Experimental And Theoretical Study on The Agglomeration Arising from Fluidization of Cohesive Particles

A project report submitted to

National Institute of Technology, Rourkela

In partial fulfillment of the requirements of

Bachelor of Technology (Chemical Engineering)

Submitted by

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2011

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CERTIFICATE

This is to certify that the thesis entitled "**Experimental and theoretical study on the agglomeration arising from fluidization of cohesive particles"**, submitted by **ASHUTOSH TIWARI** to National Institute of Technology, Rourkela is a record of authentic project work carried out by him under my supervision and is deemed fit for the partial fulfillment of the degree of Bachelor of Technology (Chemical Engineering) of the Institute.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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ACKNOWLEDGEMENT

It is with a feeling of great pleasure that I express my most sincere heartfelt gratitude to **Prof. (Dr.) Abanti Sahoo** for suggesting the topic for my project and for her ready and able guidance throughout the course of preparing report. I am greatly indebted to her for constructive Suggestions and criticisms from time to time during the progress of my work.

I thank Prof. (Dr.) R. K. Singh and Prof. (Dr.) H. M. Jena) for acting as the project coordinator.

I would like to extend my notion of thanks to Prof. (Dr.) K. C. Biswal, Head of the Department, Chemical Engineering for providing me the necessary opportunities to complete my project. I would also like to thank other staff members of my department for their invaluable help and guidance. Lastly, I thank all my class mates, who have helped me throughout during the completion of my project.

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Thanking you,

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ABSTRACT

Different aspects of agglomeration behavior of cohesive particles during fluidization have been studied in the present work. This work also helps in determining the agglomerate size during fluidization. Experiments were performed on both coarse particles and fine powders. The fluidization behaviors of these particles were thereby studied and effects of gas velocity on agglomerate size are also studied out by varying gas velocity, temperature and bed materials. Binding property of bed material plays a very important role in formation of agglomerates of cohesive particles in fluidized bed. Experimental and theoretical results indicate that agglomerate size tends to attain smaller size as the velocity of particle is increased.

Keywords: Agglomeration, cohesive particles, fluidization.

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NOMENCLATURE

Umf	Minimum fluidization velocity
$CaCO_3$	Calcium carbonate powder
TiO_2	Titanium dioxide powder
AGGLO	Agglomerate
FIG.	Figure
W	weight
Rho	density
F	Flow rate
T	Temperature
V	Volume of binder
Y	Ratio of final size of agglomerate and initial size.

CHAPTER-1

INTRODUCTION

INTRODUCTION

Particle technology as a basic technology has gained important place in the national economy in many sectors. Particle technology is that branch of science and engineering which deals with the production of materials, handling of materials, modification, and use of a wide variety of particulate materials, materials may be dry or wet, materials may be different sizes and the size of particulate materials ranging from nanometers to centimeters, so its scope is large and covers large range of industries which includes chemical, petrochemical, agricultural, food, pharmaceuticals, mineral processing, advanced materials, energy, and the environment. Particle technology can be seen as a good platform in near future.

According to (Nedderman,1992), approximately half of the particulate materials which are used in chemical industries and three quarter of raw materials are in granular form, and also large amount of sales is related to particle technology which reflects the importance of particle technology in chemical industries. Properteis of fine powders like high surface area-to-volume ratio and other special characteristics make them very attractive in the industries of advanced materials, food and pharmaceuticals etc. But the problem of handling these fine powders becomes much more difficult as their sizes become smaller.

According to the Geldart's classification of particles, particles can be divided into four types by size and density of material, namely type A, B, C and D. Fluidization quality is also related to particle properties such as particle size, its density, distribution of particle size and also on surface characteristics. As the size of the particle decreases the cohesive force between the particle increases. So as a result of this effect the fluidization of cohesive materials for fine particle becomes much more difficult in comparison to the larger size particle. The fine particle in Group C (small particle size and low particle density) fluidize poorly in Geldart's classification chart due to their strong inter-particle cohesive forces, exhibiting problems like channeling, in fluidized bed they form channels in resulting in no fluidization of particles and also tend to rise as a slug of solids. Group C particles are cohesive in nature (Geldart1973), are unsuitable for fluidization because they tend to form agglomerates since they are having strong interparticle forces between them. (Baerns.1966; Chaouki et al.,1985; Pacek and Nienow,1990; Ushiki,1995; Horio et al.,1996).

In some cases like for submicron and nanoparticles, which have the magnitude of interparticle force between particles is much stronger than the resulting gravitational forces, the bed of particles may exhibit a state of self-agglomerating fluidization due to the formation of stable and roughly mono-sized agglomerates (Molerus.,1982; Geldart et al.,1984; Rietema,1984; Jaraiz et al.,1992; Chaouki et al.,1985; Morooka et al.,1988).

