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Radial Velocity Variation in a Designed Stairmand's High Efficiency Cyclone

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ABSTRACT

Velocity distribution among other non physical parameters in cyclone dust collectors have been subjected to series of studies. The velocity profile is characterized by three velocity components: tangential, axial and radial. The tangential velocity being the dominant velocity component with established obvious effect on particle collection efficiency has been widely investigated with little or no serious attention to other components. Theoretical studies have revealed the significance of the radial velocity though the least component and its effect in drag force contribution. Experimental investigation was carried out to establish the radial velocity profile in a designed and constructed Stairmands High efficiency cyclone. This radial velocity component was directly measured with a hotwire air anemometer 28mm from the cyclone axis at ten sections along the cyclone at varying cyclone inlet velocity range of 9.15 - 24.08m/s on-load conditions. The result despite the uncertainties in the measurement, showed a consistent trend described by polynomial of the third degree for all the ten speeds considered. Result further showed that radial velocity was fairly constant along the cylindrical sections of the cyclone but increases towards the centre and along the conical section with a drop at the terminal section of the cyclone. This tendency for the maximum radial velocity at end of conical section and subsequent decrease affirms that radial velocity aids particle settling and collection.

Keywords: *Cyclone, Radial Velocity, Velocity Profile, Drag Force And Flour Particles.*

1. INTRODUCTION

The technologies of cyclone separators demand high efficiency to provide satisfactory and economic performance; ensure regulatory compliance and protect expensive downstream components. To design a cyclone abatement system for particulate control, it is necessary to accurately estimate cyclone parameters. The efficiency of such cyclone systems is a function of the particle size distribution (PSD) of entrained dust and the velocity of the air stream entering the abatement device (Wang et al., 2000). Performance evaluation of the system is usually based on varying inlet velocity, pressure drop, and particle collection among others.

Consequently velocity as an important parameter has cut the attention of researcher into several studies and investigations on velocity distributions and velocity profile in a typical cyclone. The velocity profile in a cyclone is characterized by three velocity components: tangential, axial and radial. The tangential velocity is the dominant velocity component which determines the centrifugal force ($F_c = m\frac{v_t^2}{r}$) applied to the air stream and to the particles. It has been extensively studied owing to its direct effect on the particle collection. Research results of Shepherd and Lapple (1939), Ter Linden (1949) and First (1950) indicated that tangential velocity in the annular section (at the same cross-sectional area) of the cyclone could be determined by:

$$V_t * r^n = C_1 \qquad (1)$$

In the equation, n is flow pattern factor and n is 0.5 - 0.8 in outer vortex; n is 0 at the boundary of inner vortex and outer vortex. The tangential velocity increases with a decrease of the rotational radius (r) in the outer vortex. It increases to the maximum at the boundary (r = Do/2) of the outer vortex and inner vortex. In the inner vortex the tangential velocity decreases as the rotational radius decreases as shown in figure 1below.

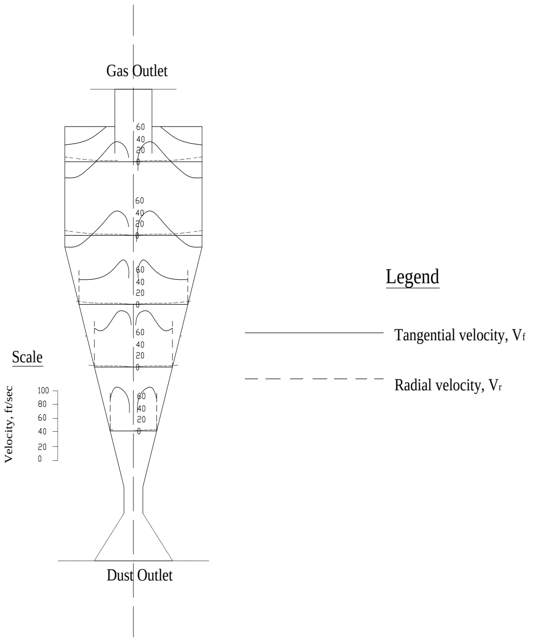


Figure 1: Variation of tangential velocity and radial velocity at different points in cyclone (Ter Linden, 1949)

Axial velocity is responsible for flows downward near the cyclone wall and upward near the cyclone axis. This downward velocity near the wall is largely complimenting tangential velocity in transporting dust from the cyclone wall to the dust outlet.

