International Journal of Scientific and Technical Advancements

ISSN: 2454-1532

Experimental Analysis of Flow through Concentric Vane Swirler in Combustion Chamber Using Atmospheric Air

Shah Jagruti[1], Mansha Kumari [2], Arvind. S. Mohite[3]
[1, 2, 3]Department of Mechanical Engineering, M. S. University, Vadodara, Gujarat, India
Email address: [1]Jadu_6483@yahoo.com, [2]manshakumari28@yahoo.com, [3]mohite21@yahoo.com

***Abstract*—**Swirling flow is main flow produced by air swirler, such flow is combination of swirling & vortex breakdown. Swirling flow is widely employed in combustion system for flame stabilization in combustion system. Swirling flow, which are highly complex, have characteristic of both rotating motion & free turbulence phenomenon encountered as in jet & wake flow. Presence of swirl results in setting up of radial & axial pressure gradient is sufficiently large to result in reverse flow along axis & generating an internal circulation zone. Swirl flows offer an interesting field of study for aerospace and mechanical engineering in general for combustion, separation and mixing of flow. Since, it involves complex interaction of recirculation and turbulent mixing. Swirling flow generates rotating flows, turbulence and free jet wakes at the downstream of swirler in combustion chamber. So there is complex interaction between pressure gradients and fluid flow. Swirling flows in both reacting and non- reacting conditions occur in wide range of applications such as gas turbines, marine combustor burners, chemical processing plants, rotary kilns, electrostatic separator and spray dryers. Electrostatic precipitator are highly efficient filtration device that minimally impede the flow gases through the device and can easy remove the fine particulate matter such as dust and smoke from the air stream. Concentric Swirler is being used to remove the particulate, especially from smoke, which after striking it, gets settle down and get collected in the accumulator. Experimental studies show that swirl has large-scale effects on flow fields: jet growth, entrainment and decay and flame size, shape, stability and combustion intensity are affected by the degree of swirl imparted to the flow. Therefore, swirling flows are commonly used to improve and control the mixing process. This work presents the design of swirler, applicable for producing the CRZ (control recirculation zone). The whole assembly is design which includes inlet pipe, swirler, expansion chamber, tail pipe. Axisymmetric Swirler model is designed with concentric swirler. The complete behavior of the flow in the chamber and the flow of gases through the device can easily remove the fine particulate matter such as dust and smoke from the air stream. Experiment has been done taking atmospheric cold air instead of hot gases in combustion chamber.

***Keywords*—**Swirl; tailpipe; CRZ; concentric chamber; electrostatic precipitator.

I. Introduction

Swirling flows offer an interesting field of study for aerospace 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 (Gx) 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 flames. A common

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method of generating a swirling flow is by employing a vane swirler.

II. 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 and figure 2. 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. Figure 3 shows the Process of recirculation in a gas turbine combustor using streamlines. 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).

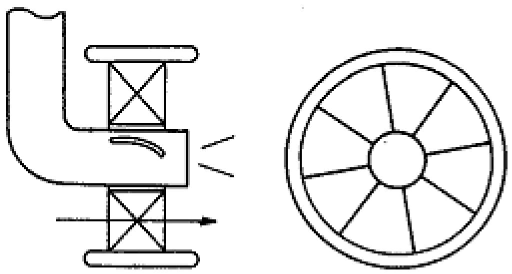

Fig. 1. Axial swirler.

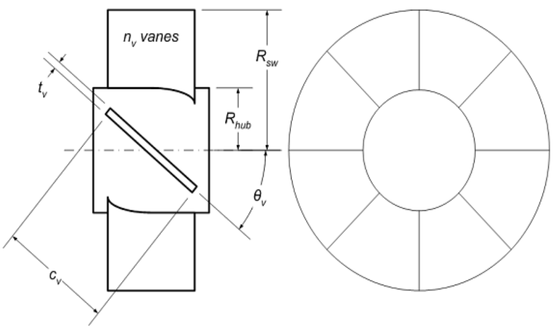

Fig. 2. Design parameters of axial swirler.

