WEIGHT OPTIMIZATION OF ELECTROSTATIC PRECIPITATOR (ESP) 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 to properly use the stiffener of correct size and shape so that the weight of the ESP can be as minimum as possible while keeping the stress and deflection of plate and stiffener within the allowable limit. The main aim behind the work is to minimize the existing weight of the ESP by 8-10%. In this present work the weight of the whole ESP is optimized with help of optimization programme in APDL and taking the simultaneous run for the model. Here each part of the ESP is optimized separately and then the results obtained are superimposed on the whole model of ESP and the weight is compared with the old design. The simulation result shows that by taking the optimization runs the software gives the idea of the stiffener size and shape to be used. But the size which is given by the software is not according to standard so for this the section modulus of the section is compared with the standard one and the final run is taken and the weight is compared. The simulation results show the appropriate distribution of the weight and use of stiffener size where needed and all the stress and deflection are within limit.**

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

I. INTRODUCTION

The particulate matters released out of the industries such as boiler, cement, power generation etc. 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 99.9% as compared to other mechanical devices such as cyclones and bag filters. 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 ESP is the main criteria behind the design. FEA simulation and optimization plays a very important role in weight optimization of the ESP and also gives the stress and deflection of the stiffener within the allowable limit. FEA plays a vital role for ensuring the optimum use of stiffener size and shape for ESP for the weight optimization.
The aim of this work is to obtain the optimum weight by keeping the stress and deflection levels within limit [4]. The modelling and weight optimization is done in ANSYS APDL itself with help of APDL programming language. It is to be noted that for the optimization of the ESP all parts such as the Nozzle, hoppers and casing are taken into consideration and the other parts such as baffles, electrodes, colleting plates, GD screen are not taken into consideration as they do not play any role in weight optimization and they are standard design. 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. While the similar example is considered and the stress and deflection of the plate and stiffener is calculated analytically and are compared with the software simulations. The simulation results are analysed and are compared with the company standard and the final run are taken and the optimized results are compared with the previous design.

Problem Statement

The weight of the ESP 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 ESP by 8-10%.

