Estimation of Tangential Velocity in Uniflow Cyclone

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***Abstract* -- In Uniflow cyclone tangential velocity is imparted to the fluid with the help of angular vanes of swirl generator installed at the entrance of the cyclone. The tangential velocity is measured by indigenously developed tangential velocity meter. The reliability of developed tangential velocity measuring instrument is compared with theoretically calculated tangential velocity using equations from literature. The present study includes the effect of vane angles 15^0, 30^0, 45^0, 60^0, 75^0 of swirl generator, radial distance from centre, axial distance from vane and linear velocity on tangential velocity in Uniflow cyclone.**

Keywords -- Uniflow cyclone, Tangential velocity, Axial Velocity, Radial Velocity, Vane angle, Swirl generator.

I. INTRODUCTION

Swirling flows have been used in several applications for the separation of a dispersed phase from a carrier fluid. One of the most obvious engineering applications of the centrifugal field generated by the swirl is the removal of particles from a stream of air. Typical uniflow cyclones include the axial flow cyclones in which dust and clean air moves in same direction. The body of uniflow cyclone consists of cylinder in which there is swirl generator or guide vane at inlet and vortex finder at outlet through which clean gas leaves. Thus, when dusty gas enters in uniflow cyclone, because of stationary swirl generator dusty gas rotates and the dust particles which are denser than gas, are forced towards the wall of cyclone by centrifugal force and are separated from gas in co-axial outlet.

The main advantage of uniflow cyclone is its high efficiency and low operating cost. Application of the uniflow cyclone as pre-separator, for dust removal from hot furnace flue gases, for removal dust from air in filtration, and in separation of oil from water offshore are discussed by Vaughan [1987], Pitchumani [1987], Akiyama and Murai [1989], Berg et. al [1985] and Frans T. M. and et al. [1995]. In spite of large application there is limited published literature for design and operating condition for uniflow cyclone. It is more important to know the optimum of inlet vane angle of swirl generator to impart maximum tangential velocity in uniflow cyclone. The present work is taken experimentally to estimate optimum vane angle of swirl generator to have maximum tangential velocity.

II. EXPERIMENTAL PROCEDURE

1) Tangential Velocity Measuring Instrument

The tangential velocity measuring instrument is fabricated in the lab by using very small Koyo™ bearing which has outer diameter of 6 mm and inner diameter of 3mm.This bearing is fitted exactly in the hallo cylinder of the Perspex which has outer diameter 10 mm and inner diameter 6 mm as that of bearing .On this hallo cylinder four plastic blades of width 11 mm, length 12 mm and thickness 0.5 are fixed with the help of stick fast. This assembly is fitted on the shaft of 3 mm diameter and 50 mm length. On the other end of shaft there is Perspex to hold shaft exactly at centre of the uniflow cyclone of 45 mm inner diameter. A non-contacting tachometer has been mounted just above the blades to measure the RPM of blade, which works on the principle of light reflection. The transparent Perspex tube is used through which light rays from tachometer passes to the blade.

2) Working principle of the instrument

It is observed that when there is no swirl generator at the entrance of the uniflow cyclone, and when air is allow to pass through it there is no rotation of the blade, and the tachometer shows no reading which indicate that there is no conversion of linear velocity into tangential velocity. The swirl generator of different vanes are fabricated in lab and when there is swirl generator with certain vane angle which is placed at the entrance of uniflow cyclone and air is allowed to pass through it, there is rotation of the blade, which is measured by tachometer. Which further indicates the conversion of the linear velocity into tangential velocity that calculated from RPM of blade as shown in Fig.1.

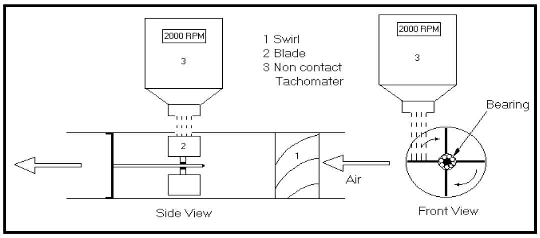
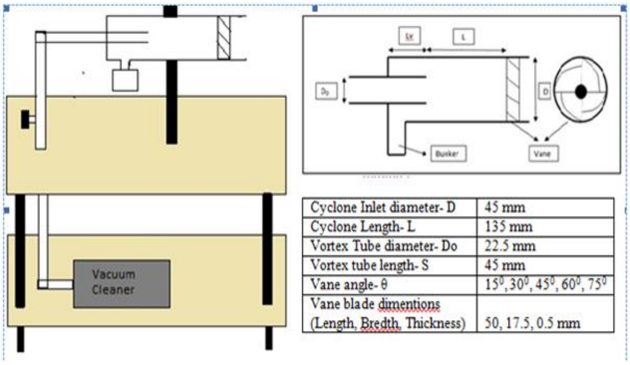


