International Engineering Research Journal
Design, development and optimization of physical scale down model of an Electrostatic precipitator

Sagar V. Bulbule[1], V. N. Kapatkar[2]

[1] PG student, Department of Mechanical Engineering, SCOE, Savitribai Phule Pune University, Maharashtra, India
[2] Assistant Professor, Department of Mechanical Engineering, SCOE, Savitribai Phule Pune University, Maharashtra, India

Abstract
This report is based on study of the optimization of electrostatic precipitators. The main reason for problem is improper flow distribution of gas. The improper flow affects the collection performance of an electrostatic precipitator . It also contains the simulation of an electrostatic precipitator. In the simulation part, regulation of flow for design of physical scale down model using CFD is done. First part of report provide theoretical view on electrostatic precipitator and its working. Later part consist of work done in project like optimization of flow by implementing modifications in electrostatic precipitator.
Keywords: *Emission control,Electrostatic precipitator, simulation,optimization.*

1. Introduction

Over recent years the particle emission from process, industries have been attracting more attention due to an anticipation of strict environmental protection agency (EPA) regulations. Industrial pollution can be controlled by energy recovery and conservation, replacing conventional industrial processes with continuous and energy efficient systems or performance optimization of the emission control devices. Electrostatic precipitators (ESP) are the most widely used devices which are capable of reducing particle emission effectively from power plants and other process industries. The flow distribution within the ESP has been reported to have varying effects on its dust collection performance depending on the arrangements of the major geometrical features inside an ESP.Electrostatic precipitation (ESP) has been a important industrial technology since the early 1990s and can be regarded as the major pollution control device in industrial applications such as purifying the flue gases from coal burning or cement production plants and diesel engine generators. In this device the particles are charged by the ionic bombardment in the precipitator channel, transported towards the collecting plates by electric forces and deposited on them. The electrostatic forces exerted on the ionic space charge by the electric field (Coulomb forces) induce the secondary electro-hydrodynamic (EHD) flow, or the ionic wind, which increases in the flow turbulence in the channel. The airflow drag forces and EHD flow also affects the particle trajectories, making them even more to predict.

Therefore the complex coupled phenomena between the electric field ,turbulent flow field and particle charging and motion must be taken into account for the full analysis of ESPs. Although most of the phenomena related to particle connection in an ESP are well understood, extensive numerical and experimental investigations are still being carried out on many detailed aspects of ESP, such as electrostatic fields, fluid dynamics, charging mechanism and particle dynamics.If local gas velocities are too high, then the aerodynamic forces upon the particles can overwhelm the electrostatic forces generated by the collecting surfaces and electrodes. This leads to degradation in collection efficiency. Similarly, if local velocities are too low, then the collecting surface is not being adequately utilized and the potential of particulate build-up in the ESP inlet and outlet ductwork increases. For these reasons, proper design of flow control devices within ESPs is critical. Typically, this design is performed utilizing a flow model of the ESP to optimize the geometry of vanes, baffles, and perforated plates.

Using theoretical formulae and with available data of ESP performance will be calculated and for validation simulation tool will be used. According to ESP performance resizing and position of vanes and baffle with different resistive coefficient of perforated plates to achieve flow optimization of ESP and design of scale down flow model analysis and calculation of body structure obtained stress and strain distribution is proposed design recommendations.

Literature review

Literature review is one of the important step while doing any project. Before designing, manufacturing or optimization of any component, understanding theoretical background is very important. In past some researchers may did some valuable contributions in that field which can be used for further development and doing detailed study of that literature. one can move forward for next work.

some important papers related to this topic are listed below which play a significant role.

S.M.E. Haque, M.G. Rasul [1],provided reviews on performance of electrostatic precipitator (ESP) ,stating that it is significantly affected by complex flow distribution. The gas flow through the ESP at local power station is modeled numerically using computational fluid dynamics (CFD)code fluent to give insight to the flow behavior inside the ESP. The flow simulation was performed using the Reynolds stress model (RSM).

