Determining Granule Movement and Attrition Breakage in a Fluidised Bed with Different Perforated Plate Designs

Larochelle Botha and Abraham F. van der Merwe

***Abstract*—**In this study the movement of ammonium nitrate granules in a fluidised bed pilot plant is investigated for three different perforated plate designs at two different fluidisation velocities each. A qualitative and quantitative study is done to evaluate the degree of mixing that takes place. The attrition breakage for each plate is determined as a secondary objective. The granulation of ammonium nitrate through fluidisation is commonly used in the manufacturing of porous ammonium nitrate.

The aim of this project is to make use of particle size analysis to determine the extent of particle movement in a fluidised bed. The bed is initially loaded with layers containing different particle sizes, making it possible to analyse how much mixing occurs while the bed is operated. In subsequent experimentation, a colourant is injected into the fluidised bed while the fluidised bed is in operation. The samples taken from the fluidised bed, representing both distance from the colourant injection point as well as depth in the bed, are being rated on the amount of colourant present in each, indicating how the colourant was distributed within the bed.

The attrition breakage in each case is investigated using a mass balance on each of the three sizes of particles present in the bed. An increase in the mass of very fine particles indicates whether breakage through attrition is present and to what extent.

***Index Terms*—**fluidised bed, perforated plate, granule movement, attrition breakage, ammonium nitrate

I. Introduction

Granulated particles are a major part of the chemical, pharmaceutical as well as food industry. Efficient granulation has benefits for both the quality of the product as well as the process downstream of the granulation [8]. The fluidising fluid distributor design contributes in large to the efficiency of a granulator, yet it is frequently neglected in research on granulator designs.

The objective of the project is to investigate the movement of ammonium nitrate (AN) granules in a fluidised bed by using different distributor plate designs as well as different fluidising conditions. The attrition breakage will also be inspected at these conditions. Specific movement of granules in a fluidised bed can achieve better granule growth, especially when the wetting probability due to increased exposure to liquid from the spray nozzles are increased.

To achieve the set objectives, the granulator is loaded with AN particles to be fluidised. Colouring agent is injected into the bed while being fluidised. Samples are taken after the granulator is operated for several minutes. A total of 27 samples are taken for each experiment. A particle size analysis as well as colour scoring analysis is done on all the samples. The product material is weighed to establish to what degree attrition breakage occurs through a mass balance over the granulator.

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II. Literature Study

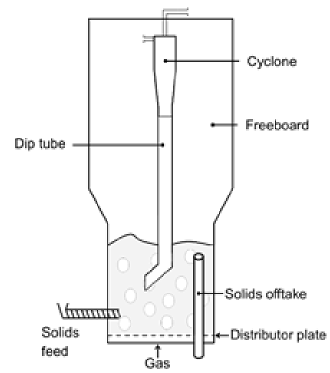

Fig. 1: Continuous gas fluidised bed [4]

A. Fluidised bed granulation

The principle of fluidisation is based on the upwards flow of a fluid through a packed bed containing a specific solid [4], as shown in

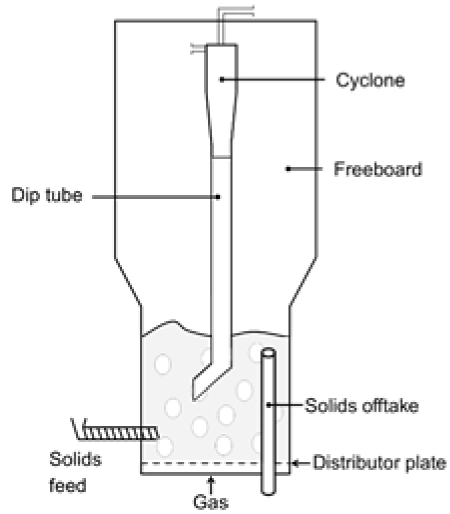

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Fig. 1. The fluid drag caused by the flow of the fluid through the solids produces a pressure drop. The goal of fluidisation is that the bed weight is equal to the fluid drag force so that the particles don't rest on each other anymore. References [7] and [9] concluded that a fluidised bed works at optimum heat and mass transfer rates as well as particle and gas residence time distribution when the gas and particle flow are counter-current, creating adequate contact between the gas and particles [7]. The distributor plate has a dual function namely distributing the fluidising gas into the bed as well as supporting the solid particle bed. An increase in vessel diameter above the bed causes the velocity of the fluidising gas to decrease so that entrained particles drop back to the bed of solid particles instead of staying suspended in the freeboard.

