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# Thermal and Transient Analysis of Boiler Chimney to Improve the Performance and Efficiency

**Prof. Ramesh B. Mali [1], Mr. Mohit Mantri[2], Mr. Pratik Pharande[3], Mr. Dnyanesh Patil[4], Mr. Yogesh Patil[5]**
Assistant Professor, Mechanical Engineering, NBNSSOE, Pune, India[1]
UG Student, Mechanical Engineering, NBNSSOE, Pune, India[2,3.4,5]

**Abstract:** *A boiler is an essential part of industrial power sector which works continuously for many days. This creates many flue gases which send to the surroundings through chimney. A chimney is an integral part of boiler system which provides ventilation for the hot flue gases while boiler working. Characteristic problem of chimneys is that, they develop deposits of creosote on the walls of the structure when used with wood as a fuel. Deposits of this substance can interfere with the airflow and more importantly, they are combustible and can cause dangerous chimney fires if the deposits ignite in the chimney. Heaters that burn natural gas drastically reduce the amount of creosote buildup due to natural gas burning. Disconnected or loose chimney fittings caused by corrosion over time can pose serious dangers for residents due to leakage of carbon monoxide into the home. Thus, it is recommended and, in some countries, even mandatory that chimneys be inspected annually / monthly and cleaned on a regular basis to prevent these problems. While cleaning it causes shut down of whole plant during cleaning which comes with the economic costs due to loss of production. The Main Objective of this project work is to survey and analysis of causes and remedies major type of corrosion i.e., fouling in industrial boiler chimney. Two modifications have been suggested, first divide the chimney cross section in two halves so that one will be used for operation while other for cleaning. This will induce certain pressure variation on surface of section plate and chimney. Second performing transient analysis for flue gases and to evaluate time taken to pass to surroundings. The mechanism proposed here if velocity of flue gases increased it will reduce the time taken by flue gases to contact with boiler surface that will reduce the problem off fouling. Finally, to find out the effective solution to overcome this problem either by modification in design parameters or change in working methodologies.*

## I. INTRODUCTION

A steam generator or a boiler is defined as a closed vessel in which water is converted into steam by burning of fuel in presence of air at desired temperature, pressure and at desired mass flow rate. The steam generated is employed for steam turbines to develop electrical energy, to run steam engines, In the textile industries, sugar mills or in chemical industries as a cogeneration plant, Heating the buildings in cold weather, Producing hot water for hot water supply. Coal is fed into the grate through the fire hole and burnt. Ash formed during burning is collected in the ash pit provided just below the grate and then it is removed manually.

The host gases from the grate pass through the flue pipe to the combustion chamber. The hot gases from the combustion chamber flow through the horizontal fire tubes and transfer the heat to the water by convection. The flue gases coming out of fire tubes pass through the smoke box and are exhausted to the atmosphere through the chimney. Smoke box is provided with a door for cleaning the fire tubes and smoke box. A chimney is a structure that provides ventilation for hot flue gases or smoke from a boiler, stove, furnace or fireplace to the outside atmosphere.

Chimneys are typically vertical, or as near as possible to vertical, to ensure that the gases flow smoothly, drawing air into the combustion in what is known as the stack, or chimney effect. The space inside a chimney is called a flue. Chimneys may be found in buildings, steam locomotives and ships. The term smokestack (colloquially, stack) is also used when referring to locomotive chimneys or ship chimneys, and the term funnel can also be used. The height of a chimney influences its ability to transfer flue gases to the external environment via stack effect. Additionally, the dispersion of pollutants at higher altitudes can reduce their impact on the immediate surroundings. In the case of chemically aggressive output, a sufficiently tall chimney can allow for partial or complete self-neutralization of airborne chemicals before they reach ground level.

The dispersion of pollutants over a greater area can reduce their concentrations and facilitate compliance with regulatory limits. Fouling is the accumulation of unwanted material on solid surfaces to the detriment of function. The fouling materials can consist of either living organisms or a non-living substance (inorganic or organic). Fouling is usually distinguished from other surface-growth phenomena, in that it occurs on a surface of a component, system or plant performing a defined and useful function, and that the fouling process impedes or interferes with this function. Fouling is generally caused by the vaporization of volatile inorganic elements in the coal during combustion. When heat is absorbed and temperatures decrease in the convection area of the boiler, compounds formed by these elements condense on ash particles and heating surface, forming glue which initiates deposition.

