WEIGHT OPTIMIZATION OF ELECTROSTATIC PRECIPITATOR (ESP) HOPPER & NOZZLE USING FEA APPROACH

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Abstract – *The particulate matters released out of the industries such as boiler, cement, power generation etc. received attention because of firm environmental protection agency (EPA). Electrostatic precipitators (ESP) developed by Frederick G. Cottrell (Professor of chemistry at the University of California, Berkeley) is the most commonly used technologies for separation of ash particles from the emission. The objective of this work is optimizing the stiffener size and shape so that the weight of the hopper and nozzle can be as minimum as possible. The main aim of this work is to reduce the existing weight of the hopper and nozzle by 9-10%. In this present work the APDL programme is built for the modelling of the hopper and nozzle and to reduce the weight. The simulation result shows that by taking the optimization runs the software gives the idea of the stiffener size and shape to be used. The results show the appropriate weight distribution and use of stiffener size where needed and all the stress and deflection are within limit.*

Key Words: Electrostatic Precipitator (ESP), Optimization, minimum weight, optimality criterion, stiffener size and shape.

1. INTRODUCTION

The particulate matters released out of the industries such as boiler, cement, sugar industries received attention because of firm environmental protection agency (EPA) [3].The Electrostatic Precipitator's (ESP's) are extensively used for cleaning flue gases from process industries by separating the ash particles from the flue gases. They can work in comprehensive range of gas temperature with efficiency 99.7% as compared to other mechanical devices. The ESP involves some complex and interconnected physical mechanism like particle charging, particle collection and removal of collection dust by rapping mechanism [1]. Due to corona discharge ionic and electronic charging of gas particles which are moving in Electro hydrodynamic field takes place and charged particles are moved towards the collecting plates [2]. The weight optimization of the hopper and nozzle is the main criteria behind the design. FEA simulation and optimization plays a very important role in weight optimization of the hopper and nozzle.

It is to be noted that for the optimization of the hopper and nozzle only the size and shape of the stiffener is varied not the distance between the stiffeners. The optimization module in the ANSYS is cross checked with the help of the analytical calculation by taking the similar example and hence the optimization method is validated.

1.1 Problem Statement

The weight of the Hopper and Nozzle is very large due to the use of large sections of stiffener, in actual practise such large sections of the stiffener is not of any use. Due to this heavy weight unnecessary wastage of material is done and finally cost of production is also increased. The main aim behind the work is to minimize the existing weight of the hopper and nozzle by 9-10%.

1.2 Objective

The objective of this work is to properly use the stiffener of correct size and shape so that the weight of the hopper and nozzle can be as minimum as possible while keeping the stress and deflection of plate and stiffener within the allowable limit.

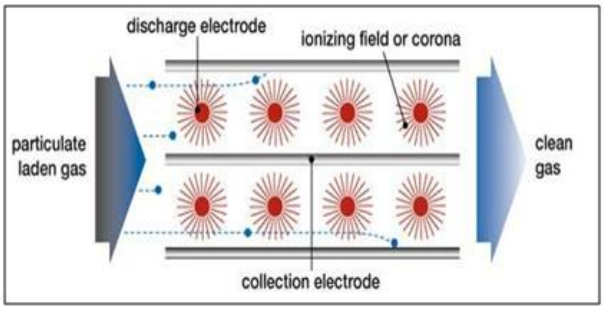

Fig-1: Schematic Diagram of Working of ESP

2. SYSTEM DESCRIPTION

The dimension of the hopper and nozzle is obtained from the supplier in form of Auto Cad drawing sheet. The modelling is done with the help of the APDL programming language so that the computation time of the software is reduced and also the model is parametric so that the quick changes in geometry is possible. The hopper and nozzle is drawn to full scale geometry and the exact boundary condition is considered such as wind load, dust density, temperature, and suction pressure. The whole model is divided into two types such as stiffener are represented as 1D elements and the other parts such as plate and supports are represented by 2D elements. In all total ESP is represented with 88600 computational elements.

