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Design and development of a laboratory scale fluidization column for experimentation through student internship program

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ABSTRACT

At Queensland University of Technology, internships are offered for foreign students to familiarize with Australian education, culture and learn from other students under a supervision of an academic to gain a valuable undergraduate experience. Under the internship of a French student preliminary calculations carried out lead to development of an experimental test rig which was designed and developed to use for student experimentation and higher degree research at the Queensland University of

Technology. Fluidization method is one of the technologies which saves energy in the processing industry not limited to agro-food and chemical sectors, also can be used any other industry. Drying can be regarded as one of the most important and most frequently applied unit operation in all sectors producing solid products. In drying process, water is the liquid evaporated in the form of moisture reduction and heated air is the commonly used as the medium which help the operation. Fluid bed drying has been known as a smooth drying procedure, with good mixing capabilities and lower the water content to a very low residual value with a high degree of process efficiency. This process is characterized by high moisture reduction offering higher heat transfer rates which enable easy thermal control capacity of the drying medium and contents compared with conventional drying processes. Hence this is a sustainable operation. In order to conduct fluidized bed drying experiments, it is necessary to design a suitable laboratory scale fluidization column. This work details the design and fabrication stages of the project.

Key words: Fluidization, drying, column, experimentation, AFD techniques

1. INTRODUCTION

When an air stream is passed through a free-flowing material resting on a permeable support, the bed starts to expand when a certain air velocity is reached. The superficial velocity of the air at this stage is the minimum fluidization velocity, with continual increase in air velocity, a stage is reached where the pressure across the fluidized bed drops rapidly, and the product is carried along the output air stream. This will enable materials to be transported to another location or empty into another vessel for further processing. The achieved velocity of heated medium at this stage is called terminal velocity as material no longer remains in the vessel. During fluidizing operations, the superficial velocity of the air should remain between minimum fluidization velocity and terminal velocity.

The Ergun equation (Ergun, 1952) is the widely accepted model to determine minimum fluidization velocity of a fluid to fluidize the particle (Kunii and Levenspiel, 1969):

$$(1-\varepsilon_{mf})(\rho_s-\rho_f)\,g = 150\frac{(1-\varepsilon_{mf})^2}{\varepsilon_{mf}^{\ 3}}\frac{\mu u_{mf}}{(\phi d_p)^2} + 1.75\frac{(1-\varepsilon_{mf})}{\varepsilon_{mf}^{\ 3}}\frac{\rho_f u_{mf}^{\ 2}}{\phi d_p} \qquad (1)$$

The Ergun equation was used to calculate minimum fluidization velocity of several food materials (Vazquez and Calvelo, 1980; Vazquez and Calvelo, 1983).

The values for fluidisation velocity obtained by the Ergun equation are mostly reliable for spherical and relatively small particles which never changed the shape during drying operations. Most agro-food materials are coming with various shapes and sizes and consist of larger particles. Therefore, the minimum fluidization values obtained from Ergun equation never agrees with experimental values (Mclain and McKay, 1981, McKay et al., 1987)

The Ergun equation consists of two terms; viscous and kinetic energy terms (1st and 2nd RHS part of the equation 1). In the case of larger particles at higher Reynolds numbers (Re > 1000) the fluidization behaviour was mainly governed by the kinetic energy term in the Ergun equation. For that situation Ergun equation can be simplified to (Kunii and Levenspiel, 1969):

$$u^2_{\ mf} = \frac{\phi\, d_p^{\ 2}}{1.75}\frac{(\rho_s-\rho_f)}{\rho_f}\, g\, \varepsilon^3_{\ mf} \qquad (2)$$

For wide variety of systems, it was found that value $\frac{1}{\phi\,\varepsilon_{mf}^{\ 3}} \cong 14$ (Wen and Yu, 1966) and a generalized equation can be applied to predict U_{mf} for larger particles when Re > 1000.

$$u^2_{mf} = \frac{d_p(\rho_s-\rho_f)}{24.5\,\rho_f}\, g \qquad (3)$$

2. EXPERIMENT RIG

Experimental rig consists of several important parts and components. The complete apparatus consists of the following components:

- Centrifugal Fan
- Heating System (Heating Element, Box, Solid State Relay, Connections)
- Control System
- Fluidisation Column
- Sensors
- Data Logging System
- Granule Collection Container

The fan will create an air flow through the heating element where heat will be transferred to the air at a set point between 30 and 60 degrees Celsius. From here, the heated air will pass through the base of the column. Particles such as grain are held in the base of the column. If the velocity of air is above a value known as the fluidisation velocity, fluidisation will occur. From the column, a series of sensors such as relative humidity, pressure, temperature and velocity will be connected to a controller so that these properties can be measured and analysed. From here, the data can be uploaded to computer for a complete analysis. Frame for the rig was welded from 30x30x3 mm square RHS steel at Queensland University of Technology workshops.

3. FLUIDISATION COLUMN

The fluidization column is made in order to be used at Queensland University of Technology and to conduct experiments on fluidization and drying. A major component of the experimental rig is the column, where fluidization of particles or drying of particles takes place. The column is vertical and is basically a thin-walled cylinder kept in a vertical position. The constraints on the decision-making process of the column design is that it must be made from a material which satisfied the following requirements;

- Transparent, therefore allowing the fluidization process to be viewed through the column
- Lightweight which means the overall weight of the experimental rig will be reduced and will be easier for the manipulations/transportation
- Ease of manufacture, which make the production of the column simpler
- Safety concerns like vibration, should not shatter during experimentation
- Low cost of production

The Colum needs to receive air from an air blower, and air need to be heated up by a heating device. The type of blower considered is centrifugal, and it will force air through a duct via the heating device before entering inlet of the fluidization column. The air passes through the distributor then fluidize particles before exiting through the top of the column. The air exiting the column travel through an enclosed container. This container act as a safety measure to catch particle that flow with the air out of the column. The transportation of solids only occurs when the velocity exceeds the terminal velocity of the particles, which is not expected to occur during experimentation. This container should be sufficiently large and have a perforated material to entrap particles and only allow air to escape so that the air pressure build up in the column is minimum. The block diagram below shows the process diagram for the design.