Objective

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

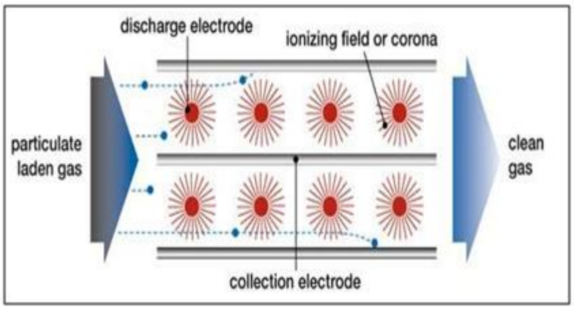

Fig.1 Schematic Diagram of Working of ESP

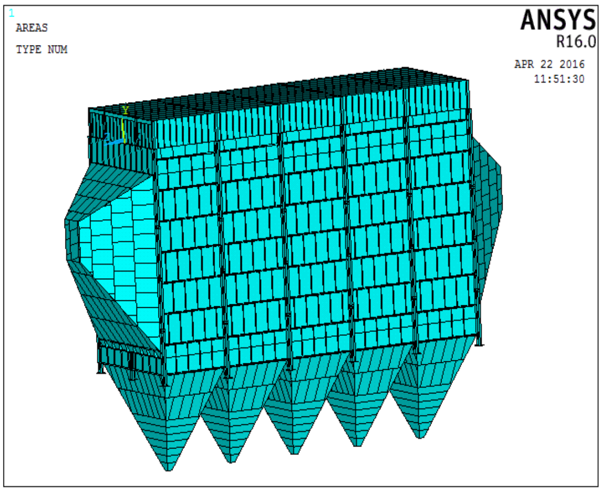

Fig.2 Typical 5 Module Geometry

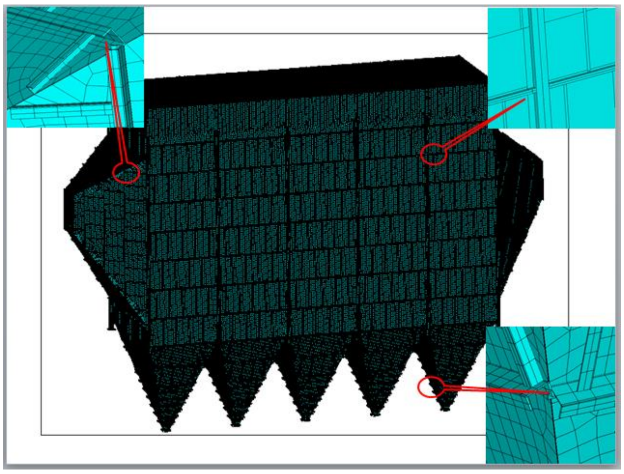

Fig.3 Meshed model of ESP

II. ESP SYSTEM DESCRIPTION

The dimension of the five modules ESP is obtained from the supplier in form of Auto Cad drawing sheet. The main components of the ESP are considered such as Nozzle, hopper and casing while modelling. The each part of the model is built 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 ESP 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 388600 computational elements. The general arrangement of the ESP is shown below:

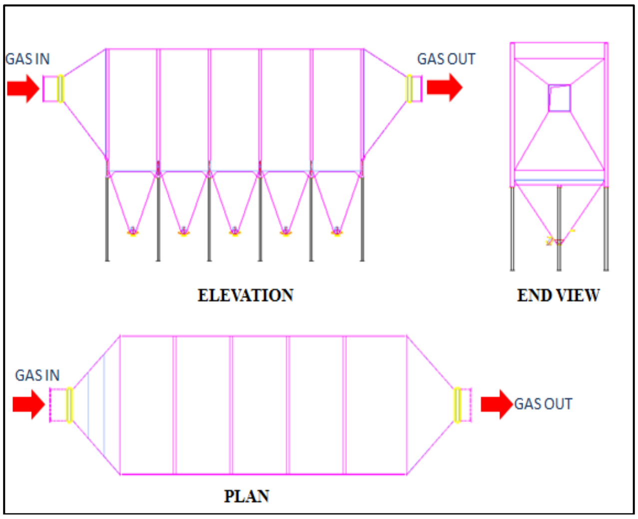

Fig.4 General Arrangement of ESP

III. ESP MODELLING AND OPTIMIZATION

The modelling of the whole ESP is done in ANSYS itself to the scale provided by the customer. The modelling is done with the help of the 1D and 2D elements. For the optimization run complete ESP is not considered but instead the parts are optimized separately and the result obtained are superimposed on the whole ESP and the final run is carried out. The modelling of each part is done separately for optimization with the help of the APDL program. 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, temperature effect and the suction pressure. The optimized results are then used and are compared with the standard stiffener section with help of the section modulus formulae.

In all total 12 cases were considered for each optimization of nozzle, hopper and casing. Each case was compared with other and the final result was concluded. The final result is then superimposed on total ESP model. The cases considered are as follows:-

1. All C-channel on main stiffener as well as on secondary stiffener.
2. C-channel on main stiffener and Flat on secondary stiffener.
3. C-channel on main stiffener and Angle on secondary stiffener.
4. All I-Beam on main stiffener and channel on secondary stiffener.
5. I-Beam on main stiffener and Flat on secondary stiffener.
6. I-Beam on main stiffener and Angle on secondary stiffener.
7. All Angle on the main stiffener and secondary stiffener.
8. Angle on main stiffener and channel on secondary stiffener.

9. Angle on main stiffener and Flat on secondary stiffener.
10. Combination1:-Channel and I-Beam on main stiffener and Flat on secondary stiffener.
11. Combination 2:- Channel and Angle on main stiffener and flat on secondary stiffener.
12. Combination 3:- Angle and I-Beam on main stiffener and Flat on main stiffener.

The result for each case is explained with the help of the graph. Each graph represents each part of the ESP which is optimized:-

