International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Investigation into Effect of Rotor RPM on Degree of Separation in Air Classifier

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Abstract: ***The development and performance optimization of an air classifier is an issue of great challenge and part of emerging nascent technology. Air classification is one of the emerging technological innovation system used in pharmaceutical, construction and powder industries. This technology uses air as a separation media and classifies a product by size, shape of granules and form. It is a dry classification method. Extensive literature survey has been done in this field but commercially available classifiers cannot be used for user specified purposes. The work here showcases all the empirical results obtained from the real time system analysis in various working conditions. The air classifier designed here is used in construction industry to separate the raw crushed sand obtained from mill into usable crushed sand (main product) and fine dust (secondary product). The capacity of the classifier is 5 tons/hour. The work is focused on settling velocity of particles in an air classifier depending upon rotor rpm. Theoretical and experimental studies are carried out to investigate the effect of settling velocities at various rotor rotations in rpm. Theoretical analysis was made to find the results and these results were then validated by experimental analysis. The desired optimum rotation is found out to be 276.7rpm, needed for classification of sand and to separate particles with size less than 2.36mm. The air flow and air velocity trajectory pattern was also studied using CFD analysis. The performance enhancement of air classifier with rotor rpm optimization could be considered as an innovation.***

Keywords: Air classifier, Centrifugal, Drag force, Settling velocity, Separation, etc.

1. Introduction

Air classification is a primitive process dates back to the 19th century. The process of winnowing of grains is the earliest known application of air classification. Air classification technology uses air as a separation media and classifies a product by size, shape of granules and form. It is dry classification method and it separates ultra-fines. This technology is used in several industries. Air classification, for different industries requires different methods of implementation and hence there exist several types of design solutions. The particles of rock, medium sized stones which in combination with fine powder of stones, are used as civil engineering material. These are called as aggregates. Aggregates or Construction aggregate is a broad category of coarse particulate material. It is used in construction and civil engineering works. It includes sand, crushed stones, gravel, recycled concrete etc. There are various tests carried on aggregate material, some of which are Sieve analysis (IS 2386 pt-1):1963, Specific gravity (IS 2386 pt-1):1963, Crushing value (IS 2386 pt-4):1963, etc. Lighter and very small particles of sand, which can be fluidized along with air, are called fines. Fines can be stated to be fine dust particles formed due to collision of stones in crushing mills. The feed includes aggregates and fines in varied quantity.

Air classification is an old technology. It is slowly evolving and some models have been created which adhere to the recent industrial requirements. Few theoretical, experimental and modeling studies have been performed. Industrial needs of the aggregates industry cannot be fulfilled by the use of commercially available air classifiers. Requirements between the industries differ according to desired cut size, production volume and classification efficiency. Depending on the industry requirement the goal of the classification process may differ. The main product for the aggregates industry is the coarse sized particles and the fines are secondary product. The primary concern with a classification system is the ability to effectively remove fines from a feed stream while also minimizing the loss of quality sand. The raw crushed sand is classified into two products which are usable crushed sand and fine dust of raw crushed sand. For industries involving aggregates there exist different problems. These problems depend on the specific requirement of that particular industry. The purpose here is to solve the specific industry problems by reducing the fines in usable crushed sand. The industry requires classification of sand in two categories, namely one with size less than 2.36mm (fines) and other equal to or greater than 2.36mm (coarse).

The air classifier designed is used in construction industry to separate the raw crushed sand obtained from mill into usable crushed sand and fine dust. This classification provides with the quality of the structure constructed using usable crushed sand. There are various factors affecting classification of test sand such as cut size, rotor rpm and guide vane angle. Study of various parameters is considered and the design of air classifier useful for construction engineering field is made. Analytical and experimental work is conducted and results are found. Also design analysis including CFD simulation is carried out in Solidworks.