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.

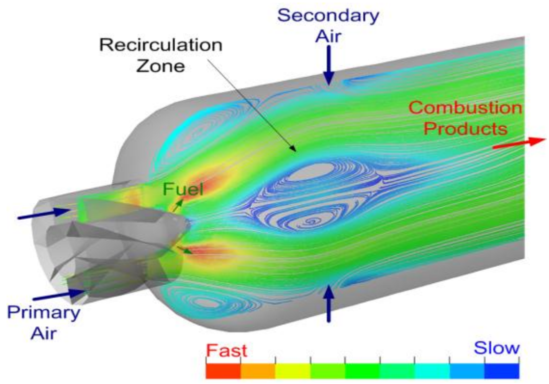

Fig. 3. Process of recirculation in a gas turbine combustor using streamlines.

III. Electrostatic Precipitator

An electrostatic precipitator (ESP), or electrostatic air cleaner is a particulate collection device that removes particles from a flowing gas (such as air) using the force of an induced electrostatic charge. Electrostatic precipitators are highly efficient filtration devices that minimally impede the flow of gases through the device, and can easily remove fine particulate matter such as dust and smoke from the air stream

Working Principle

The most basic precipitator contains a row of thin vertical wires, and followed by a stack of large flat metal plates oriented vertically, with the plates typically spaced about 1 cm to 18 cm apart, depending on the application. The air or gas stream flows horizontally through the spaces between the wires, and then passes through the stack of plates.

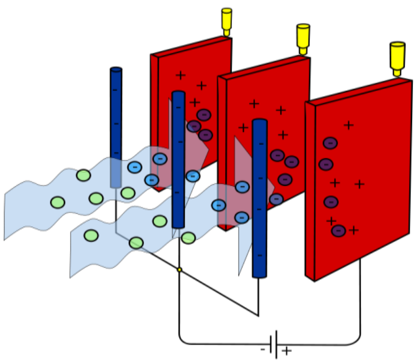

Fig. 4. Electrostatic precipitator working.

A negative voltage of several thousand volts is applied between wire and plate. If the applied voltage is high enough an electric (corona) discharge ionizes the gas around the electrodes. Negative ions flow to the plates and charge the gas-flow particles. The ionized particles, following the negative electric field created by the power supply, move to the grounded plates. Particles build up on the collection plates and form a layer. The layer does not collapse, thanks to electrostatic pressure (given from layer resistivity, electric

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field, and current flowing in the collected layer). Electrostatic Precipitator working is shown in figure 4.

Application

The two-stage design (charging section ahead of collecting section) has the benefit of minimizing ozone production which would adversely affect health of personnel working in enclosed spaces. For shipboard engine rooms where gearboxes generate an oil fog, two-stage ESP's are used to clean the air improving the operating environment and preventing buildup of flammable oil fog accumulations. Collected oil is returned to the gear lubricating system.

With electrostatic precipitators, if the collection plates are allowed to accumulate large amounts of particulate matter, the particles can sometimes bond so tightly to the metal plates that vigorous washing and scrubbing may be required to completely clean the collection plates. The close spacing of the plates can make thorough cleaning difficult, and the stack of plates often cannot be easily disassembled for cleaning. One solution, suggested by several manufacturers, is to wash the collector plates in a dishwasher.

Some consumer precipitation filters are sold with special soak-off cleaners, where the entire plate array is removed from the precipitator and soaked in a large container overnight, to help loosen the tightly bonded particulates.

Consumer-oriented electrostatic air cleaners

Plate precipitators are commonly marketed to the public as air purifier devices or as a permanent replacement for furnace filters, but all have the undesirable attribute of being somewhat messy to clean. A negative side-effect of electrostatic precipitation devices is the production of toxic ozone and NO_x. However, electrostatic precipitators offer benefits over other air purifications technologies, such as HEPA filtration, which require expensive filters and can become "production sinks" for many harmful forms of bacteria.