Objective of this project is to study agglomeration nature of different type of particles including solid particles and fine powders also what are the different factors which affects the agglomerate size both experimentally and theoretically. Since the fluidization behavior and strength of cohesive particles primarily depends on particle size, strength and size distribution but it also strongly depends on other parameters which includes fluidization parameters, like gas velocity, nature of gas, temperature and humidity and also on external effects like mechanical vibration. Mechanical vibration is used in fluidization because to reduce the effect of channeling and agglomeration of particles. Including all this factors, handling of fine particle in fluidized bed is still extremely difficult. For example agglomerate size measurement and also coating and granulation of fine particle has been regarded as very difficult process.

CHAPTER-2

LITERATURE REVIEW

LITERATURE REVIEW

Fluidization is a process in which a granular material is converted from a static state which behaves like solid state to a fluid like state which behaves like an fluid and shows properties of fluid. This process occurs when a fluid either liquid or gas or both is passed up through the granular material which has to be fluidized. If a fluid is passed through a bed of fine particles at a low flow rate, the fluid passes through the void spaces between stationary the granular particles. This condition is called as fixed bed. With the increase in flow rate of liquid or gas, particles move apart and some vibrates in column. This situation is called as expanded bed. With a increase in velocity, a velocity is reached where all the particles are just suspended by upward moving fluid. This situation is considered as case of minimum fluidization and in this situation, the pressure drop across the particles in the bed equals the weight of fluid and particles in that section. Then bed is considered to be fluidized and it's called as to as minimum fluidization case and that minimum velocity is called as minimum fluidization velocity.

In our case we have to consider cohesive particles and its behavior in fluidized bed, its well known that quality of fluidization is very much dependent on properties of particle like size, density, size distribution and also its surface properties. According to Gel dart classification of particles, they are classified into four groups namely (A, B ,C and D) which is based on their fluidization characteristics. Fine powders which belong to C (cohesive particles) group are very difficult to fluidize because of strong cohesive forces between them resulting in formation of agglomerates. Agglomerate formation affects the powder properties in many ways such as powder flow ability and chemical reactivity. Considering various aspects of group c particles generally fine powders, their fluidization is very difficult in comparison to larger size particles.

Different aspects of agglomeration are given as follows:

2.1 PARTICLE AGGOMERATION:

Particle agglomeration is a process in which the fine particles which is in moist condition collide due to the turbulence and stick to each other, which results in the formation of agglomerates of powder material. Its clump of particles gathered together, which results in compact mass. The whole of the system remains constant so it's a mass conserving process but agglomeration results in conversion of smaller size particles into bigger size particles.

Particle agglomeration basically classified into two different categories which are

- Droplet Agglomeration.
- Surface Agglomeration.

2.1.2 DROPLET AGGLOMERATION: In this type of agglomeration particles are wetted or made moist with the help of drop of liquids, liquid which is a binder material is added from top of the column drop wise to achieve agglomeration of particulate materials. This agglomeration can be achieved by spraying the binding agent from the top of the column or above the bed in which fluidization has occurring. Stability of agglomerates depends upon the quantity of binding material taken; carbohydrates are good example of binding material. This agglomeration is generally used for powders in which content of sugar is relatively high. Such as milk sugar mixtures

2.1.2 SURFACE AGGLOMERATION: In this type of agglomeration we use either steam or warm moist air with a high relative humidity as a moistening agent for fine particles or powders. With the help of condensation wetting of particles is achieved here which a driving force in attaining stickiness to particles is resulting in formation of agglomerate. In case of skim milk powders we generally use surface agglomeration. In our setup warm air is provided to the material in fluidized bed with the help of heater and also binding material is added from top of column to achieve agglomeration of particulate material.

2.2 GELDART'S CLASSIFICATION OF PARTICLES:

The Geldart's classification system is used to identify and distinguish between the fluidization properties of particulate materials in a vertical gas-solid fluidized bed at given conditions. In this system, gas flows upward through a distributor with a velocity which is enough to fluidize the particle velocity but this velocity is not so much so that particle can go out of the column. According to this system, particles which show similar kind of fluidization behavior classified into the same group which is based on particle diameter and also on density difference of two phases.