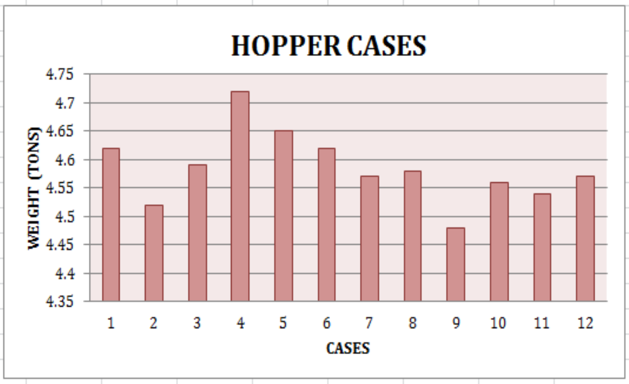

Fig.5 Comparison of different cases of hopper

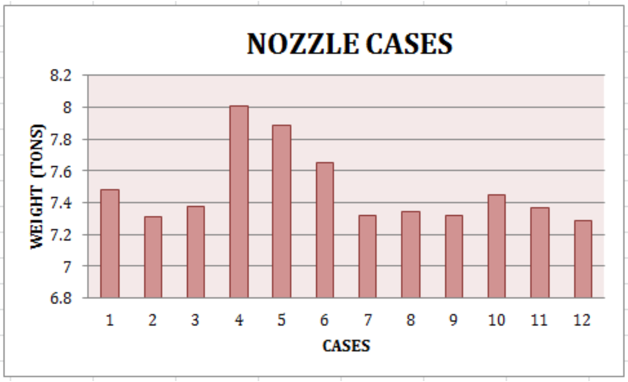

Fig.6 Comparison of different cases of Nozzle

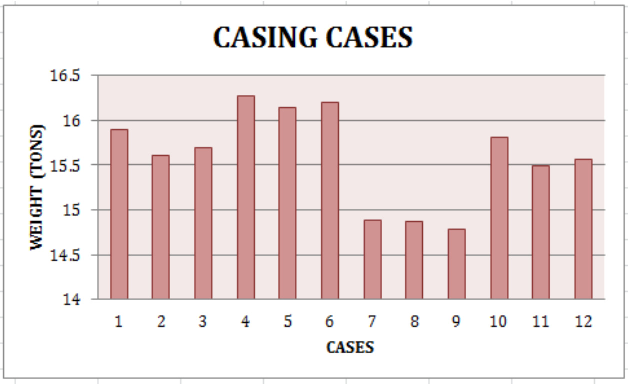

Fig.7 Comparison of different cases of Casing

IV. NUMERICAL APPROACH AND SIMULATION PROCEDURE.

A] Governing Loading Conditions:-

The flue gases along with the dust density are considered while the ESP is running. The inlet pressure of the flue gases are calculated with the help of the following formulae;

$$\frac{Pn \times Vn}{Tn} = \frac{Pa \times Va}{Ta} \qquad (1)$$

With help of the above formulae the gas flow inside ESP is applied to walls of the ESP in terms of the suction pressure

The dust density is applied to hopper in terms of gradient load. It is calculated with the help of the following formulae;

$$P_h = \rho \times Z \times K \ \ kg/m^2 \qquad (2)$$

$$P_v = \rho \times K \qquad (3)$$

$$K = \frac{(1-\sin\phi)}{(1+\sin\phi)} \qquad (4)$$

Inclined plate width factor for long and short plate

P_v long $=Y_1$
P_v short $= Y_2$
P_h long $= Y_3$
P_h short $= Y_4$

Vertical and Horizontal pressure calculation becomes;

$$\left.\begin{aligned} &P_v \text{ long} = X_1 = \rho \times Z \times Y_1 \\ &P_v \text{ short} = X_2 = \rho \times Z \times Y_2 \\ &P_h \text{long} = X_3 = \rho \times Z \times K \times Y_3 \\ &P_h \text{ short} = X_4 = \rho \times Z \times K \times Y_4 \end{aligned}\right\} \qquad (5)$$

Normal pressure calculation

$$P_n\text{\_long} = X_1(\cos\alpha_1 \times \cos\alpha_1) + X_3(\sin\alpha_1 \times \sin\alpha_1) \qquad (6)$$

$$P_n\text{\_short} = X_2(\cos\alpha_2 \times \cos\alpha_2) + X_4(\sin\alpha_2 \times \sin\alpha_2) \qquad (7)$$

Conversion of units Kg/m^2 to N/mm^2

$$P_n\text{\_long} = \left(\frac{P_n\,long}{2}\right) \times 1.2 \times 9.81 \times 10^{-6} \qquad (8)$$

$$P_n\text{\_short} = \left(\frac{P_n\,short}{2}\right) \times 1.2 \times 9.81 \times 10^{-6} \qquad (9)$$

B] Boundary Conditions:-

3D model of the ESP is shown in fig (1). The flue gas velocity is converted into the pressure and is applied to the walls of the ESP. The pressure applied to the walls of the ESP is suction pressure because at the outlet of the ESP the suction fan is 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 top part of the casing is loaded with the weight of the collecting electrodes assembly and hence the top girder is given the force of the collecting electrode assembly weight along with the weight of the dust load. The suction pressure applied to the walls of the ESP is 250 mmwc and the dust density is 1100 kg/m^3 and the top part of the casing is given the load of 10 tons. The wind load is also applied externally from the outer side of the walls of the ESP.