The flow of the fluidising gas after fluidisation has started can be described by one of two distinct types of fluidizations: aggregative and particulate fluidisation [4].

TABLE I: DISTRIBUTION PLATE PROPERTIES

	Hole diameter [mm]	Pitch [mm]	Open area [%]
Plate 1	1.6	3.0	25.80
Plate 2	1.6	5.5	7.68
Plate 3	2.0	11.9	2.56

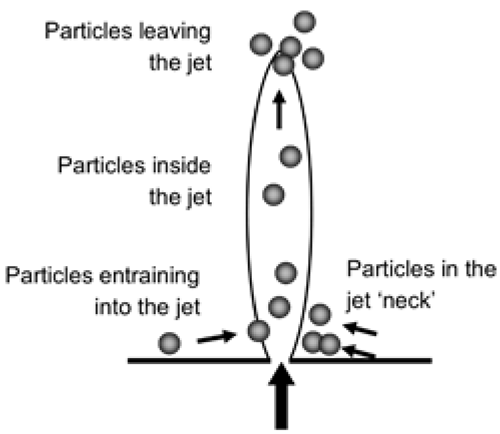

Fig. 2: Particles inside an emerging jet

In the case of particulate fluidisation, the bed will behave uniformly in a manner that the bed height increases with an increase in the flow rate of the fluidisation gas. The pressure drop across a bed wherein particulate flow occurs, will stay constant and equal to the bed weight per unit area. Aggregative flow, also known as bubbling flow, is observed when 'bubbles' of fluidising gas move rapidly through the particle bed. Reference [4] states that this type of flow is mostly observed in solid-gas fluidisation and can be considered the most important type of fluidisation in the commercial industry.

B. *Perforated plate design*

In the designing of a fluidised bed reactor, the perforated plate design is usually the aspect with the most degrees of freedom [3]. The performance of a fluidised bed is dependent on bubbling characteristics, which is in turn related to plate design, amongst others. The plate must be designed in such a manner that bubbles do not merge when they pass through the orifice. Thus, the orifice diameter and spacing must be chosen according to the size of the bubbles as well as the wake that form [10].

Reference [7] claims that a plate with large hole diameter and free area will create a comparatively uniform state of particles on the plate whereas an opposing plate with small hole diameter and free area will have a dense layer of particles below the uniform layer of particles.

Reference [4] claims another important aspect of the perforated plate is a high pressure drop over the plate, to ensure sufficient distribution of the fluidising gas across the entirety of the bed.

C. *Attrition breakage*

Reference [1] defines attrition as the breakage of particles resulting in dust or powder. Attrition is a result of the transportation of particles and reduces the quality of a specific product. Reference [5] states that the biggest disadvantage of any fluidised bed reactor is that attrition breakage occurs. The fines are created due to high mechanical stress that could be the result of inter-particle impacts or velocity gradients. Attrition breakage is divided into two distinct types: the division of a particle into smaller, equal sizes, and the abrasion of fines from a particle that stays somewhat the same size [5].

Attrition is mainly influenced by the properties of the particles, the distributor as well as the fluidised bed operating conditions. The most influential operating condition is identified as gas velocity [5]-[6]. A very high gas velocity gives rise to particles being entrained inside the jet entering the bed through the orifice of the distributor; these conditions causes attrition due to four different mechanisms occurring inside and close to the jet, shown in

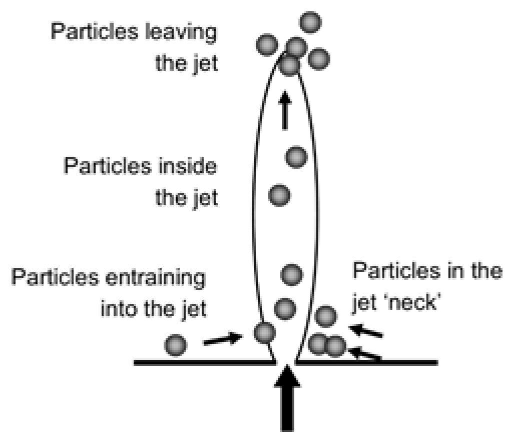

Fig. 2.