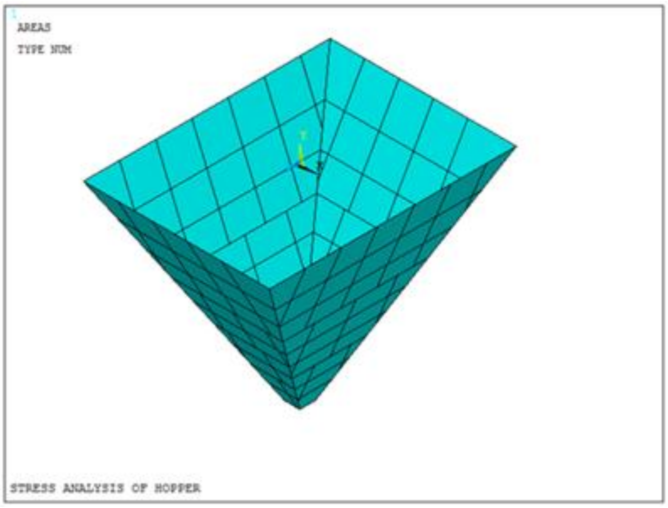

Fig-2: Geometric Model of Hopper

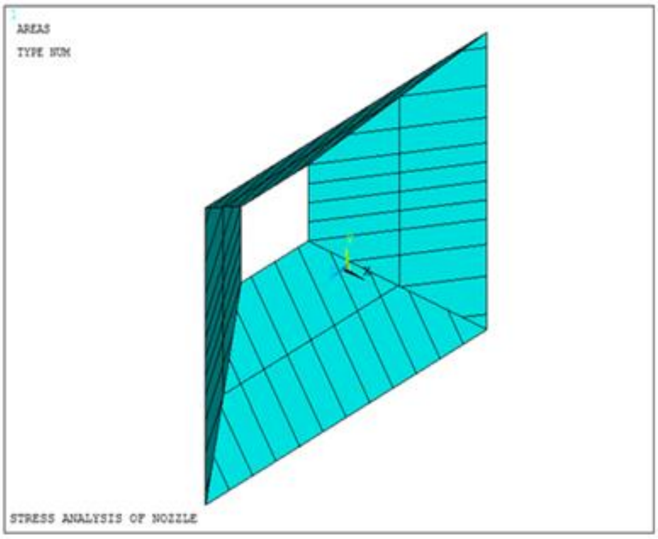

Fig-3: Geometric Model of Nozzle

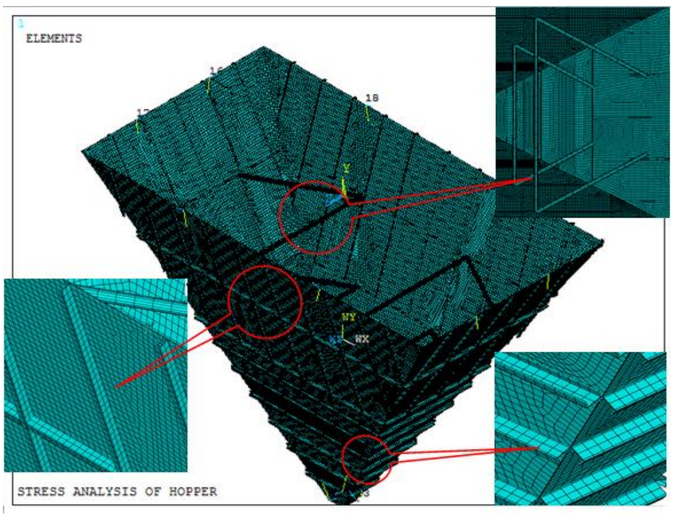

Fig-4: Meshed Model of Hopper

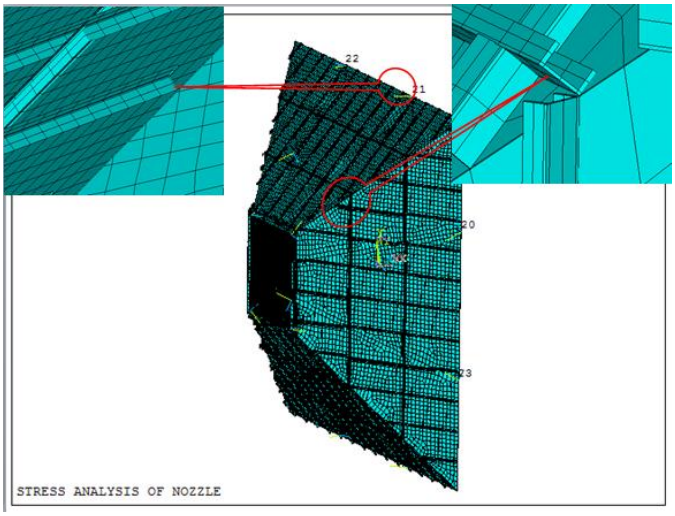

Fig-5: Meshed Model of Nozzle

The hopper and nozzle is shown below:

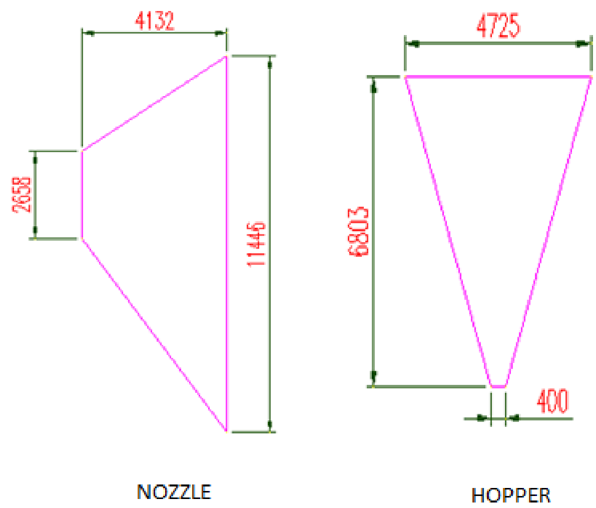

Fig-6: General Arrangement of Hopper and Nozzle

3. HOPPER AND NOZZLE MODELLING AND OPTIMIZATION

The modelling of the hopper and nozzle is done in ANSYS APDL with help of APDL programming language to the scale provided by the customer. The modelling is done consisting of the 1D and 2D elements. The programming language use different commands for the modelling [9]. For all cases the model is given with the same boundary condition such as wind load, dust density, and the suction pressure. The optimized results are then used and are compared with the previous optimized result and the comparison is done.
In all total 12 cases were considered for each optimization of nozzle, hopper. Each case was compared with other and the final result was concluded. The cases considered are as follows:-

- All C-channel on main stiffener and on secondary stiffener.

- C-channel and Flat on main and secondary stiffener respectively.
- C-channel and Angle on main and secondary stiffener respectively.
- All I-Beam on main stiffener and channel on secondary stiffener.
- I-Beam and Flat on main and secondary stiffener respectively.
- I-Beam and Angle on main and secondary stiffener respectively.
- All Angle on the main stiffener and secondary stiffener.
- Angle and channel on main stiffener and secondary respectively.
- Angle and Flat on main and secondary stiffener respectively.
- Combination1:- I-Beam and Channel on main stiffener and Flat on secondary stiffener.
- Combination 2:- Angle and channel on main stiffener and flat on secondary stiffener.
- Combination 3:- I-Beam and I-Beam on main stiffener and Flat on main stiffener.

The result for each case is explained with the help of the graph.