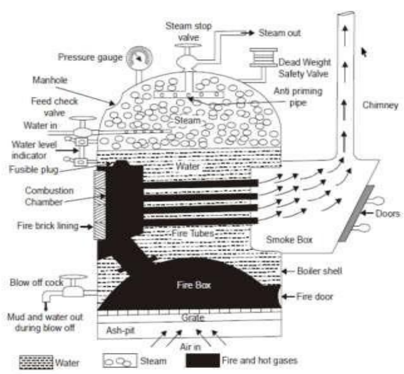


**Figure 1:** General figure of fire tube boiler

**Figure 2:** Fouling in boiler chimney

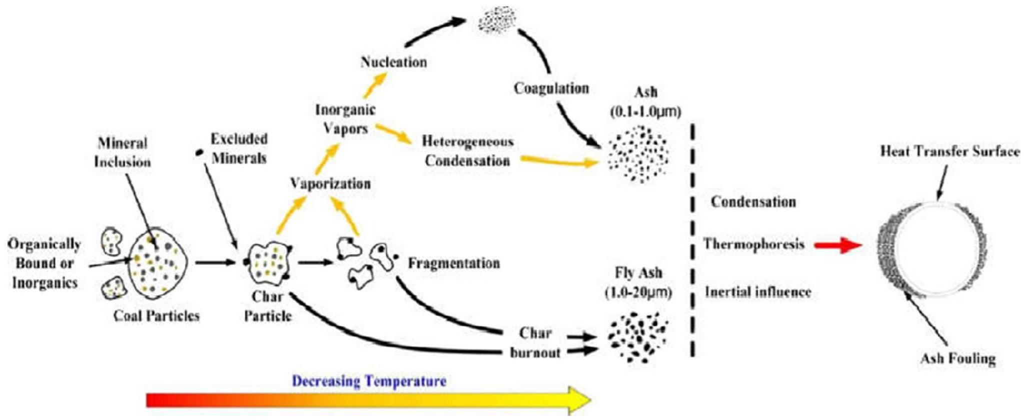


**Figure 3:** Schematic diagram of deposit formation during coal combustion

**Problem Definition**

- The industrial boilers are working on very high temperature & pressure.
- And some flue gasses forms in the boiler which required exhausting in atmosphere through chimney.
- During this process some fouling are formed on the boiler chimney surface. And after some period fouling will become considerable which affects life of chimney.
- This project is to redesigning of the boiler chimney to reduce the fouling creation in furnace, boiler surface area & duct system.

**Objective**

1. The main objective of this project was redesigning and testing of boiler chimney to reduce fouling but also not to affect efficiency.
2. An attempt is made by material modification and by introducing flappers in the fifth section of the chimney. Flappers were properly installed at various angles like 10°, 12°, 15° and results analyzed by comparing all of them.
3. Material modification by selecting material which can reduce the chances of fouling.
4. Design modification of chimney by introducing the flappers and verification of the same through FEA and validating it with actual results given by customer end.
5. Transient Analysis to determine the time it took for the exit temperature to reach a constant value. (Time response).
6. Forced Convection Test for Different Air Flow Rates for checking velocity and pressure variation of flue gases so as to reduce the time of contact between gas particles and chimney surfaces.

**Scope of Project**

1. In this project, an initial design of chimney for 15 TPH boiler, 16 bar pressure is provided.
2. This project is based on the work undertaken to redesign the flue gas duct in chimney to reduce the formation of fouling which affect the efficiency of the boiler.
3. This system was specifically designed for boiler chimney. In the completion of the design, the flappers are providing in the flue gas duct (segment II).
4. The attempt of project is to reduce the cross-section area in that particular segment to increase the flow of flue gases.