The first occurrence is particles being entrained close to the distributor plate. Particles suffer from abrasion against each other as well as secondly, the distributor plate. After this, particles are sent to the upper part of the jet with the gas flow. During the upward flow, the particles will encounter other particles that entered the jet, causing abrasion of the particles. After moving upwards through the jet, the particles are reintroduced into the dense phase at the top part of the jet, causing extreme impact with the dense phase. This also causes attrition of the particles [5].

The attrition breakage in a fluidised bed can either be due to all the above-mentioned mechanisms or due to a specific mechanism dominating, depending on operating conditions. Larger particles generally show more abrasion than smaller particles as they rarely reach the high impact velocities within the jet.

III. Experimental Methodology

A. *Materials*

AN granules are fed as seed material into the fluidised bed. The AN is divided into size ranges of smaller than 1mm to a high of 3mm. Per the Geldart particle classification [2] AN is characterized as Group B particles.

The fluidising gas used in the experiment is air at ambient temperature and pressure.

Allura Red as a 10% solution is sprayed into the bed to colour the AN particles. Allura red is an organic food colouring agent that is soluble in water but does not react with AN particles.

B. *Experimental equipment*

Measuring equipment include a manometer with a built-in function to measure ambient temperature as well as a pitot tube connected to a digital manometer.

A sampling probe is used to take samples in a three-dimensional map of the fluidised bed. The sampling probe consist of a carbon steel pipe with three 12cm compartments inside, to provide samples from three different levels in the fluidised bed.

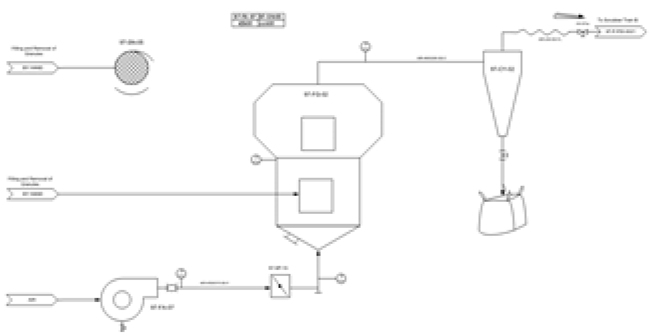

Fig. 3: Piping and instrumentation diagram of pilot plant

TABLE II: Fluidising conditions

	Condition	Damper opening [%]	Air velocity in bed [m/s]
Plate 1	Low	25	0.28
	High	63	0.51
Plate 2	Low	38	0.44
	High	63	0.54
Plate 3	Low	38	0.42
	High	63	0.55

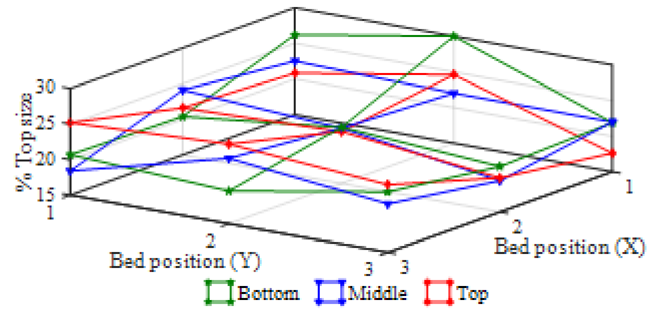

Fig. 4: Top-size particle distribution on plate 1 at low fluidisation velocity

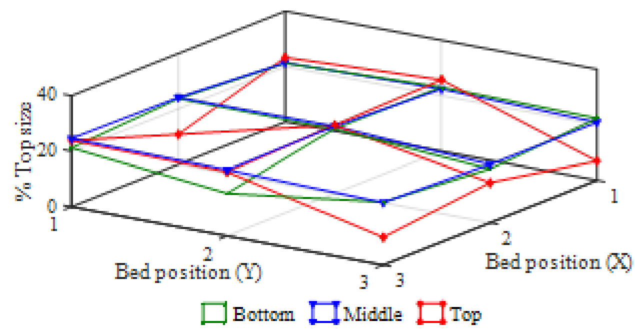

Fig. 5: Top-size particle distribution on plate 1 at high fluidisation velocity

A GoPro camera is installed in the granulator to observe movement within the fluidised bed while it is running.