Q. F. HOU, B.Y. GUO [2],This paper presents a multiscale approach to numerically simulate the gas flow in an ESP system with two parallel ESP units. firstly the flow resistance coefficients of the perforated plates with different porosities, and of the channel plate are obtained through unit cell studies. The results are validated against an empirical equation. Secondly , the simplification of the perforated plates as porous jump boundaries is justified using a simple ESP experimental rig and it is found that the anisotropic porous media has similar behavior while it is more convenient to control porosity distribution of the perforated plates.

Niels F. Nielsen, Leif Lind, [3] published simulation of the full ESP including inlet funnel with gas distribution screens precipitation sections with collector curtains and anti Sneakage baffles, hoppers with partition plates and outlet funnel with gas distribution screenthe distribution of the three dimensional flow are simulated by a commercial CFD code giving the accurate and highly detailed information over the calculated domain.

Brian J. Dumont, Robert G. Mudry [4]In this paper application of computational fluid dynamics (CFD) modeling to Electrostatic precipitator (ESPs) is discussed modeling methodology is reviewed. A range of the ESP fluid flow characteristics that can be evaluated using CFD techniques is explored. These include the analysis of velocity distribution, temperature stratification.

Shah M. E. Haque, M. G. Rasul [5] this paper gives an overview of how ESP is significantly affected by its complex flow distribution arising as a result of its complex inside geometry.Also explains how numerical calculations for the gas flow are carried out by solving the Reynolds averaged Navier stokes equation coupled with Realizable k-ε turbulence model equations.

Shah M.E.Haque, M.G. Rasul [6] The performance of the electrostatic precipitator is significantly affected by its complex flow distribution arising as a result of its complex inside geometry.This paper presents the study of through an ESP used at a local thermal power plant is modelled numerically using computational fluid dynamics (CFD) technique to gain an insight into the flow behavior inside the ESP.CFD code fluent is used to carry out the computations .

Jacobo porteiro,Ruben martin[7] A computational model for the simulation of electrostatic precipitators (ESP) operation was developed.Special attention has been paid to several parameters such flow distribution,streamline distribution.The model is applied to three dimensional geometry and validated against the experimental data carried out.

Scope and objectives

The scope and objectives of the project are summarized below:

1. Study the initial run for Flow regulation through Electrostatic Precipitator
2. Optimization of flow through ESP: Regulate the flow through ESP to give better performance for collection of dust.
3. Development of physical scale down flow model of ESP replicate the same mechanism observed in the actual ESP.
4. To regulate the flow in scale down esp.

Methodology

Following methodology was used from starst to end of the project

1) Study of electrostatic precipitator
   In electrostatic precipitator there varioussmall components that are used to make the proper gas flow in Electrostatic precipitator.such as turning vanes,diffuser baffles,perforated plates,etc.
2) Generation of different concepts
   Various concepts are gerenated to optimize flow through precipitator.variation in position and angular orientation of vanes and baffles are created,also the change in the resistenca of perforated plates.
3) Design physical scale down flow model
   Physical scale down flow model is created for reducing complex flow problems to their simplest forms prior to quantitative analysis.To check the performance of actual esp.
4) Software analysis of model
   All the models generated will be analysed using various software that facilitate the detailed analysis.Here software used is CFX solver of ansys.
5) Validation of Results
   The concepts that are yielding good results in software analysis will be validated experimentally and results will be compared for further analyss

Optimization of flow

Vanes and baffles (modifier)

A vane electrostatic precipitator controls the air flow so that the entrainrd air particles are contionously subjected to a stress in the form of drag as they flow in front an dbehind vanes electrodes in the precipitator.It is not based on achieving laminar flow over the collecting plates insted efficient collection is achieved by operating with a narrow air stream and using vane electrodes in various configurations that gradually reduce the flow rate of entrained air thereby allowing the particles to precipitate and collect on the vanes.The VEP concept is not based on achieving laminar air flow over the collecting plates as desired with standard electrostatic precipitators,but controlling the air flow so that the entrained air particles are continuously to a stresss in the form of drag,as they in front and behind vans electrodes in the precipitator.to design herein create turbulence in the air flow to improve collection efficiency.Efficient collection is achieved by using vane electrodes in various configurations and porous back plates that gradually the flow rate of the entraned air,thereby allowing the particles to precipitate and collect on the vanes.entraine air flows over the front and back sides of vanes that not only collect the particulates but continuously induce resistence to the flow of entrained air and conversely increases the chance for particle collection

