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Modelling and Analysis of Flow through an Inlet Duct in an Electrostatic Precipitator with Optimum Performance

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Abstract— *Electrostatic Precipitator (ESP) are well accepted and widely used for air pollution control due to reasonable collection efficiency, low pressure-drop, and low capital and operating costs. The objective of the present work is to improve the flow distribution in the duct. In this present work, CFD analysis of flow through the ESP inlet duct has been performed using ANSYS FLUENT, in order to improve the efficiency of duct. The analysis for path lines, velocity contours, pressure distributions for various cases involving no guide vane and with guide vanes has been done.*

Key Words— *ESP, Inlet Duct, Pressure Drop, ANSYS, CFX.*

I. INTRODUCTION

An Electro Static Precipitator (ESP) is a particle control device that uses electrical forces to move the articles out of the flowing gas stream and onto collector plates. The particles are given an electrical charge by forcing them to pass through a corona, a region in which gaseous ions flow. The electrical field that forces the charged particles to the walls comes down electrodes maintained at high voltage in the centre of flow lane. Once the particles are collected on the plates, they must be removed from the plates without re-entering them into gas stream. This is usually accomplished by knocking them loose from the plates, allowing the collected layer of particles to slide down into a hopper from which they are evacuated. Some precipitators remove the particles by intermittent or continuous washing with water. Electrostatic precipitators are used in large power plants, cement plants, incinerators, various boiler applications, chemical factories, sugar mills, etc., ESP's are well accepted and widely used for air pollution control due to reasonable collection efficiency, low pressure-drop, and low capital and operating costs. The performance of modern ESP's would be expected to be better than 99.9% particulate removal efficiency while incurring less than 100 Pa pressure drop. Although commercially available ESP's for large scale industrial gas cleaning exhibit slight variations in design characteristics, component, and mechanical cleaning style, all achieve gas cleaning quite simply by the use of electrostatic forces acting on airborne solid particles to promote their attraction to and eventual collection on charged electrodes. ESP inlet duct is one through which flue gases enter electrostatic precipitator from air pre-heater. The design of ESP inlet duct is very important that the collection efficiency and the power consumption will be affected

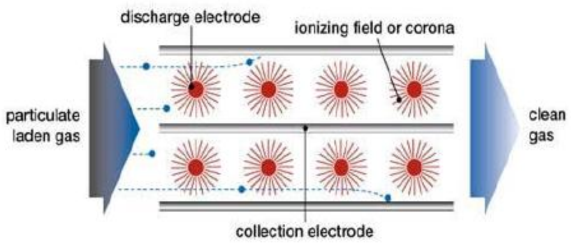

Fig 1 ESP working principle

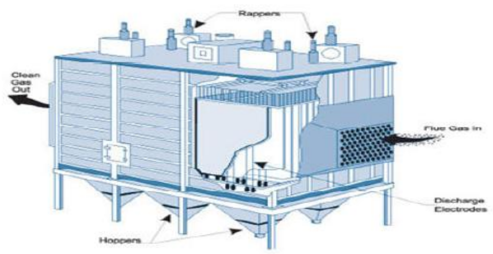
Fig 2 Overview of Electrostatic Precipitator

Collection of particles by electrostatic precipitation involves the ionization of the stream passing though the ESP, the charging, migration, and collection of particles on oppositely charged surfaces, and the removal of particles from the collection surfaces. In dry ESPs the particulate is removed by rappers which vibrate the collection surface. Wet ESPs use water to rinse the particles off. Electrostatic precipitators have several advantages when compared with other control devices. They are very efficient collectors, even for small particles. Because the collection forces act only on the particles, ESPs can treat large volumes of gas with low pressure drops. They can collect dry materials, fumes, or mists. Electrostatic precipitators can also operate over a wide range of temperatures and generally have low operating costs. Possible disadvantages of ESPs include high capital costs, large space requirements, inflexibility with regard to operating conditions, and difficulty in controlling particles with high resistivity. Disadvantages of ESPs can be controlled with proper design. An improvement of flow distribution in the duct through optimization can be achieved by placing guide vanes in the inlet duct. In this present work, CFD analysis of flow through the ESP inlet duct is to be performed without guide vanes and with guide vanes, in order to reduce the pressure drop, reduce turbulence as well as achieve uniform distributions among the streams and minimize erosion of duct walls caused due to high velocity. Reducing erosion of the duct walls results in the reduction of leakages in the ducts. Reduction of pressure drop across the duct saves the power consumption. The ESP inlet duct consists of an inlet and two outlets. In this paper Modeling and analysis of ESP inlet duct has been performed using CAD software ANSYS 15.0 CFX.

