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Drying Characteristics of Ragi using Circulating Fluidised Bed

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Abstract

A Circulating Fluidized Bed is a type of gas-solid reactor consisting of a riser in which a gas-solid suspension is transported vertically upwards and separated at the top by gas-solid separators. After separation, the suspension is recycled to the bottom via a stand pipe or down comer. The behavior of CFB differs from a conventional fluidized bed, because of absence of bubbles and entrained flow of solids. A CFB operates at much higher gas velocities than those used in conventional fluidized bed and lower than those used in pneumatic conveying. Circulating fluidized bed is finding increased industrial applications in recent years. One such application is extension of a CFB for granular materials drying. It is essentially a process of simultaneous heat and mass transfer and a very common process in many of the chemical process industries. In this article an attempt was made to study the hydrodynamic properties of ragi in Circulating Fluidized Bed. Experiments were conducted in a column of 0.05m internal diameter and 1.6m long covering a wide range of operating conditions. The transport velocity was estimated by emptying time technique, the effect of pressure drop with axial co-ordinate for different gas mass flux and solids circulation rate, the effect of voidage and the effect of solid circulation rate with pressure gradient. In the present work an attempt has been made to dry in the riser of the circulating fluidized bed covering a wide range of operating parameters. The effects of various operating parameters such as initial moisture content on exposure time, moisture content with drying rate and relative moisture content with exposure time with varying temperature of heating medium. The results obtained are quite satisfactory with literatures.

Keywords: Circulating fluidized bed, drying kinetics, food materials.

Introduction

A fluidized bed is formed when a quantity of a particulate substance is placed under appropriate conditions to cause the solid/fluid mixture to behave as a fluid. This is usually achieved by the introduction of pressurized fluid through the particulate medium. This results in the medium then having many properties and characteristics of normal fluids; such as the ability to free-flow under gravity, or to be pumped using fluid type technologies. The resulting phenomenon is called fluidization.

A fluidized bed consists of fluid-solid mixture that exhibits fluid-like properties. As such, the upper surface of the bed is relatively horizontal, which is analogous to hydrostatic behavior. The bed can be considered to be an inhomogeneous mixture of fluid and solid that can be represented by a single bulk density. In fluidized beds, the contact of the solid particles with the fluidization medium is greatly enhanced when compared to packed beds. This behavior in fluidized combustion beds enables good thermal transport inside the system and good heat transfer between the bed and its container[1]. Fluidized bed technology has been used in industrial drier for the drying of wet solid particles for many decades for drying of chemicals, polymers, fertilizers etc. Fluidized bed driers have been successfully used for drying of food grains such as Ragi, Mustard, Pepper and Mustard, Quick-cooking potato cubes, Beans and Peas, Fresh green beans, Baker's Yeast and Hazel nuts[2].

A Circulating Fluidized Bed is a type of gas-solid reactor consisting of a riser in which a gas-solid suspension is transported vertically upwards and separated at the top by gas-solid separators[3]. After separation, the suspension is recycled to the bottom via a stand pipe or down comer. Solid particles are widely used in chemical industries, in operations as mineral processing, pharmaceutical production, food processing and energy related processes, Calcinations of aluminum hydroxide to high grade alumina, ore reduction and waste incineration[4]. The operation of CFB often presents a region of high solids concentration at the bottom of the riser and a region of low solids concentration near the exit of the riser[5]. Even within these regions solids concentration varies longitudinally, presenting difficulties in scale-up and reliable estimation of kinematic performance.

The behavior of CFB differs from a conventional fluidized bed, because of absence of bubbles and entrained flow of solids[6]. CFBs are being considered as alternatives for conventional fluidized bed because of their apparent intrinsic advantages, including short and controllable residence time for the gas and solids, high turn down ratios, flexibility, good heat and mass transfer and uniform temperature distribution[7]. The CFB offers advantages such as facility to handle cohesive particles, a high degree of mixing of solids and used for heat sensitive materials[8].