Radial velocity is perceived to be the least and the most difficult component to be measured experimentally. Kessler and Leith's (1991) made attempt to measure radial velocity and they were able to establish some trends with radial velocity increasing towards the centre of the cyclone due to the conservation of mass principle. Radial velocity is responsible for the drag force generated in the cyclone. Assuming Stokes' law, the drag force in the outward radial direction that is opposing the outward velocity on any particle in the inlet stream is given by:

$$F_d = -6\pi r_p \mu V_r . \qquad (2a)$$

Therefore, $$V_r = \frac{F_d}{-6\pi r_p \mu} \qquad (2b)$$

Where F_d = Drag force

V_r = Radial velocity

r_p = radius of particle

μ = viscosity of particle

A theoretical relation was projected by Foust et al **(**1960**)** in Principles of Unit operations for evaluation of radial velocity, thus:

$$v_R = \frac{v_t}{g}\frac{v_{tan}^2}{r} \qquad (3)$$

Where v_R = Radial velocity

v_t = Terminal velocity

v_{tan} = Tangential velocity

g = Acceleration due to gravity

r = Radius from the axis of cyclone at which v_r is determined.

It can be inferred from equation 3, that the higher the terminal velocity, the greater the radial velocity and the easier it should be to separate particle. Foust et al (1960) acknowledges the complexity of evaluating the radial velocity since it is a function of terminal velocity, tangential and position from the centre of the cyclone.

However, distinct relationships among these velocity components have not been completely investigated. This work therefore, attempts to measure experimentally the radial velocity component and with the analysis of data collected, make sufficient deduction on the significance of radial velocity in the overall performance of a cyclone. It also seeks to validate the radial velocity profile and further demystify the inexplicable technology of cyclone with the overall intention of assisting the end users on cyclone selection and operation.

2. MATERIALS AND METHODS

A test rig comprising micro mill and Stairmands Cyclone designed and locally fabricated was used(see Plate 2) The Stiarmand's high efficiency cyclone of following specification: 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 (30ºC ± 2 ºC and 70 -76% RH). The hotwire anemometer (Model QDF6: Honri Air Clean Tech Co. Ltd) used was procured. Impeller angular speeds of mill 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 pipe with consequent measuring of radial velocity of air and dust through the different segments of the cyclone using hotwire anemometer shown in plate 1 below.

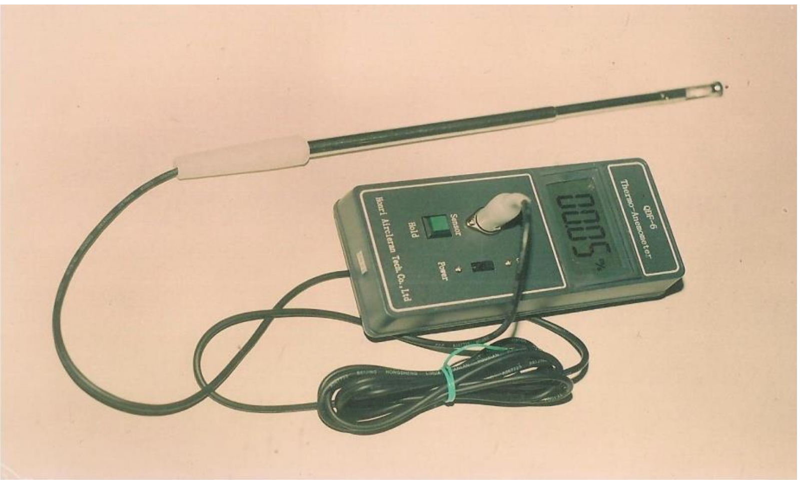


Plate1 . Standard Air flow Hot wire Anemometer (QDF6: Honri Air cleran Tech Co. Ltd)

Plate 2: Test rig Assembly (side view)

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 anemometer were mounted on 11 points along the cyclone and they were each oriented to the airflow direction and at 28mm from cyclone central axis. 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 as in Table 1. Graphs were plotted for radial velocities on load basis..