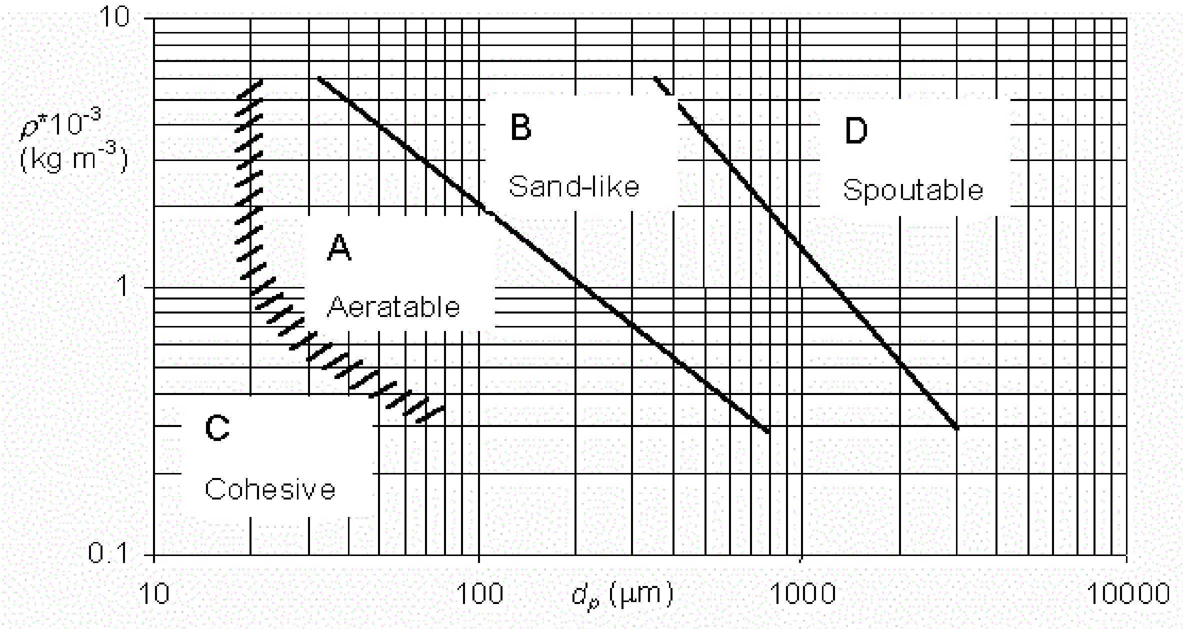

Figure Geldart's classification of powders according to fluidization properties

FIGURE 1: GELDART'S CLASSSIFICATION OF POWDERS

Here, we have to study the fluidization behavior of cohesive particles which is Group C particles and formation of agglomeration also. Cohesive particles are difficult to fluidize due to strong interparticle force between particles. (Geldart, Powder Technology,1973).

2.3 COHESIVE FORCES:

Cohesive force is a kind of physical property of the substance which shows the degree of magnitude of attraction between same kind of molecules which tends to unite molecules. Cohesion means stick together which shows the property of group C particles.

TABLE 1 : PROPERTEIS OF DIFFERENT TYPES OF PARTICLES(GELDART)

GROUP →	GROUP C	GROUP A	GROUP B	GROUP D
Most obvious characteristic	Cohesive. difficult to fluidize	Ideal for fluidization. Exhibits range of non-bubbling fluidization	Starts bubbling at Umf	Coarse solids
Typical solids	Flour, Cement	Cracking catalyst	Building Sand	Gravel, Coffee beans
PROPERTY ▼				
Bed Expansion	Low because of chanelling	High	Moderate	Low
De-aeration rate	Initially fast, then exponential	Slow, linear	fast	Fast
Bubble Properties	No bubbles - only channels	Bubbles split and coalesce. Maximum bubble size.	No limit to size	No limit to size
Solids Mixing	Very low	High	Moderate	Low
Gas Backmixing	Very low	High	Moderate	Low
Spouting	No	No	Only in shallow	Yes, even in deep beds

2.4 PROPERTEIS OF GROUP C PARTICLES:

Our main concern is with cohesive particles so here are the properties of Group C particles:

- These particles are difficult to fluidize and they have tendency to rise in column by forming slug of solids.
- They also form channels in fluidized bed which results in lower fluidization and sometimes no fluidization.
- They are having very strong tendency to be cohesive in nature which affects fluidization of particles because of strong cohesive forces between particles.
- Examples: Talcum powder, calcium carbonate, sugar powder, skimmed milk powder.

2.5. PREVIOUS WORKS:

Regarding agglomerate size analysis of cohesive particles several methods are introduced. Some of them are discussed here.

According to (Kono et al., 1990; Li et al., 1990; Wank et al., 2001; Xu et al., 2004) their experimental works shows that the particle size and its distribution not depends only on particle property but also dependent on other factors which includes fluidizing gas, gas humidity and its velocity, agglomerate sizes also depends upon external forces which includes the effect of mechanical vibration. Their works shows that due to the mechanical vibration agglomerate breaking and channeling problems can be removed which helps in easy fluidization of cohesive particles. Vibrators associated with fluidized bed are generally find it's applications in the areas of various powder processing process like granulation of particles, coating and drying of particle, particle mixing. Despite of various efforts, mechanical vibrator and effects of it on particle size a comprehensive study is yet to be done.

According to works of (Zhou and Li, 1999) which is based on fluidization of several fine powders shows that some of the particles will fluidized when the gas velocity is considerably higher than the minimum fluidization velocity of that gas, it's because of nature of cohesive particle. Some of the particles cannot be fluidized because of the formation of agglomerates. In their work they also show that drag force create by gas and the collision force between agglomerates counterbalance the force of cohesion and gravity force. This force based model shows agreement with their experimental data also. Similar kind of experimental work was also done by Bergstrom (1997) where the agglomerate size in fluidized bed is calculated with the help of force based model which uses drag force due to the gas and the van der Waals force between particles as its parameter.