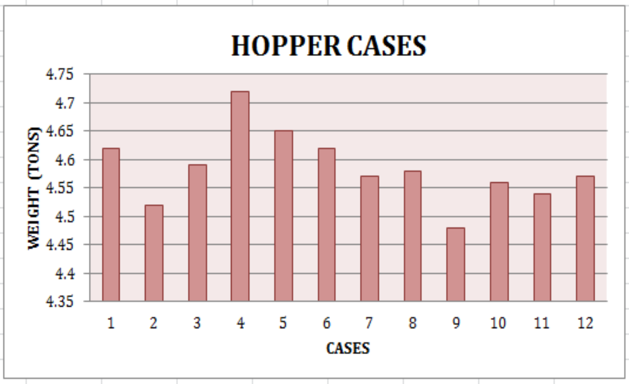

Fig-7: Comparison of different cases of hopper

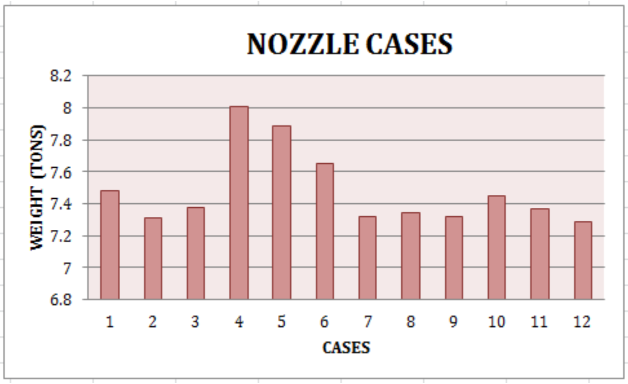

Fig-8: Comparison of different cases of Nozzle

4. SIMULATION PROCEDURE

4.1 Boundary Conditions

3D model of the hopper and nozzle is shown in fig (1). The inlet velocity is converted into the pressure and is applied to the walls of the nozzle as suction pressure. The pressure applied to the walls of the nozzle is suction pressure because at the outlet of the ESP there is suction fan located and hence the flow velocity is applied in terms of the suction pressure. The dust is collected in the hopper and is applied to the walls of the hopper in terms of the gradient load. The suction pressure applied to the walls of the nozzle is 300 mmwc and the dust density is 1200 kg/m^3. The wind load of 150kg/m^2 is also applied externally from the outer side of the walls of the nozzle.

4.2 Output results

All the results obtained from analysis should follow the IS Standard guidelines for uniform stress distribution.
According to IS-800 the stress induced in hopper and nozzle should be within allowable stress limit, the allowable stress depends upon various criterions such as factor of safety of material, yield stress, temperature of operation.
According to IS 800, Claus-3.13.1.2[10], the allowable deflection of the stiffener should be within limit

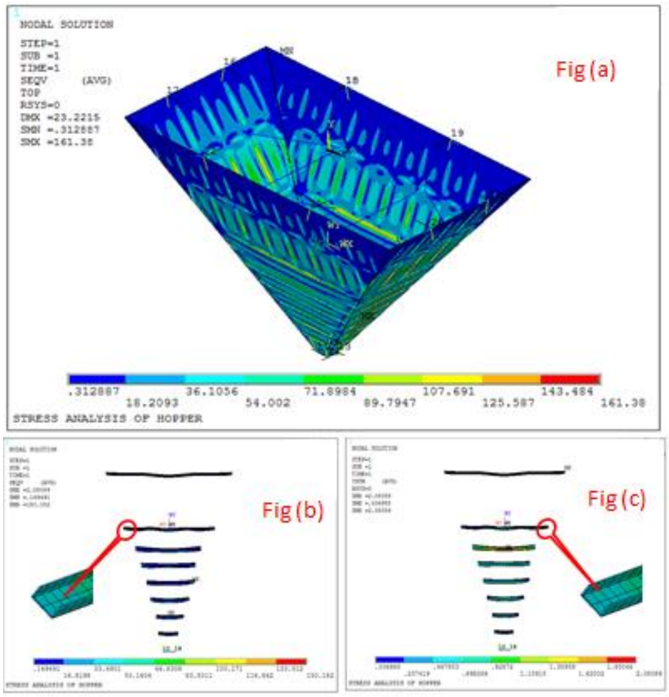

Fig-9: (a) Plate Stress, (b) Stiffener Stress, (c) Stiffener Deflection of Hopper.

5. RESULT AND DISCUSSION

The meshed model of the hopper and nozzle is as shown in the fig (4) & (5). The geometry consists of total 88600 elements. The mesh connectivity is checked and the simulation is completed with the help of the core i5 2.9 Ghz 64 bit CPU with 8 GB RAM and 1Tb hard disk.

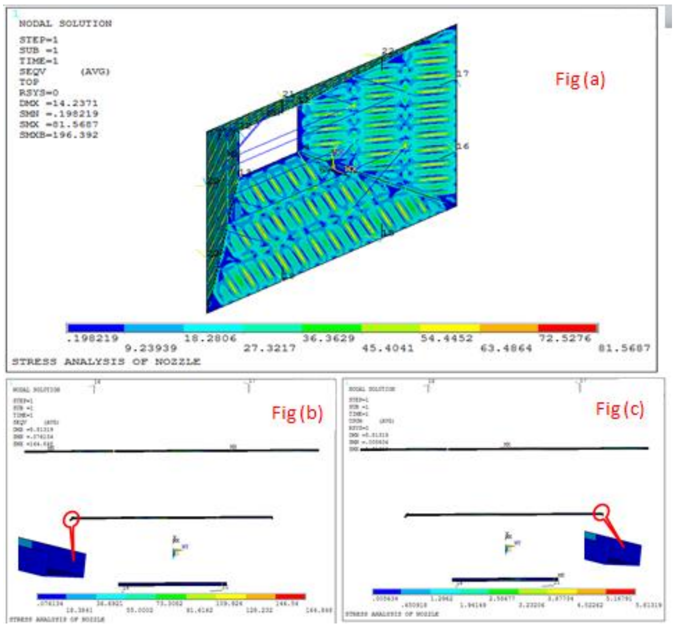

Fig-10: (a) Plate Stress, (b) Stiffener Stress, (c) Stiffener Deflection of Nozzle.

