Particle Collection Efficiency as Affected by Blower Impeller Speed in a Stairmands High Efficiency Cyclone

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***Abstract*– A study of several cyclone efficiency curves reveal that particle sizes ranging from about 25 – 100 µm are readily collected with efficiency above 85%. Very low percentages of fine particles (below 25µm) are collected with conventional cyclones, whereas collection of higher percentage of fine particles is achieved using high efficiency cyclones. In order to maximize fine particle collection, a Stairmand's cyclone was run on several entry velocities ranging from 9.15m/s to 24.08m/s. These entry velocities were achieved with the help of a micromill run at speeds between 1500rpm and 3750rpm with 250rpm increments. 2kg of toasted soyabean seeds of moisture content 9.05% (db) were crushed within an average time of 10mins and delivered into the cyclone. Samples were collected after each run and analyzed using an Ocular micrometer. Particle sizes obtained ranged from 0.1µm to 100µm. Analysis showed that the highest percentage of fine particles collected occurred at inlet velocity of 17.14m/s corresponding to 2500rpm with a value of 90%. The data obtained from this analysis would be useful in poultry feed, pharmaceutical, chemical and other such industries where specific particle sizes are required in the production of feed, drugs and chemical compounds.**

***Keywords*– Inlet Velocity, Cyclone, Particle Size and Percentage Collection**

I. INTRODUCTION

A Dust Collector is a system used to enhance the quality of air released from industrial and commercial processes by collecting dust and other impurities from air or gas. Designed to handle heavy dust loads, a dust collector system consists of a blower, dust filter, a filter-cleaning system, and a dust receptacle or dust removal system. One of the earliest centrifugal dust collectors used in the industry today is the mechanical cyclone [1]. Cyclones use inertial force to separate particles from a gas stream and because this inertial force is applied in a spinning gas stream, the inertial force is often termed centrifugal force. The first step in particle capture is the accumulation of particles along the inner wall of the cyclone due to centrifugal force. For vertically oriented cyclones, settling the particles into a hopper is the second step in the overall process of particle capture. However, unlike electrostatic precipitators and fabric filters, there is little, if any, particle agglomeration to facilitate gravity settling, until the particles reach the cyclone tube discharge spout. The particles settle at a rate that is dependent partially on their terminal settling velocities. These settling rates are quite small for particles less than 10 micrometers in diameter. Fortunately, most particles in vertical cyclones also retain some momentum toward the hopper due to the motion of the gas stream passing through the cyclone. The combined effect of gravity settling and the momentum from the gas stream are sufficient to transport the particles from the cyclone wall to the cyclone tube discharge, and eventually to the hopper [2]. Several factors affect the performance of a cyclone collector. The more important ones are the size and density of the particles, the gas velocity through the unit, the cyclone diameter, and the residence time of the gases in the cyclone. Since inertial forces are used to separate the particles from the gas stream, collection efficiency increases as the size and density of the particle increases and as the gas velocity through the unit increases. Centrifugal force increases as the radius of turn decreases. As a result, smaller diameter cyclones are more efficient than larger diameter cyclones [2].

In dust collection equipment, most or all the collection mechanisms may be operating simultaneously. Their relative importance is normally determined by the particle and gas characteristics, the geometry of the equipment and the fluid-flow pattern. It is usually possible in specific instances to determine which mechanism or mechanisms may be controlling the action in the cyclone, though the general case is exceedingly complex. Nevertheless, the difficulty of theoretical treatment of dust collection phenomena has made necessary, simplifying assumptions with the down-side being the introduction of corresponding uncertainties. Theoretical studies have been hampered by a lack of adequate experimental techniques for the verification of predictions [3]. These theoretical treatments of collector performance have been greatly expanded over the years but few of the resulting performance models have received adequate experimental confirmation within a given scope of experimental limitations. Various works abound in literature on cyclones. Ter linden [4] studied the efficiency and also pressure drop characteristics of a cyclone where he was able to vary one dimension at a time. He showed that increasing the dimension of the cyclone diameter relative to the outlet diameter gave an increase in efficiency until a 3: 1 ratio was achieved, after which further diameter increases have little effect on the efficiency.

Goldfield and Fortin [5] found that for a given flow rate, as the diameter of the outlet duct decreases, the pressure drop increases due to the added pressure drop associated with higher outlet velocity. Browne and Strauss showed how a 22 percent reduction in pressure drop can be achieved by first de-swirling the outlet flow and diffusing the resulting axially dominated flow to recover velocity energy as pressure energy [6]. Wang et al., [7] reported that cyclone performance is a function of the geometry and operating parameters of the cyclone, as well as the particle size distribution of the entrained particulate matter while Paul et al., [8] using four levels of air reported the effects of particle size and inlet velocity on cyclone separation process. From the foregoing literature review, it can be alluded that the effects of impeller angular speed on particle collection in a cyclone has not been fully established.

