EXPERIMENTAL ANALYSIS OF FLOW THROUGH ROTATING SWIRLER AND FIXED SWIRLER IN COMBUSTION CHAMBER

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ABSTRACT

Swirling jet is used as a means of controlling flames in combustion chamber. Swirl flow offer an interesting field of study for aerospace & mechanical engineers in general and for combustion engineers in particular since it involves complex interaction of recirculation & turbulent mixing, which aid flame stabilization in combustion system. Swirling flow in both reacting & non-reacting conditions occur in wide range of application such as gas turbines, marine combustor burner, chemical processing plants, rotary kilns & spray dryers. Stabilization of flame can be achieved by various techniques. The most common techniques used in modern gas turbine combustors is swirl stabilization in which swirl velocity is imparted to inlet air using vane Swirler. Swirl can reduce combustion length by producing higher rates of entrainment of ambient fluid and fast mixing close to exit nozzle & on boundaries of recirculation zone in strongly swirling zones. Experimental studies show that swirl has large – scale effect on flow fields: jet growth, entrainment & decay and flame size, shape, stability & combustion intensity are affected by degree of swirl imparted to the flow, therefore swirling flows are commonly used to improve & control mixing process. This work present design of combustion chamber. Swirler applicable for producing CRZ (Central Recirculating Zone) to control length & stability of

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flame. Whole assembly design includes inlet pipes, Swirler, diffuser, expansion chamber, and tailpipe.The core objective of this study is to present the details of the experimental swirl flow. The flow through 8 blades at 45° rotating vane Swirler is studied experimentally by using five-hole probe. Diffuser & tailpipe is provided to avoid disturbance in development of flow. Present work gives complete behaviour and knowledge about recirculation zone.

Keywords: Swirl, Tailpipe, CRZ, Guide vane, Probe.

INTRODUCTION

Swirling flows offer an interesting field of study for aero space and mechanical engineers in general and for combustion engineers in particular since it involves complex interaction of recirculation and turbulent mixing which aid flame stabilization in combustion systems. Swirling flows have practical applications in many combustion systems, such as industrial furnaces and gas turbine combustors. Swirling flows in both reacting and non-reacting conditions occur in a wide range of applications such as gas turbines, marine combustors, burners' chemical processing plants, rotary kilns and spray dryers. Swirling jets are used as a means of controlling flames in combustion chambers. The presence of swirl results in setting up of radial and axial pressure gradients, which in turn influence the flow fields. In case of strong swirl the adverse axial pressure gradient is sufficiently large to result in reverse flow along the axis and generating an internal circulation zone. In the present study, the design of vane Swirler is based on the design procedure of Mathur and Macallum [1]. The energy spent in swirl generation and the velocity and static pressure distributions in the jets issuing into the atmosphere are reported with reference to the central recirculation zone. Swirl flows can be characterized by means of a non-dimensional number called the swirl number 'S', which is the ratio of axial flux of swirl momentum ($G\Phi$) divided by axial flux of axial momentum (G_x) times the equivalent nozzle radius (R). The basic characteristic of a weak swirl ($S< 0.3$) is just to increase the width of a free or confined jet flow but not to develop any axial recirculation. This is due to low axial pressure gradient, whereas strong swirl ($S> 0.6$) develops strong axial and radial pressure gradient, which aids to form a central toroidal recirculation zone. The central toroidal recirculation zone (CTRZ) is due to the imbalance between adverse pressure gradient along the jet axis and the kinetic energy of the fluid particles flowing in the axial direction. This is due to dissipation and diffusion of swirl and also by flow divergence [3].As already mentioned, based on swirl number, the swirl flows are classified into weak, medium and strong swirl. If swirl number is less than 0.3 it is usually classified as weak swirl and if it is between 0.3 and 0.6 it is called medium swirl and if the swirl number is greater than 0.6, it is called strong swirl [4]. The recirculation zone geometry is a direct function of swirl number [2].In combustors, the central recirculation zone acts as an aerodynamic blockage or a three-dimensional bluff body. This helps in flame stabilization by providing a hot flow of recirculated combustion products and a reduced velocity region where flame speed and flow velocity can be matched. Swirling jets are used in furnaces as a means of controlling the length and stability of the flame. A common method of generating a swirling flow is by employing a vane Swirler.