Scale down process

Scale down analysis is a method for reducing complex physical problems to their simplest (most economical) forms prior to quantitative analysis or experimental investigation, i.e., reduces a problem's degrees of freedom to the minimum and thus suggests the most economical scaling laws. In the context of a chosen system of units (e.g. SI) and frame of reference it can be offered a quantitative description of reality $f(x_1, \ldots, x_n) = 0$, and in order to correctly evaluate reality on all scales, dimensional analysis permits to find the minimal and invariant description in terms of dimensionless numbers F (p1, . . . , pm) = 0, where m < n.

An ESP is modeled in 1:10th scale. The model was constructed from clear acrylic to enhance flow visualization potential. The system comprising of the electrostatic precipitators, the ducts from the air pre-heater outlet to the ESP inlet and the duct from the ESP outlet to the induced draught fan inlet, the transition duct from the outlet of induced draught fan to the inlet of the chimney and duct representation of ESP modeled to a scale of 1:10. All flow correcting devices like guide vanes in ducts, baffles, deflector plates on gas distribution screen at ESP inlet and GD screen at outlet of the precipitators etc were modeled according to the relevant drawings. The model casing and ducts were constructed from clear transparent acrylic sheets. Guide vanes and baffles in funnel were made of plastic or opaque sheets. Gas distribution screens were made of mild steel and hard boards suitably spaced and supported represented collecting plates. To establish flow through model suction fans were connected to the outlet delivery of the model. The primary principal behind physical scale modeling is Fluid Dynamic Similarity.

GEOMETRIC SIMILARITY

Geometric similarity is of primary importance for a physical model of an ESP. Typically, all ductwork and ESP elements are constructed to be accurate to within a 1:10 scale. The shape of model and full-scale plant should be identical; the same scale was used for all parts in the Electrostatic precipitators.

KINEMATIC SIMILARITY

Structural elements and patterns are scaled down to a 1:10 ratio and the smaller elements like electrodes are ignored, Collection plates are typically modeled as hard board walls, with no structural ribs.

DYNAMIC SIMILARITY

Relative influences of different force components are the same in the model and full-scale plant. The ratio between forces of inertia and viscous forces is the same in corresponding positions in the model and the full-scale plant. Dynamic similarity is ensured if the fluid Reynolds number is matched between the model and the actual ESP.

"Similarity between a model and a full-sized object implies that the model can be used to predict the performance of the full sized object. Such a model is said to be mechanically similar to the full-sized object. Complete mechanical similarity requires geometric and dynamic similarity. Geometric similarity means that the model is true to scale in length, area, and volume. Dynamic similarity means that the ratios of all types of forces are equal. These forces result form inertia, gravity, viscosity, elasticity, surface tension, and pressure."

Structural elements larger than about 4" full-scale are generally included and smaller elements are ignored, including electrodes.

Scale down is a methodology of reducing dimensions of a model by maintaining same non-dimensional number for model as well as prototype.

Reynolds Number (Non-dimensional number):

Reynolds number is a dimensionless quantity that is used to predict similar flow patterns in different fluid flow situations.

Reynolds Number is defined as the ratio of inertia force to viscous force and consequently quantifies the relative importance of these two types of forces for given flow conditions.

$$Re=\frac{\text{Inertia force}}{\text{Viscous force}}$$

Check flow rate for this velocity and accordingly change the dimensions to maintain constant flow rate through out the system.