This work analyzed particle collection efficiency in a Stairmand's high efficiency cyclone. This was aimed at establishing the maximum fine particles (below 15m) that can be collected in the cyclone within an average crushing time of 10mins.

II. MATERIALS AND METHODS

The Stiarmand's high efficiency cyclone used had; diameter (D) = 300mm; inlet height = gas exit diameter = vortex finder = 0.5D; body length = 1.5D; width = 0.2D; cone length = 2.5 D and dust outlet diameter = 0.375D. The experiment was carried out in normal conditions of temperature and humidity ($30^oC \pm 2\ ^oC$ and 70 -76% RH). The pitot tubes and manometers used were fabricated locally, calibrated and impeller angular speeds were limited to ten (with equal increments of 250rpm) starting from 1500rpm. Toasted soya bean of moisture content 9.05% (db) was reduced to dust (flour) using a micro-mill. The dust was delivered to the cyclone via a blower and Perspex tube with consequent monitoring of the flow of air and dust through the different segments of the cyclone using calibrated Pitot tubes to which manometers were attached.

III. PARTICLE ANALYSIS RESULT

The analyses of the particles were carried out at the department of Pharmaceutics, University of Nigeria Nsukka with an Ocular micro-meter (Karl Kaps; Nr: 39773). The ranges of micron particles in each collection were (0-5, 5.1 – 10, 10.1 – 15, 15.1 – 20 and 20.1 – 100 microns) are shown in tables 1-10. The micrographs of the particles are also shown in fig 1-10.

From Table 1 and Table 2 it was observed that particle sizes above 15µm had percentage collection of 58% and 56% for speeds of 1500 and 1750 rpm respectively, implying high coarse particle collection. This is better depicted in figs 11 and 12. However, the micrographs (figs 1 & 2) show a few "dark spots" indicating lesser fine particle collection as the "dark spots" were formed by fungal growth as a result of agglomeration of particles and biological activity of the samples at the stated moisture content.

Speeds of 2000 to 2500rpm showed a shift in trend with more fine particles (below 15µm) collected corresponding to 54, 72 and 90% respectively as depicted in the bar charts in figs 13 - 15. This is also shown in the micrographs (figs 3-5) as there are more occurrence of "dark spots" as the speeds increased indicating more agglomeration and fungal growth. The trend of finer particle collection continued for speeds of 2750, 3000 and 3250 rpm with values of 84, 88 and 78 respectively (figs 16-18). This shows that as speeds increased, better size reduction was achieved in the micro-mill and finer particles delivered to the cyclone for collection. Speeds of 3500 and 3750rpm gave fine particle collection percentages of 70 and 78% (figs 19 & 20) showing a slight drop from previous speeds and could have been as a result of velocity approaching Saltation velocity.

The cumulative percentage collected for particle sizes within the range of 0.1 to 15 microns were 42, 44, 54, 72, 90, 84, 88, 78, 70 and 78% respectively for all the speeds in increasing order of magnitude. This shows that speed of 2500 rpm had the best cumulative collection percentage (90%) for this particle size range (< 15µm). The cumulative frequencies in percentages were plotted against these particle size ranges and the results are presented in figs 21 to 30. The graphs were in line with what was expressed by researchers such as Calceto and Coulson and Richardson [1, 13] on cyclone efficiency. It is expected that these plots would aid in determining cyclone efficiency for any particular range of particle size for this type of cyclone.

IV. CONCLUSION

From the experimental results it can be concluded that:

- Fine particle collection efficiency of this Stairmands cyclone is maximized at entry velocities between 17.14m/s and 19.08 m/s.
- Speed of 2500rpm gave the highest fine particle collection of 90%.
- Speeds of 2750 to 3750rpm also showed high fine particle collection percentages.
- From the cumulative plots (figs 21-30), speeds of 2250-3000rpm showed similar trend of cyclone efficiency curves. The rest gave differing trends.