**Methodology**

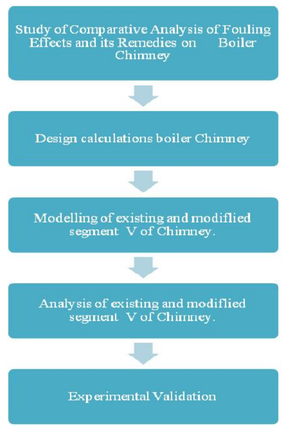


**Figure 4:** Methodology of the project work

## II. LITERATURE SURVEY

**Table 1:** Summary of Literatures

| Name of Author | Title of Paper and Year of Publication | Work Performed/Completed | Scope for further work |
|---|---|---|---|
| Ulrich Kleinhansa, Christoph Wielanda et. al | Ash formation and deposition in coal and biomass fired combustion systems: Progress and challenges in the field of ash particle sticking and rebound behaviour, ELSEVIER, 2018 | Reviewed on ash formation, ash particle transport and deposition during solid fuel combustion, with emphasis on particle sticking and rebound behaviour. | a link between the viscosity and amount of liquid phase can be modelled from the chemical and physical structure |
| Akash Singh Vivek Sharma et. al | An overview of problems and solutions for components subjected to freside of boilers, Springer (2018) | Problems (such as agglomeration, slagging, fouling, caustic embrittlement, fatigue failure and high temperature corrosion) related to boilers and their possible solutions. | Pulse detonation wave technology, intelligent soot blower, and chemical treatment technology can be used to minimize the effects of fouling. |
| Ming-Jia Li, Song-Zhen Tang et.al | "Gas-side fouling, erosion and corrosion of heat exchangers for middle/low temperature waste heat utilization: A review on simulation and experiment", ELSEVIER (2017) | Simulations and experimental studies for the fouling, erosion and corrosion of heat exchangers. | Heat exchanger designs modifications |
| Sagar Kafle , Seung HeeEuh et.al | "Tar fouling reduction in wood pellet boiler using additives and study the effects of additives on the characteristics of pellets" | Four different of control pellets without additives and three other samples each with 2% additives (dolomite and/or lime). | The detailed performance and further economic study on varying rates of different additives |

| | | | |
|---|---|---|---|
| | Elsevier (2017) | | |
| Lara Febrero Enrique Granada et. al | Influence of Combustion Parameters on Fouling Composition after Wood Pellet Burning in an ab-Scale Low-Power Boiler" (Energy article 2015) | Evaluation of the effect of differentoperating conditions on fouling composition after woody biomass combustion in an experimental low-power fixed-bed boiler. | Control mechanism of amount of chlorine deposits |
| R. K. Mishra | "Fouling and Corrosion in an Aero Gas Turbine Compressor" Springer (2015) | Study out on fouling and corrosion problems in an aero gas turbine engine which operates from coastal environment. | Design modifications and Transient analysis of flue gases |
| Suhas R Bamrotwar, Dr. V.S.Deshpande | "Root Cause Analysis and Economic Implication of Boiler Tube Failures in 210 MW Thermal Power Plant" IOSR-JMCE (2014) | Cause & effect analysis of boiler tube failures. | service condition in coal fired thermal po er plants cause failures such as the effects of high temperature, erosion, stress, vibration and corrosion combined resulting in failure of the boiler tubes |
| K.T. Ajayi and A. A. Akande | "Effect of Fouling on Heat Transfer Surfaces in Boilers" JETEAS (2012) | Developed thermal circuit, formulated mathematical model and subsequently used in the simulation of the effect of fouling on heat transfer surfaces in boilers. | Design modifications and transient analysis |

**Summarization of Literature Survey**

1. Very few works have done so far Fouling effects on Boiler chimney surfaces.
2. Velocity of flue gases can be determined and analysis to verify the time taken by the flue gases so that it won't get much time of contact between the surface and gases' particles.
3. Transient analysis can be performed to verify the above analysis.
4. FEA and CFD methods can be implemented to verify further scope of study.
5. Flappers can be introduced by design modification at various places to verify the design modifications.

## III. PROPOSED SYSTEM AND DESIGN EVALUATION

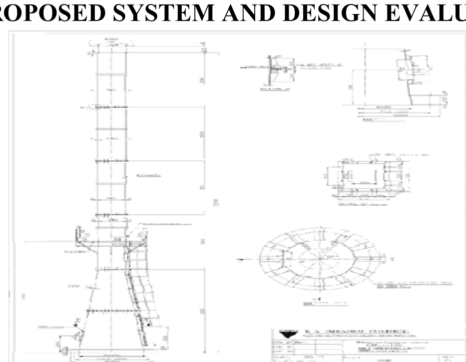

**Figure 5:** proposed design of boiler system

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**Design against Fouling**

In this system, the effect of fouling upon the component performance during the specific operation lifetime and for sufficient extra capacity to ensure the exchange will meet process specifications up-to shut down for cleaning are considered. It is also focused the mechanical arrangements that are necessary to permit easy cleaning. In this project work, the following measures have been taken to reduce the rate of fouling.