Some of the models for calculating agglomerate size are also based on energy balance .According to Morooka et al. (1988), in which agglomerates cracks when energy generated by laminar shear stress and kinetic energy of agglomerate are equals to energy between particles which is cohesive energy. In this model, minimum fluidization velocity (U_{mf}) is used in place of superficial velocity in calculating the energy produced by laminar shear stress and moving energy i.e. kinetic energy of agglomerates, on this basis a lot of questions are asked on the reliability of this model.

Several work in past from (Noda et al.,1998; Wang et al.,1998;Venkatesh et al.,1998; Castellanos et al.,1999;Wank et al.,2001;Xu et al.,2004), shows that agglomerates which formed as a result of fluidization of cohesive particle are very fragile in nature so sampling of the particles is very difficult, different methods were developed to measure the size of agglomerates.

Various methods applied for studying the sampling technique of agglomerates particles,one of the method developed by Pacek and Nienow(1990) which was named as freezing method. In this method, before sampling of agglomerate particles the agglomerate granules were frozen with the help of binder solution mainly a solution of wax which is sprayed from the top of the fluidized bed. Another technique developed which is known as particle/droplet image analysis in which agglomerate size of particle which is present on top of the bed can be directly measured (Wank et al.,2001). But this two sampling processes has its own limitations because they can measure the agglomerate size of particle which is present on the top of the bed.

Iwadate and Horio (1998) also predicted the size of agglomeration with their different kind of approach. According to them agglomerate size can be predicted by simply balancing the cohesive force between particles and expansion forces which occurred due to bubble formation.

2.6. Fractional Factorial Design:

Full and fractional Factorial Design analysis is a very common in designed experiments for engineering and scientific applications. It is required in many cases to consider the factors which effect the production process at two levels. The experimenter would like to determine if any of these changes affect the production process. The most apt approach to study the variation due to these factors would be to vary the factors of interest in a full factorial design, and try all the possible combinations of the settings..

With two cube (2^3) Factorial Design Analysis, the correlation will be represented in the following form

$$Y_{ijv} = a_0 + a_1A + a_2B + a_3C + a_{12}AB + a_{13}AC + a_{23}BC + a_{123}ABC \quad (1)$$

If four or five factors are involved, the complete factorial might involve more than a practical number of experiments. A 2^5 factorial would require 32 experiments. By careful selection of the experimental conditions it is possible with only a fraction of the total experiments required for the complete factorial to determine the main effects by aliasing them with the higher order interactions which are usually not significant. The eight experiments required for a complete three factor, two level factorial can be used to determine the change required in four, five or under ideal conditions, even in seven experimental variables to obtain the maximum change in the response variable.

As (n-p) factorial design is set up and the p factors not included in the complete 2^{n-p} factorial are aliased with one of the higher order interactions to form a generating contrast.

CHAPTER-3

EXPERIMENTATION

The experimental set-up comprises of a fluidizer, heater,air compressor, rotameter, variac motor, and digital temperature measuring device, as shown in figure- 2. The experimental setup is used for testing of fluidization of different materials in which experiments regarding agglomerate forming and coating of solid particles and as well as for fine powders also. Set up consists of cylindrical column made up of glass; height and internal diameter are 60cm and 5cm respectively. Column is transparent in nature which enables us proper visualization of fluidization of particulate materials. Two different kinds of distributors are used in the apparatus this is because for handling different types of materials. For solids of larger size mesh screens are used for the fluidization but filter cloth of small thickness is used for fine powders to prevent the material loss of fine powder. Dry air is used for the purpose of fluidizing gas and the flow rate is controlled by rotameter.

FIGURE 2: LABORATORY SET UP

3.1 CONSTITUENTS OF EXPERIMENTAL SETUP:

The experimental set up consists of the following parts:

3.1.1. ROTAMETER:

Flow rate of air is measured with the help of rotameter. Range of rotameter varies from (0-120Nm^3/hr) is used for measuring air flow rates. With the help of rotameter different flow rates is obtained and also behavior of agglomerates also noted.

3.1.2. HEATER:

Heater is used to heat up the air which is passing through heater coils. The temperature of heater is maintained at different temperature with the help of variac by which fluidization at different temperature can be carried out. So by using heater hot air at different temperature can be provided to fluidized bed for carrying out agglomeration of cohesive particles.

3.1.3. VARIAC METER:

This is used in our experiment to control the temperature of air which is used in fluidization of cohesive particles. By varying this at different temperature air at different temperature can be obtained depending upon experimental situation.