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Table 1: Data from Ocular Micrometer for 1500 rpm speed

Part Size Range	Freq	% Collection
0.1 -5	5	10
5.1 -10	6	12
10.1 -15	10	20
15.1 - 20	14	28
20.1 - 100	15	30

Table 2: Data from Ocular Micrometer for 1750 rpm speed

Part Size Range	Freq	% Collection
0.1 -5	5	10
5.1 -10	8	16
10.1 -15	9	18
15.1 - 20	13	26
20.1 - 100	15	30

Table 3: Data from Ocular Micrometer for 2000 rpm speed

Part Size Range	Freq	% Collection
0.1 -5	7	14
5.1 -10	9	18
10.1 -15	11	22
15.1 - 20	13	26
20.1 - 100	10	20

Table 4: Data from Ocular Micrometer for 2250 rpm speed

Part Size Range	Freq	% Collection
0.1 -5	9	18
5.1 -10	14	28
10.1 -15	13	26
15.1 - 20	10	20
20.1 - 100	4	8

Table 5: Data from Ocular Micrometer for 2500 rpm speed

Part Size Range	Freq	% Collection
0.1 -5	15	30
5.1 -10	18	36
10.1 -15	12	24
15.1 - 20	5	10
20.1 - 100	0	0

Table 6: Data from Ocular Micrometer for 2750 rpm speed

Part Size Range	Freq	% Collection
0.1 -5	17	34
5.1 -10	13	26
10.1 -15	12	24
15.1 - 20	7	14
20.1 - 100	1	2

Table 7: Data from Ocular Micrometer for 3000 rpm speed

Part Size Range	Freq	% Collection
0.1 -5	17	34
5.1 -10	16	32
10.1 -15	11	22
15.1 - 20	3	6
20.1 - 100	3	6

Table 8: Data from Ocular Micrometer for 3250 rpm speed

Part Size Range	Freq	% Collection
0.1 -5	19	38
5.1 -10	15	30
10.1 -15	5	10
15.1 - 20	5	10
20.1 - 100	6	12

Table 9: Data from Ocular Micrometer for 3500 rpm speed

Part Size Range	Freq	% Collection
0.1 -5	16	32
5.1 -10	14	28
10.1 -15	5	10
15.1 - 20	12	24
20.1 - 100	3	6

Table 10: Data from Ocular Micrometer for 3750 rpm speed

Part Size Range	Freq	% Collection
0.1 -5	19	38
5.1 -10	15	30
10.1 -15	5	10
15.1 - 20	5	10
20.1 - 100	6	12