A Sweco screen is used to divide AN particles into sizes of -1mm, +1-2mm, and +2-3mm.

C. *Experimental setup*

A pilot scale fluidised bed is used as experimental setup. The granulator has a cross-sectional are of 1m × 1m equipped with an interchangeable distributor plate.

Three distributor plates are being tested. The distributor plates, all having similar perforation designs, have properties as depicted in **Error! Reference source not found.**.

A fan, equipped with a 45kW motor as well as damper to regulate flow, provides fluidising air to the granulator. The fan damper is a butterfly valve that consists of 8 different percentage damper settings.

A cyclone extracts extremely fine particles, formed by attrition, leaving the granulator through the ducting. The particles are recovered from the cyclone through an opening at the bottom.

The colouring agent is injected into the fluidised bed using a dosing pump with a high flow of 44 L/h, with settings varying from 10% to 100% capacity. The pump is connected to a pneumatic nozzle to distribute the colouring agent evenly into the fluidised bed.

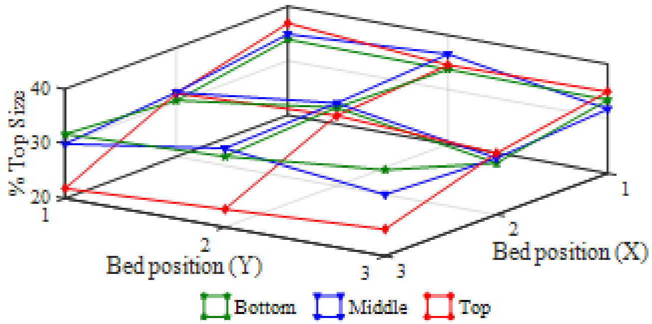

Fig. 6: Top-size particle distribution on plate 2 at low fluidisation velocity

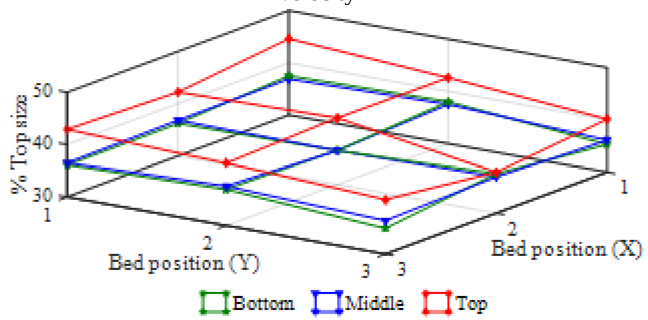

Fig. 7: Top-size particle distribution on plate 2 at high fluidisation velocity

D. *Experimental procedure*

Feed material is screened with the Sweco screen into sizes of -1mm, +1-2mm and +2-3mm. The different sizes are packed into batches of 99 kg for each experimental run.

The granulator is loaded with largest particles at the bottom. For each experiment, the seed material is fluidised at either a low or high fluidising velocity whilst the colouring agent is injected through the pneumatic nozzle.

Samples are taken with the sampling probe, in 9 different places across the cross-sectional area of the fluidised bed. Each sample is divided into three equal sizes to represent the depth of the fluidised bed.

A particle size analysis is done on each sample to establish the movement of different sizes within the bed.

As a qualitative study, the samples are also rated on a scale of 1 to 10 to calculate the amount of red colouring in each sample. The rating is done by 8 different contributors.

Attrition breakage is quantified by a mass balance over this batch operation, including the mass of particles captured by the cyclone.

IV. Results and Discussion

A. *Fluidising velocity*

EACH PLATE IS FLUIDISED AT TWO DIFFERENT VELOCITIES. FLUIDISING CONDITIONS FOR EACH PLATE IS GIVEN IN

Table II.