C] Output results:-

All the ESP's should follow the IS Standard guidelines for uniform stress distribution for optimum weight design.

1. According to IS-800 the stress distribution of the ESP 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 of ESP.
2. According to IS 800, Claus-3.13.1.2[10], the allowable deflection of the stiffener should be within limit

a) Allowable stress: $\frac{Y.S}{FOS}$ (10)

$$=\frac{250}{1.51}$$

$$= 165\ \text{N/mm}^2$$

b) Allowable deflection: $\frac{L}{325}$ (11)

Where: L = Length of the stiffener.

c) Pipe Stud Buckling Criterion

$$Rmin = \sqrt{\frac{I}{A}} \tag{12}$$

Where: I = Moment of Inertia of the pipe.

A = Cross-Section Area.

Rmin = Radius of Gyration

Then calculate the cylinderness ratio;

$$\lambda = \frac{X}{Rmin} \tag{13}$$

Where: X = Length of the Pipe Strut.

As per IS-800, for safe buckling of the pipe strut this ratio must be less than 180.

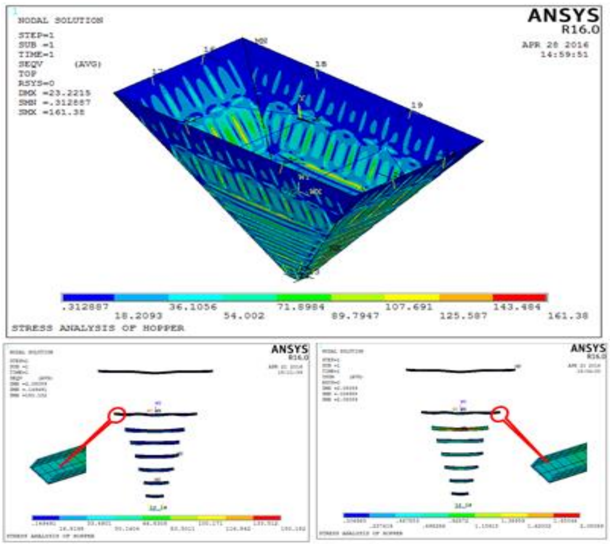

Fig.8 Plate Stress and stiffener Deflection of Hopper.

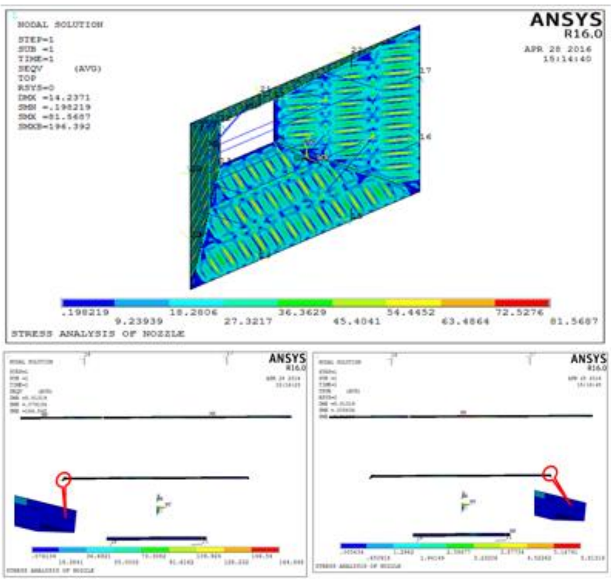

Fig.9 Plate Stress and stiffener Deflection of Nozzle.