Many works have been reported on hydrodynamics of CFB in the areas of flow regimes and pressure fluctuations, solid circulation rate, axial and radial solid distribution with and without internals[9]. Though extensive work has been reported in the literature on drying using conventional fluidized bed, on the other hand drying using CFB is not reported in the literature. Hence, a systematic work is carried out to study the drying characteristics of ragi in CFB[10].

Material and Methods

Experimental Set Up and Procedure: The schematic diagram of experimental set up is shown in figure-1. It consists of a Plexiglas column of 50mm internal diameter and 1600 mm height. The column consists of a riser with a provision for continuous feeding of the solids at a controlled flow rate from the hopper[11]. A gas-solid separator and a bag filter were provided at the top of the riser for separating solids and gas. For the co-current upward movement of the solids, air is introduced at the bottom of the column. Air enters through distributor plate of 0.8mm diameter holes from the bottom of the riser. Air for fluidization is supplied through air compressor of 8 HP. The air flow rate was controlled by using pressure regulator. The air enters through air heater which consists of six 1.5K.W capacity. The temperature of the heating medium was controlled with an accuracy of 0.1°C using PID controller attached to the heater. Then the air enters through air flow meter ranging from 100-1400LPM and passes through butterfly valve and to the bottom of the distributor plate in the riser column. Six pressure tapings and six temperature tapings are located at the riser column of 500mm, 700mm, 900mm, 1100mm, 1300mm and 1500mm from the riser bottom respectively. The pressure measurements are made using inclined manometer range from 0-50mm water. Temperature measurements are calibrated using RTD sensors and signals are processed using 16-bit Data Logger. Ball valves were provided at the solids feed point and at the column to facilitate the measurement of solid circulation rate in the riser.

Results and Discussion

Hydrodynamic Properties of Ragi in CFB: Effect of Superficial gas velocity on Time: The effect of superficial gas velocity on time is shown in figure-2. From this figure U_{tr} is determined by emptying time technique which is defined as the time required for all the solid particles to leave the bed as a function of gas velocity U_g . The tangents of the curve give the transport velocity[3] U_{tr} as shown in figure-1. As U_g increase, the bed material could be emptied in a short period of time due to sharp increase of particle carryover in the absence of solid recycle. Thus from the figure, two lines have different slopes at lower and higher U_g. The intersection of these two lines gives transport velocity. The resulting value of U_{tr} is found to be 29 m/s for ragi particles of 1.18mm diameter.

Effect of Pressure Drop Vs Axial co-ordinate with Gas Mass Flux: The effect of pressure drop with axial co-ordinate for different gas mass flux is shown in figure-3. From this figure axial pressure profiles along the riser section have been measured as a function of gas mass flux. It can be seen from figure that a typical variation of the pressure drop along the length of the riser decreases. The initial portion corresponds to the lower portion of the riser, is the higher holdup region while the upper portion of the riser with lower holdup region. It is noticed from the figure that, the pressure drop can be very different in these two regions. In lower region of riser, pressure drop is more and in upper portion of riser pressure drop is less. It can also be seen from that gas mass flux increases, pressure drop also increases along the length of the riser.

Effect of Pressure Drop Vs Axial co-ordinate with Solid Circulation Rate: The effect of pressure drop with axial co-ordinate with different solid circulation rate is shown in figure-4. From this figure axial pressure profiles along the riser section have been measured as a function of the solid circulation rate. The initial portion, corresponding to the lower portion of the riser, is the higher holdup region with high solids concentration while the upper portion of the riser with low solids concentration is the lower holdup region. It is noticed from the figure that, depending on solids flow rate is very different in two regions. The solids concentration in each of the regions depends on the flow rate of the phases, the particle size and its density. The variation in solids concentration along the riser of the CFB causes axial variation in bed characteristics including the contact time between the phases, which makes scale-up uncertain with respect to the hydrodynamics of CFB. To reduce or eliminate the in homogeneity in solids concentration along the riser length, horizontal perforated plates were placed in the riser.