2. Literature Review

The development of air classifiers started early in the 19th century and till now various studies and technological innovations have been incorporated in the design of air classifiers. The main purpose of the studies on air classifiers is the innovation in the designs and to analyze the effect of various parameters to increase the efficiency. The advancement in this technology is studied and is highlighted.

1. Shapiro, M. and V. Galperin [1] give us an overview is given of modern air classification devices and designs. Air classifiers may be distinguished by method of powder feed. Particles may be fed either within air stream, or separately by freely pouring them within the device. Choice of the classifier type is dictated by product requirements, technological and economic factors.

2. Okay Altun, Hakan Benzer, [2] In this paper various types of high efficiency classifiers operated at cement grinding circuits were sampled at the same cement quality then mass balancing studies were carried out. The sharpness parameter (α) was found to be dependent on the capacity of the separation process. Also the diameter of the classification chamber which made the model structure unique. Performance of a high efficiency classifier was influenced by feed dust loading, rotor speed and air flow.

3. Yongguo Feng , Jiaxiang Liu , Shengzhao Liu, [3] The authors conducted experimental tests of the classification performance and flow field measurement in a turbo air classifier. Air inlet velocity is held constant at about 8 m/s, and the intensity of the vortex is the least at a rotation speed of 600 r/min. Also air inlet velocity is held constant at about 18 m/s, and the intensity of the vortex is the least at a rotation speed of 1200 r/min.

4. C.Eswaraiah, S.S. Narayanan, S.Jayanti, [4] It gives the result that while the overall induced flow rate is proportional to the speed of rotation of the wheel, the circulation pattern inside the classifier depends on the configuration of stationary guide vanes. Results represent that the cut size, sharpness of separation, the bottom and top size selectivity increments are influenced strongly by the stationary guide vane configuration.

5. OkayAltun, AlperToprak, HakanBenzer, OzgunDarilmaz, [5], This paper focuses on investigating the classification behaviors of the components having different densities and flow characteristics then developing preliminary model structure where these properties are considered.

3. Design

3.1 Design of air classifier rotor

Air classifier consists double chamber with wheel, motor, v-belt and pulleys, VFD, support legs, platform, railing etc. In designing of an air classifier, the rotor design plays a vital role and so is the main component of the system. Designing of rotor needs some input values and from those values the rotor diameter can be decided. An air classifier of capacity 5tons per hour is to be designed for separating particle equal to and less than 2.36mm. Coarse particles which are of size more than 2.36mm are used as construction material along with cement to form concrete mixture. The particles less than 2.36mm size are to be used to make bricks. These particles act as good binding agents for making bricks.

Input parameters
Capacity:- 5ton/hour
Bulk density:- 500kg/m3
Static pressure:- 300mmwg
Air flow per ton (m3/hr)= capacity X bulk density=2500m3/hr
Air flow per ton (m3/min)=2500/3600=0.6944m3/min

In this system, the classification cut size is determined by both the rotor speed and the air velocity in the classification zone. The following equation is obtained. [15]

$$Dpc=(k\sqrt{Q})/N \qquad (1)$$

Where
D_{pc} = particle size = 2.36mm
k = constant
Q = Air flow in m3/min
N = rotor speed

From the above equation, by substituting values we get rotor speed as 276.7rpm

From this rotor speed and the peripheral velocity of rotor 10m/s the rotor diameter can be found out.

Rotor speed
Peripheral velocity of rotor = 10m/s
Rotor speed = 276.7rpm
Peripheral velocity of rotor= (π X Rotor blade tip diameter X Rotor speed)/(60 X 1000) (2)
Thus, Rotor blade tip diameter = 690mm
The selected standard rotor diameter = 750mm
No of blades = 8
Height of rotor = 430mm

For different capacities of feed material, the dimension of rotor, outer casing, the height of the classifier, etc. changes linearly.

The changes in the dimensions according to feed capacity are given in Table 3.1.1. These are the approximate dimensions and can be modified according to the user requirement.

