"A Comprehensive Review on the Advantages and Applications of Fluidized Bed Dryer: From Lab scale to Industrial scale"

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Abstract

This article also discusses the demonstration of a fluidized bed dryer, its principles, application, and other processing. This has led to the development of technology, processes, and equipment that not only reduce time but also increase output. A fluidized bed dryer significantly reduces drying time compared with a vacuum dryer or tray dryer. In the pharmaceutical industry, fluidized bed dryers are typically used for pellet drying, coating, and granulation. Fluidized bed drying is very well known to yield high heat and mass transfer and is hence adopted in many industrial drying processes, particularly pharmacy products. In this paper, we show the construction and working of the fluidized bed dryer. It works on the drying principle. It has several advantages and disadvantages.

Keywords:- *Fluidized; Drying; Particles; Temperature; Pharmaceutical; Methods .*

Introduction

Fluidized bed dryers (FBD) have been widely used for drying various products due to its many advantages, including high drying rates due to excellent gas-solid contact, high thermal efficiency, relatively low cost of operation, etc. [1]. In fluidized bed drying, hot air is forced through a distributor into the bed at a sufficiently high velocity to overcome the gravitational forces on the products. When the air velocity is greater than the gravitational force and the bed resistance, the products will suspend. This condition is called fluidization, which is a physical process that transforms solid particles into a fluidized state through suspension in a liquid or gas [2, 3]. The particles are fluidized in bed when the drag force created by the gas flow through the bed is equal to the weight of the particles [4]. When fluidization occurs, the solid particles have many of the properties of a liquid. One noticeable property is that the fluidized particles seek to level and assume the shape of the containing vessel. Large, heavy objects sink when added to the bed, and light particles float [5].A fluid bed dryer is a kind of equipment used extensively in the pharmaceutical industry to reduce the moisture content of raw ingredients like powder and granules. The working principle of this equipment includes fluidization of the fed materials. In this process, hot air at a high temperature and pressure is introduced into the system through a perforated bed of moist solid particulate. The solids are lifted from the bottom, are slightly wet, and are suspended in a stream of air (fluidized state). Heat transfer occurs as soon as there is direct contact between the wet solid and hot gases. The dry gas takes away the vaporised liquid. The gas exiting is partially recycled, sometimes.The purpose or hypothesis of the study is to dry the various products. [6]

Model

Fluidized bed dryer Memmrt
Type, Cap. 1kgSize: 14×14×14
Cap. 45 Ltrs ABC
Make No. of
Trays: 2

Comparative chart of model (Table no.1)

Features	Model	Applications	Size	Lab/Company Scale
Stainless Steel Construction Perforated Bowl Turbulent Motion and Uniform Drying High Drying Rate	Fluidized bed dryer (Memmrt Type)	Drying of granules in productionof tablets. Coating of granules. Used for three operations such as mixing, granulation and drying.	14×14×14	Both

Historical Background

The first commercial fluidized bed dryer was installed in the USA in 1948 to dry dolomite or blast furnace slag, reducing emissions and environmental impact. Since then, hundreds of these dryers have been installed worldwide, and the process has been applied to other materials due to their granular properties.

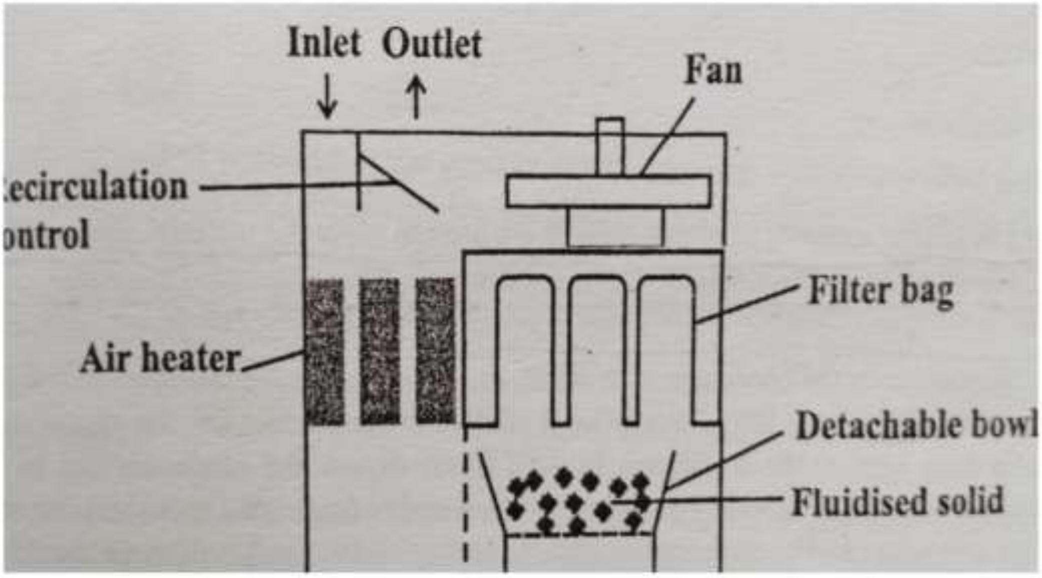
In 1922, Fritz Winkler made the first industrial application of fluidization in a reactor for a coal gasification process. [7] In 1942, the first circulating fluid bed was built for catalytic cracking of mineral oils, with fluidization technology applied to metallurgical processing (roasting arsenopyrite) in the late 1940s. [8, 9] During this time, theoretical and experimental research improved the design of the fluidized bed. In the 1960s, VAW-Lippewerk in Lünen, Germany, implemented the first industrialbed for the combustion of coal and later for the calcination of aluminium hydroxide.