Effect of Voidage Vs Axial co-ordinate with Gas Velocity: The effect of voidage with gas velocity in axial distance of riser column is shown in figure-5. From this figure it is observed that with increase in gas velocity the voidage also increases in riser. It is noticed from the graph that at low gas velocity voidage is less and gradually increase with increase in gas velocity and it remains constant after a particular gas flow rate. The voidage of the bed is less at lower air flow rate because at the beginning the terminal settling velocity of the particle will be more and by increasing the air flow rate, the terminal settling velocity will be less and the voidage is increased. Based on the diameter of the riser column the voidage may differ for particular air flow rate. The buoyancy force of the particles will be greater than the gravitational force at higher flow rates.

Effect of Pressure Gradient with Solid circulation rate and Gas flow rate: The effect of pressure gradient with solid circulation rate and gas flow rate is shown in figure-6. From this figure it can be ascertained that the pressure drop is less at low solids circulation rate and increases gradually with increase in solid circulation rate. At low solids rate, the pressure drop increases slowly, corresponding to pneumatic transport, and at high solids rate, it approaches an asymptotic value corresponding to conventional fluidization. The pressure drop is high and approaches an asymptotic value at high solids circulation rate is a sigmoidal curve. In between these boundaries, the pressure drop increases sharply with solids circulation rate. It can be ascertained that the pressure drop decreases with increasing gas velocity for a given solids rate.