PURPOSE OF THE DESIGN

The combustion chamber should have optimum efficiency to meet the desired need of the industrial application. For efficient combustion vane Swirler is induced into the combustion chamber which will reverse the flow of air & creates recirculation region and control the length and provides the stability to the flame. This combustion Swirler is designed with the compact assembly of diffuser (dump), expansion chamber, and tailpipe.

Swirler

There are mainly two types of Swirler in practical cases and modifications are made in them to improve the performance of the Swirler.

A. Axial Swirler B. Radial Swirler

Axial Swirler tend to have higher pressure losses than the radial type but are much simpler to manufacture. Parameters of interest to axial Swirler designers are depicted by Figure 1. They include the vane angle θ_v, the inner hub radius R_{hub}, the outer Swirler radius R_{sw}, the vane thickness t_v, the vane length c_v, and the number of vanes n_v. Typical axial Swirler designs have vane angle 45^o, vane thickness between 2mm, and 8 vanes. In this design curved vanes are used to obtain better results. A useful parameter for design is the Swirl number, S_n. The swirl number is ameasure of the ratio of angular momentum flux to axial momentum flux and defined by (Chigier& Beer, 1964).

October 2014 IJESR Volume 2, Issue 10 ISSN: 2347-6532

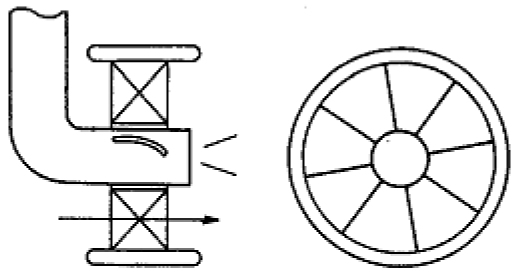

Fig. 1 Axial Swirler

The swirl number determines the criterion for recirculation. The recirculation zone increases in length and diameter as the swirl number is increased to a value of 1.5. The zone continues to increase in diameter beyond this value; however, its length begins to decrease.

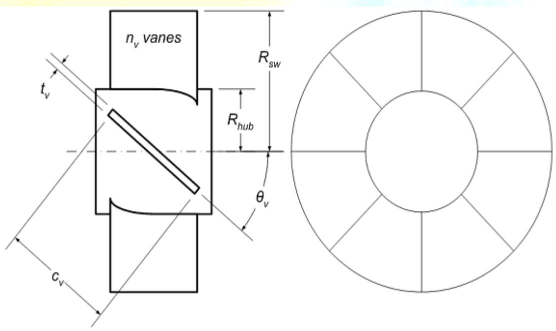

Fig. 2 Design parameters of axial Swirler

DESIGN DETAIL OF 45° AXIAL ROTATING VANE SWIRLER

The design of vane Swirler is based on Mathur and Macallum [21]. The design of 45° vane Swirler which having eight vanes 2 mm in thickness. The vanes are symmetrical, and the trailing edges of the vanes do not lie in the plane of the hub exit. The angle subtended by a vane at the axis, when viewed in the axial direction (φ), is 75°, giving an overlap of 30° between adjacent vanes. The length of the hub is 175 mm and a hemispherical bluff body is attached upstream of the hub in order to smoothly guide the fluid particle circumferentially, impinging on the hub. The three-dimensional Swirler geometry is made from transparent Perspex material and it consists of an inlet pipe of length 350 mm, outer diameter 120mm and hub diameter of 40mm. The vane Swirler is placed in the inlet pipe with vane tip made to coincide with the exit plane of inlet pipe. Hub to tip ratio is 0.3.