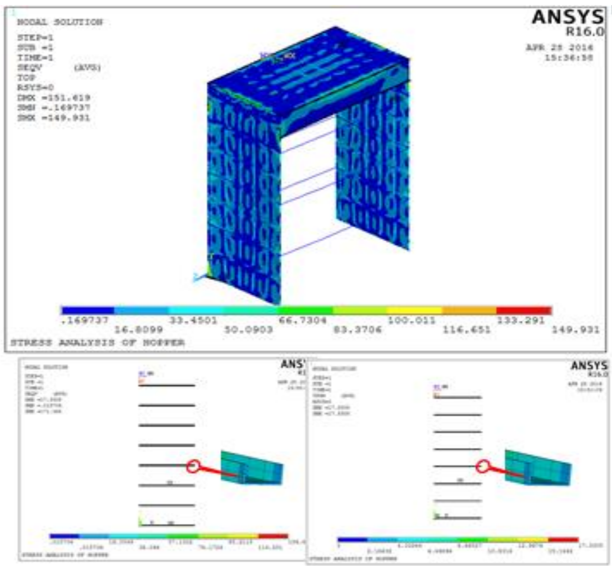

Fig.10 Plate Stress and stiffener Deflection of Casing.

V. ANALYTICAL CALCULATION

A] Weight optimization by analytical method.

As the optimization of nozzle, hopper, casing is very time consuming that's why here similar case is considered for optimization. Here the plates with stiffeners are considered. The results obtained from the simulation are compared with the analytical standard formulas. The weight optimization can be carried out with the help of following method:-

1) Allowable stress $(\sigma_{all}) = \frac{\sigma_{yt}}{F_s}$ (14)

2) Maximum Stress is $(\sigma_b) = \frac{Mmax \times y}{I}$ (15)

3) Checking the factor of safety for design,

$$F_s = \frac{\sigma_{all}}{\sigma_b} \tag{16}$$

If the factor of safety is greater than the taken factor of safety then the selected size of the channel can be considered as safe. This shows that there is scope for the optimization, the sizes of the stiffener is reduced and again the calculation are taken, the procedure is repeated till the factor of safety are same or slightly greater than the given factor of safety[7]. The value shows the detail insight of the results obtained analytically and numerically. The fig (11) shows the plate which is optimized in Ansys and the results are cross checked with help of analytical method. Table 1 shows that the results obtained analytically and numerically, the values are near to each other. Hence the method is validated.

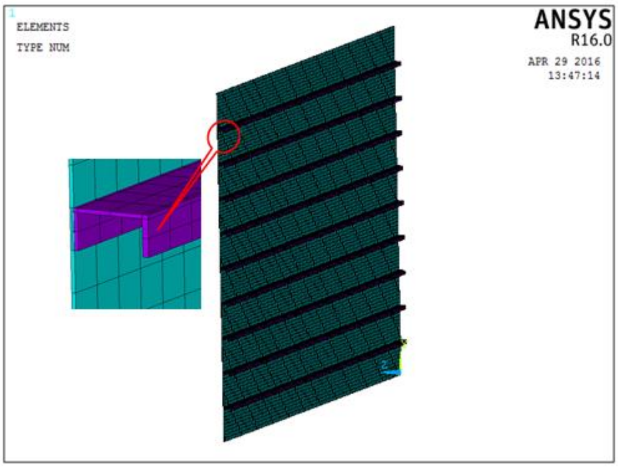

Fig.11 Plate with Stiffener

Table 1 Detail Comparison of Analytical and Numerical Results

Type of Method	Weight of the plate before optimization (Tons)	Weight of Plate after optimization (Tons)
Analytical	1.720	1.545
Numerical	1.723	1.438

B] Calculation of plate stress and stiffener stress and deflection analytically.

The plate stress and the stiffener stress and deflection can be validated with the help of the following formulas.

The relation for rectangular plate with all edges fixed are shown below,

1) $\frac{Y}{T}$ (17)

2) $\frac{\sigma \times B^2}{E \times T^2}$ (18)

3) $\frac{P \times B^4}{E \times T^4}$ (19)

The formulae for stiffener stress calculation is,

$$\frac{M}{I} = \frac{\sigma}{y} \quad (20)$$

$$\sigma = \frac{M \times y}{I} \quad (21)$$

The formula for stiffener deflection is calculated by following formulae;

$$Y = \frac{5WL^3}{384EI} \quad (22)$$

Table 2 Detail Comparison of Analytical and Numerical Results

Type of Method	Plate Stress	Stiffener Stress	Stiffener Deflection	Percentage difference
Analytical	13.6	63.66	13.27	5.89%
Numerical	14.16	58.57	12.48	

VI. RESULT AND DISCUSSION

The meshed model of the ESP is as shown in the fig (3). The geometry consists of total 388600 elements. The mesh connectivity is checked and the simulation is completed with the help of the core i7 3.1 Ghz 64 bit CPU with 8 GB RAM and 1Tb hard disk.

