International Journal of Engineering Sciences Paradigms and Researches (IJESPR)
Vol. 48, Special Issue, (TAME-2019, April 4-5, 2019)
(An Indexed, Referred and Impact Factor Journal approved by UGC- Journal No. 42581)
ISSN (Online): 2319-6564
www.ijesonline.com

EXPERIMETAL ANALYSIS OF THE LOW REYNOLDS NUMBER BEHAVIOUR OF 2-HOLE OFFSET PROBES

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ABSTRACT

Two-hole offset probe (S-type probe) is used to determine the stack gas velocity and volumetric flow rate for stack or dusty environment. During the calibration of S-shaped pitot tubes in wind tunnel, it was observed that the calibration constant has a slight dip over a Reynolds number range from 650 to 4000 (corresponding velocity range 3m/s to 14 m/s). For higher Reynolds numbers the calibration constant displays almost a constant value. The objective of this work is to analyze this variation in the value of the calibration constant. To conduct the analysis S-shaped pitot tubes of diameters ranging from 1.23mm to 9.54mm was fabricated, which were then calibrated against the standard pitot tube (L-shaped). S-shaped Pitot tubes showed very scattered values of probe coefficient in the velocity range from 3 to 14 m/s, and displayed almost constant values after that.

Keywords: *S-Type Probe, L-Type Probe, Reynolds Number.*

1. INTRODUCTION

Two-hole offset probe (S-type probe) and Pitot-static probe (L-type probe) are pressure measurement instruments used to measure fluid flow velocity. It is widely used for high concentration slurry because obstruction does not occur during flow in the tube. The working principle and objective of both probes are similar, but the geometries are different. The pitot-static probe has a coefficient close to one (±0.5%) and hence can be used without calibration while the probe coefficient of the two-hole offset probe is sensitive to slight variation in geometry and hence needs calibration before use.

L-type probe is bent by 90˚ between leg length and nominal length therefore obstruction occurs during the slurry flow. When particles pass through bend, they are trapped and this type of obstruction stops the fluid flow in L-type probe. Therefore S-type probe is used instead of L-type probe. Manufacturing process of S-type probe is easier than L-type probe, and manufacturing cost is also less.

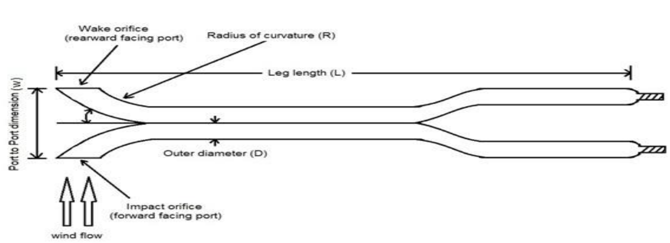

Fig 1: S-type probe with nomenclature

Nomenclature

$C_{p\ s-type}$= coefficient of S-type probe

v = air velocity in wind tunnel (m/s)

p_a = pressure measure in the rearward facing port of S-type probe (pa)

p_f = pressure measure in the forward-facing port of S-type probe (pa)

p_t= total or stagnation pressure of L-type probe (pa)

p_∞=pressure far ahead of L-type probe (pa)

2. LITERATURE REVIEW

1. **Kang et al (2015)** conducted experimental and numerical studies to determine the factor that effect the accuracy of flow rate measurement using S-type probe. They found that deviation and uncertainty of S-type probe coefficient

in the range of 3000<Re<22,000 were less than 0.3% and 1.2% respectively. Hence as we manufactured S-type probe properly, there will no effect on probe coefficient by changing Reynolds numbers.

2. **Crowley et al (2013)** developed a procedure for accurate calibration of multi-hole pitot probes. Flow separation and recirculation are common phenomena, therefore, the hysteresis that we observed is likely to occur during the calibration of other multi-hole pitot tubes.
3. **Trang et al (2012)** studied the measurement of velocity of gas stream in ducts with the help of S-type probe. The varia of of coefficient of S-type probe was observed on five different manufactures of S-type probe. The result of these experiment indicate that the coefficient curve of S-type probe fluctuated at small velocities around from 0.2% to 0.7%.
4. **Williams and Dejarnette (1977)** studied the effect of geometry, construction and use on the accuracy of S- type probes. They found that the probe coefficient decreases slightly as the velocity increase, but this decrease is sufficiently small for the probe coefficient to be represented by an average value in this range of velocities, and its probe coefficient would change less than 5% of the accepted value of 0.85, therefore, it is recommended for future applications.