IV. Design Detail Of 45^{o} Axial Concentric Swirler

There is concentric pipe, consisting of inner and outer pipe. Inner pipe is 120mm in diameter, 300 mm in length. It consists of hub of diameter 40mm, on which 8 vanes of 2 mm thickness is mounted. Length of hub is 60 mm. Vanes are at 0° inlet and 45° outlet angle. Height of vanes is 30 mm which consist of inner length of 580 mm and outer length of 850 mm. Vane Swirler is placed inlet pipe with vane tip made to coincide with exit plane of inlet pipe. Hub to Tip ratio is 0.3. Outer pipe is 250 mm outer diameter and inner diameter is 235 mm. it consist of 6, small rotating hub of diameter of 20 mm. Each hub consists of 3 vanes, placed at 120° angle. Length of hub is 50 mm, height is 30 mm. Vanes are symmetrical, trailing edge of vane do not lie in plane of hub exit. Angle subtended by vane at axis, when viewed in axial direction (φ), 75°, giving an overlap of 30° between adjacent vanes. Figure 5 shows concentric vane swirler with hub.

Expansion Chamber

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. Table I. Different stations points at downstream of swirler.

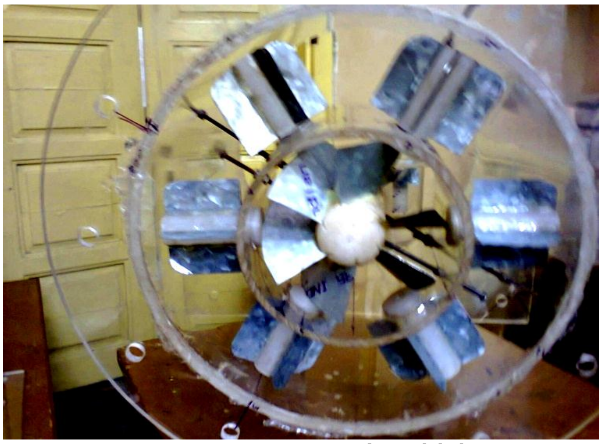

Fig. 5. Concentric vane swirler with hub.

Table I. Different station point at downstream of swirler.

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

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.

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.

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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.

Experimental setup is being fabricated which include inlet pipe, swirler, expansion chamber, tailpipe as shown in figure 8

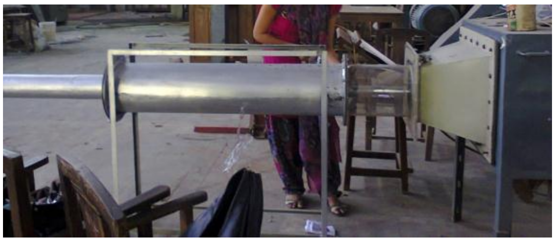

Fig. 8. Experimental setup.

V. Experimental Procedure to Find Out Axial Velocities at Different Stations for Concentric Vane Swirler

First of all set the blower to such a speed that its velocity becomes 9 m/sec. keeps blower running at 46 Hz. Here, the impeller used is of backward flow type. So that we get velocity at the inlet duct is of 9 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 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 h. 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 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 (70, 15), (90, 15), (130, 15), (170, 15), (210, 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 I. 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

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

$U = \bar{U} \cos\beta \cos\alpha$
$V = \bar{U} \sin\alpha$
$W = \bar{U} \cos\alpha \sin\beta$