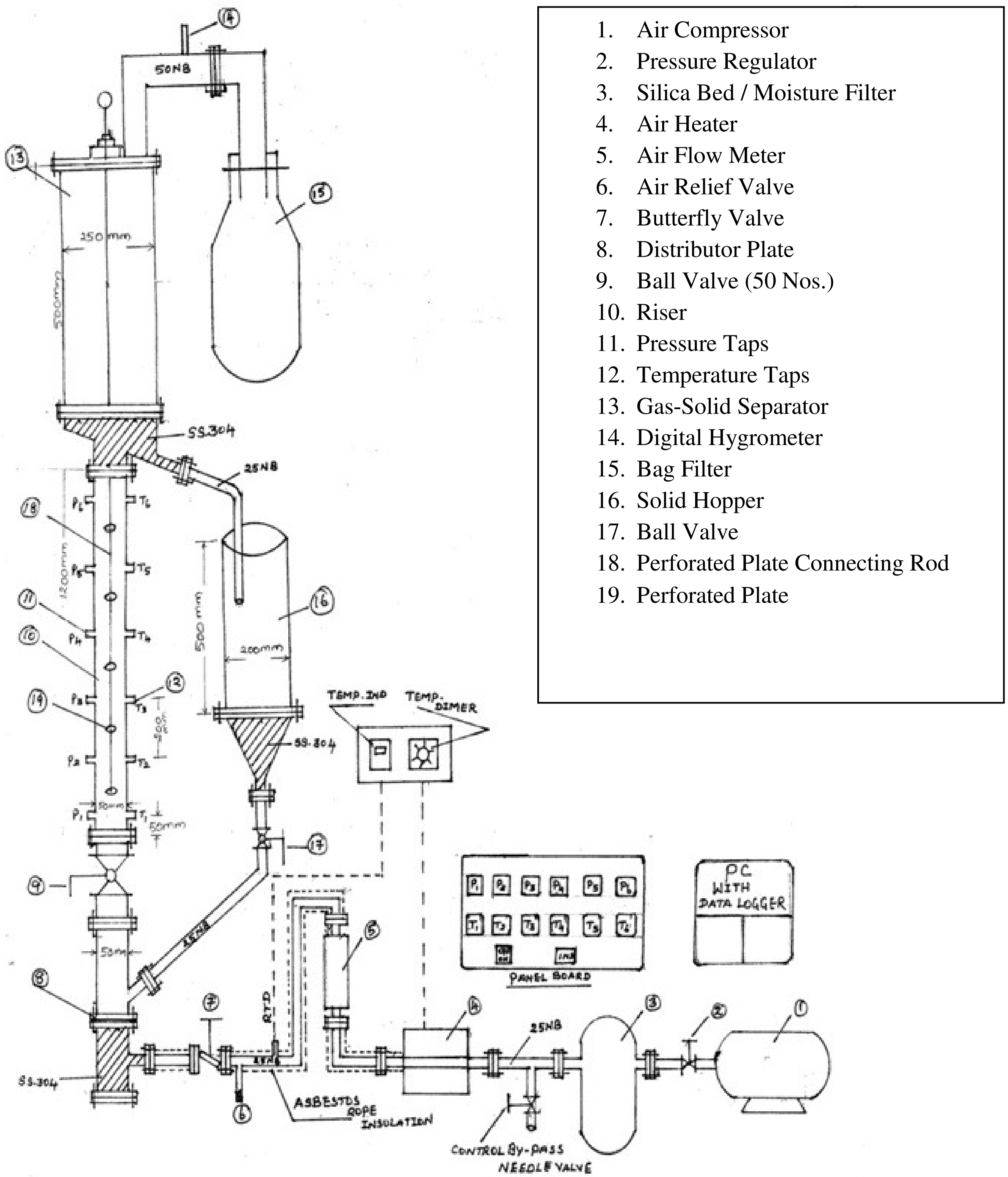

Figure-1
Schematic Diagram of Circulating Fluidized Bed

Drying Kinetics of Ragi in CFB: Effect of Relative Moisture content with Exposure Time: The effect of relative moisture content on exposure time is shown in figure-7. It can be observed that increase in air velocity reduces the drying time. The material exhibits only a falling rate period in the CFB. Further, the increase in the flow rate of the heating medium provides a larger heat input, resulting in increased drying rate.

Effect of Moisture content with drying rate: The effect of moisture content with drying rate is shown in figure-8. From this figure, the drying rate is sharp at the beginning of the process and reduces gradually with drying time. The material exhibits only a falling rate period. This may be because the moisture is available near the surface at the beginning of the process and the moisture needs to be transported to the surface when time progresses, resulting in a higher drying rate with time. It can also be seen that the drying rate increases with increase in flow rate of the heating medium. The falling rate period is observed for ragi particles.

Effect of Relative Moisture content with Exposure Time for different heating Medium: The effect of relative moisture content with exposure time is shown in figure-9. From this figure it can be ascertained that the increase in inlet temperature of the heating medium reduces the outlet moisture content of the material. This is due to the fact that an increase in temperature results in higher thermal input into the system, which increases the surface temperature of the material. This leads to lower surface humidity and increases the rate of evaporation from material surface.