3. EXPERIMENTAL SETUP

Both the S-type probe and L-type probe are fixed properly in the center of test section (0.58m × 0.34m × 0.34m) of wind tunnel at the same downstream location. Case was taken to ensure that the probes are properly aligned with the flow so that yaw and pitch effects are not introduced. The two probes were kept sufficiently apart so that no aerodynamic interference was present. Now both pitot tubes are connected with manometer through plastic pipes properly. Leakage of air around the test section in wind tunnel is also checked.

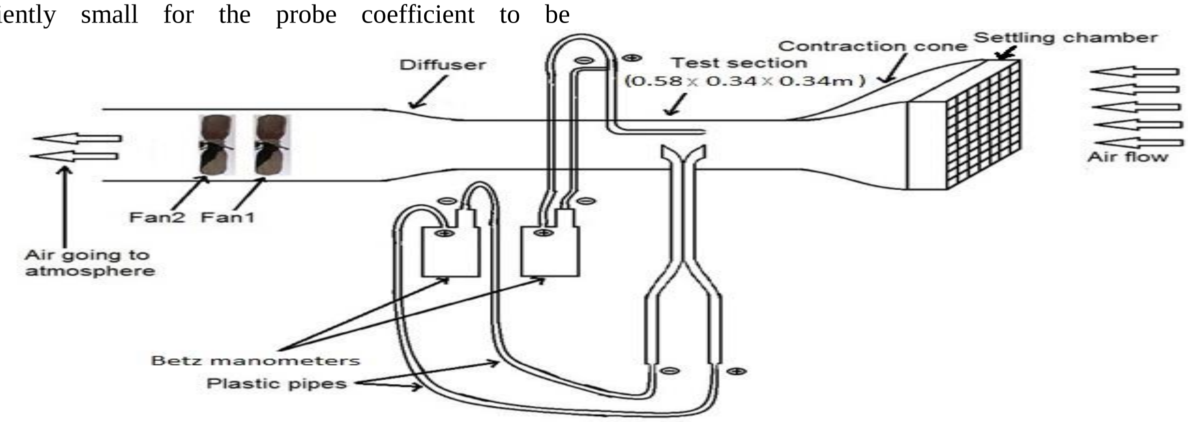

Fig 2: Systematic diagram of experimental setup.

Pressure measurement by manometer is rather simple and inexpensive. A manometer consists of a U-tube by which pressure difference is measured by balancing the weight of a fluid column.

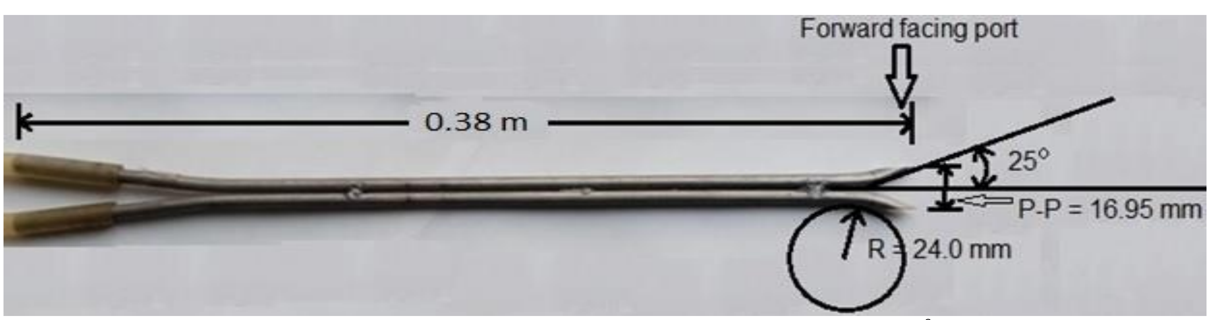

Fig 3: Diagram of 6.0 mm S-type probe at 25^0

S-type probe is made of metal tubing (*e.g.* stainless steel) as shown in Fig.4. External tubing diameter (D) is taken between 1.23mm and 9.54mm. There is equal distance from the base of each leg of the pitot tube to its face opening plane. Eight S-type probes are fabricated with different diameter, when fixed the angle at 25^0.