3.1.4. TEMPERATURE MEASURING DEVICE:

This is digital instrument which helps in measuring the actual temperature of air which is going into fluidized bed, with the help of this we can set the temperature which is suitable for our needs. A temperature sensor is connected with the help of wire to this instrument and sensor is placed in the path of hot air which gives the actual temperature of the air.

3.1.5. DISTRIBUTOR:

Distributors are used for distributing gas velocity in fluidized bed. In our experiment we used two different kinds of distributors. One is kind of mesh screen of diameter 2 mm approximately and another one is cloth as a distributor, Mesh type distributors are used for solid particles of larger sizes like polypropylene balls, spherical glass beds of sizes 2.5-5 mm. For handling fine powders like $CaCO_3$, TiO_2 and sugar powder we use cloth of given thickness.

3.1.6. CYLINDRICAL FLUIDIZER:

The fluidizer in our experimental setup is cylindrical in shape and it's made of glass. Height of fluidized bed column is 60 cm and internal diameter of column is 5 cm. both ends of column is fixed.

3.1.7. SPRAYER:

The binder solution and the coating liquid are sprayed onto the bed from the top of the column through a sprayer and distributor of different sizes (2mm, 3mm, 4mm, and 5mm).

3.2. EXPERIMENTAL PROCEDURE AND MATERIALS:

In the present work, experiments were carried out on fine powders and coarse particles of small sizes. The procedure is almost same for both types of materials.

The sample size for coarse particles is measured initially and weight of the particles is also noted on which agglomeration studies are to be carried out. The bed height of the sample is measured, then the minimum fluidization velocity is also noted and then the bed was made to fluidize by slowly increasing the velocity. When the bed is fully fluidized some binding material is added from the top of the column. By adding binder, particles start to bind with each other resulting in formation of lump of particles. The lump size of particle is tried to be broken by increasing velocity. At the end of experiment, the size of particle which sticks to each other forming agglomerates is measured and the degree of coating and agglomerate size of final particle is thus calculated.

Similar process is also carried out for fine powders. The extent of velocity is less for fine particles in comparison with the coarse particles. But the degree of lump formation with the fine particles is more than that of coarse particles. Depending upon the amount of binder more and more powders tend to form agglomerates.

For the coating experiment of solid particles wheat flour was taken as our coating material and the solution of wheat flour was prepared, the solution of coating material was prepared for different concentration. Polypropylene balls, spherical glass beds and black peppers are particles on which coating experiment was done.

For the agglomeration experiment, sucrose solution acts as the binder and in the fluidized bed bed, different samples were taken which includes Calcium Carbonate powder ($CaCO_3$), Titanium Dioxide (TiO_2) powder and Sugar powder.

The initial average particle size of glass beads is 2.58mm, polypropylene balls are 5mm and black peppers is 3.5mm.

Calcium carbonate powder of average size 15 micron and density 0.7gm/cc, titanium dioxide of average size 25 micron and density 0.77gm/cc and sugar powder of average size 60 micron(µ) and density 0.6gm/cc were taken.

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CHAPTER-4

RESULTS AND DISCUSSION

4.1 RESULTS:

Three samples (glass beads, polypropylene balls and black pepper) were taken and wheat flour as coating material. And the results are shown in Table 2 for different materials and operating conditions. Here are our results of agglomeration forming behavior of cohesive particles in fluidized bed:

Table 2. Effect of various parameters on particle growth in a agglomeration experiment:-

SAMPLE/ PARAMETERS	GLASS BEADS I	GLASS BEADS II	POLYPROPYLENE BALLS(III)	BLACK PEPPER(IV)
INITIAL AVG SIZE (mm)	2.58	2.58	5	3.5
WEIGHT OF SAMPLE (gm)	100	100	35	40
FLUIDIZING AIR FLOW RATE (Nm^3/hr)	70	80	70	60
FLUIDIZING AIR TEMP.(^0C)	50	60	43	60
BINDER CONC.(gm/ml)	0.5	0.33	0.5	0.5
NEW AVG SIZE (mm)	3	3.2	5.75	4.75
Agglomerate size(mm)	10 * 5 mm Comprising of 7-8 glass beads	10*5mm Comprising of 7-8 glass beads	10*15mm Comprising of 7-8 glass beads	10*12mm Comprising of 8 - 12 glass beads

FIG.3 . Experimental result of coating on spherical glass beads.

FIG.4: Experimental result of coating On Polypropylene balls.

Figure 3 and Figure 4 shows the result of agglomeration of particles in fluidized bed, it shows that particle tend to agglomerate with each other whereas some or not. Initially with the effect of binder, solid particles forms lump of particles but as we increase the velocity, lump breaks into smaller particles in which 2-3 particles stick to each other resulting in agglomeration forming. Agglomeration of particle depends upon the nature of the surface characteristics. More rough nature of surface leads to larger agglomeration formation.