5.1 Optimized Results of Hopper and Nozzle

Modelling, simulation and post processing of hopper and nozzle is done in Ansys APDL with help of the programming language. Twelve different cases are considered for the optimization of each part. In that twelve cases twenty iteration were carried out for each case separately. Here more than twenty iteration give the same results so twenty iteration were taken. From the graph for hopper shown above for the various combinations of stiffeners used we get case 11 as optimized weight of all other cases by keeping and deflection within limit. Similarly if we see the graph of nozzle then we can see that the case 12 is optimum. Below shown are the comparison of the existing and the optimized part comparison. The values obtained from the ANSYS for the different cases considered are as follows

Table-1: Values of weight of Hopper for different Cases

Cases	Total Volume	Weight (Tons)
Case-1	58.97x10^7	4.62
Case-2	58.26x10^7	4.52
Case-3	58.57x10^7	4.59
Case-4	59.6x10^7	4.72
Case-5	59.2x10^7	4.65
Case-6	59.1x10^7	4.62
Case-7	57.2x10^7	4.51
Case-8	57.8x10^7	4.58
Case-9	57.1x10^7	4.48
Case-10	58.2x10^7	4.56
Case-11	57.9x10^7	4.15
Case-12	58.1x10^7	4.57

Table-2: Values of weight of Nozzle for different Cases

Cases	Total Volume	Weight (Tons)
Case-1	9.82x10^8	7.48
Case-2	9.31x10^8	7.31
Case-3	9.40x10^8	7.38
Case-4	1.02x10^9	8.01
Case-5	1.00x10^9	7.89
Case-6	9.74x10^8	7.65
Case-7	9.324x10^6	7.32
Case-8	9.35x10^8	7.34
Case-9	9.33x10^8	7.319
Case-10	9.49x10^8	7.45
Case-11	9.38x10^8	7.37
Case-12	9.286x10^8	7.29

Table-3: Detail Comparison of Existing and Modified design

Part Name	Existing Design		Modified Design	
	Volume	Weight (Tons)	Volume	Weight (Tons)
Nozzle	1.09x10^9	8.58	9.29x10^8	7.29
Hopper	6.14x10^8	4.82	5.23x10^7	4.11