The Reynolds number for the scale model must be equal to the Reynolds number of the prototype for the flow measurements of the scale model to correspond to the prototype in a meaningful way. This can be written mathematically, with the subscript m referring to the scale model and subscript p referring to the prototype, as follows:

$$(Re)_{model} = (Re)_{prototype}$$

$$Re_m=\frac{\rho m \; Vm \; Lm}{\mu m}=\frac{\rho p \; Vp \; Lp}{\mu p}=Re_P$$

where

V is the mean velocity of the object relative to the fluid

L is a characteristic linear dimension,

μ is the Dynamic Viscosity of the Fluid

ρ is the density of the fluid

Observing the equation above it is clear to see that while the Reynolds numbers must be equal for the scale model and the prototype, this can be accomplished in many different ways, for example, in this problem by altering the scale of the dynamic viscosity of the model to work with the scale of the length. This means, the scales of different quantities, for example a material's elasticity in the scale model versus the prototype, are governed by equating the dimensionless quantities and the other quantity's scaling within the dimensionless quantity to ensure the dimensionless quantity of interest is of equal magnitude for the scale model and prototype.

Scaling

With the above understanding of similitude requirements, it becomes clear the scale often reported in scale models refers only to the geometric scale, (L referring to length), and not the scale of the parameters potentially important to consider in the scale model design and fabrication. In general the scale of any quantity i, perhaps material density or viscosity, is defined as:

$S_i = I_p/I_m$

where

I_p is the quantity value of the prototype

I_m is the quantity value of the scale model

This relationship must be applied to all quantities of interest in the prototype, observing similitude requirements so the scale model can be built using dimensions and materials that make scale model testing results meaningful with respect to the prototype. One method to determine the dimensionless quantities of concern for a given problem is to use dimensional analysis.

Data comparison in CFD simulation-

A direct comparison of field test data to CFD model results is made for ESP.three specific case studies are discussed indetail to relate the general comparison process

1)Contour plots-the test and the model data at the available locations are plotted as colour contour plots indicating flow direction in the axial flow directionthe model and test data are normalized by dividing the appropriate average velocity.Ths allows the velocity distributions to be compared on an equivalent colour scale.

2)comparison of flow distributions is done.the velocity deviation from a target flow distribution is a typical statistic desired by ESP designers and owners.This is generally qualified at both the inlet and outlet plane in one of two ways.

3)a comparison of distribution in initial run and post optimization run is done.

The specifications of electrostatic precipitator are known.to perform Computational fluid dynamics analysis a model is constructed in CATIA modelling software and then entire fluid domain is divided in to small elements which is known as meshing and it is don eby using software Hypermesh.Then this mesh model is imported in ANsys CFX and analysis is done.the optimization is done according to flow patterns seen in CFX.various modifiers are used to make the flow proper through ESP.such as turning vanes in inlet duct,baffles,perforated plates of different porosity.in th eintial run therer are no baffles ,turning vanes etc.through variousCFX run we come to know about the flow patterns and hence accordingly we can suugest various smodifications.the modifires like turning vanes and baffles are need to be change their angles and again perform iterations until optimized flow is optimized.

Specification of Model:

The operating conditions of electrostatic precipitator as follows:

Flow rate-140.6 m^3/sec

Operating temperature-205 C

Operating pressure-400 mm WC

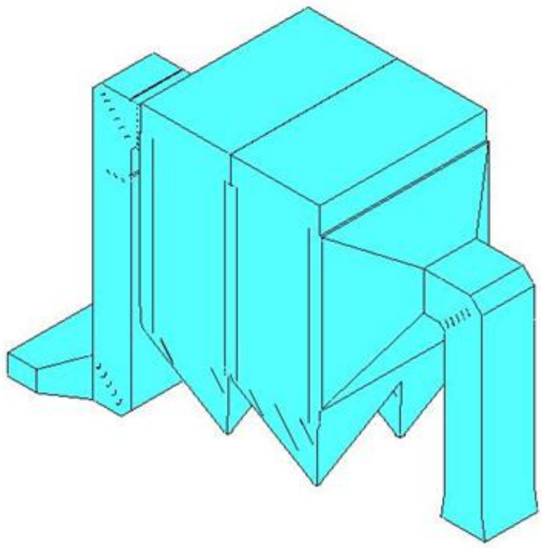
Number of fields-29

Length of collection chamber-12.2 m

Height of collection chamber-11.4 m

ESP Model-

According to given dimensions a 3d model is created.