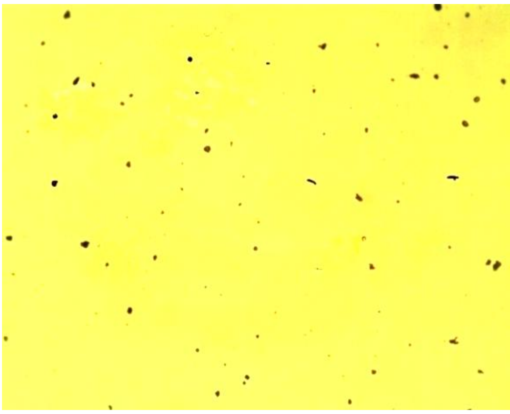

Fig. 1: Micrograph for 1500 rpm sample

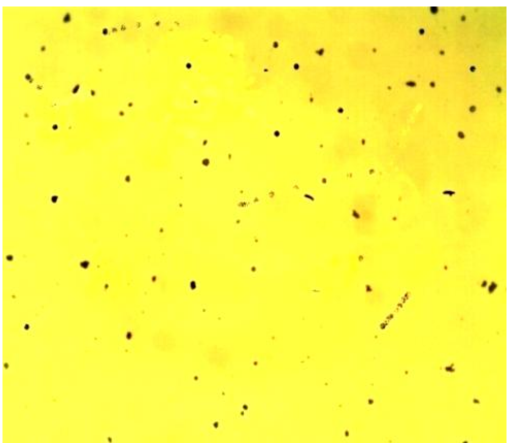

Fig. 2: Micrograph for 1750 rpm sample

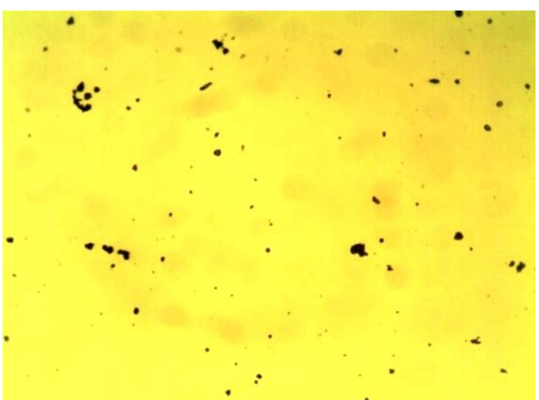

Fig. 3: Micrograph for 2000 rpm sample

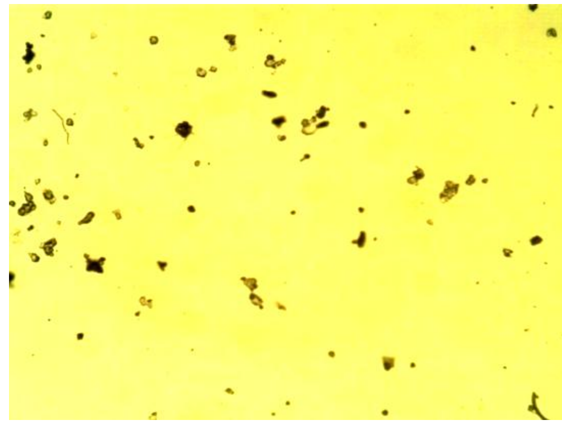

Fig. 4: Micrograph for 2250 rpm sample

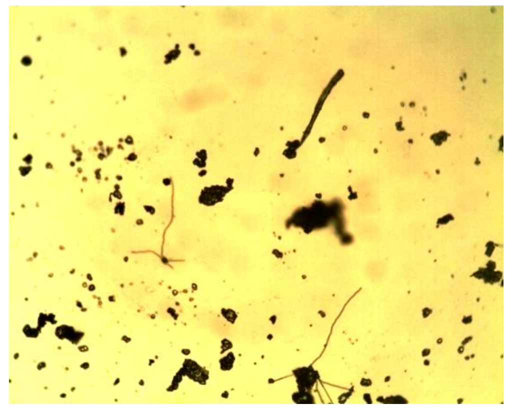

Fig. 5: Micrograph for 2500 rpm sample

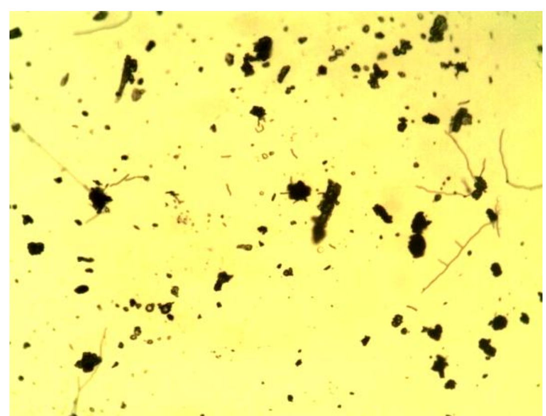

Fig. 6: Micrograph for 2750 rpm sample

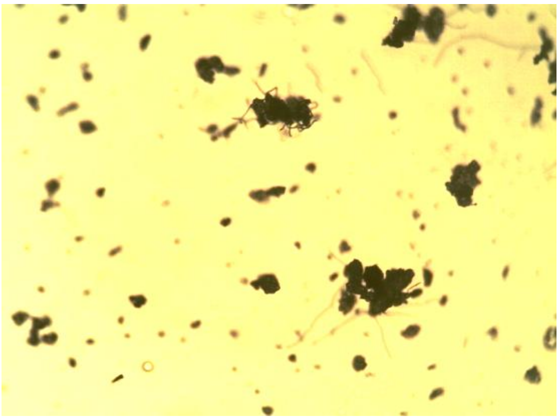

Fig. 7: Micrograph for 3000 rpm sample