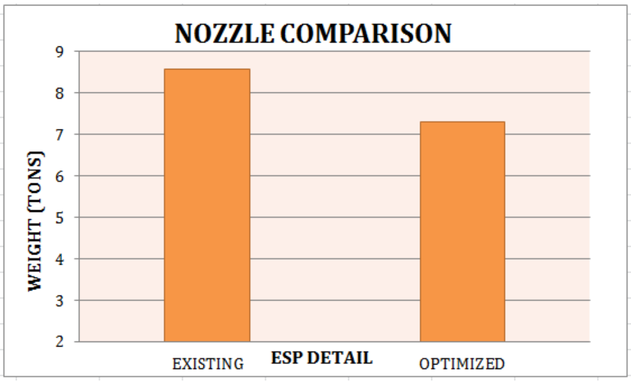

Fig-11: Comparison of Weight Optimized Between Existing and Optimized Nozzle

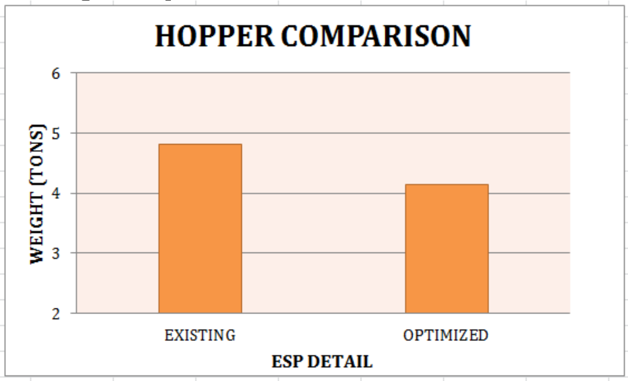

Fig-12: Comparison of Weight Optimized Between Existing and Optimized Hopper

6. CONCLUSIONS

The whole work is divided into three parts modeling and simulation to the weight optimization by changing the stiffener size and shape. The program which is constructed for the modeling and optimization run can be used for any type of the ESP to be optimized. The results obtained after the optimizations are compared with the existing hopper and nozzle weight and it is found that in all 1.9 tons of the weight is reduced. In terms of the cost the total cost of material reduced is Rs120000. The result shows the optimal use of stiffener shape and size by keeping the stress and deflection within allowable limit. It can be found that the improved optimization method can easily deal with the complex ESP also and gives optimum stiffener size and shape. Also with help of this method the time required for optimization is also less and the accuracy is also high.

NOMENCLATURE

Pn = Atmospheric Pressure.
Vn = Gas flow at site in Nm^3/ hr.
Tn = Atmospheric temperature.
Pa = Site barometric Pressure - ESP suction ÷ 13.6.
Va = Gas flow inside ESP in N-m^3/ hr.
Ta = Operating Temperature.
P_h = Horizontal Pressure
Φ - Is the Angle of Repose of the material and is generally taken as 35^0
P_v = Vertical pressure
ρ - Is the density of ash in 'kg/m^3
Z – Vertical inclined distance in 'm'
α_1 and α_2 are the angle of inclination of long and short plate respectively
Y.S = Yield Strength
FOS = Factor of Safety
L = Maximum Length of the Stiffener
A = cross-sectional area of the pipe
σ_{yt} = Yield strength of the material
Fs = Factor of safety
Mmax = Bending Moment
Y= Deflection
T= Thickness of plate
σ= Stress induced in plate
B= width of plate
E= modulus of elasticity
A= Length of plate
P= Uniform Pressure on plate
σ = Stress induced
M = Sending moment
I = Moment of inertia

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REFERENCES

[1] Nakhorn Thongleka, Chanchai Dechthummarong and Tanongkiat Kiatsiriroat, "Soot Treatment by Using High Voltage Pulse Energized Electrostatic Precipitator", *Sciverse Science Direct*, 9, 2011, pp. 292-298.

[2] S.H. Kim, K.W. Lee, "Experimental study of electrostatic precipitator Performance and comparison with existing theoretical prediction models", *Journal of Electrostatics*, 48, 1999, pp. 3-25.

[3] Shah M. E. Haque, M. G. Rasul, M. M. K. Khan, A. V. Deev, and N. Subaschandar, "Numerical modelling for optimizing flow distribution inside an electrostatic precipitator", *International Journal of Mathematics and Computers in Simulation,* Issue 3 Volume-1. 2007, pp. 255-261.

[4] S.-M. Remaoun, A. Tilmatine, N. Hammadi, F. Miloua, K. Medles, "Optimisation of one stage electrostatic precipitator for welding fume filtration", *Scientia Iranica*, 19, 2012, pp. 1861-1864.

[5] Jin Ji and Xiaohong Ding, "Stiffener Layout Optimization of Inlet Structure for Electrostatic Precipitator by Improved Adaptive Growth Method", *Hindawi Publishing Corporation*, Volume-2014, 2014, pp. 8-15

[6] Jin Ji, Xiaohong Ding, Min Xiong, "Optimal stiffener layout of plate and shell structures by bionic growth Method", *Computers and Structures*, volume 135, 2014 pp. 88-99.

[7] Mr Amol.B. Kharage, Balaji Nelage, Ketan Dhumal, "Analysis and Weight Optimization of Gravity Roller Conveyor System", PGCON, Volume-120,2015, pp. 85-89.

[8] G.N.Xie, B.Sunden, Q.W.Wang, "Optimization of compact heat Exchanger by Genetic Algorithm", *Science Direct*, 28, 2007, pp. 895-906.

[9] Keping Yan, 'Electrostatic Precipitation", 11th International Conference on Electrostatic Precipitation, 2008, pp. 1-738.

[10] ANSYS Mechanical APDL Command Guide (2013), ANSYS.Inc.

[11] IS-800 General Construction Steel Code of Practise.