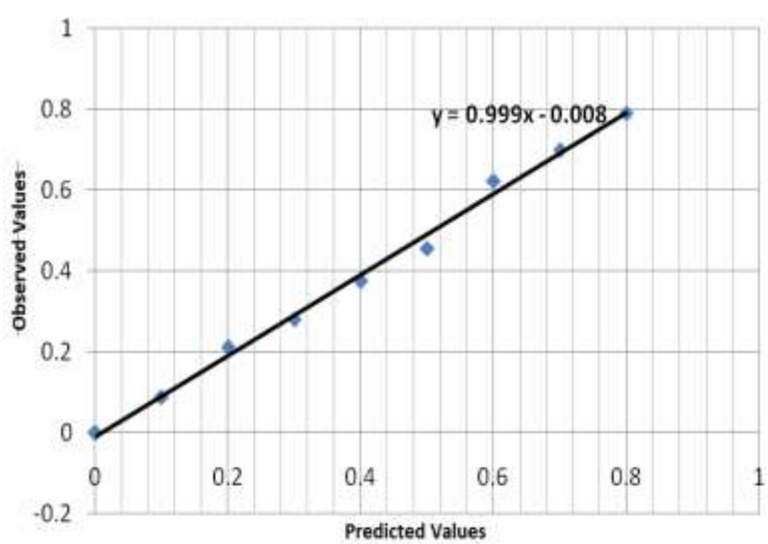


Figure (6) Comparison between the observed and predicted values of minimum fluidization velocity.