4.1.1 Variation of Binder:

This table shows the how the binder quantity affects the agglomeration of powders. Sample of $CaCO_3$ fine powders were taken. Effect of binder quantity on particle growth in an agglomeration experiment

TABLE 3:

Amount of powder(gm)	Density of powder(gm/cc)	Flow rate(Nm^3/hr)	Fluidizing air temp(^0C)	Amount of binder (ml)	AGGLO size formed(cm)	Fraction growth
30	0.7	45	50	25	3.44	2293
30	0.7	45	50	15	2.95	1967
30	0.7	45	50	10	2.495	1663

Binder quantity plays a very important role in formation of agglomerates. It is observed from the above table-3, the size of the agglomerates increases with increase in the amount of binding material. As the amount of binder varies, agglomeration behavior changes. As the binder amount increases particles tend to form more agglomerates but as amount of binder decreases agglomerate size are also reduced. Here same powder is taken but amount of binder is changed in every run.

Figure of calcium carbonate powder sample on next page shows the effect of amount of binder material on size of agglomerate.

FIGURE 5. Experimental results showing effect of binding material taken in considerable amount($CaCO_3$ sample).

FIGURE 6. Experimental result showing effect of binding material taken in less amount($CaCO_3$ sample).

4.1.2 Temperature Variation

Sample-sugar powder.

TABLE 4. Effect of temperature on particle growth in a agglomeration and coating experiment.

Amount of powder(gm)	Density of powder(gm/cc)	Flow rate (Nm^3/hr)	Fluidizing air temp(^{0}C)	Amount of binder (ml)	AGGLO size formed(cm)	Fraction growth
40	0.56	50	50	2	1.6041	267
40	0.56	50	60	2	1.27	211
40	0.56	50	70	2	0.817	13.616

Effect of temperature on agglomerate size shows that as the temperature of particle increased the agglomerate size is also reduced, since at higher temperature particles breaks into smaller part and thus particle size reduced.

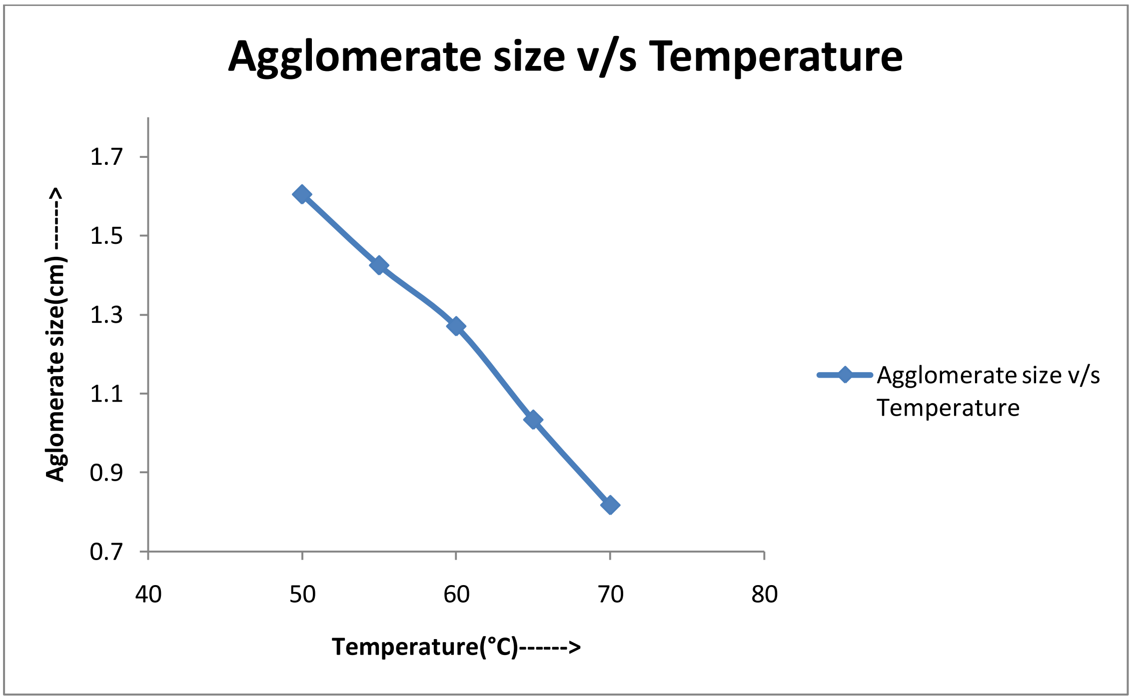

FIGURE: 7.Variation of agglomerate size vs. temperature.

4.1.3 Variation of amount of material in the bed: Sample-sugar powder.

Table 5**:** Effect of amount of initial material taken on particle growth in agglomeration experiment

Amount of powder(gm)	Density of powder(gm/cc)	Flow rate (Nm^3/hr)	Fluidizing air temp(^0C)	Amount of binder (ml)	AGGLO. size formed(cm)	Fraction growth
30	0.56	45	50	5	1.631	272
40	0.56	45	50	2	1.6041	267

In this set of experiment the flow rate and fluidizing air temperature are kept constant, only amount of material and binding material are changed. Here the agglomerate size of particles increases with increase the amount of binding material as shown in previous table 3 also. But as the amount of powder is increased, the volume of binding material requirement is reduced and thus there is reduction in size of agglomerates of powders.