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

VI. Experimental Results

Experimental Results for Concentric Swirler with Hub
Axial Velocity Contours

At station H, 20 mm downstream of the concentric swirler in Expansion Chamber region, at the center, reverse velocity is observed which become positive and increases from mid-plane to near of the wall. At station I, 50 mm downstream of the concentric swirler in Expansion Chamber region, at the center, reverse velocity is observed which become positive and increases from mid-plane to near of the wall. At station J, 90 mm downstream of the concentric swirler in Expansion Chamber region, at the center, reverse velocity is observed which increase in the mid-plane. It become positive near of the wall. At station K, 130 mm downstream of the concentric swirler in Expansion Chamber region, at the center, reverse velocity is observed which increase near the wall. At station L, 170 mm downstream of the concentric swirler in Expansion Chamber region, at the center, reverse velocity is observed which remains constant to near of the wall. At station M, 210 mm downstream of the concentric swirler in Expansion Chamber region, at the center, reverse velocity is observed which decrease near the wall. At station N, 250 mm downstream of the concentric swirler in Expansion Chamber region, at the center, reverse velocity is observed which increase 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 expansion chamber. In the recirculation zone axial velocity decreases up to -18 to -24 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 24 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.

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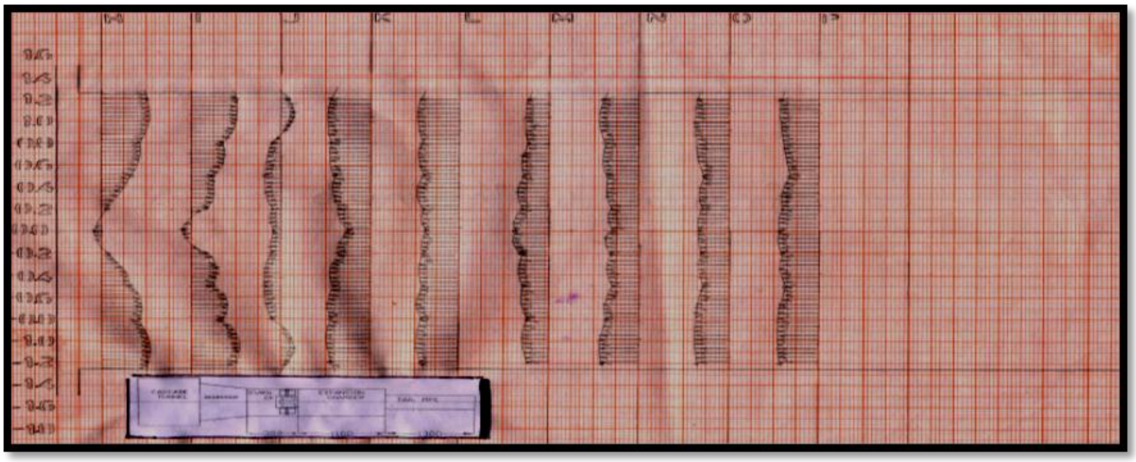

Fig. 9. Experimental graph for concentric swirler with hub.

VII. Conclusions

From results it is observed that near the wall flow is not showing deviation as compare to at the center of the chamber from swirler to up to certain stage. So in this region measurement with help of five hole probe was not possible. In the chamber, as increase in velocity so fluctuation were observed during the measurement. Velocity rise in the chamber, on the downstream of the swirler can be varied with the help of changing the swirler cross section area. In the Swirler rising velocity, give rise to uniform flow in the chamber. Flow can be allow to pass as per requirement with different conditions, at inlet to the Swirler flow in the chamber is deviating from center towards the wall. So this can helpful in Precipitator to operate on full range. With and without hub Flow is not much distorted in the chamber.

Without hub Swirler shows circulation Zone at center as compared to with hub Swirler. Rotating Swirler can be act as a obstruct to the particulate in the flow and also helpful to controlling flow. Rotating swirler can be set at different angle which can be made fixed, so that we can get swirl flow at the periphery of the chamber. The recirculation zone in the mid plane downstream of the swirler is shown in the figure 9 for concentric swirler with hub the region with reverse velocity is termed as central recirculation zone which necessary for flame stabilization and for proper mixing.

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