II. LITERATURE REVIEW

Bhasker [3, 4] has done flow simulation in inlet ducts with several guide vanes used in electrostatic precipitator (ESP) analyzed to understand the flow pattern at its exit location. The geometry of inlet duct has refined with guide vanes placed at several locations. The domain of duct geometry around guide vanes were decomposed with several volumes and filled with hexahedral elements. The resulting computational grid has been used in fluent solver to predict its flow pattern in the duct. Simulation for the specified conditions predicted uneven flow distribution in the ESP inlet duct. Due to large flow recirculation and turbulent losses in the duct, non-uniform averaged mass flow rates were noticed at duct exit locations. Simulation results suggested that the improvement of flow distribution in the duct through optimization can be tried by placing more guide vanes in the inlet duct. In order to ensure that the results obtained from fluent are meaningful and in right direction, in the absence of measurement data, simulation was benchmarked with other industry standard commercial flow solvers.

Seralathan S. et al [1] presented a paper in which CFD analysis of flow through the ESP inlet duct is performed by placing the guide vanes, in order to reduce the pressure drop, reduce turbulence as well as achieve uniform distributions among the streams and minimize erosion of duct walls caused due to high velocity. Reducing erosion of the duct walls results in the reduction of leakages in the ducts. Reduction of pressure drop across the duct saves the power consumption [Ref. 8]. The ESP inlet duct consists of an inlet and two outlets. The simulation studies involving the flow through the ESP inlet duct is performed using commercial code, FLUENT 6.3 using structured hexahedral mesh. The path lines, velocity contours, pressure distributions for various cases involving no guide vane and six guide vanes are analyzed. The ESP inlet duct with six guide vanes shows lesser pressure drop with uniform distributions across the duct. The numerical analysis of the flow through ESP inlet duct has been performed involving various cases – no guide vane and six guide vanes. Reduction of pressure drop around 30 % in the proposed model with six guide vanes as compared to the existing layout of duct without guide vanes, which in turn results in saving of power consumption in inlet draught fan and improves the performance of ESP. Going through the literature it has been observed that in duct designing, different methods has been applied to improve the efficiency of duct. This improvement may be in the form of reduction in pressure, making smooth the streamline through the duct or reducing the turbulence of flow.

III. NUMERICAL VALIDATION OF MODEL

The modeling of the inlet duct of ESP is done using ANSYS 15.0. Triangle surface mesh is generated and used in the simulation studies to create the fluid domain. Table 4.1 shows the number of elements and number of nodes for the present model using ANSYS 15.0 Workbench. Analysis has been done using CFX and meshing is done with triangle surface elements type. The entire domain is in the stationary frame of reference. The boundary conditions specified are mass flow rate at the inlet and static pressure at the outlet. The velocity at inlet is 6 m/s. The walls are defined no slip condition. The monitoring parameter is pressure for the entire case studies. Steady state solutions are computed until the residual values of computations converged. Reference pressure used for simulation is 101.325 Pa and hence the static pressure at inlet is given as zero Pascal.