Table 1: Dimension of S-type probes with different diameters at fixed angle 25^0

S.No.	Diameter (D) in mm	Angle of bend (θ)	Port to Port dimension (w) in mm (w/D)	Radius of curvature (R) in mm (R/D)
1	9.54	25^0	26.95 (2.82)	38.16 (4.0)
2	8.0	25^0	22.60 (2.82)	32.0 (4.0)
3	6.40	25^0	18.08 (2.82)	25.60 (4.0)
4	6.0	25^0	16.95 (2.82)	24.0 (4.0)
5	4.0	25^0	11.30 (2.82)	16.0 (4.0)
6	3.0	25^0	8.47 (2.82)	12.0 (4.0)
7	1.25	25^0	3.53 (2.82)	5.0 (4.0)
8	1.23	25^0	3.47 (2.82)	4.92 (4.0)

4. MATHEMATICAL FORMULA

Atmospheric pressure, kinematic viscosity and Reynolds number are calculated by these formulas

$$p_{atm} = \rho_{Hg} \times g \times \Delta h_{atm}$$

$$\vartheta_{air} = \frac{\mu_{air}}{\rho_{air}}$$

$$Re = \frac{v_{air} \times D}{\vartheta_{air}}$$

The wind tunnel test section velocity is determined from the measured pitot and static pressures on the elliptical nosed pitot static tube. Since coefficient of L-type probe is unity, the velocity is related to the measured pressures and the air density by

$$v_{air} = \sqrt{\frac{2(p_t - p_\infty)}{\rho_{air}}} \tag{1}$$

The velocity is determined from the measured pressures on the fore and aft legs of the S-type probe tube from the following relations

$$C_{p\,s-type} = \frac{v_{air}}{\sqrt{\frac{2(p_f - p_a)}{\rho_{air}}}} \tag{2}$$

Combining Equations (1) and (2)

$$C_{p\,s-type} = \sqrt{\frac{p_t - p_\infty}{p_f - p_a}}$$

Coefficient of S-type probe is obtained from Equation (3) and the velocity in the wind tunnel is obtained directly from Equation (1). The air density (ρ) is not measured directly but may be determined from the equation (4).

$$\rho_{air} = \frac{p_{atm}}{R \times T_{atm}}$$

Where R = gas constant

5. RESULT AND DISCUSSION

To investigate the effect of Reynolds number on probe coefficient, the wind tunnel experiment of S-type probes were conducted in the range of 250 < Re < 19500 and the corresponding velocity range from 3 m/s to 34 m/s. It is assumed that, the flow in the wind tunnel for testing of S-type probes is uniform. Only those values which showed less than 5 % error in probe coefficient were considered for plotting graphs. At wind speed less than 1.0 m/s, both probes (S-type probe and L-type probe) showed nearly same values for probe coefficient and the accuracy of the pitot coefficient calculated was found to be unacceptable, since the error in coefficient value was greater than 5%. When diameter of S-type probe is less than 3.0 mm, wait for 3-5 minute for each reading. When the velocity of air varies in the wind tunnel, Reynolds number also varies simultaneously. Therefore, Reynolds number effect can be find indirectly through the variation of velocity. Plots 'coefficient of S-type probe (C_p) vs. Reynolds number' and 'coefficient of S-type probe (C_p) vs velocity' are similar because Reynolds number is product of velocity and constant value ($\frac{D}{\vartheta_{air}}$).

Result of S-type probes with different diameters at fixed angle 25^0

For 9.54 mm diameter of S-type probe at 25^0

From fig. 4, experiment was conducted for S-type probe with diameter 9.54 mm in the range of 2114 < Re < 19238. Coefficient value shows more scatter for Reynolds number 2990 to 10059 and corresponding coefficient value ranges from 0.863 to 0.834. Thereafter coefficient value decreases upto 0.833where Reynolds number is 11486 and then shows nearly constant value. Therefore, coefficient value (Cp) is normalized to 0.833 and 45.4% of coefficient values in set of data are smaller than or equal to normalized value (0.833).

