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Correlation Between Entry Velocity, Pressure Drop And Collection Efficiency In A Designed Stairmands Cyclone.

Oriaku, E.C., Agulanna C.N., Edeh C.J. And Adiele I.D.
*Engineering Research; Development and Production **(ERDP)** Department.*
*Projects Development Institute, **(PRODA)** Emene, Enugu.*

Abstract: - Three non physical parameters are of interest in an assessment of the design and performance of a cyclone. These parameters are inlet velocity, pressure drop and collection efficiency of the cyclone. An accurate prediction of cyclone pressure drop is very important as it relates directly to operating costs. Variation of entry velocities to the cyclone results in variable collection efficiencies for a given cyclone, with a decrease or increases in the pressure drop across the cyclone. An experimental rig comprising a micromill connected to a Stairmands high efficiency cyclone and toasted soyabean of moisture content 9.05% db was employed in this study. Entry velocity was varied from 9.15 to 24.08m/s with corresponding particle collections noted, and pressure drop across the cyclone investigated. Analysis of the data generated revealed that higher resulted to velocities give higher collection efficiencies to a certain level for the cyclone, though this increased the pressure drop across the cyclone. A correlation study of the entry velocities, pressure drops and collection efficiency was carried out and the results analyzed. The correlation coefficient showed that for a given pressure drop determined by entry velocity, collection efficiency can be predicted.

Keywords: *- Correlation coefficient, Cyclone, Inlet velocity, Pressure drop, Particle collection efficiency*

I. INTRODUCTION

Cyclones are devices that employ a centrifugal force generated by a spinning gas stream to separate particles from the carrier gas (Gimbun et al., 2005). Fluid mixture enters the cyclone and makes a swirl motion and, due to centrifugal force, the dense phase of the mixture gains a relative motion in the radial direction and is separated from main flow (Avci and Karagoz, 2003). Cyclone separators are the simplest and least expensive dust collection devices for industrial air pollution control. Operation and maintenance are simple because they have no moving parts. Cyclone collection efficiencies can reach 99 % for particles bigger than 5 µm, and can be operated at very high dust loading(Cooper and Alley, 2002).. Cyclones are used for the removal of large particles for both air pollution control and process use (Silva et al.,2003). Application in extreme condition includes the removing of coal dust in power plant, and the use as a spray dryer or gasification reactor (Gimbun, 2005). Engineers are generally interested in two parameters in order to carry out an assessment of the design and performance of a cyclone. These parameters are the collection efficiency of particle and pressure drop through the cyclone (Dirgo and Leith, 1985).

An accurate prediction of cyclone pressure drop is very important because it relates directly to operating costs. Higher inlet velocities give higher collection efficiencies for a given cyclone, but this also increases the pressure drop across the cyclone (Griffiths and Boysan, 1996). The vortex finder size is an especially important dimension, which significantly affects the cyclone performance as its size plays a critical role in defining the flow field inside the cyclone, including the pattern of the outer and inner spiral flows. The vortex finder affected the collection efficiency and pressure drop of cyclones, and proposed an energy-effective cyclone design (Lim et al., 2003). The efficiency of cyclone systems is a function of geometric, operating parameters as well as the particle size distribution (PSD) of entrained dust and the velocity of the air stream entering the abatement device (Wang et al., 2000). The particle size distribution of most aerosols can be described by a log-normal distribution (Hinds, 1999). A study by Ter Linden on efficiency and pressure drop characteristics of cyclone revealed that efficiency of cyclone is affected by variation of cyclone geometric

parameter (diameter) up to a certain range.
With the foregoing, the geometric influence on the efficiency can be checked by choosing and fixing optimal geometric parameters of a cyclone so as to allow the study of the effect of non physical and operating parameters. However, the relationships among these variable quantities have not been fully established. This work therefore, attempts to correlate inlet velocity, pressure drop and collection efficiency. The overall aim is to establish a data template from the correlation studies which will guide designer in predicting and making sound judgment on the parameters for an optimal performance and efficient cyclone. Randomizations, trial and error often used by designers are further eliminated.