Table 1 Details of elements and nodes of the computational domain

Case	Description	No. of Elements	No. of Nodes
1	Without Guide vane	24363	5636
2	With 6 Guide vanes	29318	6817

As pointed by Bhaskar [3&4], the simulation studies are performed by placing more guide vanes in the inlet duct to improve the flow distribution in the duct of the ESP. In this project the CAD model has been generated using ANSYS 15.0 software and the model has been validated with the base paper (Reference 1) for following two cases:-

Case A Inlet Duct without Guide vanes

Case B Inlet duct with six guide vanes.

3.1 Case A- ESP Inlet Duct Without Guide Vane

Using the CAD software ANSYS 15.0 ESP Inlet Duct model without guide vanes has been generated. The computational model view of ESP inlet duct without vane is shown in Fig 3

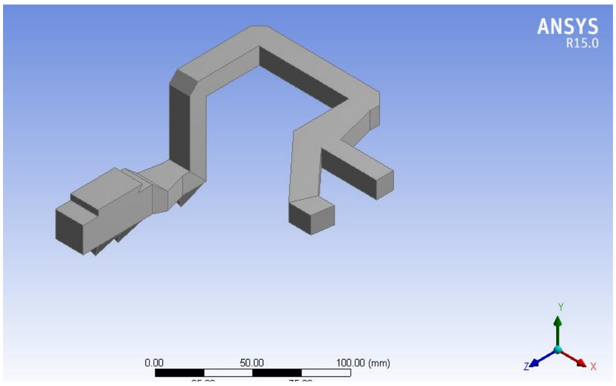

Fig 3 Computational model view of ESP inlet duct without guide vane

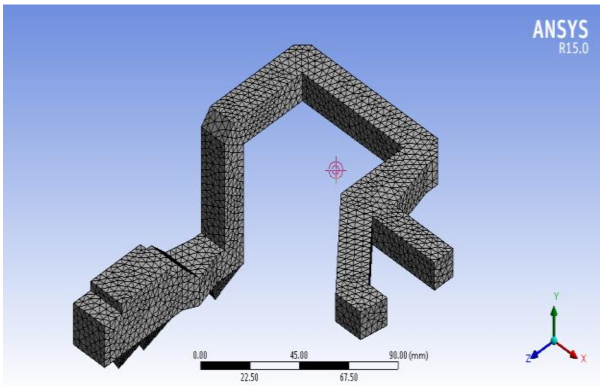

Fig 4 Meshing of CAD model of Inlet duct without Guide vane

After generating computational model meshing has been done using triangular surface element shown in Fig 4. The boundary conditions are same for all the cases as mentioned earlier. Fig 5 shows the velocity distribution flow through the inlet duct of ESP.

The computational fluid analysis of CAD model has been done using ANSYS 15.0 CFX for calculation of pressure drop. The velocity at the outlet of ESP inlet duct is increased compared to the inlet section. At first, velocity increases and there is stagnation at the corner of the duct and then gradually increases again. A high velocity zone at the sharp edge is noticed and velocity decreases sharply and then increases. Therefore there is non- uniform distribution of velocity of flue gases within the duct. Pressure drop across the ESP inlet duct is 641.8 Pa (Fig 6). Pressure at inlet is high and then it reduces gradually and there is stagnation at the corners and then drop in the pressure is very high. Therefore, the power consumption will be high, so the pressure drop can be reduced by placing guide vanes.