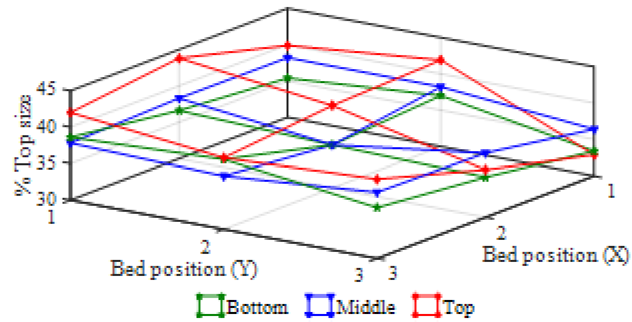

Fig. 8: Top-size particle distribution on plate 3 at low fluidisation velocity

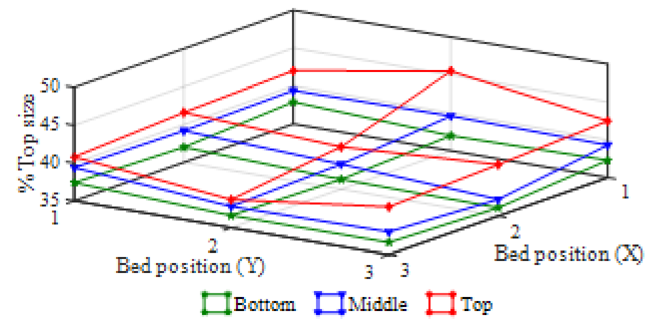

Fig. 9: Top-size particle distribution on plate 3 at high fluidisation velocity

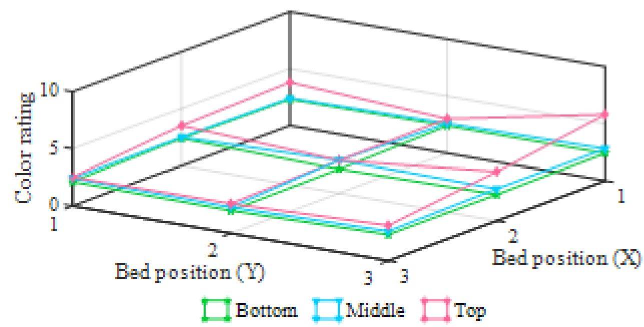

Fig. 10: Colour rating of plate 1 at low fluidisation velocity

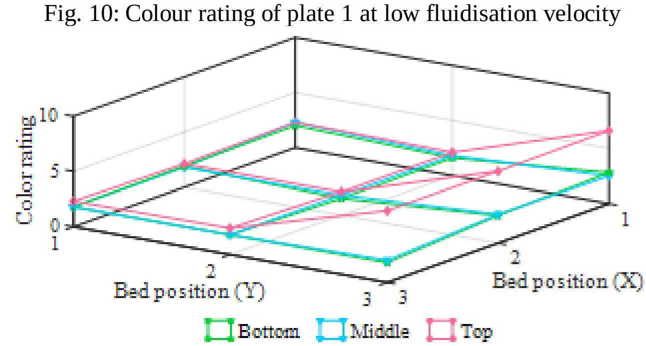

Fig. 11: Colour rating of plate 1 at high fluidisation velocity

B. *Particle size analysis*

Analysis is done on three different layers in the fluidised bed, namely top, middle and bottom layers. The mixing efficiency is quantified by two factors; the locality of each size fraction on each layer as well as the difference in the bottom layer size fraction. The bottom layer is packed with 100% large particles before fluidization, meaning a small difference with regards to 100% depicts poor distribution into the vertical position.