II. MATERIALS AND METHODS

The Stiarmand's high efficiency cyclone used had; diameter (D) = 300mm; entry 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^{o}C ± 2 ^{o}C and 70 -76% RH). The pitot tubes and manometers used were fabricated locally 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) in a cycle time of 10 minutes using a micro-mill. The dust was delivered to the cyclone via a blower and Perspex pipe with consequent monitoring of the flow of air and dust through the different segments of the cyclone using calibrated Pitot pipes to which manometers were attached(See set up).

Fig 1: Complete assembly of experimental rig

Toasted soya bean of moisture content 9.05% (db) weighing 2kg was used for material loading for each of the specified speeds. It was fed into the micro-mill at steady state speed and the crushed powders were collected from the cyclone dust hopper. This continued until no more flour is collected at the collection point and the experiment was repeated with the various speeds and data collected. The pitot- static tubes were mounted on 11 points along the cyclone and they were each oriented to the airflow direction. The test rig was run at speeds ranging from 1500 rpm to 3750 rpm on load basis and velocity distribution across the system was recorded. The pressure drop across the cyclone at load basis was also determined by subtracting exit pressure from entry pressure**.** Graphs were plotted for varying parameters and correlation coefficients determined using MICROSOFT EXCEL 2007

III. RESULTS AND DISCUSSION

Table 1: Determination of Pressure Drop

S/No	Rpm	Inlet		Exit		Inlet pressure ($p_a + \rho g\delta h$), n/m^2	Exit pressure ($p_a + \rho g\delta h$), n/m^2	Pressure drop P_{entry}-P_{exit} (N/m^2)
		V(m/s)	**Δh(m)**	**V(m/s)**	**Δh(m)**			
1	1500	9.15	3.72	3.43	1.13	101369.32	101338.46	30.86
2	1750	10.22	4.32	6.73	2.51	101376.47	101354.90	21.57
3	2000	11.37	5.03	8.04	3.13	101384.93	101362.29	22.64
4	2250	14.26	7.04	9.72	4.03	101408.87	101373.01	35.86
5	2500	17.14	9.38	10.98	4.78	101436.75	101381.95	54.80
6	2750	19.08	11.15	12.68	5.90	101457.84	101395.29	62.55
7	3000	18.79	10.87	13.86	6.74	101454.51	101405.30	49.20
8	3250	19.30	11.36	15.74	8.20	101460.34	101422.69	37.65
9	3500	21.72	13.79	16.45	8.79	101489.29	101429.72	59.57
10	3750	24.08	16.40	16.94	9.21	101520.39	101434.73	85.66

(Source: Oriaku, 2013)

Δh (m) = Entry and Exit pressure head

Collection efficiency was obtained by dividing the mass of particles collected by the total mass of sample fed into the system and multiplying the result by 100. The values obtained are shown in Table 2.

Table 2: Collection efficiency of the cyclone

S/no	Speed (rpm)	Mass of crushed particle collected(kg)	Efficiency of collection (%)
1	1500	1.41	70.34
2	1750	1.56	78.07
3	2000	1.80	89.80
4	2250	1.85	92.70
5	2500	1.88	93.80
6	2750	1.84	91.95
7	3000	1.76	88.16
8	3250	1.68	84.22
9	3500	1.55	77.38
10	3750	1.28	64.22

(Source: Oriaku, 2013)

Table 3: Entry Velocity, Pressure Drop and collection efficieny

S/No	**RPM**	**Entry Velocity(m/s)**	**Pressure drop**(N/m^2)	**Collection efficiency** (%)
1	1500	9.15	30.86	70.34
2	1750	10.22	21.57	78.07
3	2000	11.37	22.64	89.80
4	2250	14.26	35.86	92.70
5	2500	17.14	54.80	93.80
6	2750	19.08	62.55	91.95
7	3000	18.79	49.20	88.16
8	3250	19.30	37.65	84.22
9	3500	21.72	59.57	77.38
10	3750	24.08	85.66	64.22

(Source: Oriaku, 2013)