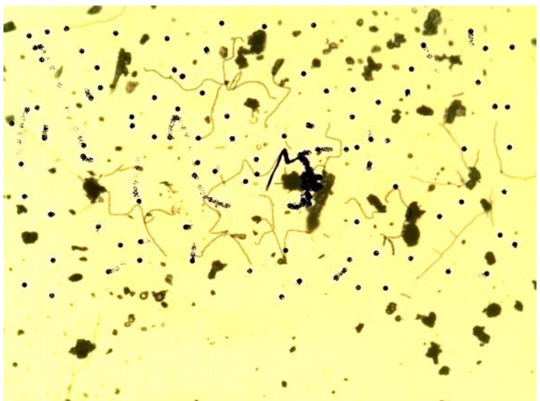

Fig. 8: Micrograph for 3250 rpm sample

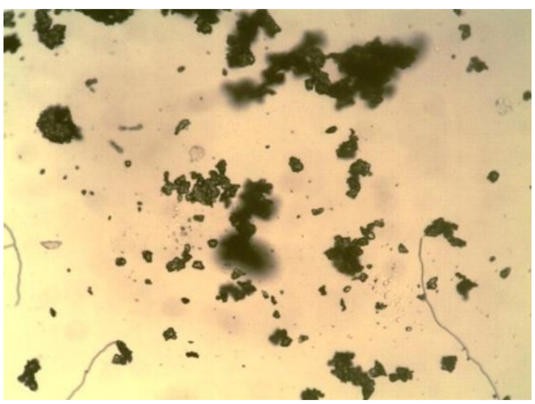

Fig. 9: Micrograph for 3500 rpm sample

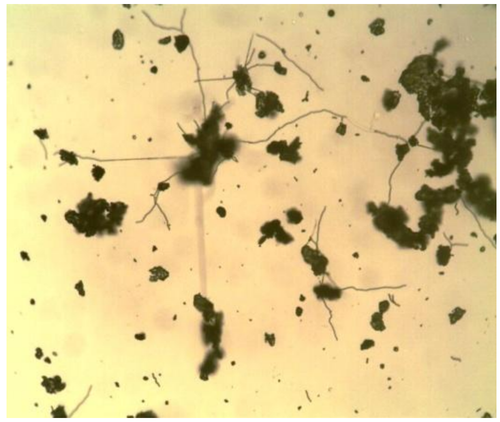

Fig. 10: Micrograph for 3750 rpm sample

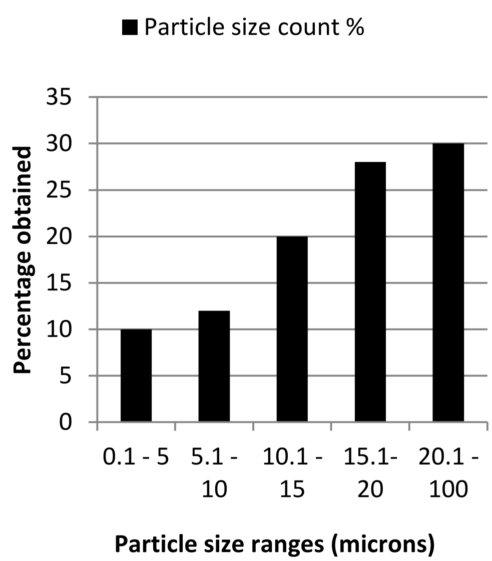

Fig. 11: Percentage particle count (1500rpm)

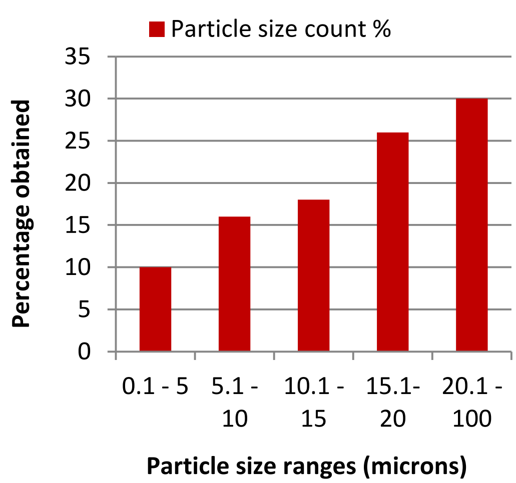

Fig. 12: Percentage particle count (1750rpm)

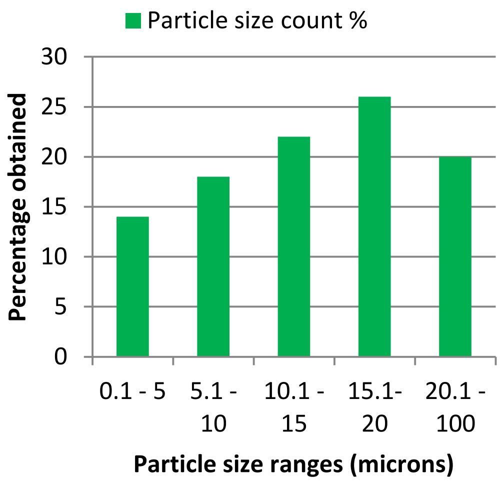

Fig. 13: Percentage particle count (2000rpm)

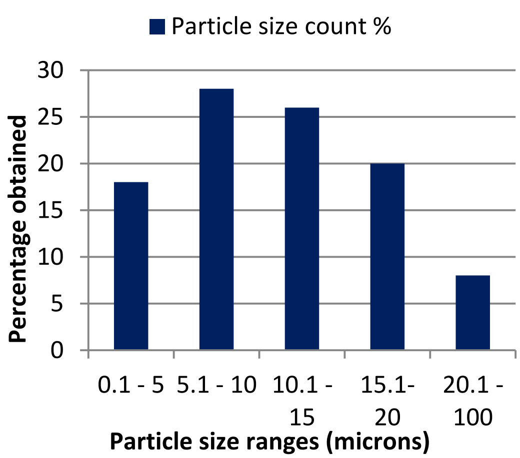

Fig. 14: Percentage particle count (2250rpm)