Also the industry in which the air classifier is to be installed plays a major role and a deciding factor for dimensions and material to be used. For example, in pharmaceutical industry, anti-corrosive lining needs to be employed to prevent material corrosion. In milk powder and dry food powder industry, food grade quality material is compulsory.

3.2 Theoretical Analysis

In an air classifier, particles of varying size, shape and density are acted upon by fluid drag, gravity and buoyancy forces. Buoyancy is often neglected because the density of air is much lesser than the density of solid particles. When under free fall motion, particles accelerate continuously due to their weight, but the influence of a fluid drag force resists their free fall, that is the downward motion. When particles are fed to the air classifier, if the drag force exceeds the weight, particles get swept out of the top of the classifier. Conversely, when the weight exceeds the drag force, particles travel downwards and are collected at the bottom.

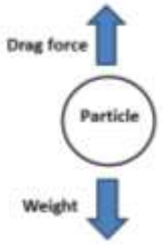


Figure.3.2.1 Force balance on particle

Fig.3.2.1 shows the drag force and the weight acting on the particle.

$$Drag\ force = \frac{\pi C_d \rho_g V^2 d_p^2}{8C_c} \tag{3}$$

$$Weight = \frac{\pi \rho_p g d_p^3}{6} \tag{4}$$

On equating drag force and particle weight, particle settling velocity (v) is written as

$$v = \left(\frac{4 \rho_p g d_p C_c}{3 C_d \rho_g} \right)^{1/2} \tag{5}$$

The above equation can be used to predict the necessary air velocity required for separation.
Assume spherical particles.
Where
ρ_g = air density= 1.225 kg/m^3
ρ_p = particle density=1680 kg/m^3
V= particle settling velocity
d_p = particle diameter
C_c = Cunningham slip factor = It is significant for the particle sizes <15µm, for air at ambient conditions
C_d = Drag coefficient of sand= 0.47
g = gravitational acceleration= 9.81m/s
The particle size (Diameter) has been taken as per Sieve analysis (IS 2386 pt-1):1963.
The particle settling velocities for particle sizes ranging from 10mm to 75µm are calculated and shown in Table 3.2.1.

Table 3.2.1: Particle Settling Velocity

Particle Size(Diameter)	*Particle settling velocity m/s*
10 mm	19.536
4.75 mm	13.464
2.36 mm	9.490
1.18 mm	6.710
600 µ	4.785
300 µ	3.383
150 µ	2.3926
75 µ	1.6918

The velocity can be easily found out for various rpm

$$v = r\omega \tag{6}$$

where
r = radius of rotor = 0.375m
ω = rotor rpm
v = linear velocity of particle
And the value is as given by the table below

Table 3.2.2: Particle Angular And Linear Velocity-Analytically

Sr.no	*Angular Velocity ω (rpm)*	*Linear Velocity v (m/s)*
1	200	7.854
2	300	11.781
3	500	19.635
4	1000	39.270

For separating the particles with size less than 2.36mm, a linear velocity nearly equal to 10m/s is needed. The velocity is 10.866m/s at 276.7rpm, obtained analytically.

3.3 Simulation Work

The simulation work includes geometric modeling of various components according to the design specifications, the assembly of the components with appropriate mates. The part modeling of components and the CFD analysis is carried out using solidworks software.

The following procedure was adopted to carry out simulation
1) Design analysis software used: Solidworks2013
2) Part Modeling of various components according to design dimensions
3) Assembly of the components
4) Providing rotational motion to the rotor in rpm and studying the velocity pattern
5) Animating the effect to clearly visualize the velocity pattern of air carrying fine particles.