Table 4: Velocity Index, Pressure Index and Particle collection efficiency

RPM	Entry Vel. (V_E M/S)	Terminal Vel. (V_c m/s)	Entry Velocity Index(V_{iE})	Pressure Index (Z_E)	Collection Efficiency (∫/100)
1500	9.15	3.23	10.04	0.62	0.7034
1750	10.22	6.72	23.34	0.35	0.7807
2000	11.37	8.43	32.57	0.29	0.8980
2250	14.26	10.21	49.47	0.30	0.9270
2500	17.14	11.19	65.17	0.31	0.9380
2750	19.08	13.33	86.42	0.29	0.9195
3000	18.79	15.72	100.37	0.23	0.8816

3250	19.30	17.07	111.94	0.17	0.8747
3500	21.72	18.49	136.46	0.21	0.7738
3750	24.08	19.78	161.84	0.30	0.6422

(Source: Oriaku, 2013)

Where $\mathbf{V_{iE}}$ and $\mathbf{Z_E}$ were generated using dimensional analysis as stipulated by Walton 1974 in the equation;

$$l_s = f\left(\frac{v_i \tau}{D}, Z_E\right) = f\left(\frac{v_i \tau}{D}, \frac{\Delta P}{\rho \frac{v_i^2}{2}}\right) \quad (1)$$

Z_E is a constant for a given type of cyclone

The correlation coefficient equation given below is used to determine the correlation coefficient in Table 5`

$$\text{Correlation (r)} = \frac{N\sum XY - (\sum X)(\sum Y)}{[(N\sum X^2 - (\sum X)^2)(N\sum Y^2 - (\sum Y)^2)]^{1/2}} \quad (2)$$

Where N = Number of values of elements (data points)

X = First data

Y = second data to be correlated

$\sum XY$ = Sum of the product of 1st and 2nd data

$\sum X$ = sum of 1st data

$\sum Y$ = Sum of second data

$\sum X^2$ = sum of squares 1st score

$\sum Y^2$ = sum of square 2nd scores.

Table 5: Correlation Coefficient

	Entry Vel. (E)	Pressure Drop (PD)	Terminal Velocity(T)	Velocity Index (VI)	Pressure Index (PI)	Collection Efficiency,ʃ
Entry Vel. (E)						
Pressure Drop (PD)	0.8842					
Teminal Velocity(T)	0.9688	0.7574				
Velocity Index (VI)	0.9786	0.8365	0.9816			
Pressure Index (PI)	-0.6527	-0.2825	-0.7703	-0.6398		
Collection Efficiency,ʃ	-0.1070	-0.2914	-0.0874	-0.2477	-0.4252	

(Source: Oriaku, 2013)

Table 6: Correlation coefficients of Entry Velocity, Velocity Index, Pressure Index and Collection Efficiency

	Entry Vel. (E)	Velocity Index (VI)	Pressure Index (PI)
Velocity Index (VI)	0.9786		
Pressure Index (PI)	-0.6527	-0.6398	
Collection Efficiency,ʃ	-0.1070	-0.2477	-0.4252

(Source: Oriaku, 2013)