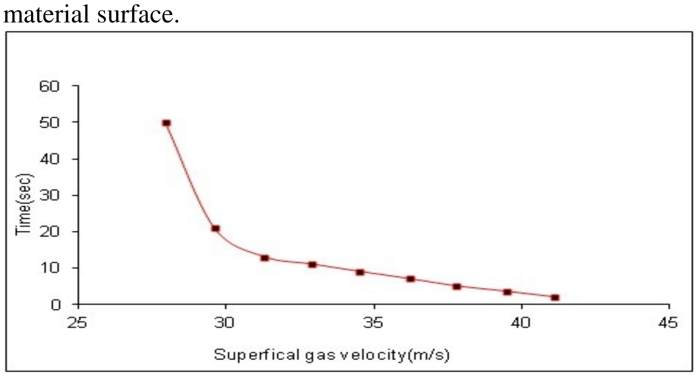

Figure-2
Effect of Superficial Gas Velocity on Time

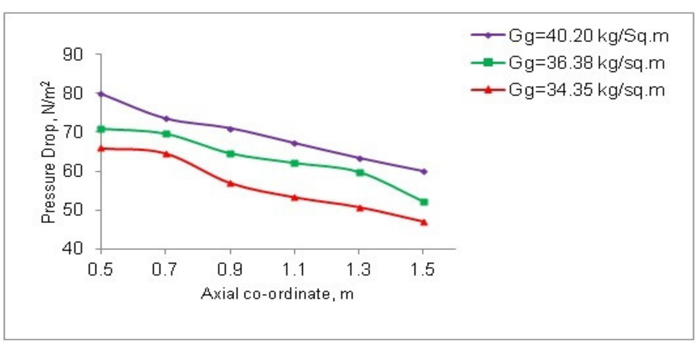

Figure-3
Effect of Axial Co-Ordinate Vs Pressure Drop with Gas Mass Flux

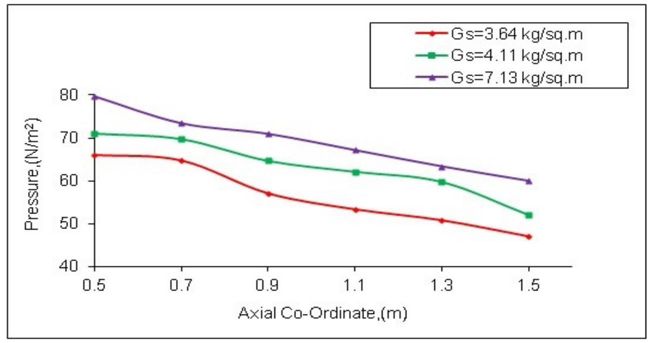

Figure-4
Effect of Axial Co-Ordinate Vs Pressure Drop with Solid Circulation Rate

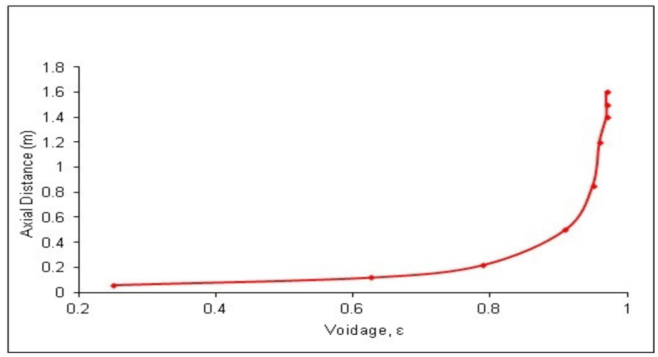

Figure-5
Effect of Voidage Vs Axial Co-Ordinate with Gas Velocity

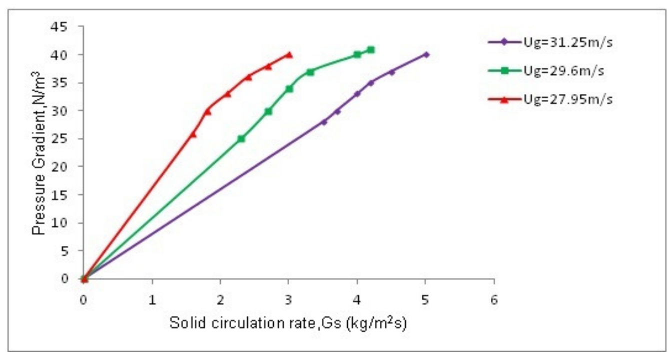

Figure-6
Effect of Solid Circulation Rate Vs Pressure Gradient with Gas Flow Rate