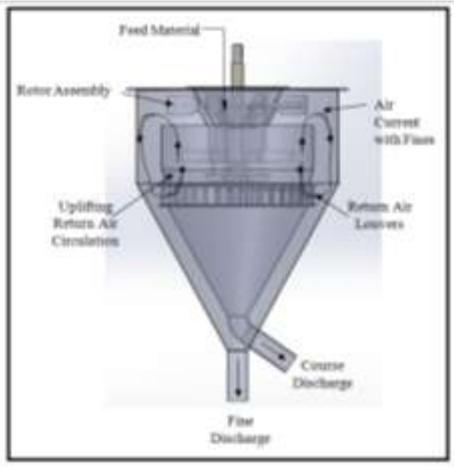


Figure.3.3.1. 3D Model of Air Classifier Assembly

The theoretical analysis and the experiment carried out gives the idea that the velocity needed to separate particles less than 2.36 mm should be nearly equal to 10m/s.

When CFD analysis of the assembly is carried out at the given environmental, inlet, outlet and the applicable boundary conditions, the velocity obtained at r=0.375m is 9.660m/s.

Also as particle rises due to the drag force it is carried along with air due to the velocity of air and gets transferred to the outer cone. The coarse and fine discharges are collected through the separate cone opening pipes as shown in Fig.3.

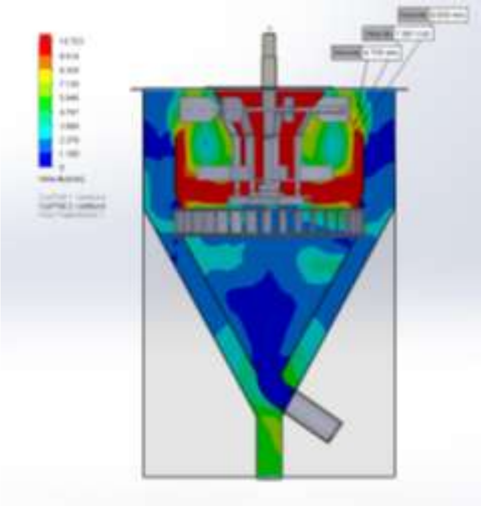


Figure 3.3.2: CFD analysis for velocity in an Air Classifier Assembly

3.4 Experimental Analysis

The experimentation is carried on a custom designed Air classifier for sand and cement industry. The experimental setup is as shown in Fig.2.

Figure.3.4.1 Experimental Set up

Table 3.4.1.Specifications

Sr.no.	*Description*	*Value*
1	Motor	10HP/2 Pole
2	Variable Frequency drive	ABB make 3-Phase; 380 to 480V at 50/60 Hz
3	Capacity	5 ton/hour

The working of air classifier system is as follows:

1) The feed material is fed through the top of the air classifier.
2) The rotor rotates with varying rpm with the use of VFD (variable frequency drive) and pulleys.
3) The rotational motion generates an air velocity which fluidizes the sand particles in air.
4) The velocity separates the fines from the coarse particles.
5) Coarse particles are collected through the inner cone and fines are collected through outer cone.
6) The velocity is measured by the use of anemometer at different rpm and rpm is measured by using digital tachometer.
7) The reading is noted and given by Table 3.4.2

Table 3.4.2: Particle Angular And Linear Velocity-Experimentally

Sr.no	*Angular Velocity ω (rpm)*	*Linear Velocity v (m/s)*
1	200	3.200
2	300	8.931
3	500	15.210
4	1000	30.624

The experiment was conducted at 276.7 rpm by adjusting the rotor rpm between 250rpm and 300rpm with the use of VFD as the particle separation obtained was optimum at this rpm. The velocity is 8.69m/s at 276.7rpm, obtained experimentally

4. Results and Discussions

Particles with the size less than 2.36mm are considered fines in this particular application of air classifier. Particles with a size greater than or equal to 2.36mm are considered coarse particles. Initially analytical studies were carried out to obtain the velocity and then experimental studies were made to obtain the values of velocity with practical approach.