Fig.3 Eight Rotating vane Swirler

Fig. 4 Eight fixed vane Swirler

The Swirler model with vane angle 45° is made in transparent, Perspex material. The geometry consists of an inlet pipe of length 350 mm, 120 mm outer diameter and hub diameter of 40 mm. In First design, Inlet pipe consist of rotating Swirler of 8 blades at 0° inlet angle and 45° outlet angle. Outer length, inner length, height & thickness of blade is 83mm , 58 mm , 30mm & 0.25mm respectively. Rotating hub is 60mm long & 40 mm in diameter. Design is shown in Figure:3.

The length of the hub is 175 mm and a hemispherical bluff body is attached upstream of the hub in order to smoothly guide the fluid particle circumferentially, impinging on the hub. The three-dimensional Swirler geometry is made from transparent Perspex material and it consists of an inlet pipe of length 350 mm, outer diameter 120mm and hub diameter of 40mm. The vane Swirler is placed in the inlet pipe with vane tip made to coincide with the exit plane of inlet pipe. Hub to tip ratio is 0.3. Design is shown in Figure : 4

DIFFUSER DESIGN

The Dump diffuser is used for this experiment which has two parts prediffuser and step region. The prediffuser is designed is 120mm and 155mm as inlet and outlet diameter respectively and length is 166mm.The divergence angle 2θ is 12^{o}. The outlet diameter of step region is 250mm having length of 48mm and divergence angle is 45^{o} to prevent the corner recirculation. Holes of 10mm diameter are drilled downstream of the Swirler at various stations (A to G) shown in Figure:5.

Fig. 5 Diffuser

EXPANSION CHAMBER

The diffuser is followed by expansion chamber where size of recirculation zone and amount of air recirculate is measured. The diameter and length of the chamber is designed 250mm and 1100mm respectively. The tailpipe of 120mm diameter and 1300mm length is provided to avoid the atmospheric disturbance, as shown in Figure:6 to measure the axial velocity.

Fig. 6 Expansion chamber

TAIL PIPE

The tail pipe is provided after the expansion chamber to prevent the back flow of air and avoid the disturbance of atmosphere so pressure loss can be minimized to a considerable extent. The tailpipe of 120mm diameter and 1300mm length is provided to avoid the atmospheric disturbance, as shown in Figure 7.

Fig. 7 Tail pipe

Station	A	B	C	D	E	F	G	H
X	20	40	70	100	140	180	220	260
x/d	0.08	0.16	0.28	0.4	0.56	0.72	0.88	1.04
Station	I	J	K	L	M	N	O	P
X	290	320	360	400	450	520	590	660
x/d	1.16	1.28	1.44	1.6	1.8	2.08	2.36	2.64

Table 1. Different stations points at downstream of Swirler

FLOW MEASURING DEVICE

The flow measuring device consists of probe holding device and traversing devices. Traversing mechanism consists of Main body, Main lead screw, Support rod, Nut, End plates, Handle and Platform.

MANOMETER

Manometer having water as fluid is used for the pressure measurement. Readings are taken by keeping the manometer at 90^o with reference to the horizontal. The Table 1 shows the different stations where readings are taken to find axial and tangential velocities with help of five hole probe. Experimental setup is being fabricated which include inlet pipe, Swirler, diffuser, expansion chamber, tailpipe as shown in Figure:8

Fig. 8 Experimental setup

ZERO SETTING ADJUSTMENT

The probe may not be perfectly symmetrical about the axis of the central tube due to unavoidable errors in fabrication. Therefore it must be adjusted so that when the probe is aligned with the yaw direction as indicated by the equalization of pressure in the side tubes 2 & 4. The pointer reads zero on the circular scale. This was carried out in calibration section attached ahead of blower. The probe stem was rotated till pressure readings of the two tubes were equal. A circular probe stem disc having the hole, which the pin provided in the recess of the probe holder was then rotated and soldered with the probe stem.