Error bar has been drawn for some coefficient point in the graph. The error in coefficient value decreases when Reynolds number increase, for Reynolds number range of 250 to 4000 the error is in between $\pm$5%and$\pm$1%. Also, for

Reynolds number greater than 4000, error is less than $\pm 1\%$. After investigation it has been found that this type

of error trend is shown in all experiments for S-type probes with different diameters at fixed angle 25^0.

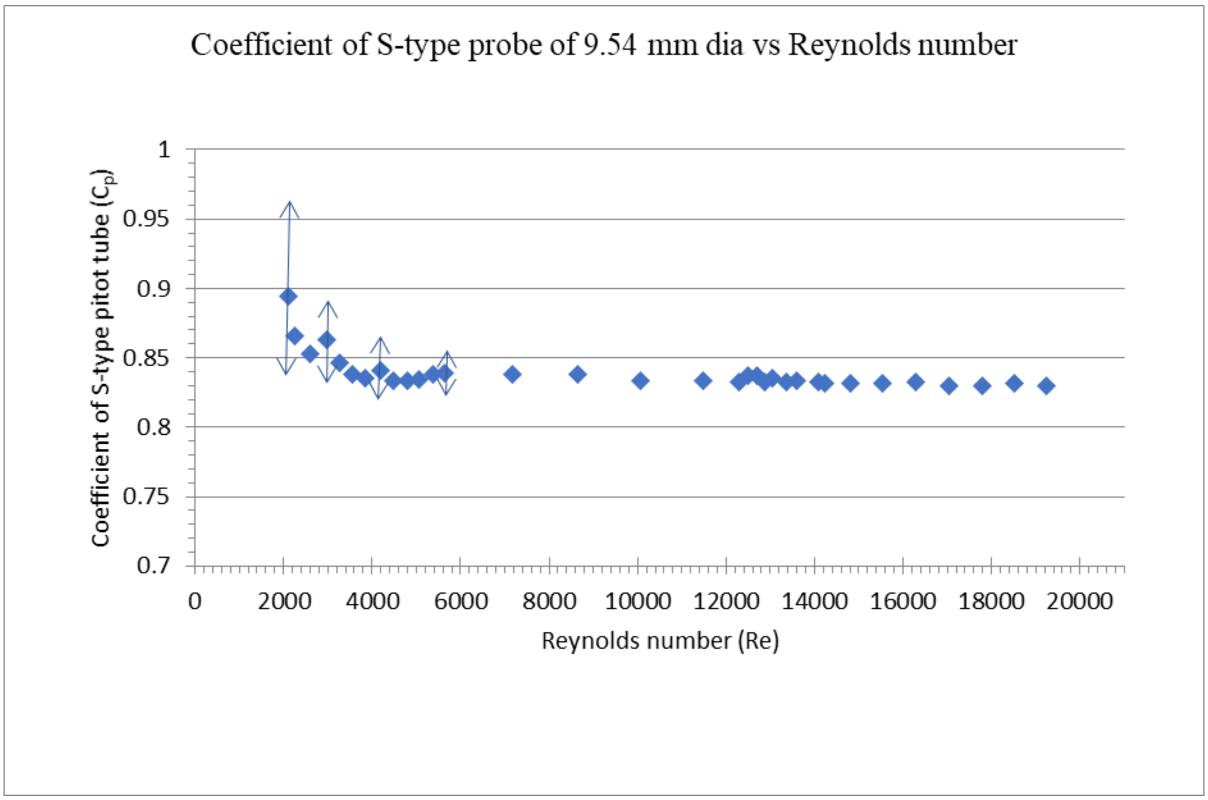

Fig 4: Reynolds number effects on the 9.54 mm diameter of S-type probe

Table 2: Result of S-type probes with different diameters at fixed angle 25^0

In 1.25 diameter of S-type probe, mostly small eddies are generated in between these two ports due to very large flow separation. But, fluctuation in pressure difference is very less than that of 3.0 mm diameter S-type probe. Due to very less fluctuation in pressure difference it is advisable to wait for 3-5 minute for each reading of pressure difference.