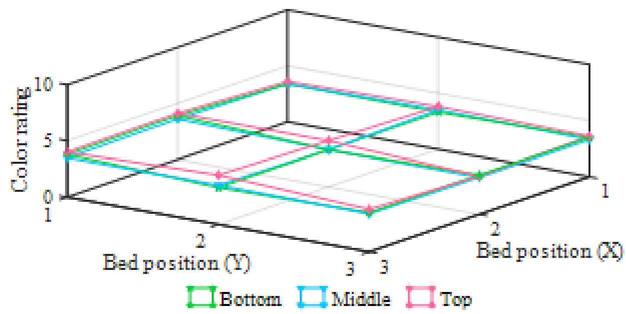

Fig. 12: Colour rating of plate 2 at low fluidisation velocity

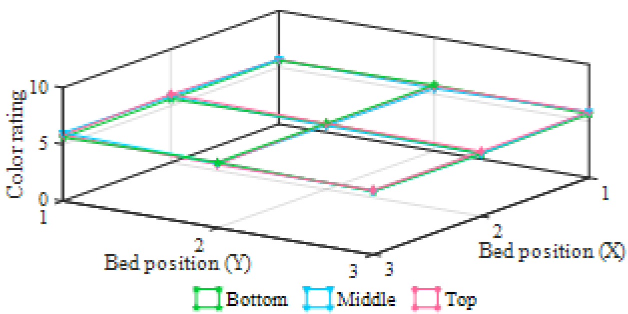

Fig. 13: Colour rating of plate 2 at high fluidisation velocity

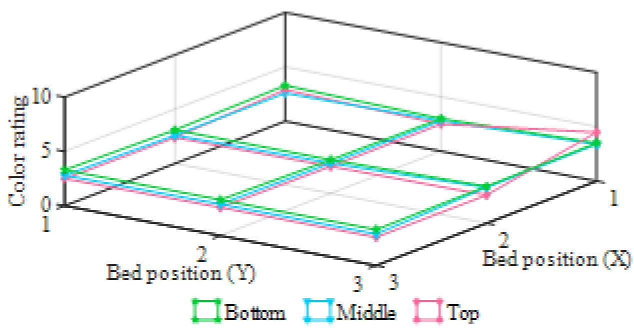

Fig. 14: Colour rating of plate 3 at low fluidisation velocity

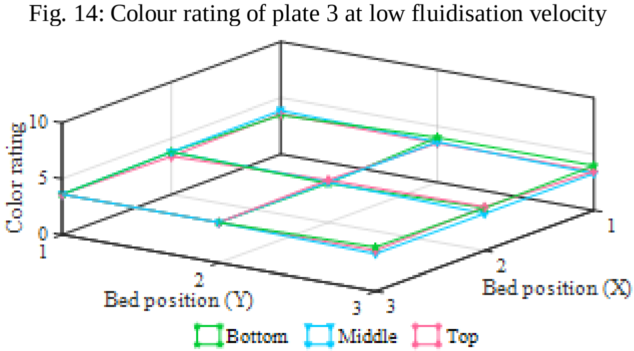

Fig. 15: Colour rating of plate 3 at high fluidisation velocity

In each figure, bed position X shows the front of the granulator (where the granulator door is), whereas bed position Y is the side of the granulator.

1) Plate 1

The first plate, at a fluidising velocity of 0.28 m/s delivered a top size particle distribution as shown in Fig. 4. The pressure drop over the plate is measured as 1 kPa. The figure shows extremely good mixing in the centre of the bed, with moderate to poor mixing on the sides. The right-hand side of the fluidising bed (X-position 1) has the worst mixing, possibly caused by dead zones in the granulator.

A fluidisation velocity of 0.51 m/s delivers a pressure drop of 1.2 kPa over the distributor, resulting in a top-size particle distribution shown in Fig. 5. Results shows an even distribution of top-size particles in the fluidised bed, except for the top layer by the door. The percentage top-size particles at the door in the top layer is lower than other areas, showing possible uneven distribution of fluidising air.

2) Plate 2

Plate 2 is first fluidised at a fluidising velocity of 0.44 m/s, giving a pressure drop of 1 kPa over the distributor. Fig. 6 shows the resulting top-size particle distribution; an even distribution of top-size particles is observed except for the left-hand side of the fluidised bed. A small fraction of top-size particles in the top layer shows stagnant zones are present here, which can be due to localised inflow of air through the duct. The flow enters from the left, meaning it is possible for the flow to the left side of the fluidised bed to be inefficient.

Fig. 7 illustrates the top-size particle distribution of a fluidised bed with plate 2 at a velocity of 0.54 m/s. The pressure drop over the plate is measured as 3.4 kPa. A high fraction of top-size particles in the top layer indicates the fluidisation velocity is high, causing larger particles to have moved to the top being evenly distributed through the fluidised bed.

