Advanced Powder Technology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Advanced Powder Technology

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

Original Research Paper

Hydrodynamics of a multi-stage counter-current fluidized bed reactor with down-comer for amine impregnated activated carbon particle system

Dipa Das [a], Debi Prasad Samal [a], Nafeez Mohammad [a], B.C. Meikap [a,b,*]

[a] Department of Chemical Engineering, Indian Institute of Technology (IIT) Kharagpur, West Bengal 721302, India
[b] Department of Chemical Engineering, School of Engineering, Howard College, University of Kwazulu-Natal, Durban, South Africa

ARTICLE INFO

Article history:
Received 5 August 2016
Received in revised form 13 November 2016
Accepted 10 December 2016
Available online xxxx

Keywords:
Hydrodynamic
Fluidization
Down comer
Activated carbon
Pressure drop
Amine impregnation

ABSTRACT

In the present investigation, the hydrodynamic study on the four-staged fluidized bed reactor with solid and gas flowing in the counter-current direction has been carried out. The gas phase was air, and the solid phase was amine impregnated activated carbon. By changing the operating condition like weir height, solid flow rate, gas velocity and particle size, pressure drops were determined at the steady and stable operation of the column without loading and flooding. At the low velocity of gas (0.188 m/s) with maximum solid flow rate (4.12 kg/h) and maximum weir height (70 mm), the maximum pressure drop occurred in the column was 220 N/m^2. The minimum pressure drop occurred in the column was 92.2 N/m^2 at high velocity of gas (0.353 m/s), with minimum flow rate of solids (2.15 kg/h) and low weir height of 30 mm. The maximum pressure drop occurred for lowest particle size (467 μm) at gas velocity (0.309 m/s) was 169.1 N/m^2 at 50 mm weir height and the minimum pressure drop occurred at the same condition for highest size particle size (635 μm) was 124.8 N/m^2 at the same weir height.

1. Introduction

Now a day's lots of greenhouse gases are emitted into the atmosphere. Carbon dioxide (CO_2) is the major component of greenhouse gases (GHGs) in the atmosphere that causes global warming. 60% of the global warming is caused by CO_2 [1]. The emissions of the total anthropogenic greenhouse gas are from large emission sources which are stationary like power plants, refineries, gas processing industries, iron and steel industries, chemical, petrochemical industries, and cement industries. There are four different methods for CO_2 capture from flue gas like absorption, adsorption, cryogenic distillation and membrane separation. Among these methods, adsorption is one of the most important methods for CO_2 capture [2,3]. Fluidized bed is a useful technique for gas-solid contact in chemical industries. Fluidized bed reactors are broadly used in chemical process industries for different operations like, reforming of hydrocarbons, coal carbonization, coking, ore roasting, aluminum production, coating preparation cracking of high molecular weight petroleum fraction, gasification, combustion of coal, drying, gas adsorption, etc. The major advantages of fluidized beds are uniform temperature throughout the bed; the surface area of the bed is high and the high level of internal mixing of particulate phase and the fluid phase. In case of single stage fluidized bed there is non uniform residence time distribution of solid, so low contact efficiency between gas and solid phase. Non uniform residence time of solid leads to non-uniformity of the product and efficiency of conversion is less. So to overcome such drawback associated with single stage fluidized bed, some modifications have been made inside the fluidized bed reactor, i.e., section the bed vertically [4–6] known as multistage fluidized bed. The provision of internal baffles and the staging of a fluidization column with the perforated plate decreases the axial mixing of the phases and restrict the formation of growth of bubbles. The flow approaches plug flow [5–7]. There are many advantages in multistage fluidized bed reactor like operation can be controlled on a large scale, high heat and mass transfer rate, narrow residence time distribution, temperature of reaction is low and sufficient reaction time [6,7]. The solid product is more uniform due to multiple contacts. Gas requirement is less. Thermal efficiency and conversion efficiency for both gas and solid phase is high. Effect of gas bypassing reduces. The addition of perforated plate helps in

---

* Corresponding author at: Department of Chemical Engineering, School of Engineering, Howard College, University of Kwazulu-Natal, Durban, South Africa. Fax: +91 3222 282250.

E-mail address: bcmeikap@che.iitkgp.ernet.in (B.C. Meikap).

http://dx.doi.org/10.1016/j.apt.2016.12.011

Please cite this article in press as: D. Das et al., Hydrodynamics of a multi-stage counter-current fluidized bed reactor with down-comer for amine impregnated activated carbon particle system, Advanced Powder Technology (2017), http://dx.doi.org/10.1016/j.apt.2016.12.011

eliminate slug, break bubbles and agglomerate. So separation efficiency is more and the size of the equipment reduces. Therefore multistage fluidized bed reactor is the good option for flue gas treatment industry. Development of baffles system helps for the staging of fluidized bed, with some provision for separate passage for gas and solid flow [8,9]. Multistage fluidized bed reactor may be divided into two types (i) those with down comer; and (ii) those without down comer. In both cases the vessel is divided into a few stages, solid fed from the above and fluidizing gas is introduced into the reactor from the bottom part of the column. Material undergoes fluidization at each stage. The functions of down comers are the transfer of the solids from an upper bed to lower fluidized bed [9]. Solid particles are coming from upper stage to a lower stage through the down comer. The solid hold up is more in multistage fluidized bed than the single stage system.