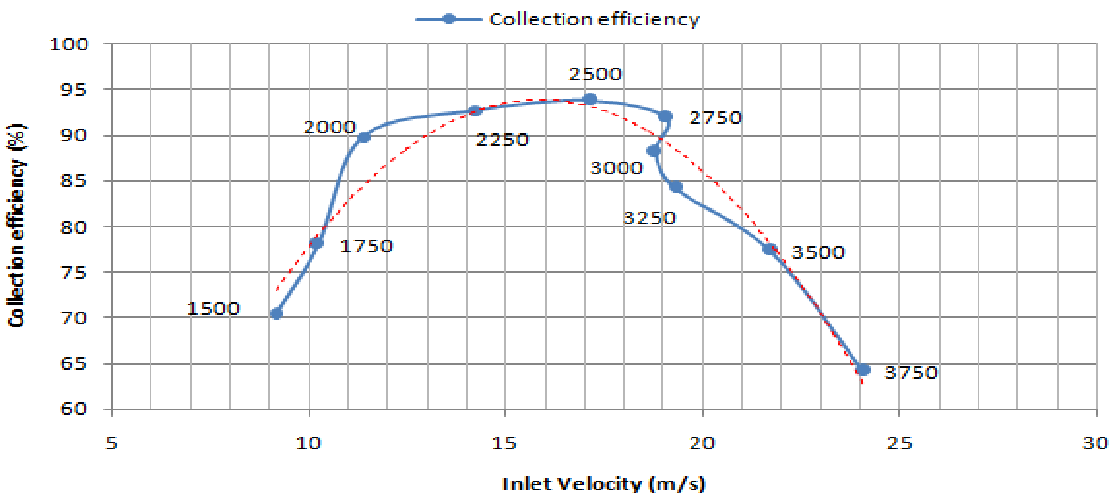

Fig 2: Collection efficiency versus Inlet velocity

$Y = -0.462x^2 + 14.67x - 22.50 \quad (R^2 = 0.926) \quad (3)$

The plot (Fig 2) shows the relationship between collection efficiency and inlet velocity for the various speeds employed in the cyclone. It can be seen that this relationship is best described by a quadratic function with R^2 values of 0.926 as given in equation 3. It can be deduced that as speed was increased the inlet velocity increased with attendant increase in particle collection. This trend continued until 2500rpm speed which had the highest collection percentage. From this point, further increase in speed resulted in decrease in particle collection percentage. This is similar to what was obtained by Zhao 2006 where it was reported that efficiency was found to be less significant with increase in velocity.

Fig 3 and 4 showed the relationships between inlet and exit pressure and collection efficiency and it was observed that they followed a similar trend to that obtained for inlet velocity. This can be said to show that pressure is dependent on the velocity in a high efficiency cyclone. The result is similar to what was reported by researchers such as Xiang *et al.*, 2001 and Baker and Hughs, 1999. The highest value of particle collection with respect to the inlet and exit pressure was also obtained at speed of 2500rpm.

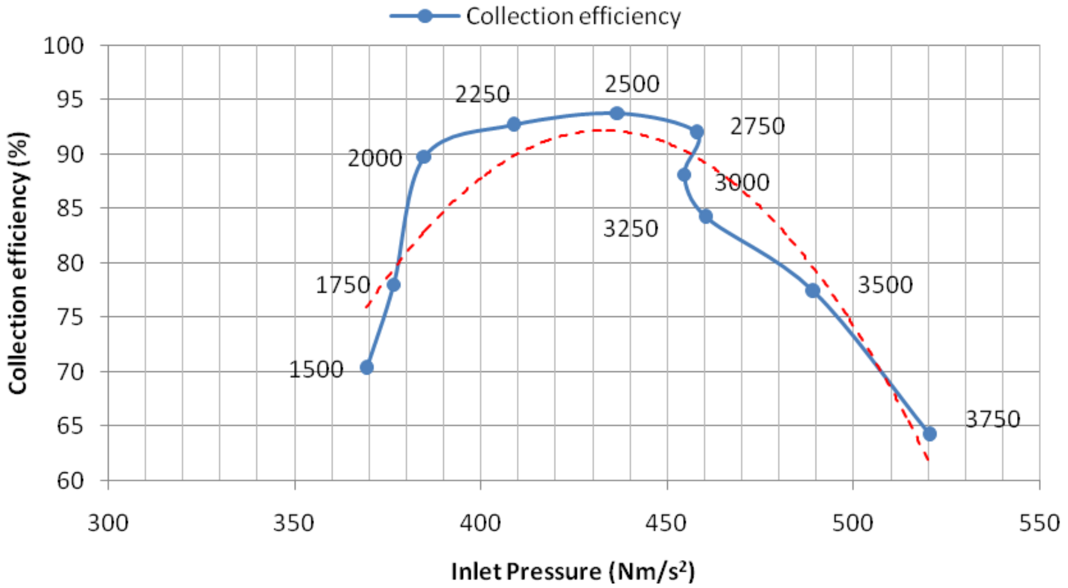

Fig 3: Collection efficiency versus Inlet Pressure

$Y = -0.004x^2 + 3.465x - 658.3$ ($R^2 = 0.853$) (4)