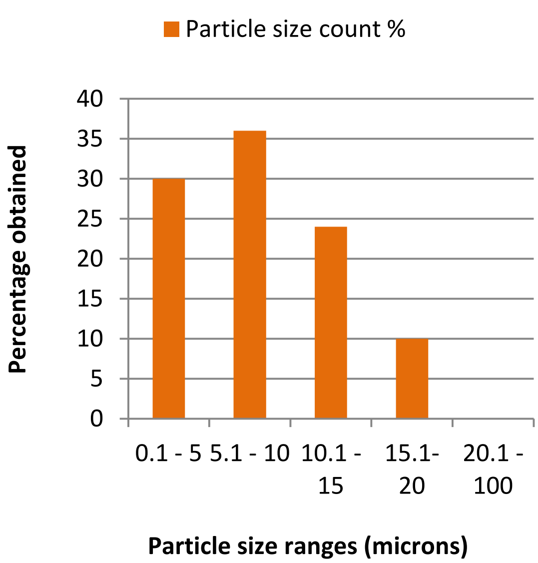

Fig 15: Percentage particle count (2500rpm)

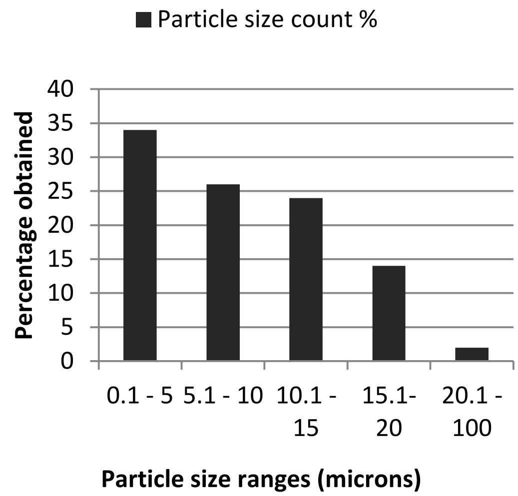

Fig. 16: Percentage particle count (2750rpm)

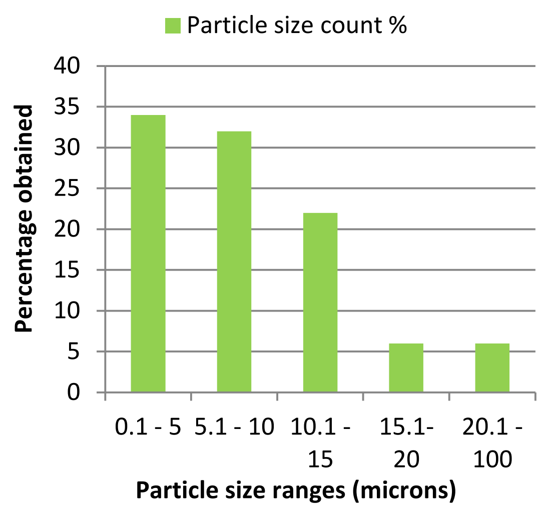

Fig. 17: Percentage particle count (3000rpm)

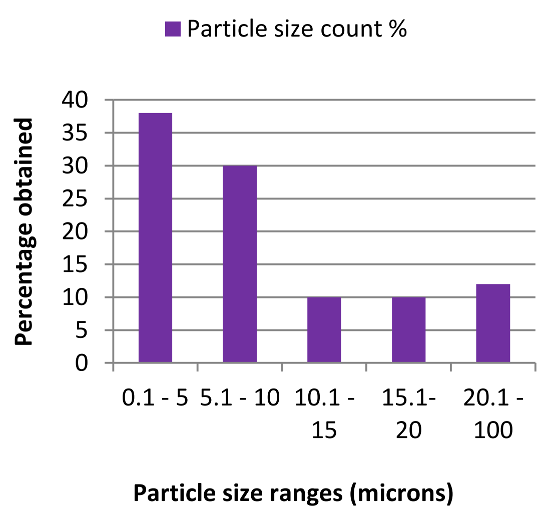

Fig 18: Percentage particle count (3250rpm)