1.1

S.No.	Diameter (D) in mm	Port to Port dimension (w) in mm (w/D)	Fluctuation in pressure difference
1	9.54	26.95 (2.82)	0.41% more than 8.0 mm diameter
2	8.0	22.60 (2.82)	0.3% more than 6.40 mm
3	6.40	18.08 (2.82)	0.21% more than 6.0 mm
4	6.0	16.95 (2.82)	0.29% more than 4.0 mm
5	4.0	11.30 (2.82)	0.38% more than 3.0 mm
6	3.0	8.47 (2.82)	0.15% more than 1.25 mm
7	1.25	3.53 (2.82)	0.16% more than 1.23 mm
8	1.23	3.47 (2.82)	Very very less

Table 3: Some experimental data of S-type probes with different diameters at fixed angle 25^0

1.2

1.3 S.No.	Diameter (D) in mm	Port to Port dimension (w) in mm (w/D)	1.4 Dip occur	1.5 Experiment was conducted in the range of Reynolds number	1.6 Scatter in the range of Reynolds number and corresponding probe coefficient values	1.7 Flat curve found after Reynolds number	1.8 Normalizing value of probe coefficient	1.9 Coefficient value in the set of data are smaller and equal to normalized value
1.10 1	9.54	26.95 (2.82)	1.11 Not	1.12 2114 to 19238	1.13 12990 to 10059 (0.863 to 0.834)	1.14 11486	1.15 0.833	1.16 45.4%
1.17 2	8.0	22.60 (2.82)	1.18 Not	1.19 1242 to 17385	1.20 1242 to 9251 (0.836 to 0.827)	1.21 11514	1.22 0.828	1.23 60.60%
1.24 3	6.40	18.80 (2.82)	1.25 Yes	1.26 1127 to 13913	1.27 1127 to 3381 (0.832 to 0.846)	1.28 9631	1.29 0.853	1.30 84.84%
1.31 4	6.0	16.95 (2.82)	1.32 Yes	1.33 1270 to 13010	1.34 1270 to 4619 (0.827 to 0.826)	1.35 5411	1.36 0.825	1.37 78.78%
1.38 5	4.0	11.30 (2.82)	1.39 Yes	1.40 849 to 8700	1.41 849 to 3079 (0.874 to 0.866)	1.42 5785	1.43 0.863	1.44 51.51%
1.45 6	3.0	8.47 (2.82)	1.46 Not	1.47 529 to 6539	1.48 529 to 2205 (0.866 to 0.861)	1.49 4523	1.50 0.853	1.51 45.45%
1.52 7	1.25	3.53 (2.82)	1.53 Not	1.54 260 to 2692	1.55 260 to 944 (0.833 to 0.852)	1.56 1776	1.57 0.845	1.58 48.48%
1.59 8	1.23	3.47 (2.82)	1.60 Not	1.61 251 to 2650	1.62 251 to 1405 (0.866 to 0.852)	1.63 1937	1.64 0.846	1.65 24.24%

From fig.5, it can be seen that the probe coefficient of S-type probes shows more fluctuation in the range of Reynolds number from 250 to 4000 and shows almost constant value after that, therefore coefficient of S-type probes is normalized. Fluctuation in pressure difference increases when the diameter of S-type probe is increased. Fluctuation in pressure difference of 1.25 mm diameter of S-type probe is very less than that of 6.0 mm diameter which in turn is lesser than that of 9.54 mm diameter. When Port to Port dimension is small, pressure fluctuation is large because the stream is not stable and gap between ports is sufficient to generate the stream. If Port to Port dimension is larger, forward port pressure do not affect the rearward