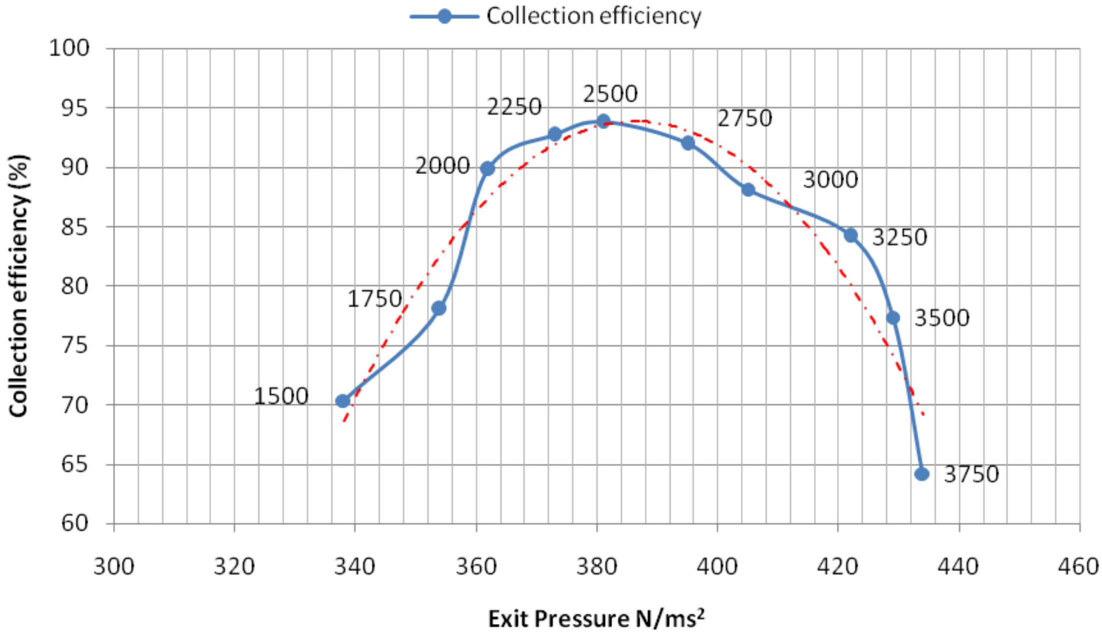

Fig 4: Collection efficiency versus Exit Pressure

$Y = -0.010x^2 + 8.362x - 1521.$ ($R^2 = 0.906$) (5)