A] OPTIMIZED RESULTS OF EACH PART OF THE ESP

Modelling, simulation and post processing of each part of the ESP 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. We can conclude that by changing the stiffener size and shape the weight optimization is obtained. From the graph for hopper shown above if the combination of various stiffeners are used as in case 11 we get the 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 and in case of casing 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 3 Values of weight of Hopper for different Cases

Cases	Total Volume	Weight (Tons)
Case-1	58.97E7	4.62
Case-2	58.26E7	4.52
Case-3	58.57E7	4.59
Case-4	59.6E7	4.72
Case-5	59.2E7	4.65
Case-6	59.1E7	4.62
Case-7	57.2E7	4.51
Case-8	57.8E7	4.58
Case-9	57.1E7	4.48
Case-10	58.2E7	4.56
Case-11	57.9E7	4.15
Case-12	58.1E7	4.57

Table 4 Values of weight of Nozzle for different Cases

Cases	Total Volume	Weight (Tons)
Case-1	9.82E8	7.48
Case-2	9.31E8	7.31
Case-3	9.40E8	7.38
Case-4	1.02E9	8.01
Case-5	1.00E9	7.89
Case-6	9.74E8	7.65
Case-7	9.324E6	7.32
Case-8	9.35E8	7.34
Case-9	9.33E8	7.319
Case-10	9.49E8	7.45
Case-11	9.38E8	7.37
Case-12	9.286E8	7.29

Table 5 Values of weight of Casing for different Cases

Cases	Total Volume	Weight (Tons)
Case-1	2.024E9	15.89
Case-2	1.988E9	15.61
Case-3	1.99E9	15.69
Case-4	2.072E9	16.27
Case-5	2.025E9	16.14
Case-6	2.063E9	16.20
Case-7	1.896E9	14.89
Case-8	1.89E9	14.87
Case-9	1.887E9	14.79
Case-10	1973E9	15.49
Case-11	2.01E9	15.81
Case-12	1.982E9	15.56

Table 6 Detail Comparison of Existing and Modified design.

Part Name	Existing Design		Modified Design	
	Volume	Weight (Tons)	Volume	Weight (Tons)
Nozzle	1.09E+09	8.58	9.29E+08	7.29
Hopper	6.14E+08	4.82	5.29E+08	4.54
Casing	2.11E+09	16.53	1.85E+09	15.49