EXPERIMENTAL PROCEDURE TO FIND OUT AXIAL & TANGENTIAL VELOCITIES AT DIFFERENT STATIONS FOR ROTATING SWIRLER

First of all set the blower to such a speed that its velocity becomes 20 m/sec. keeps blower running at 26 Hz. Here, the impeller used is of backward flow type. So that we get velocity at the inlet duct is of 20 m/sec. measure the velocity at the inlet of duct through anemometer and Pitot tube. Measure the velocity and pressure at inlet of the Swirler through pitot tube, which gives conditions at inlet. Make exit of the Swirler to be X = 0 plane. Create planes at different stations such as at A,B,C,D,E,F,G,H,I,J,K,L,M,N,O,P at different distances such as X.At stations A the axes line indicates that Y = 0 plane at X = 20.Now locate the five hole probe at location X = 0 and Y = 0 at station A. Hence the coordinate is (0, 0). Take readings at this point. While taking readings keep the probe to move in horizontal direction such that it's top and bottom hole are set at zero setting adjustment. Note down the readings of different hole of probe such as left (2), right (4), top (1), bottom (3), and middle (5).Now moves the probe at different points in the X direction such as at (40, 0), (70, 0), (100, 0), (140, 0), (180, 0) etc. and take readings at these different points. Now try to take readings along Y- direction means at point X = 0 and Y = 15. So, coordinates becomes (0, 15). Now again move the probe at different points in the X direction such as (40, 15), (70, 15), (100, 15), (140, 15), (180, 15) and take readings at these different points. Likewise keep and move the probe at different points in X- and also Y-direction and take readings of five hole probe at these different points.Now move the probe to the next station such as at station B. And repeat the procedure as described above. At the end measure the velocity and pressure at the exit of the expansion chamber and tail pipe with help of Pitot tube, which gives condition at the exit of the expansion chamber and tail pipe respectively. Now to find the different velocity components at different points the following equations are used and the values of pressure which we get from the five hole probe are placed in these equation

$$\bar{U} = \frac{\sqrt{2(p_2 - p_4)}}{\rho K_{24}}$$

U = Ū cos β cos α

V = Ū sin α

W = Ū cos α sin β

So, we get the different components of velocity (axial, radial and tangential) and by getting these values, plot the graphs of axial and tangential velocities at different points.

EXPERIMENTAL RESULTS

ROTATING VANE SWIRLER

At station A, 20 mm downstream of the rotating vane Swirler in Diffuser region, at the centre, reverse velocity is observed which become positive in mid-plane and near the wall. At station B, 40 mm downstream of the rotating vane Swirler in Diffuser region, at the centre, reverse velocity is observed which become positive in mid-plane and near the wall. At station C, 70 mm downstream of the rotating vane Swirler in Diffuser region, at the centre, reverse velocity is observed which become positive in mid-plane and near the wall. At station D, 100 mm downstream of the rotating vane Swirler in Diffuser region, at the centre, reverse velocity is observed which become positive in mid-plane and near the wall. At station E, 140 mm downstream of the rotating vane Swirler in Diffuser region, at the centre, reverse velocity which increases in the mid-plane and become positive near the wall. At station F, 180 mm downstream of the rotating vane Swirler in Diffuser region, at the centre, reverse velocity which decreases near the wall. At station G, 220 mm downstream of the rotating vane Swirler in Diffuser region, at the centre, reverse velocity which decreases near the wall. At station H, 260 mm downstream of the rotating vane Swirler in Expansion Chamber region, at the centre, reverse velocity is observed. In the mid-plane it become positive. Near the wall it becomes negative. At station I, 290 mm downstream of the rotating vane Swirler in Expansion chamber region, at the centre, reverse velocity is observed. It varies and becomes positive in between the mid-plane is observed. At station J, 320 mm downstream of the rotating vane Swirler in Expansion Chamber region, at the centre, reverse velocity is observed. It decreases in the mid-plane, near the wall it increase. At station K, 360 mm downstream of the rotating vane Swirler in Expansion Chamber region, at the centre, reverse velocity is observed, which varies and remain constant.