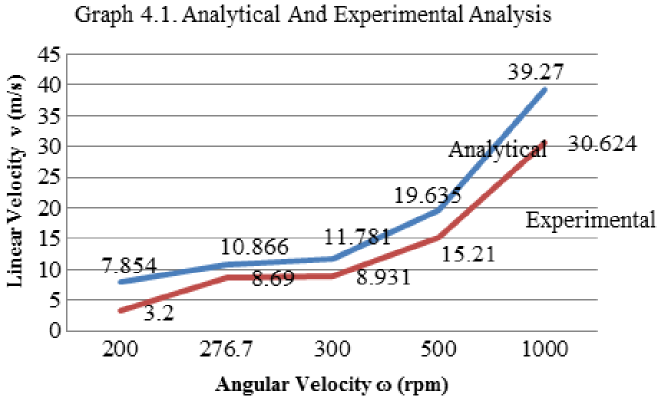
Table 4.1:Velocity-Analytically And Experimentally

Sr.no	*Angular Velocity ω (rpm)*	*Analytical Linear Velocity v (m/s)*	*Experimental Linear Velocity v (m/s)*
1	200	7.854	3.200
2	276.7	10.866	8.69
3	300	11.781	8.931
4	500	19.635	15.210
5	1000	39.270	30.624

The analytical and experimental results show similar values with some deviation. This deviation can be found out in terms of percentage.

Table 4.2: Percentage Difference In Analytical And Experimental Values

Analytical Linear Velocity v (m/s)	*Experimental Linear Velocity v (m/s)*	*Difference between analytical and experimental values*	*Percentage difference*
7.854	3.200	4.654	59.25%
10.866	8.69	2.176	20.02%
11.781	8.931	2.850	24.19%
19.635	15.210	4.425	22.53%
39.270	30.624	8.646	22.01%

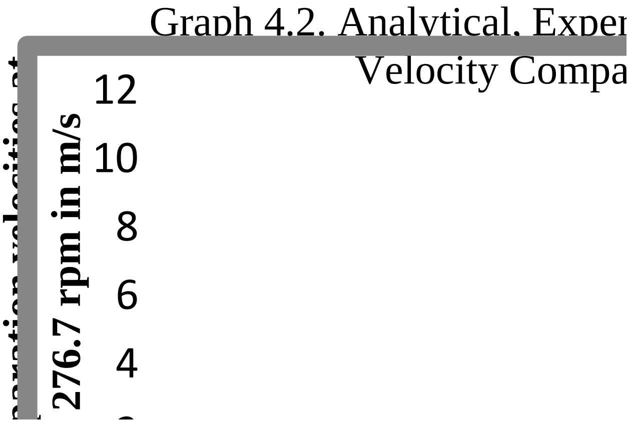


It is observed that the least percentage deviation is 20.02% and it is for 276.7rpm. This means that the velocity is least deviated at 276.7rpm value and the separation of particles less than 2.36mm can be optimized at this velocity.

Implementation of the method of Computational fluid dynamics is carried out in accordance with the specific need to obtain particles less than 2.36mm. The velocity obtained through CFD analysis nearly matches the experimental and analytical value.

Table 4.3:Comparison Of Particle Separation Velocities At 276.7 Rpm

Angular Velocity ω (rpm)	*Analytical velocity m/s*	*Experimental velocity m/s*	*CFD velocity m/s*
276.7	10.866	8.69	9.660



5. Conclusion

The correlation between velocity from analytical calculation and experimentation shows a good agreement. Also the value of generated velocity in CFD simulation is obtained and has a good match with the theoretical and experimental value. The velocity at particular needed location is adequately captured in the analysis. The effect of rotor rpm in the form of velocity is studied to find out the degree of separation of fines from coarse material in an air classifier. Comparison between the analysis show that there is very less difference between velocity values of analytical, experimental and simulation results. **The optimum rotor rpm of 276.7rpm gives the desired degree of separation for the Industrial purpose.**

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