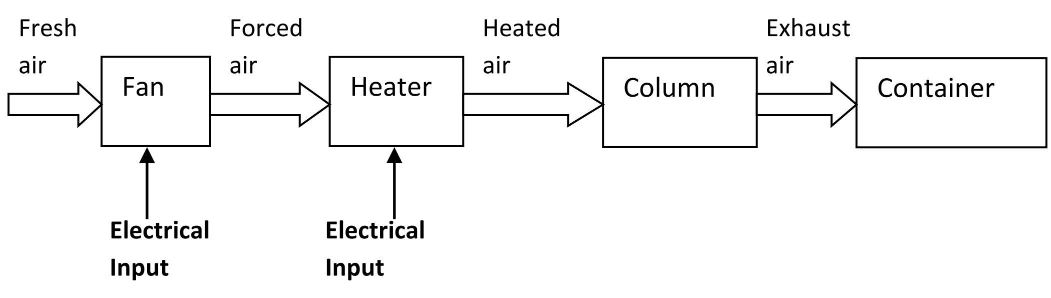

FIG. 1. Block diagram corresponds to the schematic diagram below

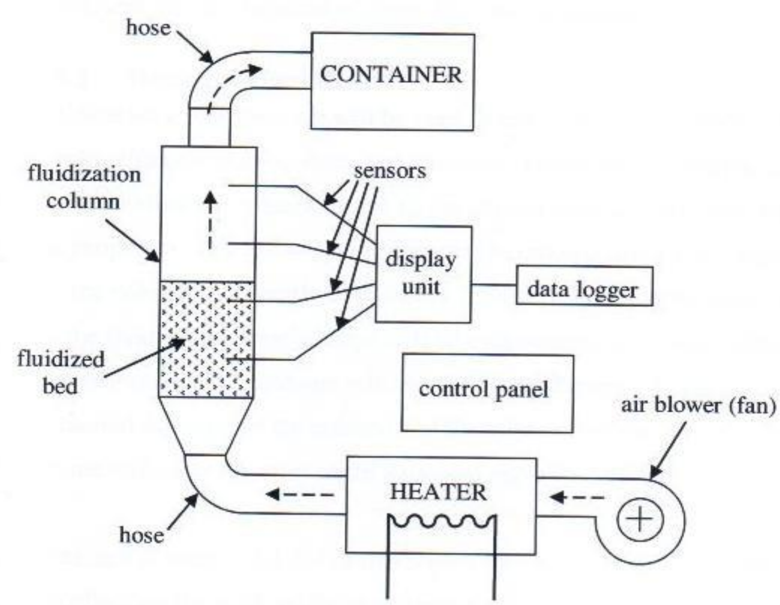

FIG. 2. Schematic of the setup

The fluidization experiment rig is made to test all kinds of particles food and non-food, with different shapes, sizes, and densities. Therefore, it is almost impossible to design the fluidization column in order to suit all the experiments possible with the different particle properties. The known dimensions of the column that are not expected to change are that the column is currently designed for fluidized solid particles using flowing air as the fluid is assumed. However certain assumptions made to the internal diameter of the column and the inlet air velocity in order to cater for most of the expected experiment scenarios.

The internal diameter of the column was selected to prevent edge effects (column diameter> 10 X particle diameter) and can influence the mode of fluidization. Undesired phenomenon can occur if the fluidizing container is very narrow compared to its height or compared to its length. Therefore, the column should have a reasonable height/diameter ratio. So, we have this ratio of approximately 3. All that is need now is either an initial estimate for the height or internal diameter of the column. Internal diameter of the column should be between 130 and 150 mm in order to be sure that it will be sufficient for all the experimentations. A diameter of this size is enough to test future materials which will have approximately the same size than traditional food. Before the design, a search has been performed regard to dimensions and transparent tubes with several manufacturers. The results of this search showed that the more adapted size was an internal diameter of 144mm. Also, the height of the column was kept at 400 mm. to accommodate it in the test rig.

4. PRESSURE DROP ACROSS FLUIDIZED BED

Ergun equation (Equation 1) was used to calculate the pressure drop across the particle fluidized bed column to the height of 100 mm. Three major geometrical shapes spherical, cylindrical and parallelepiped shaped foods were prepared according to geometrical shape. Green peas, diced green beans and diced potatoes were prepared for spherical, cylindrical and parallelepiped shapes, respectively (Fig. 3). Maximum dimension of the particle was 30 mm. We knew, only two parameters in this equation. It was the height of the bed and the air velocity. The viscosity and density of air both depend on temperature. So, we can assume the air will be heated to 30, 40 and 50^{o} C. Figure 4 shows the exploded view of the column.

5. BLOWER

Another important design parameter for the column is the air inlet velocity (referred to as the superficial gas velocity). The air velocity affects the pressure drop in the fluidized bed and determines the size of the blower required to deliver that velocity. For cater for most particle sizes an air inlet velocity of 3 m/s was assumed. This velocity can be increased or decreased in experiments by varying the blower speed with the use of a variable speed drive.

The required volume flow rate of the blower and the pressure drop across the fluidized bed was calculated. Since the height of the column is 400 mm, assumed maximum particle bed height is kept at 100 mm. Test Rig with blower (Gamut 500) is shown in Figure 5.