At station L, 400 mm downstream of the rotating vane Swirler in Expansion Chamber region, at the center, reverse velocity which varies in mid-plane and near the wall. At station M, 450 mm downstream of the rotating vane Swirler in Expansion Chamber region, at the centre, reverse velocity is observed, which increase in the mid-plane and decrease near the wall. At station N, 520 mm downstream of the rotating vane Swirler in Expansion Chamber region, at the centre, reverse velocity which decreases near the wall. From the contours of axial velocity, it can be clearly seen the recirculation zone takes place at the exit of the Swirler in the diffuser and expansion chamber. In the recirculation zone axial velocity decreases up to -17 to -18 m/s in case of axial velocity contour. The velocity magnitude in the central zone has only negative values. The flow downstream of the Swirler shows maximum reverse velocity of 18 m/s which shows the formation of recirculation zone. The contours are obtained by plotting the axial velocities which ranges from zero to maximum negative value within the recirculation zone.

FIXED VANE SWIRLER

The negative velocity exists only at the centre point which is mainly due to the presence of hub and the axial velocity increases gradually as we move from the centre to 20 mm for eight vanes Swirler. The increase in the axial velocity is due to impart of kinetic energy to the moving fluid by the vane Swirler.

For eight vanes Swirler, reverse velocity occurs from station A to station M and maximum reverse velocity occurs is of 4.92 m/s at station J in the central portion.

It can also be seen from the profiles that the values of axial velocities are positive from station N to P for eight vanes Swirler.

For eight vanes Swirler, minimum corner negative velocity occurs from station K to P where at these different stations high velocity occurs up to 5.29 m/s at station K means at 360 mm downstream of the Swirler.

Minor negative velocity occurs near the wall region for eight vanes Swirler, from 360 mm downstream to 660 mm downstream

CONCLUSIONS

By comparing fixed vane Swirler with Rotating vane Swirler, it has found that complete recirculation zone (From centre to wall) occurred in rotating vane Swirler while torroidal central recirculation zone occurred in fixed vane Swirler.

From results it is observed that large deviation occurs at mostly all the stations. The above discrepancies are due to the fact that during the measurement the five hole probe could not be made to null accurately close to the Swirler hub due to large flow fluctuation all these stations. Due to the tailpipe of 120 mm diameter attached at the end of the expansion chamber low pressure region occurs in the expansion chamber. Tail pipe will avoid the atmospheric disturbance and detain the atmospheric entering into the chamber. In the entire Expansion Chamber, The expansion chamber is connected with the tail pipe at the end for avoiding atmospheric air to enter in the expansion chamber and to get good air-fuel mixing with good flame stabilization. The recirculation zone in the mid plane downstream of the Swirler is shown in the Figure: 9 for 45^o 8 vanes fixed Swirler and Figure: 10 for 45^o 8 vanes rotating Swirler.

A good mixing of the reactants with air occurs due to the high turbulence generated by high shear stresses.

This recirculation zone encloses a large torroidal vortex reverse flow situated in the centre of the jet.It is found to produce highly stable flames and also enables matching of zones of high turbulence intensity with those of high fuel concentration, resulting in higher combustion efficiency.