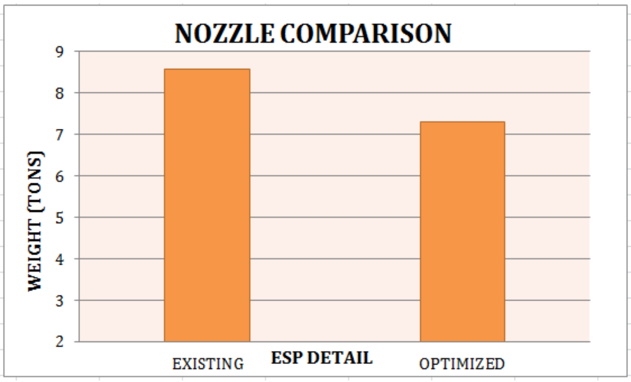

Fig.12 Comparison of Weight Optimized Between Existing and Optimized Nozzle

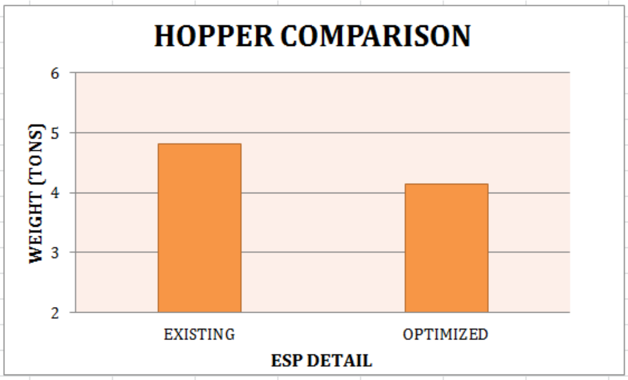

Fig.13 Comparison of Weight Optimized Between Existing and Optimized Hopper

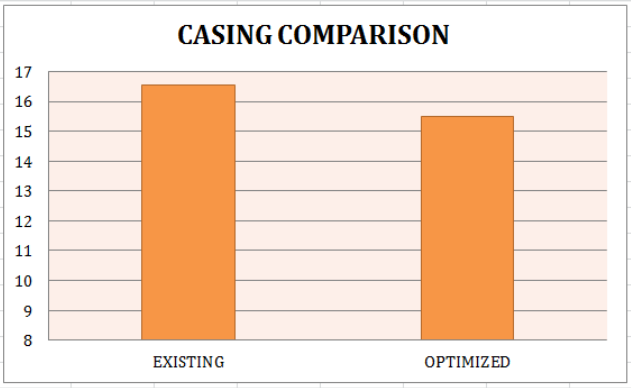

Fig.14 Comparison of Weight Optimized Between Existing and Optimized Nozzle

B] WEIGHT OPTIMIZATION OF WHOLE ESP:

Two simulations are carried out for ESP, one is done with all the geometric modification obtained from optimized results and other simulation is without any geometric modifications. Geometric modification includes the use of different size and shape of the stiffener such as the C-channel, I-beam, angle, flat, pipe stud. We can see from the graph shown below the weight of the modified ESP is less than the weight of the old ESP model. The table gives the detail insight of the weight optimized. In all total 13.93 tons of the weight is reduced. Fig. 16 shows the stress plot of optimized ESP showing that the plate stresses are within limit.

Table 7 Detail comparison between existing and optimized ESP with percentage reduction in weight

Type of ESP	Volume	Weight (Tons)	Percentage Reduction
Existing ESP	2.05459E10	161.354	8.63%
Optimized ESP	1.878043E10	147.42	

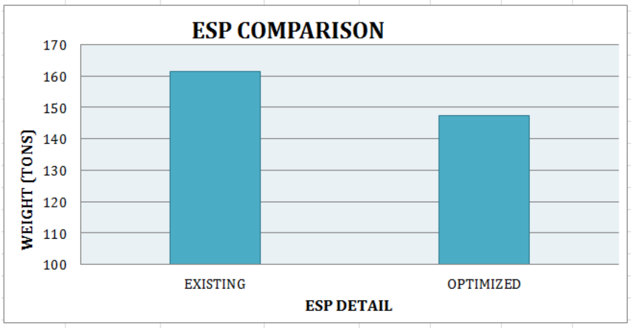

Fig.15 Bar chart showing Weight Comparison of Existing and Optimized model of whole ESP

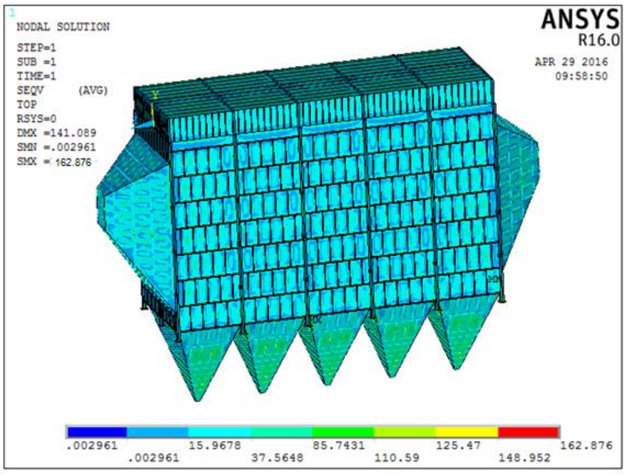

Fig.16 Plate Stress Plot of Whole ESP

VII. CONCLUSION

The whole work is divided into three parts modeling and simulation to the weight optimization by changing the stiffener size and shape. The values obtained by numerical method is cross checked with the analytical method and it is found that the values are very near to each other. This shows that our method of the optimization is correct and answer which we have obtained is right. 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 ESP weight and it is found that in all 13.93 tons of the weight is reduced, nearly 8.63% weight is reduced. In terms of the cost the total cost of material reduced is Rs7, 66,150. 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
I = Moment of Inertia
A = cross-sectional area of the pipe
σ_{yt} = Yield strength of the material
Fs = Factor of safety
Mmax = Bending Moment
I = Moment of Inertia
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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