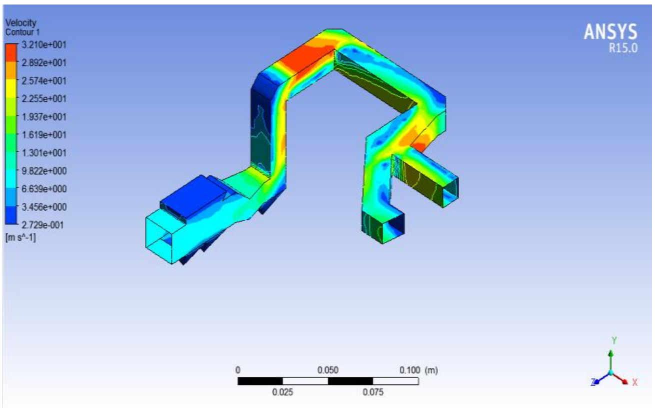

Fig. 5 Velocity contour of ESP inlet duct without guide vane

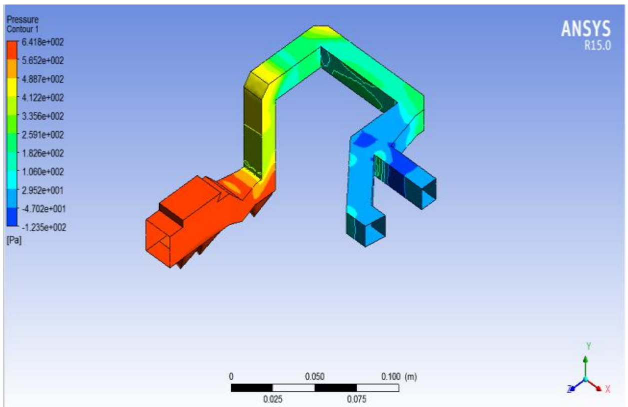

Fig. 6 Pressure distribution in ESP inlet duct without guide vane

3.2 Case B- ESP Inlet Duct With six Guide Vanes

Fig 7 shows the location of ESP inlet duct with six guide vanes. The guide vanes are placed at the six corner bends of the inlet duct. By placing guide vanes in these cases, the uniform flow of flue gas is achieved and pressure drop is also decreased compared to all the earlier cases. The flow is made more uniform by using six guide vanes. The guide vanes are curved in shape and radius of curvature is 9mm. Flow variations in the outlet duct compared to previous cases are much reduced. This causes the uniform flue gases distribution throughout the duct. The velocity distribution is more uniform throughout the entire region from inlet to outlet in this case. This makes the flue gas distribution uniform. The velocity pattern at the outlet portion is also uniform. This uniform distribution is due the introduction of guide vanes at outlet region of the ESP inlet duct. Fig 8 shows the velocity contour of ESP inlet duct with six guide vanes. The velocity distribution is more uniform throughout the entire region from inlet to outlet in this case. The velocity at inlet increases and the velocity at the corners decrease slightly because of the presence of guide vanes. This makes the flue gas distribution uniform. The velocity pattern at the outlet portion is also uniform. This uniform distribution is due to introduction of guide vanes at outlet region of the ESP inlet duct.

Pressure drop at ESP inlet duct with six guide vanes is 510 Pa as seen in Fig. 9. The pressure at the entry of the duct is high and then it reduces at the first bend and it again reduces at the next bend and the pressure is uniform. Again, at the outlet region the pressure further decreases.