Points of measurement on the cyclone were identified as:

1. Entry Velocity
2. BCS- Beginning of cylindrical section
3. CCS - Centre of cylindrical section
4. ECS – End of Cylindrical section
5. BCNS – Begining of conical section
6. CNS2 – Conical Section 2
7. CNS3 – Conical section 3
8. CNS4 – Conical section 4

9. ECNS – End of conical section
10. TS - Terminal Section(Terminal Velocity)

3. RESULT

Table 1 Measured Radial Velocity along the Cyclone Sections on load basis

S/N	Impeller speed	ENTRY VEL.	BCS	CCS	ECS	BCNS	CNS2	CNS3	CNS4	ECNS	TS
1	1500	9.15	2.84	1.31	1.87	1.38	1.82	1.74	2.16	2.29	2.00
2	1750	10.22	2.56	2.79	2.17	2.63	2.57	2.71	2.58	3.93	3.65
3	2000	11.37	4.07	3.02	2.78	2.64	3.10	3.41	4.07	4.65	4.56
4	2250	14.26	4.50	4.44	3.53	3.53	3.78	4.25	4.38	4.96	5.62
5	2500	17.14	4.48	4.62	4.89	4.86	4.18	5.18	6.13	5.44	4.85
6	2750	19.08	6.27	5.03	7.05	5.68	5.25	5.68	7.06	7.61	4.95
7	3000	18.79	6.87	6.26	6.56	5.87	6.40	6.06	7.46	8.26	6.04
8	3250	19.30	7.04	7.44	6.58	6.04	7.19	6.54	8.83	8.97	6.20
9	3500	21.72	7.87	7.88	6.95	6.46	8.10	6.90	9.80	9.82	6.38
10	3750	24.08	8.62	9.26	7.20	6.91	8.33	7.12	10.77	11.36	6.68

