REST Journal on Emerging trends in Modelling and Manufacturing
Vol:3(1),2017
REST Publisher
ISSN: 2455-4537

Website: www.restpublisher.com/journals/jemm

Parameters affecting the Fluidized bed performance: A review

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Abstract

Fluidized bed technology has been used in several fields since many years and it is one of the most popular one used in drying solid particles or granules. Fluidised bed drying is the most extensively used method for drying particles or granules majorly in pharmaceutical and food industries. The paper consists of detailed study of fluidised bed technology which includes classification of fluidized bed, fluidized bed combustion and heat transfer in the same. Out of several applications of fluidised bed technology – mentioned further - more emphasis is given on the fluidized bed dryer since it is one of the most beneficial and efficient of the dryers used in the industries due to the phenomenon of direct contact between the fluid and the particles. The controlling parameters regarding the same are mentioned and elaborated precisely. Our study depicts that the fluid-toparticle type of heat transfer has been accentuated by the researchers while on the other hand, wall-to-fluid type of heat transfer has been least focused on. It has been found that the parameters like temperature and humidity affect the evaporation rate of the moisture from the particles and the velocity as well as the flow rate of air account for heat and mass transfer.
Keywords: heat transfer; combustion; fluidized bed.

I. Introduction

A fluidized bed technology is the one where direct contact between the particles and the gas is achieved thereby the making drying process efficient. Therefore, it is extensively used in the chemical industries, pharmaceutical industries, mineral processing industries and thermal power generation for drying, granulation, blending, combustion and gasification processes. The main purpose of using a fluidized bed is to enhance the rate of drying. [1] It consists of multiple phases such as solid particles, moisture in solid particles, air and moisture in air. The fluidized bed technology comprises of combustion of the solid particles in a sluggish material bed like sand. These particles are fluidized due to the flow of a gas. In this flow, there are number of variables to be taken into account due to the gas–solid interaction and chemical reaction, characterizing a complicated process. In thermochemical conversion processes, various chemical reactions and heat and mass transfer between gas and solids has great significance because it affects the efficiency and reduces the drying time of the process making the process exceptional. [2] Therefore, a hydro-dynamic study of the fluidized bed is imperative to improve the process by determining the dispersal of the phases and the kinds involved. In a gas solid inter phase model in a fluidized bed, generally a two-phase model which consists of one dense phase and a dilute phase. Due to reduction of thermal effects and bubbles passing through emulsion, solid motions occur. The high turbulence generated in the bed is responsible for high heat and mass transfer, as well as adequate mixing of the solids and gases within the bed. [3] This serves as a primary advantage of the fluidised bed dryer. One of the disadvantages in fluidised bed dryer is that since the solid particles are at temperature equivalent to the temperature of the gas it needs to be cooled to the temperature useful for further processing of particles. Fluidization largely depends on the characteristics of the particles. [4] Fluidisation will be smooth, easy and homogenous for small size particles (30-150μm) and low density (less than 1.4g/cm^3). It can be operated with low gas flows and also the growth and speed of the bubbles can be regulated. For medium particle size (40–500μm) having density between 1.4 and 4 g/cm3, the bubbles tend to grow a lot at the commencement of fluidization; nevertheless, it is good for high gas flow rates. Fluidisation for dense and large particles (greater than 500μm), is difficult and non-uniform. But with decrease in particle size, the size of the bubbles decreases. The principle of working of fluidised bed dryer says that when a gas is passed through a layer of particles on a grid in an upward direction, the gas will - at low flow rates - simply percolate through the fixed bed of particles. Increase in gas velocity, results in increase in the pressure-drop across the particle layer until it corresponds to the weight of the particles per area of the bed. [5]

II. Classification of Beds

Formation of fluidised bed takes place when a number of solid particles comes in contact with the pressurized gas due to which it starts behaving like a fluid. A fluidised bed simply consists of a mixture of fluid and solid. Fluidised beds are used for reactors, combustion (boilers) and many other industrial applications.