In our present analysis, a four staged counter current gas-solid fluidized bed reactor has been developed, designed, to study the hydrodynamic characteristic. The adsorbents used for this study is amine impregnated activated carbon because it is very efficient adsorbent for CO_2 capture [10–12]. For air pollution control, this type reactor is the most suitable equipment. A properly designed down-comer guarantees the flow of solids between the stages without dragging them or clogging the tubes. A good flow of solids has been observed when the pressure drop of the down comer approaches the pressure drop of the gas when going through the upper stage [13,14]. In this way, the gas is homogeneously distributed in every stage between the surface of the distributor and the down comer. The hydrodynamic study includes the effect of the flow rate of the gas phase, solid phase, particle size, shape and density, perforated plate geometry on pressure drop [14,15]. The CO_2 capture using a fluidized bed reactor is a very recent concept. Due to recent research efforts, numerous methods and equipment have been proposed for capturing CO_2. The multistage fluidized bed reactor with a down comer has recently gained importance for recovery of gaseous pollutants as an air pollution control system in industry [16,17]. So multistage fluidized bed reactor with down comer is the most suitable air pollution control equipment for the removal of gaseous pollutants from the industrial flue gas.

2. Experimental

2.1. Material preparation and its characterization

The material used for this investigation was amine impregnated activated carbon prepared from green coconut shell purchased from the nearby local market, Kharagpur (India). It is a most commonly naturally occurring which is quite cheaper as compared to other forms of raw materials and contains high carbon content and low ash content. The activated carbon prepared from this is subjected to impregnation with amine solution [11,12]. A representative sample of 2 kg was selected for the hydrodynamic study.

Properties of solids and fluids are the two most important factors that have to be determined before starting the experiment. Air density and viscosity are the two most important fluid properties during the fluidization of solids and it depends on the temperature and pressure which can be found from the literature. On the other hand density of the solid (ρ_p), particle size (d_p), porosity (ε) and sphericity (Φ_s) are the main properties of solid that are affecting fluidization. Particle size can be determined by standard sieve analysis (B.S. Seive). Particle size ranges were kept as (300–700 μm). The diameter of the particle is determined by the average diameter of the sieve through which the particle passes through and the diameter of the sieve through which the particle retained is taken as the diameter of the particle. Density of the particle was determined by water displacement method. Porosity is defined as the fraction of total volume which is void and it can be represented as

$$\varepsilon \equiv \frac{\text{Volume of the bed}}{\text{Volume of the entire bed}} \equiv \frac{\text{Volume of the bed-Volume of the particle}}{\text{Volume of the entire bed}} \equiv \frac{\pi R^2 h - \frac{\text{Weight of all particles}}{\text{Particle density}}}{\pi R^2 h}$$

where R is inside radius of the column and h is the height of the solid bed.

Sphericity (Φ_s) is determined by pressure drop equation. The pressure drop was determined by Ergun's fixed bed equation written in the following form.

$$\frac{\Delta P}{H_{mf}} = \frac{150(1-\varepsilon_{mf})\mu_g u_{mf}}{\Phi_s^2 \varepsilon_{mf}^2 d_p^2} \tag{1}$$

Physical properties of the amine impregnated activated carbons are shown in Table 1, and the pore structure parameters are shown in Table 2.

3. Experimental set-up and procedure

Four-staged fluidized bed reactor was developed and used in this study and the schematic diagram, and the pictorial view is shown in Figs. 1 and 2. The fluidized bed column is consisted of four stages (0.21 m height per stage and 0.095 m internal diameter). Stages were assembled with a flanged joint. Four stainless steel made plate (S_1, S_2, S_3, S_4) of 0.002 m thick were present in between the two stages and used as internal baffles. Each hole of diameter 0.002 m in a triangular pitch arrangement was there on the plate. To avoid solids falling through the plate, grid plates were covered with fine weir mesh (100 mesh size) with openings smaller than particle size. Down comers (D_1, D_2, D_3, D_4) were made up of Perspex cylinder of 0.024 m internal diameter and height of 0.265 m. Each section was provided with down-comers, and it was further fitted with a cone of diameter 0.007 m and 0.024 m height at the exit end so that up-flow of the gas through the down-comer was reduced as a result of which stable operation was maintained. On the gas distributor, the down-comers were further fitted by special threading arrangement. There was a provision for adjustment of weir height as required. The weir height was considered to be bed height. The material flows from stage to stage through the down-comer. There were provisions for measuring pressure drop. For uniform distribution of the gas to the fluidization column, the gas distributor was there at the bottom of the column. Schematic diagram down comer, sieve plate and weir mesh were shown in Fig. 3. Calibrated rotameter was fitted to measure the air flow rate. A conical hopper was attached at the bottom of the column for storage of the solid. A feeding funnel was there at the top of the column to hold the activated carbon particle, and it was fitted to the screw feeder. Screw feeder was fitted to a motor of 0.25 HP and the speed of the motor was guarded by a variable rheostat. The compressor was used to supply the air as fluidizing gas having capacity 5HP. The solids were fed to the first stage of the down-comer from the top of the funnel connected to screw feeder and then through Perspex tube (0.011 m internal diameter). The gas leaving the top stage is passed through 0.14 m diameter

Table 1
Physical characteristics of amine impregnated activated carbon.

Property	Value
Particle size (μm)	300–700
Particle density (kg/m^3)	2810
Porosity (ε_{mf})	0.62
Sphericity (ϕ_s)	0.75

Please cite this article in press as: D. Das et al., Hydrodynamics of a multi-stage counter-current fluidized bed reactor with down-comer for amine impregnated activated carbon particle system, Advanced Powder Technology (2017), http://dx.doi.org/10.1016/j.apt.2016.12.011