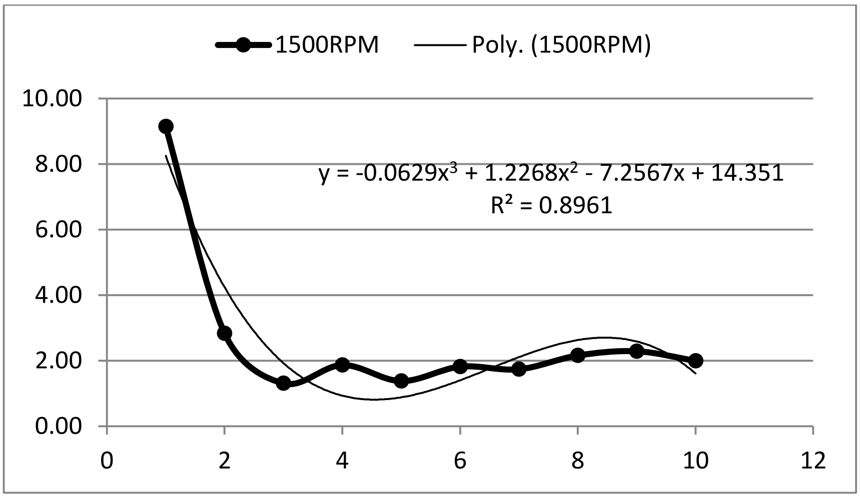


Figure 2. Radial Velocity Variation along cyclone @1500RPM

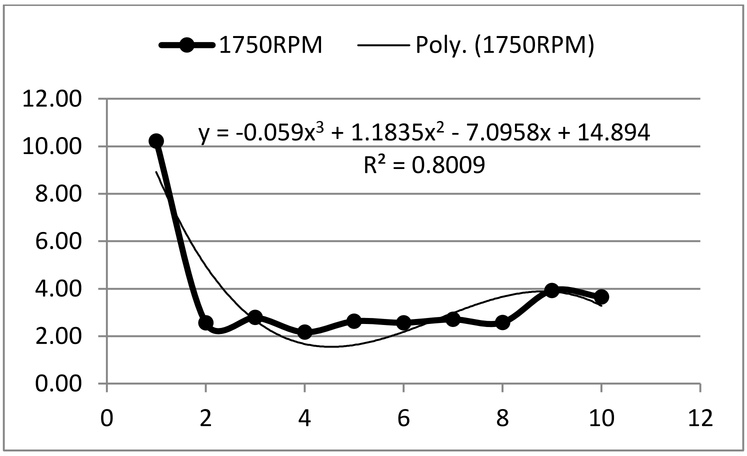


Figure 3. Radial Velocity Variation along cyclone @1750RPM

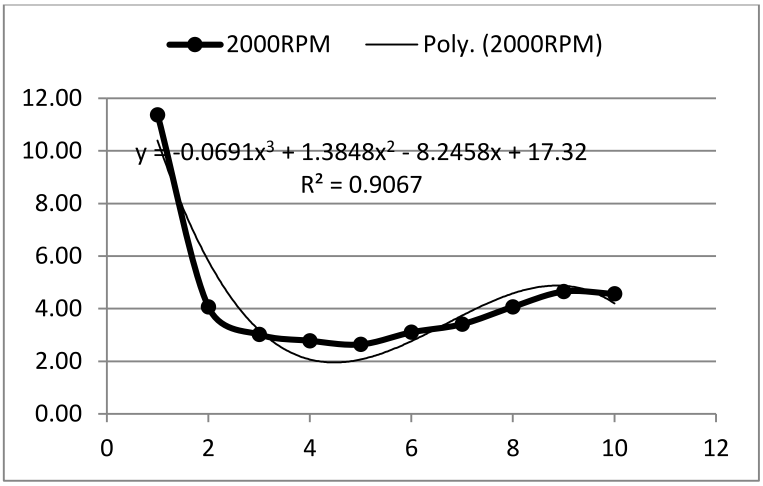


Figure 4. Radial Velocity Variation along cyclone @2000RPM