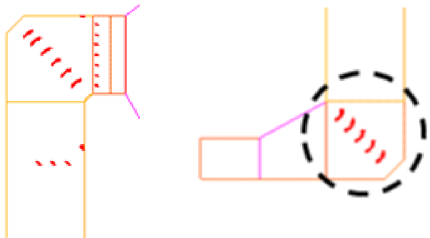


ISOMETRIC VIEW

Meshing-

For simulation of computational fluid dynamics it requires 3d mesh element as fluid domain for fluid domain and 2d elements for boundary conditions.

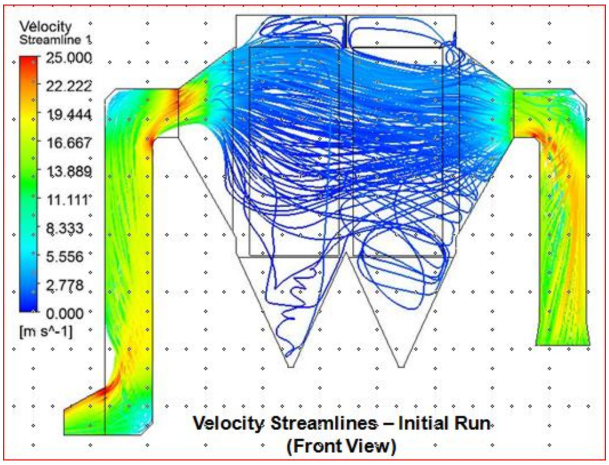
Modifier-



Simulation

Anlysis of fluid dynamics is done in cfx solver in ansys.according to given specifications and boundary conditions following results are obtained.

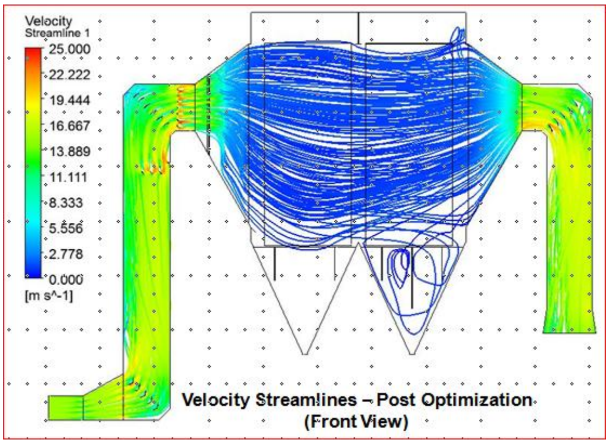
As shown in the figure incoming flow distribution in the inlet duct of ESP is highly non-uniform and highly turbulent flow.such disturbed gas flow and other unbalanced erratic flow conditions causes heavy reentrainment loss from the electrodes and hoppers concern the efficiency of cleaning device.In order to provide insights for developement optimized duct configuration,the fluid domain for Esp uptream duct with turning vanes has been comprehensively studied by means of computtional fluid dynamic techniques.Due to short and wide angles used in the contruction of duct geometry,the velocity distribution exhibits highly non-uniform and noticed strong flow circulation at several locations inside the duct.the momentum loss due to uneven flow simulation indicates flow distribution from its exit locations are unequal.the optimization of flow by addition of more number of turning/splitter vanes in thevanes in the ESP essential either through trial and error method or can be accomplished using advanced techniques like moving grids in transient flow simulation.due to uncertainty sources such as input forcing,model parameters ,complex geometry and exchanges of flow among different domains in surface.despite considerable in electrostatic precipitator regard to the impact of dynamic ineractionamong different flow domains



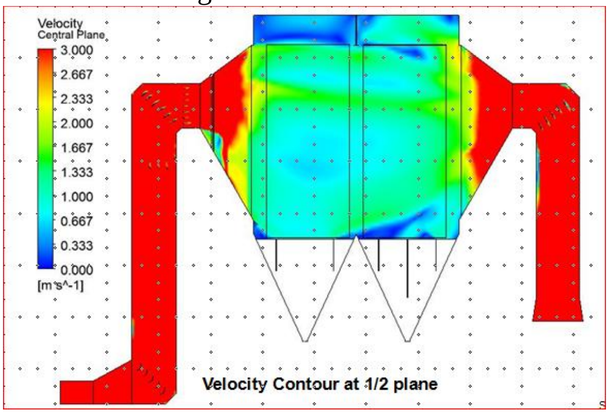
Above figure shows the velocity streamlines for initial run.the flow is observed to be very non-uniform.this non-uniform flow causes the decrease in collection efficiency of ESP.