3) Plate 3

The last plate delivers a pressure drop of 1.5 kPa over the distributor for a fluidising velocity of 0.42 m/s. A uniform top-size particle distribution (Fig. 8) shows efficient mixing within the fluidised bed, except for the back, right-hand corner. A high fraction of top-size particles in the top layer is conceivably the result of high fluidisation velocities in this area.

Plate 3 is fluidised at a velocity of 0.55 m/s, resulting in a distributor pressure drop of 2.8 kPa. Fig. 9 gives the top-size particle distribution. Poor mixing occurs under these conditions, since top-size particle migration to higher levels are dissimilar.

C. Colour profiling

The colouring agent is injected while the bed is fluidised, resulting in the same fluidising conditions for both top-size particle distribution analysis and colour profiling.

Each sample taken after fluidisation is rated by 8 individuals to qualitatively determine the mixing efficiency, measured in colourant distribution, in the fluidised bed. The ratings are from 1 to 10 with 1 being completely white and 10 being completely red. Both situations indicate stagnant zones in the fluidised bed.

1) Plate 1

The first plate, at low fluidising conditions, shows an average colour rating of 2.5, indicating poor mixing with mostly white particles. The colour rating of the top layer is slightly higher than other layers, as shown in Fig. 10. This is due to the injection nozzle injecting the colouring agent mostly into the top layer and particles not moving sufficiently within the fluidised bed for all particles to be discoloured.

At high fluidising conditions (Fig. 11), plate 1 shows an average colour rating of 2, with particles close to the door of the fluidising bed having a colour rating of higher than 5. This indicates that particles close to the injection nozzle are coloured extremely well and does not move around within the bed for colourant to be evenly distributed.

2) *Plate 2*

Plate 2 has a colour rating of 4 at low fluidising conditions. The colour rating is evenly distributed over the fluidising bed (Fig. 12), indicating that the fluidising conditions are favourable.

High fluidising conditions with plate 2 results in an average colour rating of 5.5 with a very close relation between the layers in the bed. Fig. 13 demonstrates the conditions are advantageous to the application at hand as excellent mixing was achieved throughout the fluidising bed.

3) *Plate 3*

Plate 3, at low fluidising conditions, indicates a colour rating of 3, with the bottom layer having the highest rating (Fig. 14). This is the result of too low fluidising fluid velocity, causing the particles to not travel high enough to reach the colouring liquid spray.

An average colour rating of 4 is achieved with plate 3 at high fluidising conditions, resulting in better distribution of the colouring agent than observed at low fluidising conditions (Fig. 15).

D. *Attrition breakage*

A qualitative observation shows that most attrition breakage occurs for plate 1 with an estimated 30 % top-size particles breaking into smaller sizes. Plate 2 results in the least attrition breakage, while plate 3 shows moderate to high breakage from top-size particles.

V. Conclusion

Plate 1 shows poor top-size particle distribution for both low and high fluidising velocities, with the lower fluidising velocity having worst results compared to the higher fluidising velocity. Colour profiling collaborates with the particle distribution analysis that the mixing for plate 1 is poor, with particles being almost completely white for both low and high fluidising velocities.

Plate 2 displays better mixing at a lower fluidising velocity compared to the higher fluidising velocity except for a stagnant zone in the left-hand side of the fluidised bed. High fluidising velocity also causes an increase in top-size particles in the top layer of the fluidised bed. Colour profiling shows that the distribution of colour is better at higher fluidisation velocity, supporting the analysis that a higher fluidising velocity causes particles to move up within the fluidised bed.

Plate 3 shows poor mixing at both low and fluidising velocities per the top-size particle distribution analysis. Colour profiling indicates the same results as distribution analysis with a higher fluidising velocity displaying slightly better mixing results compared to the lower fluidising velocity.

For both the particle size analysis as well as colour ratings, plate 2 shows better mixing and distribution of colour than plate 1 and 3. Fluidising conditions have an impact on the efficiency of the fluidising bed, with too low flow rates resulting in inefficient mixing whilst too high flow rates cause particles to move to the top without distributing through the fluidised bed.

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