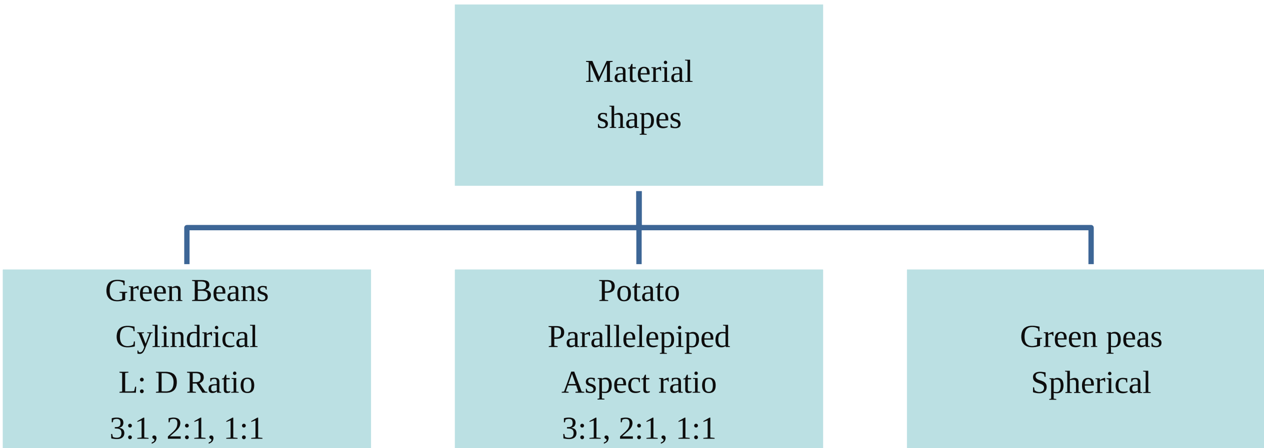

FIG. 3. Material selection

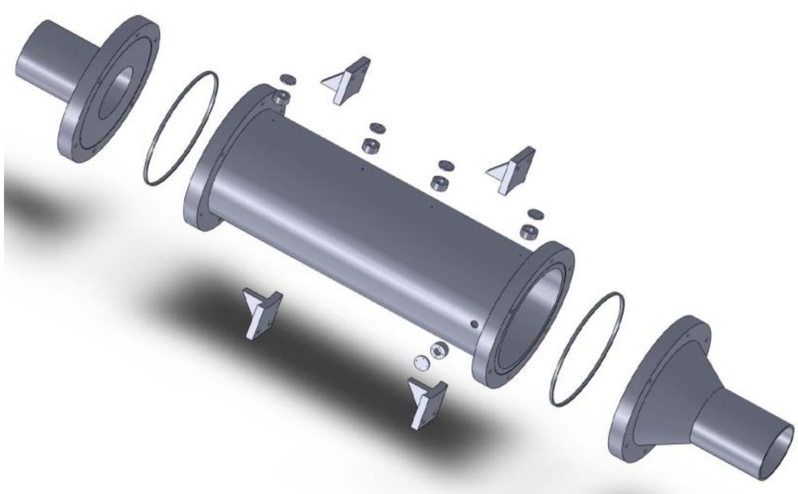

FIG. 4. Exploded view of the column

6. HEATING ELEMENT

A 3000 KW heating element was needed to carry out heating requirements successfully. According to this requirement a heater element was purchased. The element is a W shaped element within a boxed structure with a smaller element. The only issue with this is the heating element must be fastened far enough away from the duct transitions so it must be placed in the correct position to allow the air to settle in a laminar form. Also, a greater amount of heat transfer will be gained through more contact with the element. The disadvantages to this is the increased size, cost and trying to effectively position the heating element in a safe and effective manner whilst adhering to appropriate standards.

Insulation serves its main purpose to suppress heat loss through an element such as a wall. Also, safety is a big issue as the outside of the system can burn. Insulation can be used to cool this down to an appropriate temperature. Heat loss can decrease the efficiency of this system dramatically since more energy is required to provide the air at a specified temperature. Many types of insulation exist for different applications all with advantages and disadvantages. Cost and effectiveness also contribute greatly to the overall choice of insulation materials chosen. Glass or mineral fibre is one of the cheapest insulation choices and is also effective. This can be bought either loose or in sheets. For the heater box, this can be laid in sheets within the internals of the box and fastened with mill board. Mill board is a protective layer that is heat resistant and cannot transmit heat or burn easily. This will protect the insulation from overheating or catching fire whilst also acting as an extra layer of insulation.