4.1.4 Variation of material in the bed: Table 6**.** Effect of various materials taken on particle growth in an agglomeration experiment

Amount of powder(gm)	Density of powder(gm/cc)	Flow rate (Nm^3/hr)	Fluidizing air temp(^0C)	Amount of binder (ml)	AGGLO. size formed(cm)	Fraction growth
30	0.56	45	50	5	1.631	272
30	0.7	45	50	15	2.95	1966
30	0.77	45	50	5	0.57	228

Different sample of fine powders were taken with same initial amount. The flow rate and fluidizing air temperature are kept constant. Amount of binder is varied from 5 -15 ml, the results shows that as the density of particle is increased and amount of binder is kept constant, the resulting agglomerate size formed is smaller in comparison to lower density particle.

4.1.5 Variation of fluidizing velocity: sample-Calcium carbonate powder ($CaCO_3$).

Table 7. Effect of fluidizing air flow rate taken on particle growth in a agglomeration experiment

Amount of powder(gm)	Density of powder(gm/cc)	Flow rate (Nm^3/hr)	Fluidizing air temp(^{0}C)	Amount of binder (ml)	AGGLO. size formed(cm)	Fraction growth
30	0.7	60	50	15	2.21	1473
30	0.7	45	50	15	2.95	1967

This result were carried out on same particle in both run in which amount of sample taken, flow rate of air, amount of binding material and also the fluidizing temperature were kept constant. This shows that as the flow rate of air is increase there is clear declination in size of the agglomerates.

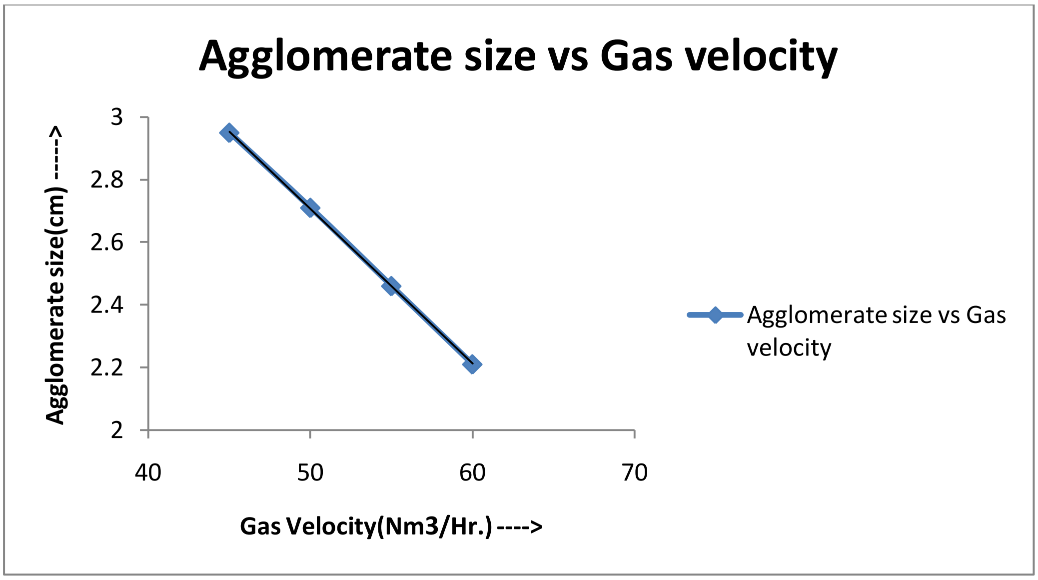

FIGURE.8.Variation of agglomerate size of particles with increase in flow velocity.

FIGURE.9: Low air velocity results in larger agglomerate particles.

FIGURE.10: Higher flow velocity results in smaller agglomerate particles

From above figure 9 and 10 it can be concluded that and also the from the graph of agglomerate size versus velocity obtained, shows that as the velocity of fluidizing air is increased results in the decrease in the size of the final agglomerate particle. Due to increase in velocity the intra-particle forces between cohesive particles tend to break so as a result of it particle- particle interactions decreases and thus breaks apart in smaller sizes agglomerates.

4.6. Statistical Analysis approach for Correlation: After getting all the experimental data's an attempt has been made to develop a statistical correlation showing the effects of various parameters such as weight of material in the column bed , type of material i.e., the density , fluidizing air flow rate , temperature of fluidizing air and the volume of binders sprayed on the fractional growth of granule. The correlation developed is

Y=ratio of final agglomerate size and initial agglomerate size.