Principle

Fluid bed dryers work on the principle of fluidization, a process where a material is converted from a static solid-like state to a dynamic fluid-like state. In this process, hot gas or air is introduced through a perforated distribution plate into the area holding the material. This hot gas pumps through the spaces between solid particles. As the velocity of the gas or air increases, the upward forces on the particles increase, causing them to equal the gravitational forces below. This creates a state of fluidization where the particles are suspended in what appears to be a boiling bed of liquid. What once moved in a solid way can now flow like water. Each particle is in direct contact with, and surrounded by, the hot gas or air– creating an efficient and uniform drying process.[10]

In this process, hot air is introduced at high pressure through a perforated bed of damp solid particulate. However, the solid particles are blown-up and remain suspended in the air channel, If air is allowed to flow through a bed of solid material in the upward direction with a velocity higher than the settling rate of the patches. Heat transfer is achieved by direct contact between the wet solid and hot gases. The use of hot air to fluidize the bed increases the drying rate.[11]

Instrumentation



Instrumentation on Fluidize Bed Dryer (Fig.1)

1. Air inlet
2. Air outlet
3. Fan
4. Filter bag
5. Detachable bowl
6. Fluidised solid
7. Air heater
8. Recirculation control [12]

Construction

The fluidized Bed reactor was constructed from a 3 inch diameter, 5ft high 304 stainless steel pipe.304 stainless steel was chosen because it is inexpensive and would suit the application.

The melting point of the steel is 1450 °C, which is significantly higher than the design and operating temperature of the reactor. The 304 stainless steel has good resistance to oxidation for intermittent use, up to 870 °C and up to 925 °C . It is important to keep the operating temperature below this upper temperature limit to keep the integrity of the steel intact. The importance of this upper temperature limit is also there to prevent the formation of ash from occurring, which can cause fluidization and operational problems.

The reactor is externally heated with three different sets of ceramic heaters, capable of reaching the target operating temperature for fluidized bed combustion and gasification. These three sets of heaters divide the reactor into three distinct heating zones, which will be discussed further in the controls section. The reactor contains 2.7 kg of sand which acts as the fluidizing medium for all the experiments. This corresponds to a bed height 30.5 cm of sand. All of the experiments were carried out at this bed height. This amount of sand was based off of preliminary calculations using the coal feeding port as an initial reference point. . For the distributor plate, a 304 stainless steel perforated plate, with staggered holes was used.[13]

- There is a removable bowl on the side of the stainless steel fluidized bed dryer, and the pressure chamber is made of stainless steel.

- Air handling units, product vessels, exhaust filters, exhaust blowers, control panels, air distribution plates, spray nozzles, and solution delivery apparatuses are typical fluidized bed dryercomponents.
- Fluidization is stable and even when the proper distributor is used during the drying process.
- A suitable pressure drop across the distributor is necessary to ensure proper fluidization.[14]

Working

A fluidized bed dryer works by passing Hot air with high pressure through a perforated bed of moist solid particles. The hot air passes at a velocity greater than the settling velocity of the particles resulting, particles starting to suspend in the air. As the moist particle suspends in hot air, the moisture content of solid particles reduces to achieve the desired loss on drying (LOD). The drying vapors carry the vaporized liquid away from the moist solid particles. In some cases, the leaving gas is recycled to conserve energy.[15] the process involves placing wet granules in a detachable bowl and placing them in a dryer. The air is heated through a heat exchanger and fan, causing the granules to remain partially suspended in the gas stream. The high-velocity gas causes the granules to rise and fall back in a fluidized state, allowing the gas to completely dry them. The material is left in the dryer for 40 minutes before being discharged.

Two types of bed dryers are available

1. Vertical fluid bed dryer
2. Horizontal fluid bed dryer [16]

Optimizing Parameters[17] (Table no. 2)

Processing parameters	**Process 1**	**Process 2**
Material Conveyance Air velocity Shaker duration Shaker frequency	3000 cfm None None	2800-3000 cfm 10 seconds 1 minute
Drying Air velocity	3000-3300 cfm	0-10 minutes: 2800 cfm 10-20 minutes: 2400cfm 20-30 minutes: 1800cfm 30-46 minutes: 1400cfm

Shaker duration Shaker frequency Drying time	30 seconds 3 minutes 19 minutes	30 seconds 3 minutes 46 minutes

Controlling Parameters

Fluidized bed drying eliminates moisture by fluidizing particles, requiring control of gas flow,heater position, air velocity, flow rate, humidity, and temperature.[18]

Position of the Heaters: Heaters position should be appropriate for desired air flow and temperature, as close proximity can hinder temperature.