Model is created in CATIA,and then meshing is done in hypermesh and followed by simulation in CFD.

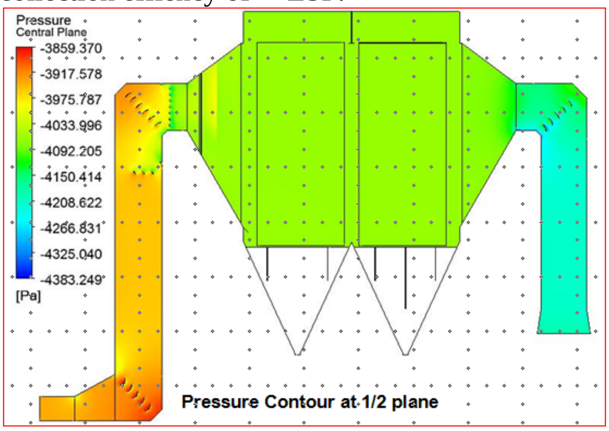
Above figure shows the velocity streamlines for initial run.the flow is observed to be very non-uniform.this non-uniform flow causes the decrease in collection efficiency of ESP.various modifiers are used to regulate the flow in ESP.such as turning vanes, baffles in diffuser portion.also perforated plate with different porosity are used.



Above figure shows the velocity streamlines for optimized flow.the flow is observed to be very uniform and in contact with electroplates.this causes the increase in collection efficiency of ESP.this is possible because of various modifier sused in the inlet duct and diffuser section.also changes in porosity of perforated plates in diffuser has made a great impact in making the flow to be very uniform. Due to uncertainty sources such as input forcing,model parameters,complex geometry and exchanges of flow among different domains in surface.despite considerable in electrostatic precipitator regard to the impact of dynamic interaction among different flow domains.



Above figure shows the velocity contour at mid-plane of ESP.it is seen that velocity of gas is more uniform in collection chamber.this uniform velocity of gas in contact with electroplates in collection chamber is very important since it increases the collection effiency of ESP.



Above figure shows the pressure conour at mid-plane of ESP.it is seen that pressure is uniform in Collection chamber portion.it is found to be minimum at the outlet duct of ESP.

Conclusion-

The following conclusion are made from the analysis done,

1.it is seen thatflow became more uniform after post optimization.

2.flow is more in contact with electroplates.

3.This causes the increase in collection efficiency of the collection chamber and hence ESP

References

1) S.M.E. Haquel,M.G. Rasul,"Nimurical simulation of turbulent inside the electrostatic precipitator of a power plant",IASME International conference on fluid mechanics,Miami,Flofrida,USA,January 2006.
2) Q.F. Houl,B.Y. Guo"Numerical Simulation of gas flow in an electrostatic precipitator",CFD Simulation of gas flow in in an electrostatic precipitator", CFD in the minerals and process industries,Dec 2009
3) Niels F. Nielson,Lief Lind"CFD simulation of gas flow and particle movement in ESPs",Denmark.
4) Brian J. Dumont, Robart G.Mudry"Computational Fluid dynamics modeling of Electrostatic Precipitator"
5) Shah M.E. Haque,
6) Q.F. Houl,B.Y. Guo"Numerical Simulation of gas flow in an electrostatic precipitator",CFD Simulation of gas flow in in an electrostatic precipitator", CFD in the minerals and process industries,Dec 2009
7) Niels F. Nielson,Lief Lind"CFD simulation of gas flow and particle movement in ESPs",Denmark.
8) Brian J. Dumont, Robart G.Mudry"Computational Fluid dynamics modeling of Electrostatic Precipitator"
9) Shah M.E. Haque,