Y(cal)=296.625+(-239)*A+247*B+(-185)*C+305*D+(-221)*E+275*AC+(-155)*BC… (2)

Y(exp.)	Expts.	A	B	C	D=ABC	E=AB	AC	BC	a0	a1	a2	a3	a4	a5	a13	a23
268	1	-	-	-	-	+	+	+								
271	a(de)	+	-	-	+	-	-	+								
500	b(de)	-	+	-	+	-	+	-								
240	ab	+	+	-	-	+	-	-								
268	c(d)	-	-	+	+	+	-	-								
256	ac(e)	+	-	+	-	-	+	-								
270	bc(e)	-	+	+	-	-	-	+								
300	abc(d)	+	+	+	+	+	+	+								
296.625									296.625	-239	247	-185	305	-221	275	-155

W	Rho	F	T	V	Y(expt.)	A-effect	B-effect	C-effect	D-effect	E-effect	AC-effect	BC-effect	Y(calc.)	%dev
30	0.6	32	50	10	268	-1	-1	-1	-1	1	1	1	167.625	37.45
40	0.6	32	70	2	271	1	-1	-1	1	-1	-1	1	191.625	29.289
30	0.77	32	70	2	500	-1	1	-1	1	-1	1	-1	2023.625	-304.72
40	0.77	32	50	10	240	1	1	-1	-1	1	-1	-1	-56.375	123.48
30	0.6	60	50	10	268	-1	-1	1	1	1	-1	-1	167.625	37.45
40	0.6	60	70	2	256	1	-1	1	-1	-1	1	-1	71.625	72.02
30	0.77	60	70	2	270	-1	1	1	-1	-1	-1	1	183.625	31.99
40	0.77	60	50	10	300	1	1	1	1	1	1	1	423.625	-41.208

Here percentage deviation is very large which implies that some of the measurement are not accurate but this method of sampling is primary and on that basis sizes were measured. A,B,C,D and E are the different parameters which affects the final value of quantity which has to be calculated.

4.2 DISCUSSION:

On the basis of our results several factors came into play which affects the particle agglomeration size in fluidized bed. Several factors like air velocity, amount of binding material, fluidizing air temperature, density of particle and surface characteristics of particles are very prominent factors in determining agglomerate size in fluidized bed.

- Effect of gas velocity is very important because with the increase in gas velocity, attrition among particles takes place and the agglomerates break down into smaller particles. From the table 7 the effect of gas velocity can be seen on the size of agglomerates. Here fluidizing air temperature, volume of binding material and amount of material were taken are constant, as the flow rate of air is increased the particles tend to break apart as a result of it magnitude of cohesive force is reduced.

- Depending upon the volume of binding material the growth mechanism of the particles takes place. If the amount of binder is more then agglomeration will result and if the volume is less then formation of small granules will take place. From table 3,it can be shown that when for same particle were taken in which fluidizing temperature and flow rate of kept constant, so as the amount of binding material is increased leads to formation of more agglomerates.

- Particle agglomeration also depends upon on temperature, if the temperature of fluidizing air is increased particle growth will take place but agglomerate size reduced. From table 4 effect of temperature study carried out on the particles which shows that higher the temperature of particle smaller the agglomerates formed.

- If the amount of particle in bed is less it will promote agglomeration and also if the surface of particle is rough in nature then it will help in coating of particle. In case of solid particles ex. Black pepper shows more tendencies towards coating because of its rough nature surface characteristics. From table 2, different sample of solid particles are taken in which surface properties are little bit different with each other, spherical glass beds, polypropylene balls and black pepper .Out of these samples, black pepper shows highest degree of coating.

- Agglomeration behavior also depends on binding property of material, in our sample $CaCO_3$ shows maximum binding properties among powders which results in more amounts of agglomerates.

CHAPTER- 5

CONCLUSION

CONCLUSION

It is observed that the agglomeration behavior of cohesive particles in fluidization varies with the different operating condition which was studied by using different types of fine powders and coarse particles. Due to strong interparticle force between cohesive particles, handling problem is associated with this material in industries, agglomeration problem results in de-fluidization of materials. Flow problems are also associated with cohesive particles leading to bridging, channeling.

In the present experiment the agglomerate nature of cohesive particles was observed and it was noted that agglomerate size of particle depends on various factors which include fluidizing gas velocity, air temperature and volume of binding material and surface characteristics of the particles. From experimental data it was observed that as the velocity of fluidizing gas is increased the size of agglomerate obtained was decreased. This experimental nature also shows agreement with other previous works and also with theoretical studies. Agglomerate size also depends upon nature of material taken, volume of binding material and temperature at which fluidization is carried out. The values that we obtained in our experiment can be assumed to be quite close to the real values.

Since fluidization process plays a very important role in industries and its applications lies in various field including pharmaceutical industries as well as in various medicine fields. Also helps in determining powder flow ability criteria with the help of this handling and transportation problems can be reduced in chemical industries. This process is also economical.

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