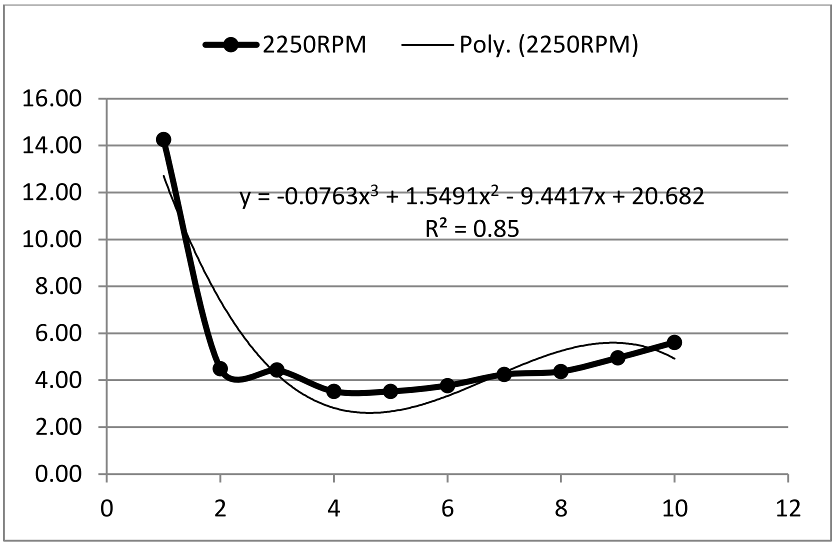


Figure 5. Radial Velocity Variation along cyclone @2250RPM

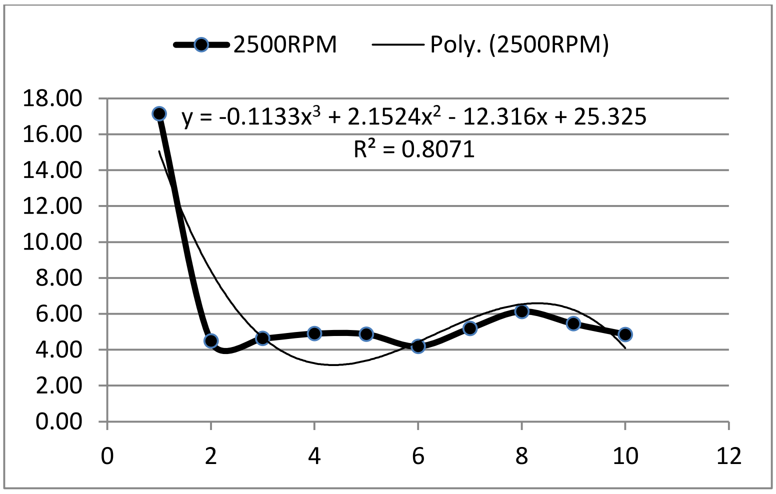


Figure 6: Radial Velocity Variation along cyclone @2500RPM

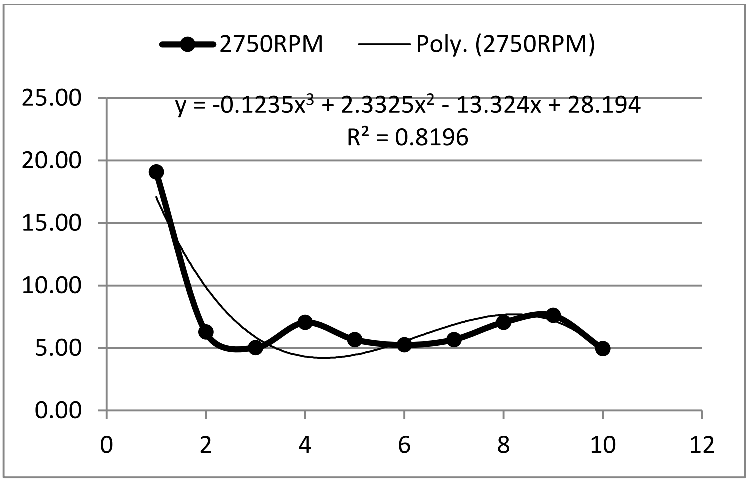


Figure 7: Radial Velocity Variation along cyclone @2750RPM