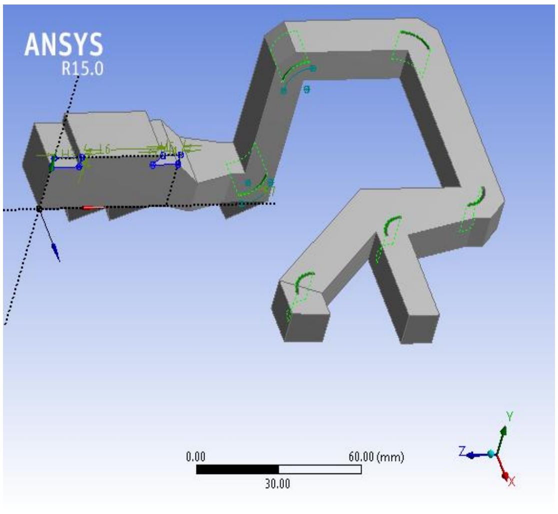

Fig 7 Computational model view of ESP inlet duct with six guide vanes

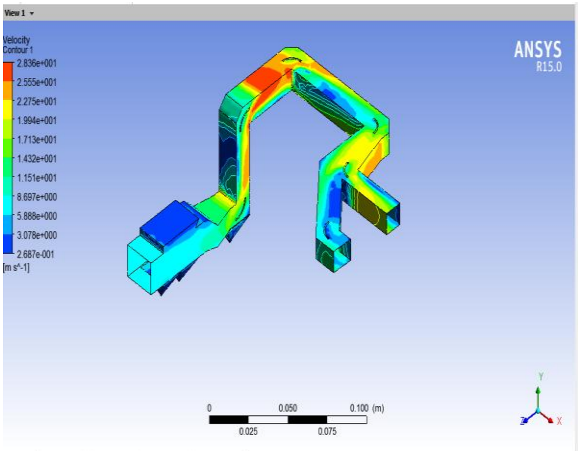

Fig 8 Velocity contour of ESP inlet duct with six guide vane

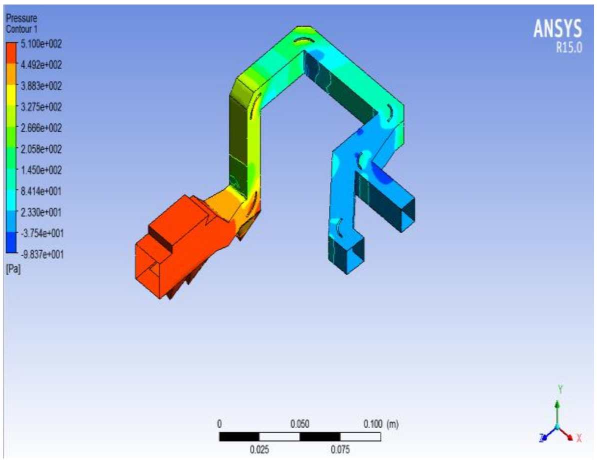

Fig 9 Pressure distribution in ESP inlet duct with six guide vane

Table 2 and 3 shows the comparison of pressure drop and velocity for present computational model using ANSYS 15.0 CFX and results obtained in base paper [1] using FLUENT 6.1.

TABLE 2 Validation of present results (for Pressure) with previous literature [1]

CASE	Pressure Drop (Pa)		%age Variation
	Present Result	**Reference 1**	
A (Without Guide Vanes)	641.8	692.8	+ 7.36
B (With 6 Guide Vanes)	510.0	490.62	- 3.95

TABLE 3 Validation of present results (for velocity) with previous literature [1]

CASE	Maximum Velocity (m/s)		%age Variation
	Present Result	**Reference 1**	
A (Without Guide Vanes)	32.1	33	+ 2.73
B (With 6 Guide Vanes)	28.36	27.3	- 3.88

Table 2 and 3 shows that using ANSYS 15.0 Software, variation of pressure drop and maximum velocity is within ±10%, which is under acceptable range. Also the pressure drop is reduced from 641.8 Pa to 510.0 Pa. The presence of guide vanes reduces the pressure drop around 20.53 %. This reduces the power consumption. Hence computational model for inlet duct of ESP is validated and now the further optimum performance is to be done for reducing the pressure drop and improving the efficiency of the duct.

IV. RESULTS AND DISCUSSIONS

The aim of this research is to further increase the duct performance by improving the flow. It has been achieved by increasing the number of vanes at the bends and also by giving fillet at the corners. The computational domain for five case studies involving the simulation studies of flow through the inlet duct of ESP is performed by considering inlet duct with 12 guide vanes, 18 guide vanes, 6 guide vanes with fillet, 12 guide vanes with fillet and 18 guide vanes with fillet respectively. The boundary conditions for all the cases are similar and same as taken in the base paper [1].

4.1 ESP Inlet Duct with Twelve Guide Vanes

The maximum pressure value has been reduced from 641.8 Pa for without guide vane to 402.1 Pa with 12 guide vanes (Fig 10). The increase of guide vanes from 6 to 12 further reduces the pressure drop around 37.34 %. This reduces the power consumption and increasing the duct efficiency.