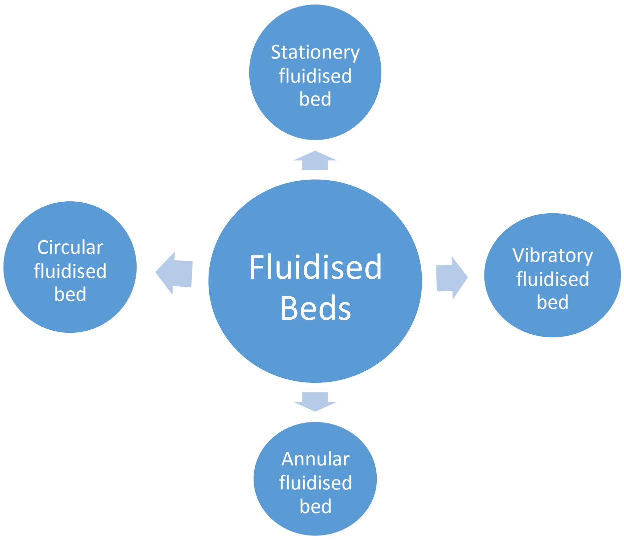

Figure 1: Types of Beds

Bed types can be coarsely classified by their flow behaviour, including: - **Stationary fluidized beds.**

It is also known as Bubbling fluidised bed. In this type of beds, low velocity gases are used. Fluidization of the solids is comparatively stationary, with some fine particles being carried along. Bubbles in fluidised beds have two basic properties. In general, their size increases at predetermined velocity, and grow further in size because of static pressure or coalescence.

Circulating fluidized beds.

In circulating fluidized beds, high velocity gases suspend the particle bed, due to fluid high kinetic energy. As such the surface of the bed is less smooth and larger particles can be carried away from the bed than for stationary beds. Recirculation of entrained particles occurs through an external loop into the reactor bed. Circulating fluidized beds are implemented in many different fields like oil and gas power stations. This technology has a number of benefits and hence it is used in various engineering fields. Some of the common applications of circulating fluidized bed are circulating Fluidized Bed Scrubber and Circulating Fluidized Bed Gasification System. The function of fluidized bed scrubber at power stations is to utilize calcium hydroxide to decrease the amount of pollutants like, hydrochloric acid (HCL), SO_2 and SO_3 from a flue gas stream. In Fluidised Bed Gasification, the bio waste is converted into synthetic gas without combustion.

Vibratory fluidized beds.

When mechanical vibrations are added in the process of stationary bed, then the bed is known as Vibratory Fluidized Bed. The purpose of adding the vibration is to excite the particles in order to increase entrainment. Hence we can say that it is nothing but an improvement over stationary fluidised bed with a vertical gas flow on the conveyor belt. The main benefit of this type of fluidised bed is that, since the feed will move along the vibrating conveyor, they would get dried up adequately by getting in contact with the gas which will in turn cause low amount of agglomerates in the feed. Agglomerates form when particles contain high amount of moisture and are dried up. [6] The advantages of introducing mechanical vibration are: increased heat and mass transfer coefficients, reduction in agglomerates, improvement in solid circulation, decrease of pressure drops and channelling through the beds. [7] **Annular fluidized beds (AFB).**

Annular Fluidized Bed (AFB) presents high velocity gas from the bottom of the large central nozzle and additional fluidized gas through an annular nozzle ring. This ensures that the mixture of gas and solid in the bottom part of the dense mixing chamber flows up in the riser. The cyclone in the riser separates both gas and solids according to the fixed velocities. This gas then percolates via a bag filter whereas the solids move downward at the bottom repeating the process again. When the gas reaches a certain velocity by the central nozzle, bubble starts forming, moving in upward direction. Further increase in velocity results in increase in bubble size and bubble velocity.