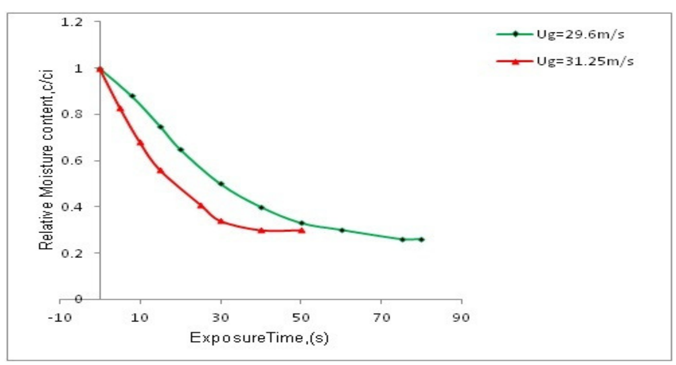

Figure-7
Effect of Exposure Time Vs Relative Moisture Content

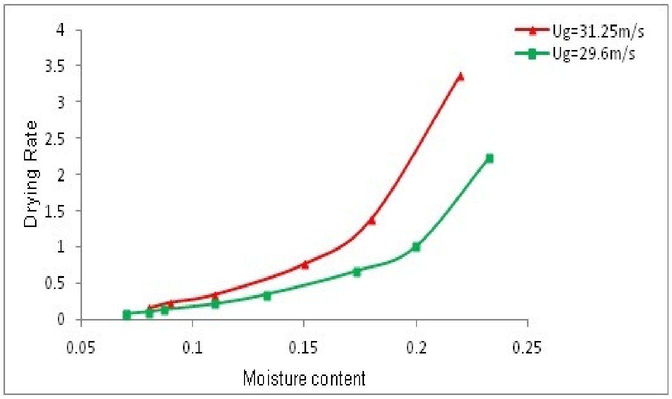

Figure-8
Effect of Moisture Content with Drying Rate

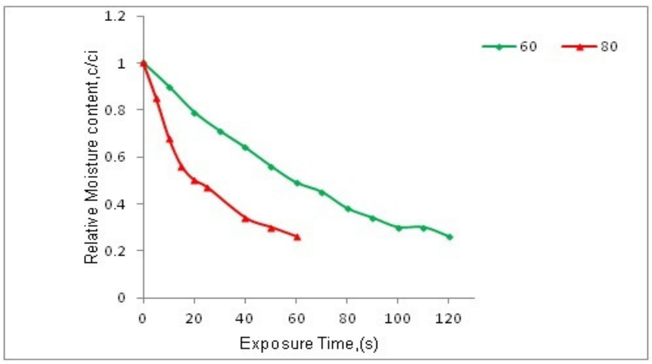

Figure-9
Effect of Exposure Time Vs Relative Moisture Content for Different Heating Medium

Conclusion

Experiments were carried out to study the drying kinetics of ragi in the riser of a circulating fluidized bed. The Pressure drop increases linearly with increasing gas mass flux and solids circulation rate. The pressure drop does not vary from stage to stage for the entire length of the riser; it decreases from bottom to top. The effect of solid moisture content with drying time, flow rate of the heating medium, temperature of heating medium and the effect of drying time with moisture content has been critically examined. It has observed from the present experimental result that the rate of drying in the circulating fluidized bed is influenced by the initial moisture content, flow rate and temperature of the heating medium.

Nomenclature: C: moisture content of ragi at any time (kg of moisture/kg of dry solid), C_i: initial moisture content of ragi grain (kg of moisture/kg of dry solid), C/C_i: relative moisture content, D_p: particle diameter (µm), G_g: gas mass flux (kg/m2s), G_s: solids circulation rate (kg/m2s), H: height of water column (m), Id: inside diameter (m), P: pressure drop (N/m2), R: difference in manometer (m), U: air velocity (m/s), U_g: gas velocity (m/s), U_{mf}: minimum fluidization velocity (m/s), U_t : terminal velocity (m/s), U_{tr}: transport velocity (m/s), P_p: particle density (kg/m3), ε: bed voidage.

Abbreviations: CFB: Circulating Fluidized Bed, FCC: Fluid Catalytic Cracking, HP: Horse Power, KW: Kilo Watts, LPM: Liters per Minute, PID: Proportional-Integral-Derivative Controller, RTD: Residence Time Detectors.

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