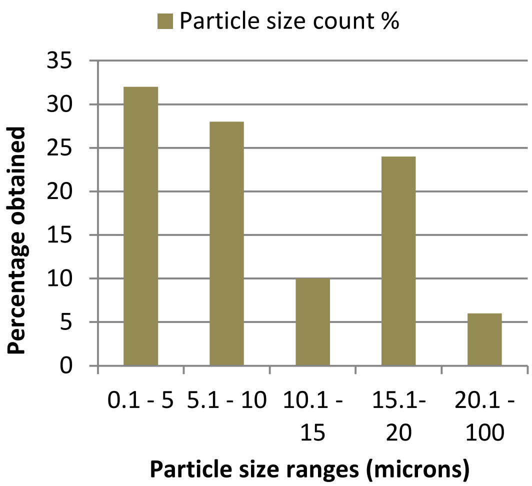

Fig. 19: Percentage particle count (3500rpm)

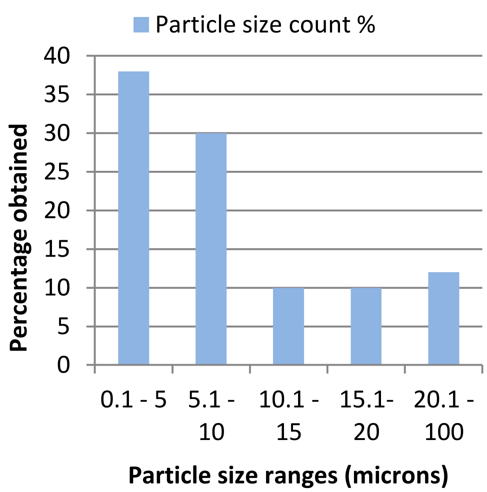

Fig. 20: Percentage particle count (3750rpm)