III. Fluidised Bed Combustion: -

Fluidized bed combustion (FBC) is a technology that is very well established today for power or heat generation or a combination of both. The principle of the Fluidised Bed Combustion technology involves heating of a fluidized bed of solid particles by start-up burners with oil or gas until a certain temperature (around 600ºC) has been reached and then additional fuel is introduced for ignition to commence. After ignition, the firing is shut down. This combustion of the fuel is maintained at temperature of around 850ºC. These type of system contains cooling surfaces within the furnace walls which helps us to control the heat-balance of the bed and hence maintain the temperature of combustion constant. Sometimes boilers are designed without the cooling surfaces in the furnace; instead the furnace walls are refractory lined. In this case, most of the heat is extracted in down-stream of the surface in the back-pass. Due to the large size of these boilers, their surface to volume ratio is very less; hence not sufficient to cool the bed. For such large boilers their wall surfaces for cooling are accompanied with heat exchangers (either internal or external). Internal heat exchangers are generally in vertical form which completely extend along the furnace vertical walls. One of the important advantages of the fluidized bed combustion technology is that it offers fuel flexibility which is a need in today's world. This means a number of fuels can be burned within a same unit. Pulverised coal fired boilers (PC) are major competent of fluidized bed. In addition, the FBC technology is utilised in large power generation boilers as a co-firing unit.

IV. Controlling Parameters

Fluidized bed drying, as mentioned before, is a technology that involves elimination of moisture by fluidization of the particles. This process involves different parameters regarding the gas flow as well as the constructional parameters to be controlled. They are position of heaters, air velocity, air flow rate, humidity and temperature.

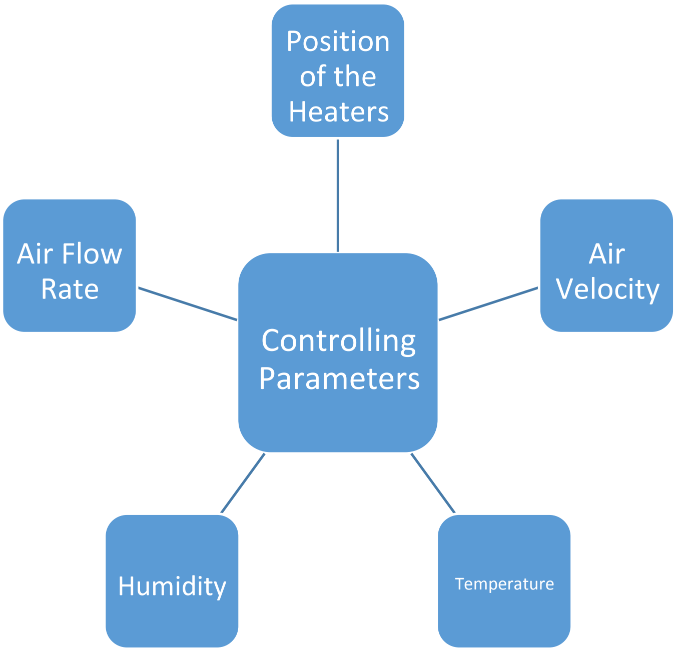

Figure 2: factors affecting fluidized bed performance

Position of the Heaters

The heater's position should be appropriate so as to obtain desired flow of air at desired temperature. If the heaters are placed very close to the blower outlet, then the desired temperature would not be achieved.

Air Velocity

The discharge of air through the blower should be optimum. The moisture content of the particles rapidly reduces at higher air velocity. [8] Also, at the high air velocity, the particles are easily fluidized and as a result, the mass and heat transfer in the bed can be easily carried. Increase in air velocity may also lead to increase in bubble size in the bed. Air velocity also concerns with mass and heat transfer in the fluidized bed. Velocity of the gas dominates the performance of the fluidised bed dryer than the temperature. [9] **Temperature**

The inlet air temperature is inversely proportional to the drying time. [10] The drying rate depends on the resident temperature of the solids in the bed. [11] In the drying process, air temperature also has an impact on moisture diffusion. At higher temperature, the particles absorb more heat for water evaporation than at lower temperature and hence increasing the evaporation rate. **Humidity**

Humidity of the air has inverse effects on the drying just like temperature. It should be as low as possible for faster drying rate. Also, moisture in the inlet air has intense effects on the rate of evaporation and temperature profile. [12] Moisture can be reduced from the particles by keeping the diameter of the particles less due to the fact that larger size particles contain long diffusional paths which causes internal resistance to induce against mass transfer. [13]

Air Flow Rate

Air flow rate must be meticulously controlled for efficient fluidization to occur. Generally, air flow rate must be optimized to achieve an efficient drying process. If it is too fast, then the gas would not be heated to optimum level whereas if it is too slow fluidization would not occur.