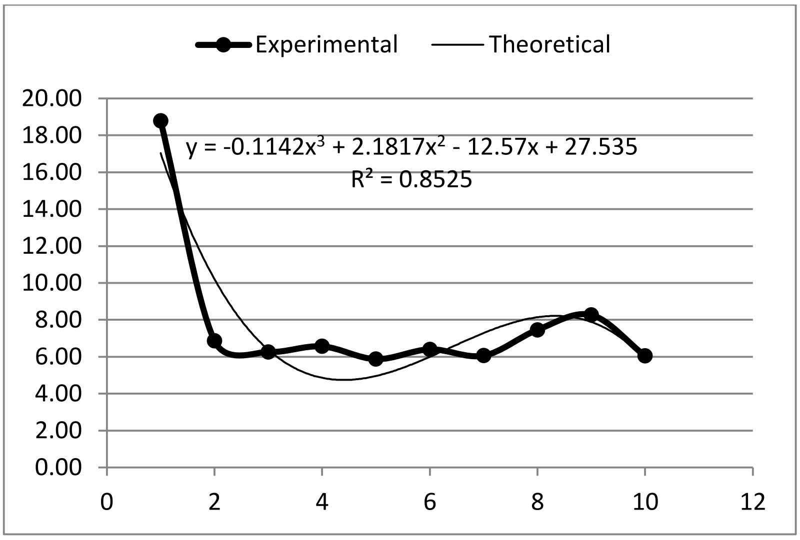


Figure 8: Radial Velocity Variation along cyclone @3000RPM

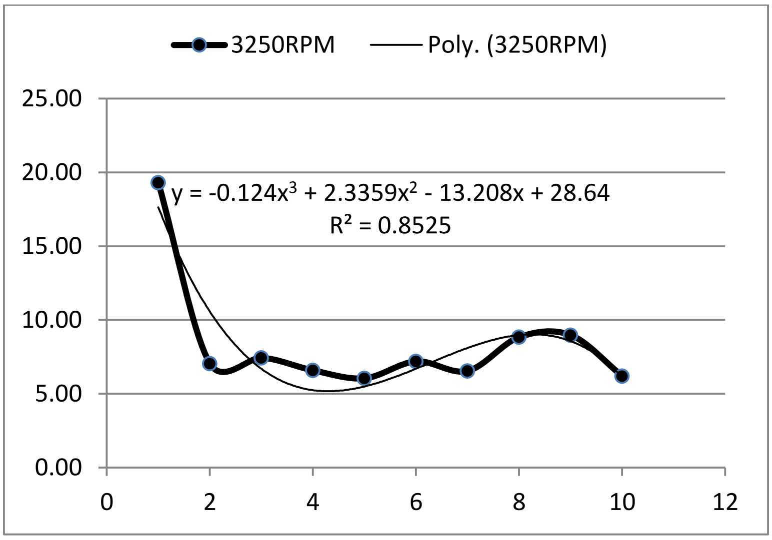


Figure 9: Radial Velocity Variation along cyclone @3250RPM

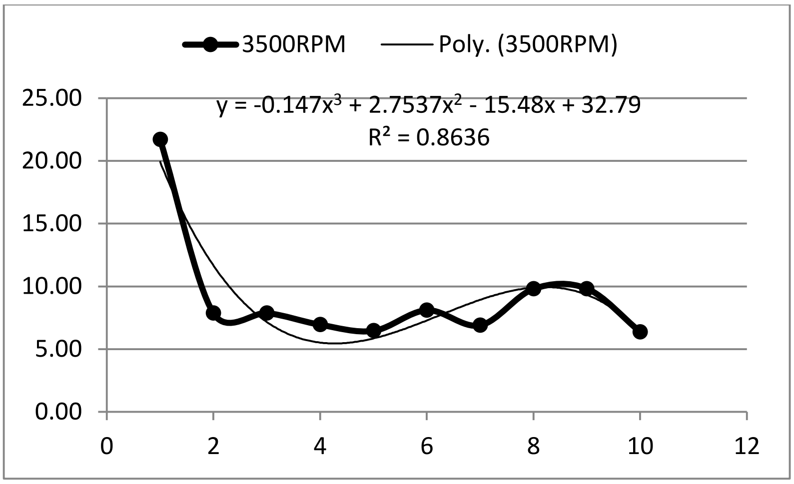
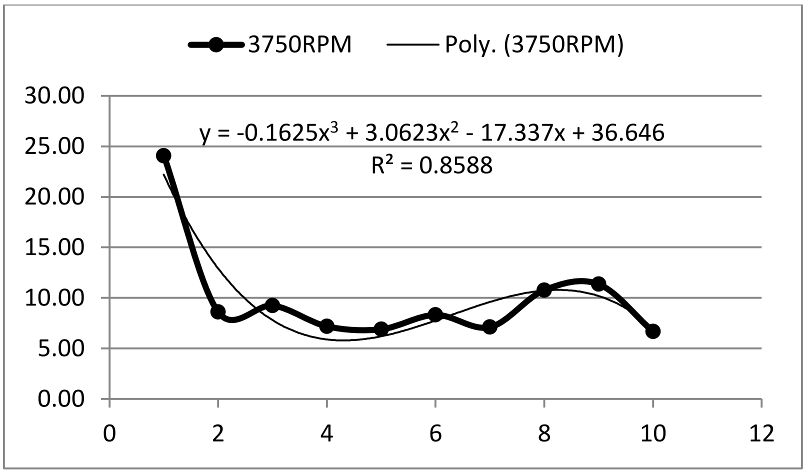