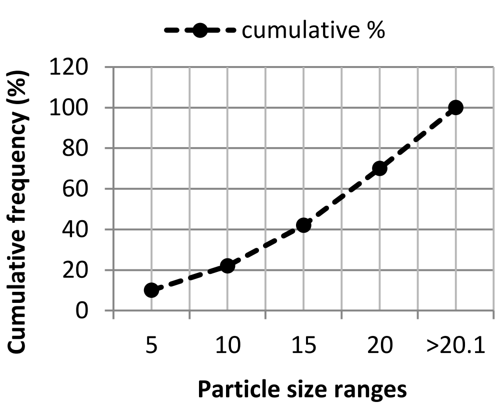

Fig. 21: Cumulative plot for 1500 rpm speed

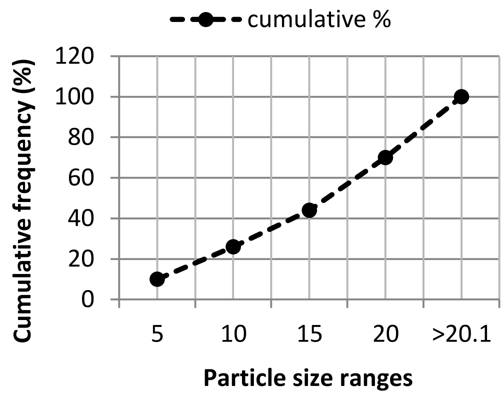

Fig. 22: Cumulative plot for 1750 rpm speed

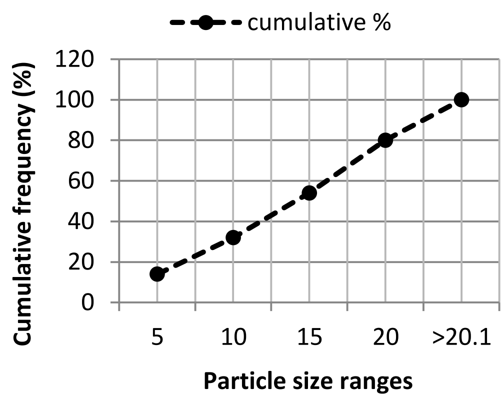

Fig. 23: Cumulative plot for 2000 rpm speed

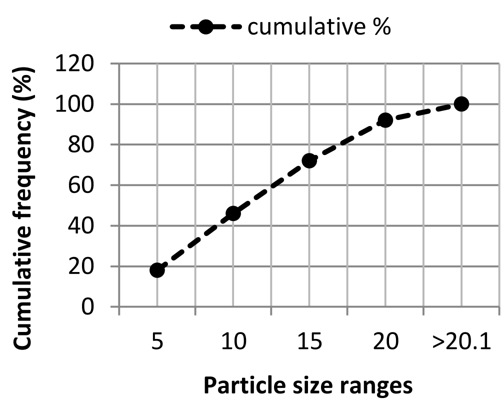

Fig. 24: Cumulative plot for 2250 rpm speed

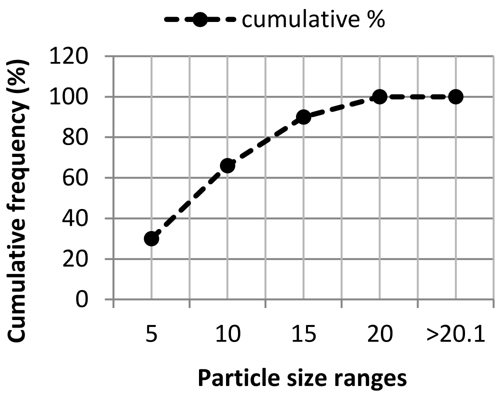

Fig. 25: Cumulative plot for 2500 rpm speed

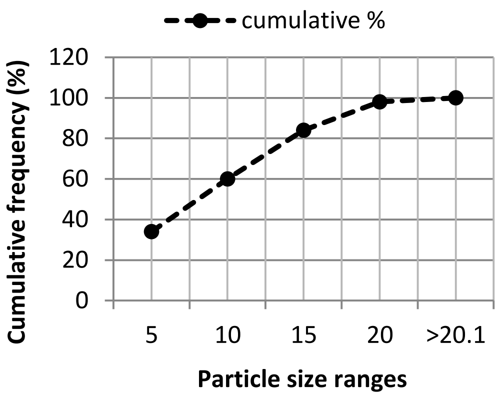

Fig. 26: Cumulative plot for 2750 rpm speed

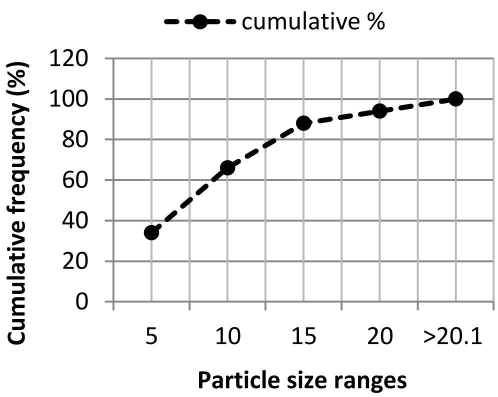

Fig. 27: Cumulative plot for 3000 rpm speed

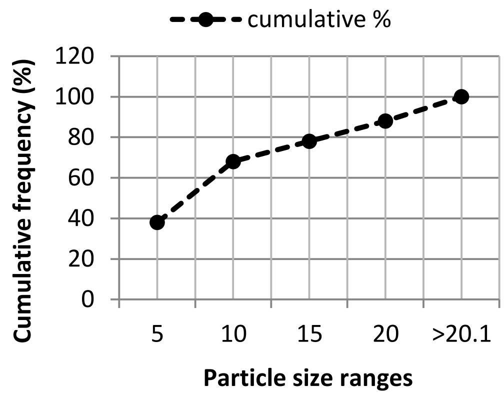

Fig. 28: Cumulative plot for 3250 rpm speed

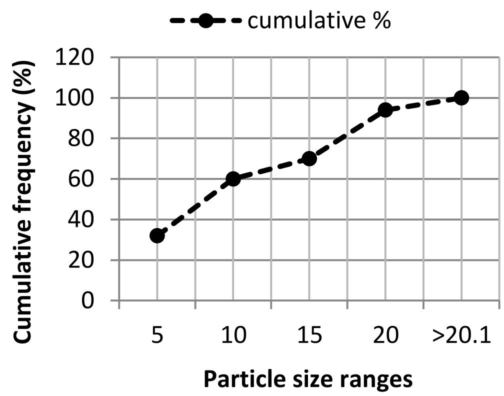

Fig. 29: Cumulative plot for 3500 rpm speed

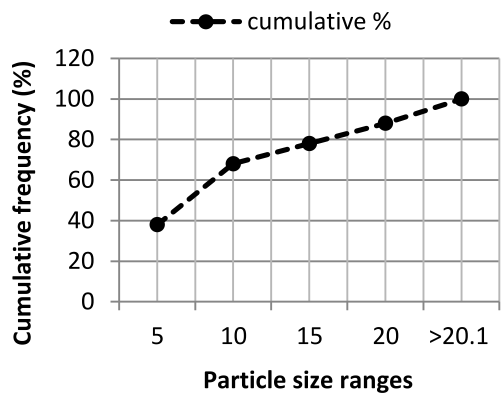

Fig. 30: Cumulative plot for 3750 rpm speed