Fig. 1: Tangential Velocity Measuring Instrument

3) Experimental Set Up

Experimental set up consists of uniflow cyclone, vacuum pump, connecting pipe and control valve as shown in Fig 2. In the mainline, tangential velocity measuring instrument is kept to measure tangential velocity in uniflow cyclone. A digital anemometer is placed at the entrance of uniflow cyclone to measure linear velocity. One bypass line with control valve is provided to control the flow rate through mainline. Thus flow rate in mainline is varied by using the valves to have different inlet linear velocity. The Eureka Forbes industrial duty [Model no. 837] vacuum pump has used for suction of the air.



Cyclone Inlet diameter- D	45 mm
Cyclone Length- L	135 mm
Vortex Tube diameter- Do	22.5 mm
Vortex tube length- S	45 mm
Vane angle- θ	$15^0, 30^0, 45^0, 60^0, 75^0$
Vane blade dimentions (Length, Bredth, Thickness)	50, 17.5, 0.5 mm

Fig. 2: Experimental Setup

III THEORY

Meissner [1978] related tangential velocity, V_θ with stream velocity, U and vane angle, θ of swirl generator as given by equation 1.

$$V_\theta = U * \cos(\theta) \qquad \text{------------ (1)}$$

Stream velocity, U is function of inlet axial velocity, V_i, inlet cross sectional area, A_i and actual cross sectional area of stream, A_a as indicated in equation 2

$$U = V_i * \frac{A_i}{A_a} \qquad \text{------------ (2)}$$

Actual area, A_a of stream can be expressed in terms of width of vane, b_v, thickness of vane, t and diameter of shaft, d as shown in equation 3.

$$A_a = A_i - 4 * b_v * t - \frac{\pi}{4} d^2 \qquad \text{------------ (3)}$$

A_i is calculated from cyclone diameter, D_c from equation 4.

$$A_i = \frac{\pi D_c^{\ 2}}{4} \qquad \text{----------- (4)}$$

Ramchandran [1994] reported equation 5 to estimate tangential velocity, V□□ from inlet axial velocity, V_i, radius of cyclone, R_c and pitch, P.

$$V_\theta = 2\pi R_c * \frac{V_i}{P} \qquad \text{----------- (5)}$$

In equation 5 $V_i/P = \Omega$ is the angular velocity of gas in revolution per second and pitch, P is defined as the axial distance traveled by the gas in one revolution, which is determined from length of vane, l_v and vane angle, □ □ through equation 6.

$$P = l_v * \sin(\theta) * \frac{360}{4\theta} \qquad \text{------------ (6)}$$

Andrew Maynard [2000] has given tangential velocity, V□□ as function of inlet axialvelocity, V_i, radius of cyclone, R_c and pitch, P as equation 7

$$V_\theta = \frac{2\pi R_c V_i}{\left(P^2 + 4\pi^2 R_c^{\ 2}\right)^{\frac{1}{2}}} \qquad \text{--------------- (7)}$$

IV. RESULT AND DISCUSSION

1) *Effect of Linear Velocity on Tangential Velocity*

Experiments were carried out for the range of linear velocity from 4 m/s to 14 m/s, for this range tangential velocity varies from 0.4 m/s to 21 m/s for different vane angles of 15^0, 30^0, 45^0, 60^0, 75^0 of swirl generator in uniflow cyclone with 45 mm diameter. The results of experiments are given in Fig. 3. It is observed that, as inlet velocity increases tangential velocity increases for all vane angles of swirl generator. However, at any particular value of linear velocity for smaller vane angle, tangential velocity is low and for greater vane angle tangential velocity is high. Thus, for 5m/s of linear velocity maximum tangential velocity is 10.5 m/s for vane angle of 75^0. This increase in tangential velocity with linear velocity may be due to the increase in linear momentum that increases the rotational momentum due to which tangential velocity increases as expected. It is concluded from above results that tangential velocity is directly proportional to the linear velocity for any vane angle of swirl generator.