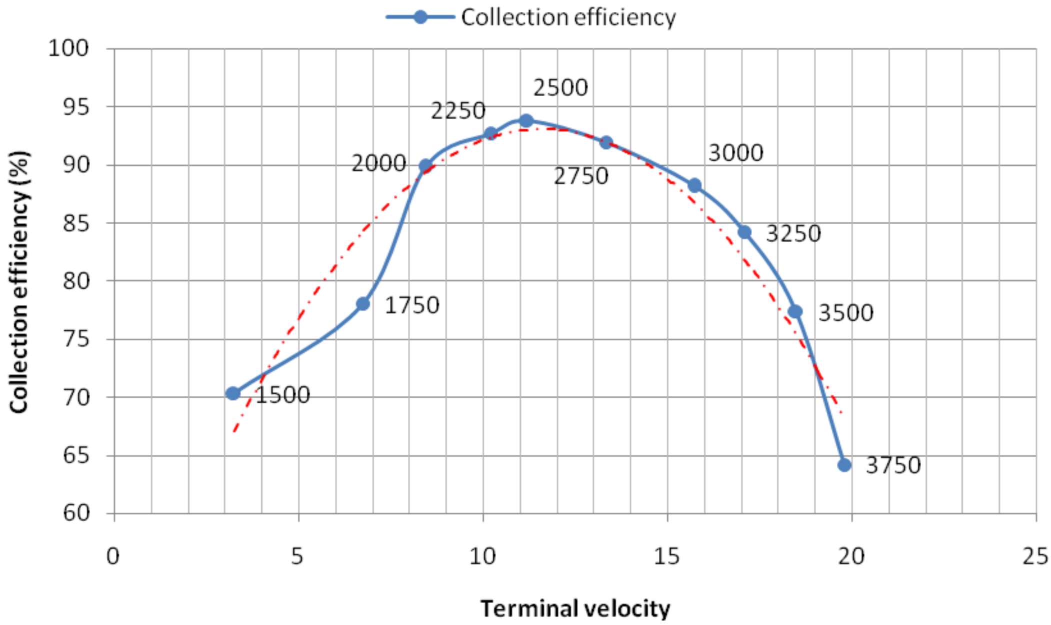

Fig 5: Collection efficiency versus terminal velocity

$Y = -0.371x^2 + 8.622x + 43.13$ ($R^2 = 0.918$) (6)

Fig 5, shows the plot of collection efficiency against particle terminal velocity. This was also best described by a quadratic function as shown in equation 6. It can be seen that the terminal velocity tended to decrease in almost equal values. This is an indication that further increase in speed beyond 2500rpm affected particle collection negatively.

From equation 1, after pressure index and velocity index have been determined dimensionally, the pressure index is held constant and values generated are plotted against collection efficiency and the graph is shown in Fig 6. The plot exhibited similar trend with previous plots and was also defined by a quadratic function.

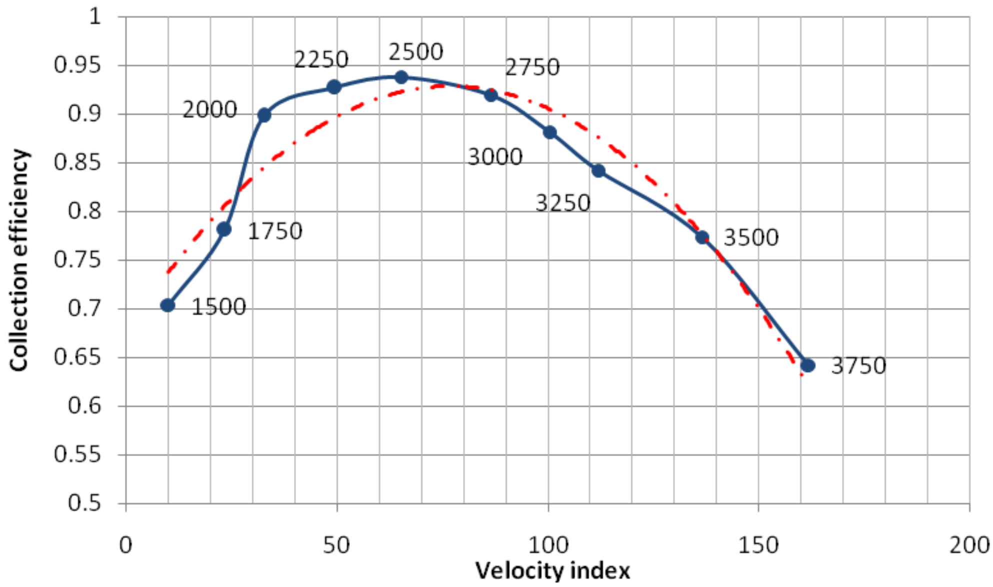

Fig 6: Collection efficiency versus Velocity Index

$Y = -4E\text{-}05x^2 + 0.006x + 0.675$ ($R^2 = 0.913$) (7)

IV. CONCLUSION

Form the results obtained it can be concluded that the relationship that exists between particle collection efficiency and the observed variables (inlet velocity, inlet and exit pressures and terminal velocity) is quadratic with R^2 values in the range of 0.853 to 0.926. This implies that for the designed high efficiency cyclone, when pressure drop is constant, the collection efficiency can be calculated for a given range of inlet velocities. The correlation was consistent in trend and showed that increase in velocity or pressure usually results in increase in particle collection up to a given point (often referred to as saltation) where further increase in these variables yields decrease in particle collection

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