4.2 ESP Inlet Duct with Eighteen Guide Vanes

Fig 11 shows the pressure distribution throughout the ESP inlet duct with 18 guide vanes. The maximum pressure value has been reduced from 641.8 Pa for without guide vanes to 479.2 Pa with 18 guide vanes. The increase of guide vanes to 18 further reduces the pressure drop around 25.33 %.

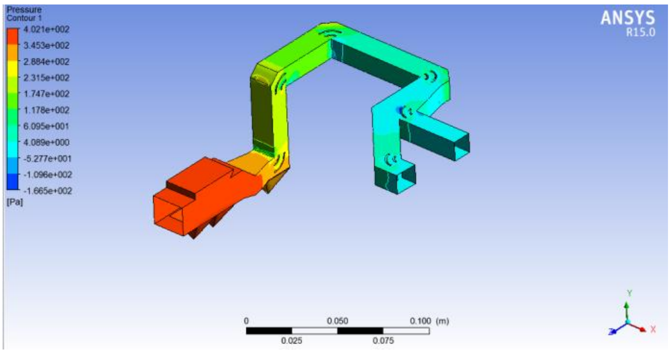

Fig 10 Pressure distribution in ESP inlet duct with twelve guide vane

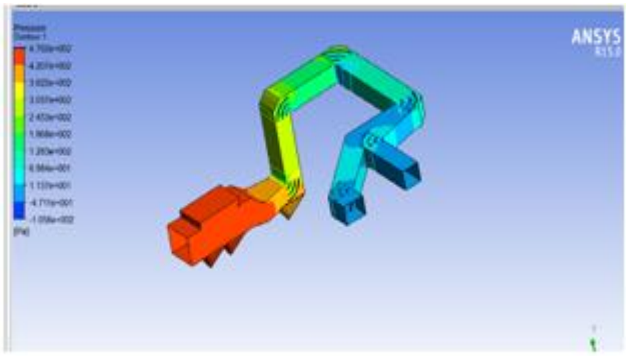

Fig 11 Pressure distribution in ESP inlet duct with eighteen guide vane

4.3 ESP Inlet Duct with Six Guide Vanes and Fillet at corner

Fig 12 shows the pressure distribution throughout the ESP inlet duct with 6 guide vanes and fillet at corners. The maximum pressure value has been reduced from 641.8 Pa for without guide vanes to 186.5 Pa. The pressure drop reduces to 70.9 %.

4.4 ESP Inlet Duct with Twelve Guide Vanes and Fillet at corner

Fig 13 shows the pressure distribution throughout the ESP inlet duct with 12 guide vanes and fillet at corners. The maximum pressure value has been reduced from 641.8 Pa for without guide vanes to 208.2 Pa. Hence pressure drop further reduces around 67.56 %.

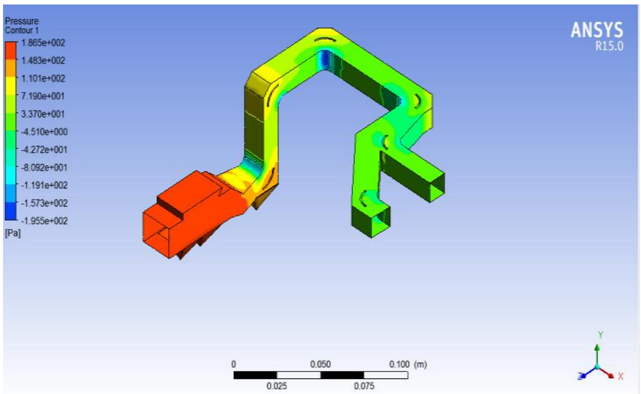

Fig 12 Pressure distribution in ESP inlet duct with six guide vanes and fillet at corners