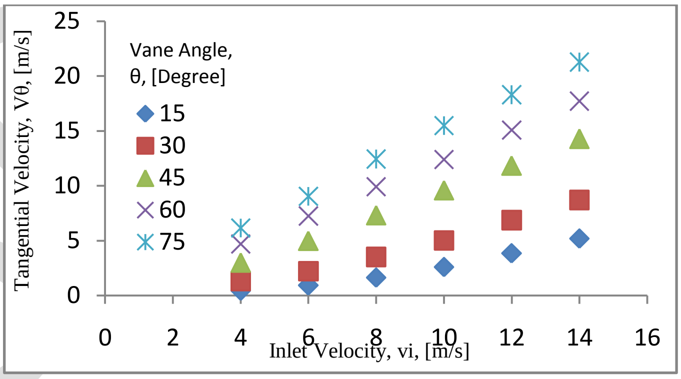


Fig. 3: Effect of Inlet Velocity on Tangential Velocity

2) *Comparison of Experimental and Theoretical Tangential Velocity*

The experimental tangential velocity, V_θ is related to radius of fan blade, r and number of rotations of blade per minute, n then the tangential velocity calculated by the equation 8

$$V_\theta = \frac{2 * \pi * r * n}{60} \qquad \text{----------- (8)}$$

The Fig. 4 shows the comparison between experimentally measured tangential velocity which is measured with tangential velocity measuring instrument and predicted tangential velocity by Meissner [1978], Ramchandran [1994] and Andrew Maynard [2000] for vane angle of 45^0 of swirl generator and inlet velocity is varied from 4 to 14 m/s. It is observed that the experimental measured and theoretically predicted values are very closer and obtained a minimum experimental error for Andrew Maynard [2000] which has RMS error of 2.36. As the linear velocity increases the error also increases this may be because of higher linear velocity, the flow is becomes more turbulent and tangential velocity increases, so fluid may hit the wall of cyclone and reverse its direction. it may changing flow of fluid in cyclone.

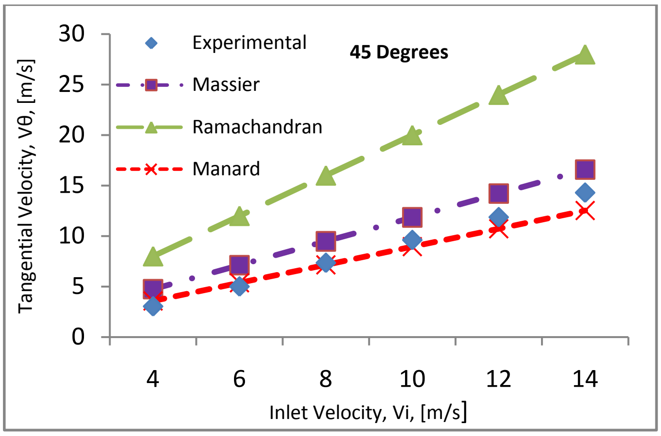


Fig. 4: Compaision of Tangential velocity with model equations

3) *Effect of Pressure drop*

Fig.5 shows the variation of pressure drop with inlet velocity for different vane angles of swirl generator. It is observed that the pressure drop increases with increase in inlet velocity and also with increase in vane angle. The pressure drop increases slowly from 15^0 to 45^0 and after that it increases drastically up to 75^0. This is due to increasing inlet velocity and increase in vane angle the flow became turbulent, Which created more number of peaks inside, hence pressure drop increases.

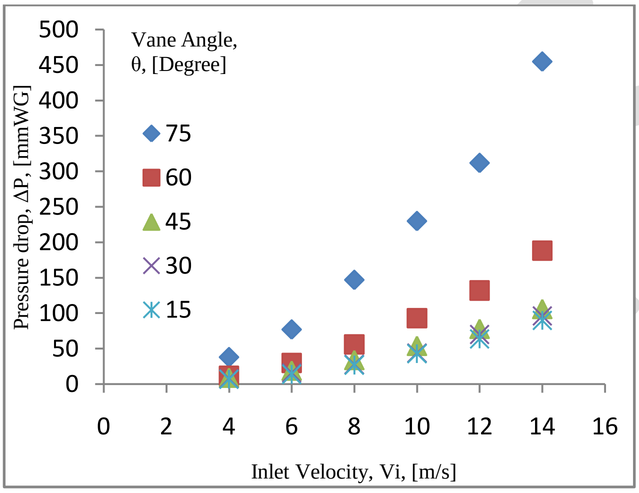


Fig. 5: Effect of Inlet Velocity on Pressure drop

4) *Effect of Radial distance on tangential velocity*

The response of tangential velocity with linear velocity for different radial positions for 45^0 vane angle at a distance 1.5D from vane is shown in Figure. 6. The tangential velocity increases with linear velocity and also increases with radial distance. The tangential velocity shows maximum value at outer radius. It is due to the centrifugal force of rotational motion of fluid which is maximum at outer radius. Therefore, the tangential velocity gradually decreases from outer radius to centre. The variation of tangential velocity with inlet velocity for diffferent horizontal distance from vane is studied. It is observed that a negligible variation in results. Hence, it is an insignificant parameter in measuring tangential velocity.