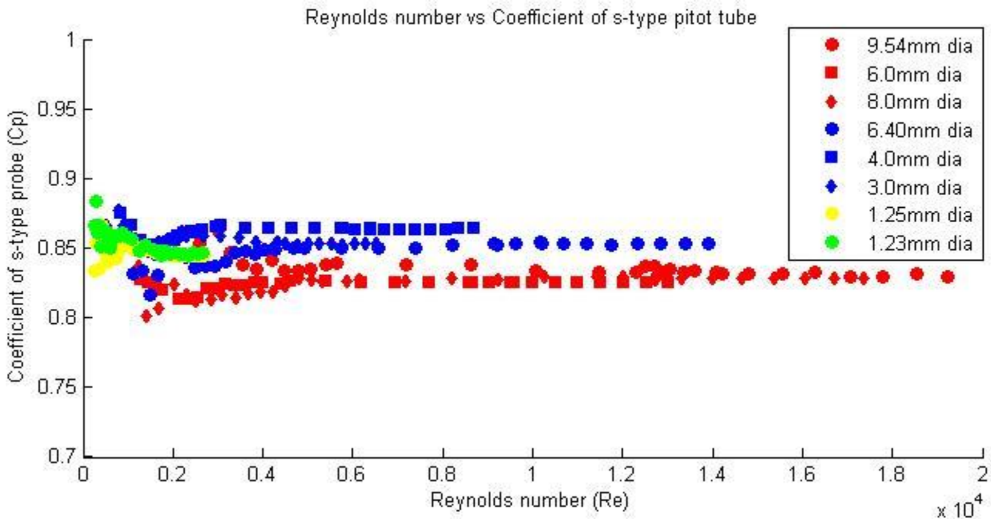

Fig 5: Combine graph of coefficient of S-type probes vs Reynolds number for different diameter of probes at fixed angle 25^0 angle.

After normalizing the coefficient value of S-type probes, it is found from fig.6 that dip only occur with two probes (like 6.40, 6.0 and 4.0 mm) and there is no dip with other S-type probes at 25^0angle.Dip occurs in some S-type probes due to low value of Reynolds number.

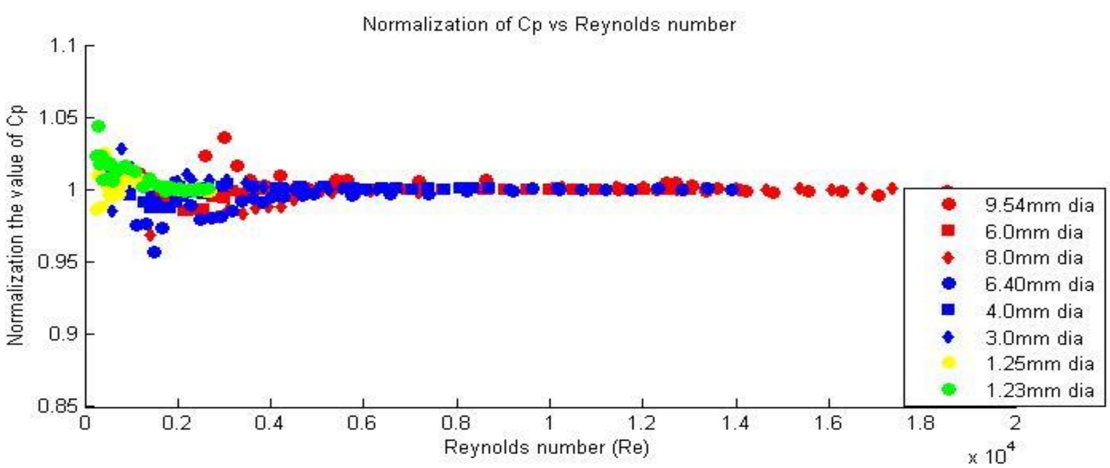

Fig 6: Normalization of coefficient of S-type probesvs Reynolds number for different diameter of probes at fixed angle 25^0 angle

6. CONCLUSION

It is observed that coefficient value shows more scattered value at low range of Reynolds number than larger one. It is also observed that no consistent dip occurs. S-type probes showed very scattered value of probe coefficients in the range of 3m/s to 14 m/s velocity and displayed almost constant values after that. For the velocity greater than 14m/s, probe coefficient is almost constant and scatter lies between $\pm 1\%$. As diameter of S-type probe increases, the fluctuation in the manometer reading also increases because as the diameter increases turbulence intensity increases in the region between forward port and rearward port. Coefficient value scatters for wide range of velocity, if diameter of S-type probe is less than 4.0 mm. Therefore S-type probe of less than 4.0 mm diameter is not beneficial.

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