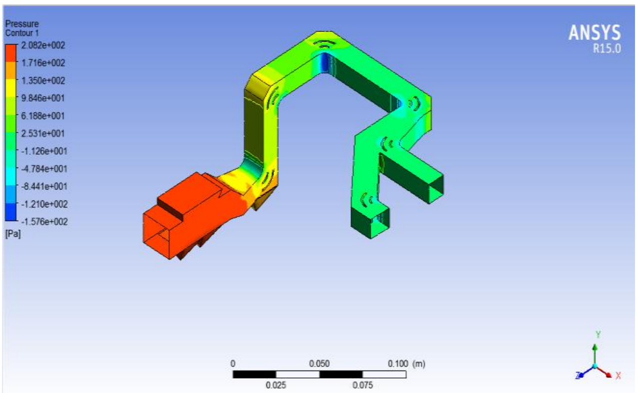

Fig 13Pressure distribution in ESP inlet duct with twelve guide vanes and fillet at corners

4.5 ESP Inlet Duct with Eighteen Guide Vanes and Fillet at corner

Fig 14 shows the pressure distribution throughout the ESP inlet duct with three guide vanes at each corner in total 18 guide vanes and fillet at each corner. The maximum pressure value has been reduced from 641.8 Pa for without guide vanes to 249.6 Pa. The increase of guide vanes to 18 with providing fillet at each corner further reduces the pressure drop around 61.1 %.

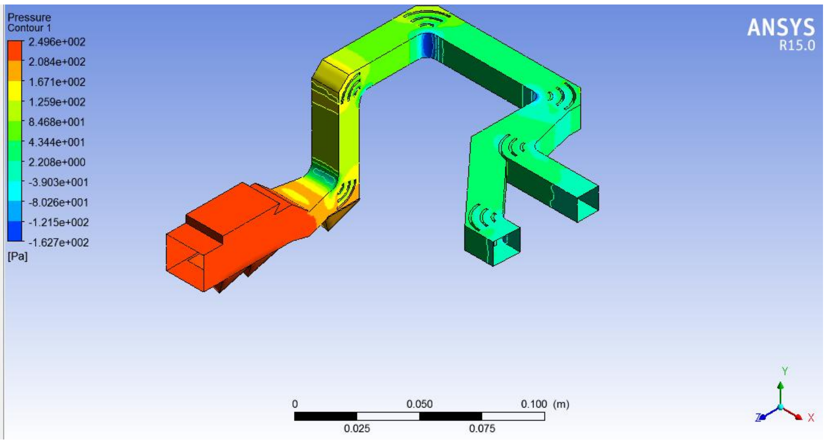

Fig 14 Pressure distribution in ESP inlet duct with eighteen guide vanes and fillet at corners

Table 4 shows the comparison of reduction in pressure drop for all the cases mentioned above with the case of inlet duct without guide vanes.

Table 4 Comparison of reduction in pressure drop for all the cases

	Without guide van	6 guide vanes	12 guide vanes	18 guide vanes	6 guide vanes with fillet	12 guide vanes with fillet	18 guide vanes with fillet
Maximum Pressure (Pa)	641.8	510.0	402.1	479.2	186.5	208.2	249.6
% Reduction	----	20.53	37.34	25.33	70.9	67.56	61.1

V. CONCLUSIONS

The numerical analyses of the flow through ESP inlet duct are performed involving various cases – no guide vane, with six, twelve, eighteen as well as six, twelve and eighteen guide vanes with fillet. The flow distribution among the stream are studied both for existing and proposed layout.

- It has been concluded from this research that with six guide vanes the pressure drop reduced by around 20.53%, with 12 guide vanes the pressure drop is reduced by 37.34%, with 18 guide vanes the pressure drop is reduced by 25.33%, in the proposed model as compared to the existing layout of duct without guide vanes, which in turn results in saving of power consumption in inlet draught fan and thereby improves the performance of ESP.
- Further analysis has been done by taking fillet of 5 mm at each corner of the inlet duct. With 6 guide vanes and fillet pressure drop is reduced by 70.9 %, with 12 guide vanes and fillet pressure drop is reduced by 67.56 % and with 18 guide vanes and fillet pressure drop is reduced by 61.1 % as compared to the duct without guide vanes.

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