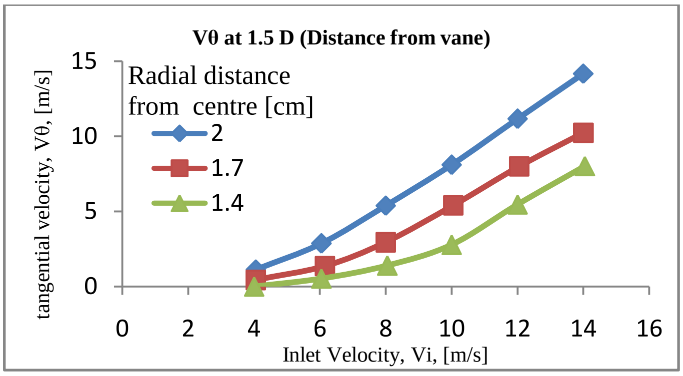


Fig. 6: Effect of Tangential Velocity with Radial Distance

5) *Effect of Inlet Linear Velocity and Vane Angle on Tangential Velocity in Uniflow Cyclone*

The response surface is shown in Fig.7 to evaluate the dependence of tangential velocity on the inlet linear velocity and vane angle of swirl generator. The inlet velocity is varied from 2 to 14 m/s and vane angle is varied from 15^0 to 75^0. The tangential velocity varies from 2 to 21 m/s for this range. Each contour in Fig 7 shows the variation of different values of inlet linear velocity and vane angle of swirl generator for constant values of tangential velocity. It is observed from Fig 7 that at constant inlet linear velocity as vane angle goes on increasing the tangential velocity goes on increasing and for a constant vane angle as linear velocity increases tangential velocity goes on increasing. The increase in tangential velocity with increase in vane angle at constant linear velocity may be due to higher rotation of the fluid at higher vane angle. At higher vane angle there is more conversion of the linear momentum into rotational momentum at the cost of pressure energy. Here vane angle is defined as angle made by tangent drawn on the edge of the vane with the plane horizontal to the direction of the flow. For any vane angle as linear velocity increases tangential velocity increases. This may be due to the reason that at lower linear velocity linear momentum will also be less for that angle.

It can be concluded that with increase in vane angle tangential velocity increases and with increasing inlet linear velocity tangential velocity increases

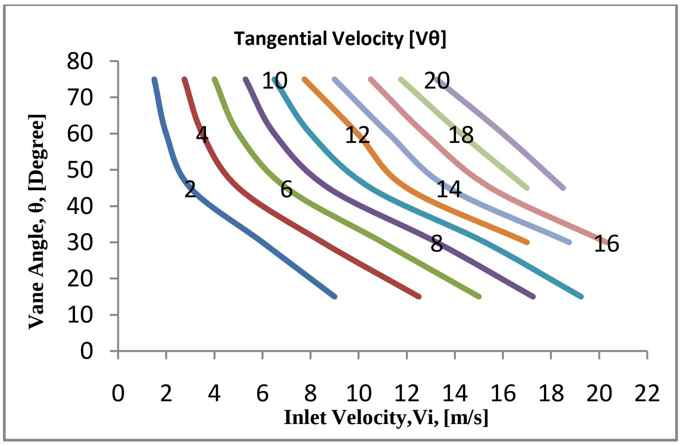


Fig. 7: Effect of Inlet Velocity and vane angle on Tangential Velocity

V. CONCLUSIONS

The tangential velocity and pressure drop both increases with increase in linear velocity and also with increase in vane angle. From the observations and keeping in view of cyclone performance the optimum vane angle for uniflow cyclone is 45^0 which gives reasonably high tangential velocity and low pressure drop

The experimental tangential velocity values are compared with model equations and Andrew Manard [2000] model is well matched with experimental values for 45^0 vane angle.

The tangential velocity varying along the radius of cyclone decreases from outer radius to centre of cyclone. The tangential velocity does not have any change with horizontal distance from vane.

NOMENCLATURE

A_a	- Actual Cross section area of stream	[m^2]
A_i	- Cross sectional area of uniflow cyclone	[m^2]
b_v	-Breadth of vane of swirl generator	[m]
D_c	-Diameter of uniflow cyclone	[m]
d	- Diameter of shaft	[m]
l_v	- Length of vane	[m]
n	- RPM of fan blade	[RPM]
P	- Pitch of swirl generator	[m]
r	- Radius of blade	[m]
Q	- Volumetric flow rate	[m^3/hr]
R_c	-Inlet radius of uniflow cyclone	[m]
t	- Thickness of vane	[m]
U	- Stream velocity	[m/s]
V_i	-Inlet linear velocity	[m/s]
V_θ	-Tanngential velocity	[m/s]
θ	- Vane angle	[^{0}]
Ω	- Angular velocity	[Revolution./s]

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