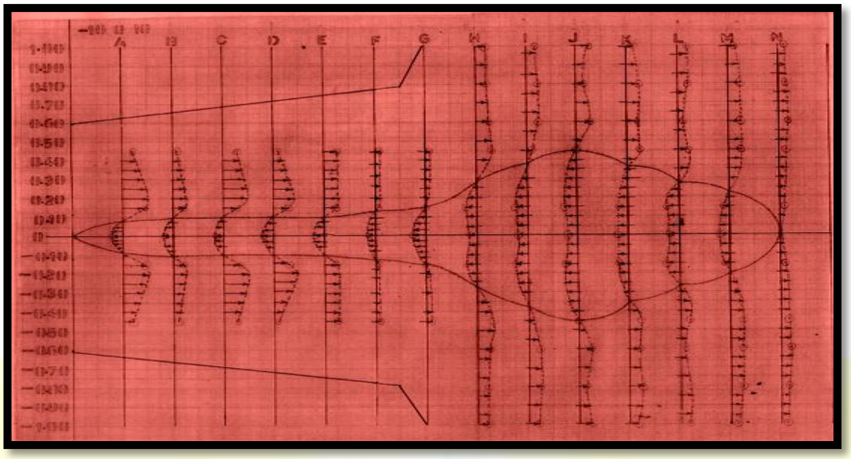

Fig. 9 Recirculation zone for 45° 8 vanes fixed Swirler

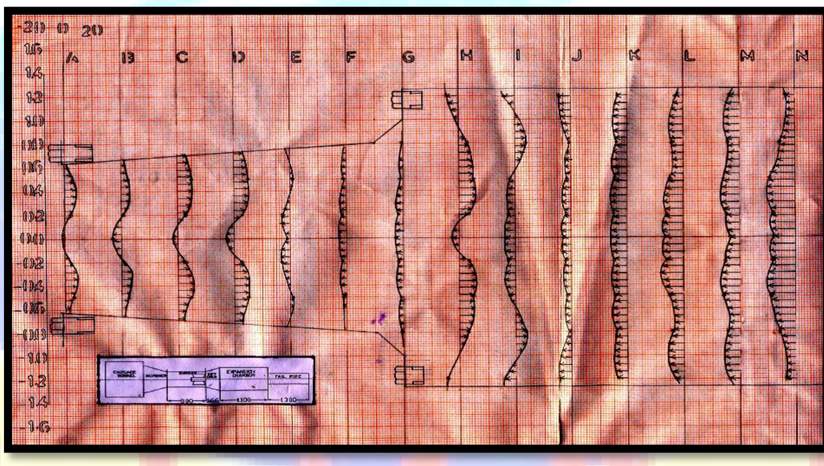

Fig. 10 Recirculation zone for 45° 8 vanes rotating Swirler

REFERENCES

1. M.L. Mathur, N.R.L.Maccallum, Swirling air jets issuing from vane Swirler. Part 1: free jets, Journal of the Institute of Fuel 214 (1967) 214–225.
2. R.F. Huang, F.C. Tsai, Observations of swirling flows behind circular disks, AIAA Journal 39 (2001) 1106–1112.
3. 3.B.T. Vu, C. Goulding, Flow measurements in a model swirl combustor, AIAA Journal 20 (5) (1982) 642–651.
4. V. Ganesan, Recirculation and turbulence studies in an isothermal model of a gas turbine combustor chamber, Ph.D. Thesis, I.I.T.-Madras, Chennai, India, 1974.
5. Mark R.J.Charest, Design Methodology for a Lean Premixed Prevaporized Can

Combustor, April 2005, 13-66.

6. E.Kilik, Better Swirl Generation by using curved vanes, California state university, Long Beach, California.
7. R ThundilKaruppa Raj & V Ganesan, Experimental study of recirculating flows induced vane Swirler, Indian Journal Engineering & Material Science, Vol.16, February 2009, pp. 14-22.
8. M.R.Pawar, A.S.Mohite, A.R.Patel, Investigation and Validation of swirl generation in Combustion chamber, ICAME,2010. SVNIT, SURAT.
9. Mohite A S, Shah B. K, Dhakiya A K;" Experimental Study on the effect of various parameters of recirculation flows induced by vane Swirler." IJERD-ISSN:2278-067X,p-ISSN:2278-800X, Volume3, Issue4 (August 2012),pp.38-44.
10. Mohite A S, Shah B K, Dhakiya A K ," Enhancement in the design of combustion chamber Swirler." The Journal of technical education, ISSN- 0971-3043.May, 2012.