FIG. 5. Test Rig

FIG. 6. Column in the test rig

For the mounting of the heating element onto the supporting frame, specific mounting instructions were given due to the thread size and the required clearance holes.

Due to the length of the thread, an appropriate thickness of supporting plate would be 5mm. This ensures that fastening with nuts can occur whilst ensuring strength. Because of the length of the U-shaped element, it may be necessary to support the element near the outlet nozzle with a metallic support so bending or contact with the outer shell does not occur. The box does not have this problem since it is facing directly downwards so will be held correctly due to gravity.

7. CONTROLS FOR THE COLUMN

The column consists of four probe and sensor input ports, mounting brackets, an inlet tube and an outlet tube. For this project it was a desired outcome that the temperature of the incoming air be controlled automatically once a temperature input from a user had been set. Several types of control systems to regulate the power produced and supplied to the heating element were examined until an appropriate solution was found. Both analogue and digital thermostats and also several PID controllers were compared to each other and it was found that most required several extra components and were also more complicated to initially set up.

Innotech was the company chosen as the manufacturer of the control system due to the ease of use, reliability and the cost. Components required for the temperature control were an Innotech Maxim 2 controller, Single Channel USB to RS485 Converter, SENP3 304 stainless steel temperature detector, Solid State Relay and a 1 Amp, 24V Plug Pack (Plugs into a standard 240V power socket).

Further sections of this project which have not yet been completed are sensors and data logging system. The required sensors will be required to measure velocity, pressure and relative humidity. Due to relative humidity sensors generally rated to 50 degrees Celsius, the humidity sensor can be placed in the inlet tube and calculations can be performed to work out the humidity in the column. Also, these sensors will be researched in greater detail to obtain information on the possibility of a higher range of operating temperatures.

8. DESIGN REFINEMENT OF THE DRYER USING AFD™ TECHNIQUE

The Anticipatory Failure Determination technique was developed by the Ideation Int. Inc. (USA) (Triz.com) and proved to be very effective tool both for machinery failure analysis and project documentation analysis for the purpose of revealing design flaws at early stages. The AFD™ technique was used to refine the design of the dryer. It includes the following nine stages (Terninko et al., 1996):

1. Formulation of the original problem
2. Converted the problem into an inverted problem
3. Expand the inverted problem for easy simplification
4. Search for the apparent solution to the inverted problem
5. Identification and utilisation of resources available in the system (substance, space, field, time and information resources)
6. Search for the needed efforts
7. Search for new solutions (if the selected effects do not lead to an adequate result)
8. Formulation of hypotheses and tasks for verification
9. Development of means of prevention of failures

The use of the AFD™ technique for the dryer design analysis resulted in the following suggestions for improvement:

- Adjustements in the blower flow rate will result in pressure fluctuations, which is detrimental for the dryer performance. A different kind of pump should be considered or a device throttling the flow without affecting the pressure should be installed.
- What will prevent the dryer from overheating if the pump fails to operate and no flow in the system ? A feedback circuit with an overheating protection should be installed.
- The hot air exiting the system is wasted and it can be recycle and return back to the system to increase its efficiency.

These design refinements have been implemented during the dryer development.

9. CONCLUSION

Heating methods are used extensively in industry for drying, heating spaces, cooking and numerous other applications. Through HVAC methods and control systems, an effective heating control system can be designed to accurately and effectively automatically detect temperature and then send a signal to change a temperature. By optimising the layouts and carefully selecting components to minimise cost and also to minimise the size, the best option can be found. Anticipatory failure determination will be used to refine design during dryer development.

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Authors Contributions

Wijitha Senadeera: Supervised the Intern student, suggested the project and handled all design and fabrication tasks, manuscript preparation and editing

Vladis Kosse: Contributed to Anticipatory Failure Determination in the manuscript and editing

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Conflict of Interest

The authors declare that there are no conflicts of interests.

Peer-review

External peer-review was done through double-blind method.

Data and materials availability

All data associated with this study are present in the paper.

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