V. Heat Transfer

The phenomena of heat and mass transfer in fluidized bed is associated with the contact between the phases involved. Heat transfer takes place due to conduction and convection depending upon the phases between which the same occurs. [14] To illustrate the heat and mass transfer in the gas and particle phases, a Kunii-Levenspiel three-phase model is employed. [15] This model represents the three phases namely solids phase, interstitial gas phase and a dilute phase. [16] The contact between the phases should be higher to increase the heat and mass transfer coefficients for better performance of the reactor. The solid particles have a tendency to resist mass transfer more than that of heat transfer. This means that the heat of convection is not utilized to evaporate water but instead to increase the temperature of the solid. [17] This leads to higher coefficient of moisture transfer inside the solid particle and higher partial vapour pressure at the solid-gas interphase. This ultimately leads to higher drying rates. Heat transfer can happen in two ways. The first occurs between gas and solid particles, the usual way, like in many other processes and in the second way, heat transfer takes place between the bed phases i.e. bubbles, clouds and emulsion which occurs in fluidized bed system only. Bubbles in fluidized beds act just like liquid bubbles with low viscosity. The gas fluid bed is characterised by having good transfer properties between the fluidised layer and the heating surfaces. This heat transfer is important parameter design in fluid bed and estimation of the same is necessary. The three main aspects that are connected with fluidized bed heat transfer:

- Wall to fluid transfer
- Particle to fluid transfer
- Fluid to particle transfer [18]

Heat transfer between fluids to particle

The heat transfer between fluid and particle occur at very high rates as compared to others since the gas is in direct contact with the particles. It occurs due to both conduction and convection phenomenon. In this type of heat transfer, the surface temperature of the particle can be evaluated from the known temperature of the fluid. Evaluation of particle surface temperature is significant because it affects the kinetics of the reaction and large variations take place in the rate of reaction due to small changes in temperature. The temperature of particle surface directly affects the kinetics reaction and little changes in temperature often due to large variations in reaction rate [19]. It is desired to know real particle temperature when working with heat delicate materials. A high air humidity and a low solid flow rate assures a better physical quality of particles.

Heat transfer between particles to fluid

This study becomes necessary, especially for the conventional design of catalytic reactors. The heat transfer from solid particles to the fluid largely depends on the flow around the individual particles. The interaction between the particles play a significant role in determining the heat transfer, especially the frequency and the striking velocity. Particle to fluid heat transfer occurs due to particle convection.

Heat transfer between walls to fluid

The main resistance to heat transfer occurs at the wall of the heated column, in the thin layer of fluid and all of the radial temperature drop between wall and fluid occurs in an appreciable amount. The heat transfer coefficient is maximum in this case and is subjected to increase with an increase in mass velocity of the fluid. With further increase in mass flow the heat transfer coefficient reaches maximum followed by gradual decrease in the same. Particles with high specific heat and high particle size tend to affect the rate of heat transfer between the walls and the fluid. [20]

VI. Conclusion

In a fluidized bed dryer, earlier mentioned parameters have major effects on the factors that influence the performance. Factors like evaporation rate, heat and mass transfer coefficients largely depend on these parameters which in turn affects the efficiency of the dryer. Higher temperature assures high evaporation rate and high drying time. At high velocity, mass and heat transfer can be easily carried. Different types of fluidized beds are used as per the application in the industries. Due to the presence of high moisture content of particles, the evaporation rate decreases. Therefore, higher temperature, lower relative humidity, and higher fluidization velocity are favourable for drying. Fluidized bed combustion offers high fuel flexibility which means any fuel can be used in the same unit. Hence, the cost can be reduced by using low-grade solid fuels. This system is advantageous because it has high combustion efficiency. This is due to a fact that heat transfers and chemical reactions in the system takes place more rapidly than other combustion processes. Thus, it has a high combustion efficiency. Heat transfer in fluidised beds occur due to conduction and convection. It largely depends upon the contact between the phases, air flow around individual particles, velocity of the air and specific heat and size of the particles. High heat transfer rates are desired for better efficiency of the system.

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