Air velocity: Air velocity is crucial for optimal discharge, as moisture content reduces at higher speeds.[19] High air velocity facilitates particle fluidization, mass and heat transfer in the bed, and may increase bubble size. Gas velocity dominates fluidized bed dryer performance, surpassing temperature.[20]

Temperature: The inlet air temperature is inversely proportional to the drying time.[21] Drying rate depends on bed temperature of solids.[22]

Humidity: Air humidity impacts drying, with low levels promoting faster rate and reducing evaporation and temperature profile.[23] Reduce moisture in particles by reducing diameter due to diffusional resistance and internal resistance.[24]

Air flow rate: Air flow rate must be optimized for efficient fluidization, ensuring gas heating and fluidization, ensuring optimal drying process without overheating or underheating.[25]

Applications

- The most common application for fluid bed dryers is probably in the pharmaceutical business. This automated system has long since taken the place of traditional drying trays in the powder processing sector of the business.[26]

- A fluid bed dryer is a special type of equipment which can be utilized for applications such as drying granule, drying of powders, blending of powders and agglomeration.[27]

- Pharmaceutical and Nutraceutical Industry
- Chemical and Dyes Industry
- Food Preparation Industry
- Fertilizer and Pesticide Industries
- Dairy Industries [28]

Validations

The proof of validation is obtained through the collection and evaluation of data . Beginning from the process development phase and continued through in to the production phase. Validation is necessarily includes process qualification, material, equipment, system, personnel.[29]
Establishing documented evidence that provides a high degree of assurance that a specific process will consistently produce a product meeting its predetermined specifications and quality attributes." Validation applies to processes or analytical methods. Validation provides an approach to prove quality, functionality and performance of a pharmaceutical/biotechnological manufacturingprocess.[30]

Advantages and DisadvantagesAdvantages

1.Fluidized Bed Dryers Guarantee Fast and Homogeneous Drying.

2.Fluid Bed Dryer is Suitable for Heat Sensitive Products.[31]

3.Fluid Bed dryer are efficient to dry material at low temperature.

4.Handling of FBD is easy and less labour intensive.[32]

5. No Hot Spots on the Final Products.

6. Fluid Bed Dryer Is Suitable for both Continuous & Batch Material Processing.[33]

Disadvantages

1. The need to suspend the entire bed in gas results in significant pressure dropsand high energy costs.
2. A high thermal efficiency operation requires increased gas handling due to thesubstantial recirculation of exhaust gas.
3. Whether the feed is too wet, there is insufficient fluidization and flexibility.
4. During drying, this equipment is not recommended when organic solventsmust be removed.
5. Some fluidized bed dryers don't produce uniformly high-quality products.
6. Fine particles can aggregate in some situations and attrition is a high risk.
7. There is a risk of fire or explosion if flammability limits are exceeded whenprocessing poisonous or flammable substances using traditional hot air fluidized bed dryers.[34]

Recent Developments

Poor fluidization quality for Geldart's class 'C' and class 'D' particles; the quality can be improved mechanically by agitation, vibration, pulsation, etc. Use of internal heat exchangers for internal heat transfer Improvement of the gas distribution system, Superheated steam drying, low pressure drying, hoover drying; novel chamber designs; variations of spouted bed dryers; spout-fluid beds;combining fluidized beds with heat pump systems.[35]

A combination of an incremental model with an axial dispersion and cross-flow model of drying medium would improve predicting power. Poor fluidization of Geldart group C particles could be improved by the assistance of external means such as vibration, agitation, rotation and centrifugation.[36]

Comparison with tray dryer

In regular tray dryers, heat travels a greater distance, however in fluid bed dryers, heat travels through floating material and vapour diffuses over a shorter space, which speeds up the drying process.

The product or ingredients are retained in a single container in a fluid bed dryer, which saves time, labour, cleaning, loading and unloading compared to a tray dryer.[37]

Future Prospects

The Fluidized-Bed Dryer market report provides valuable insights for business strategists from 2019-2029, including key segments, revenue, and supply data. Technological advancements make it a promising platform for emerging investors.[38]
The fluidized bed dryer market is forecasted to reach a multimillion – dollar valuation by 2030, exhibiting an unexpected CAGR during the forecast period of 2023 – 2030, as compared to data from2016 to 2022.[39]

Conclusion

his study concludes that the significance of fluidized bed dryer over the traditional dryer for drying of product. Fluidization in dryer improves quality, hue, and texture of product with a significant decrease in moisture content. Fluidization provides maximum surface area due to which transfer of heat, mass in dryer occur evenly due to which drying time is minimised. Fluidized bed drying significantly reduces the moisture content of product improving energy and exergy efficiencies, hydrodynamics effect and reducing energy devour for drying.

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