Figure 10: Radial Velocity Variation along cyclone @3500RPM



Radial11: Velocity Variation along cyclone @3750RPM

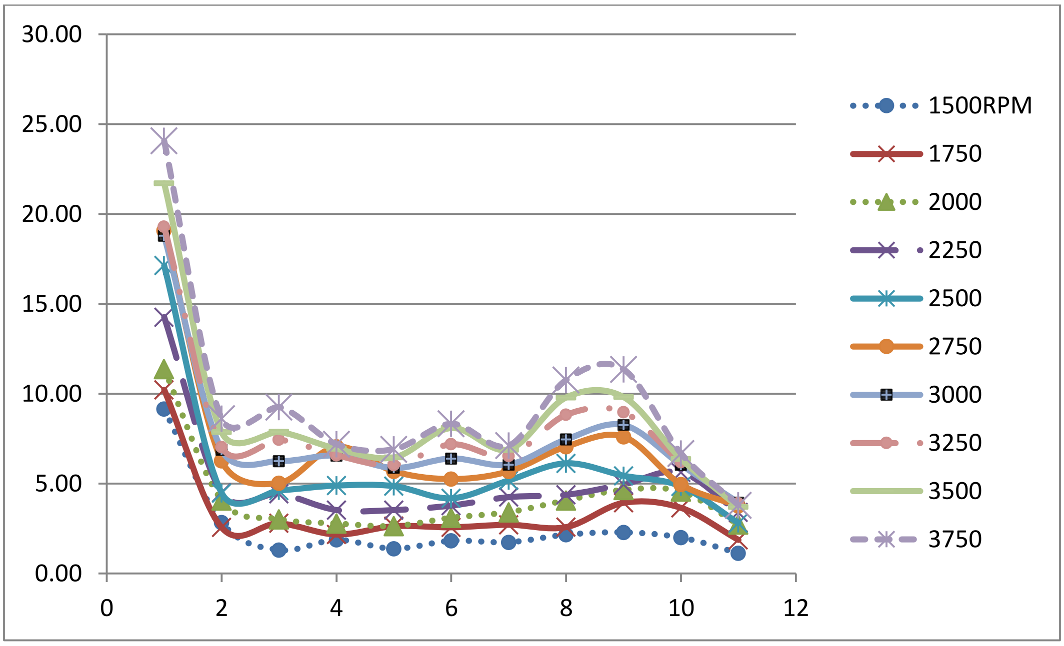


Figure 12.Combined Radial Velocity Variation along cyclone on Load basis

4. DISCUSSION AND CONCLUSION

Table 1 is the result of the measured radial velocities along the cyclone sections under load, varying from 1500rpm to 3750rpm. From the results of this table, it is observable that the radial velocities at different sections of the cyclone increase with an increase in the impeller speed. The entry section at all the impeller speeds recorded the highest air velocity range of 9.15 to 24.08m/s (impeller speed range of 1500 to 3750rpm). Obviously, it is this entry velocity that accounts for the three components of the velocity This is followed by the velocity at the end of the conical section(ECNS) with radial velocity range of 2.97 to 11.36m/s and the velocity at the conical section 4(CNS4) which has the radial velocity range from 2.16 to 10.77m/s. Other sections such as beginning of cylindrical section (BCS), center of cylindrical section (CCS), End of cylindrical section(ECS), conical section 2 and 3(CNS2 and CNS3) and the terminal section (TS) have lower radial velocities as compared to the former three sections in the order listed, they respectively have the following radial velocity range: 2.84 to 8.62m/s, 1.31 to 9.26m/s, 1.87 to 7.20m/s, 1.38 to 8.33m/s , 1.82 to 8.32m/s, 1.74 to 7.12m/s and 2.00 to 6.68m/s.

Figure 2 to 11 showed the plot of radial velocity on the ordinate and cyclone sections on the abscissa indicating the variation in the radial velocities along the cyclone sections at different impeller speeds. The curves showed the same trend, as evident in Figure 12 and trend equations, decreasing from the entry velocity points at the entry section of the cyclone to a particular point downward (beginning of the cylindrical section) though undulating but with fairly constant radial velocity (depending on the rise or drop in the radial velocities in the various sections) extending horizontally to the end of the cylindrical section and significantly increasing along the conical section peaking at ECNS and terminates at the cyclone section with the minimum radial velocity at the terminal section.

In the cone, the air stream is compressed because of change of the body shape resulting in the increase in the radial velocity obeying continuity equation principles in fluid dynamics

The radial velocity flow pattern follows a polynomial model of the third degree from the top of the cylindrical through the conical part to the intersection of the vortexes interface and terminal section. R squared values of 0.8 to 0.9 was observed for all the speed considered.

The consistency in the flow trend and fairly constant R-square value implies that radial velocity is significant in the particle collection and overall performance of a cyclone.

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