1. Provision for particulate filters.
2. Introduction of turbulent flow upstream of the exchanger core

**Table 2:** Boiler Specifications

| | | | |
|---|---|---|---|
| Boiler steam capacity | 15 TPH | Surface temp of boiler | 65 ºC |
| Working steam pressure | 15 bars | Wind velocity around boiler | 4 m/sec |
| Fuel | Coal | Total surface area of boiler | 118 $mm^2$ |
| Fuel firing rate | 2023 kg/hr | G cv of bottom ash | 700 K.cal/kg |
| Steam generation rate | 8954 kg/hr | G cv of fly ash | 395 k.cal/kg |
| Steam pressure | 14 bars | Ratio of b. A/ f.a | 90;10 |
| Feed water temperature | 90ºC | Fuel analysis in % | |
| % Of co2 in flue gases | 8% | Ash content in fuel | 7.80% |
| % Of coin flue gases | 167 | moisture in coal | 29% |
| Average flue gas temperature | 210 ºC | carbon content | 38% |
| Ambient temperature | 027 ºC | Humidity in ambient air | 0.018kj/kg of dry |

**Table 3:** Data Required for Design Calculation

| | Top diameter (mm) | Bottom diameter (mm) | Height (mm) | Shell thickness (mm) | Avg. diameter (mm) |
|---|---|---|---|---|---|
| Seg 1 | 900 | 900 | 5000 | 6 | 900 |
| Seg 2 | 900 | 900 | 5000 | 6 | 900 |
| Seg 3 | 900 | 900 | 5000 | 6 | 900 |
| Seg 4 | 900 | 900 | 5000 | 8 | 900 |
| Seg 5 | 900 | 1575 | 5000 | 10 | 1237.5 |
| Seg 6 | 1575 | 2250 | 5000 | 10 | 1912.5 |

- Height of flare = H = 1/3(30) = 10 m
- Vb = basic wind speed at the site =37m/s for Pune.
- adopting a shape factor of 0.7, wind pressure fz= (Pz.D.Δz) 0.7.
- Total W= (241.482+12.074) =253.556KN
- The maximum compressive force per unit length = 147.1520 KN/m
- Allowable bearing pressure, $\sigma c$=4N/mm2
- Width =147.1520/4 =36.788mm, Provide 37 mm wide base plate.
- Provide 4 bolts of 39mm nominal diameter on a circle diameter

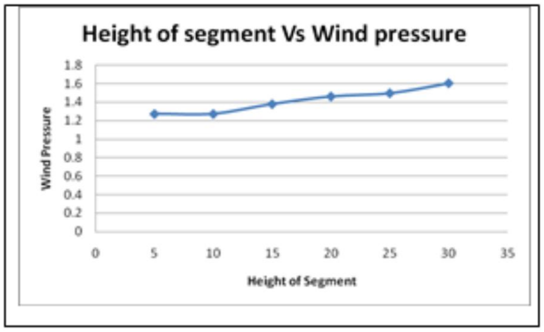


**Figure 6:** variation of Height of segment vs wind pressure

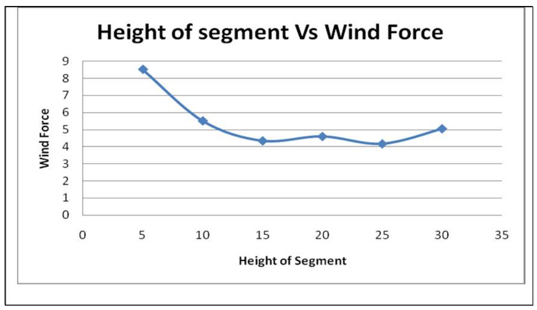


**Figure 7:** variation of Height of segment vs wind force

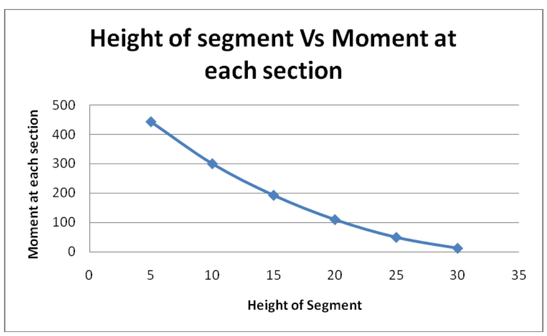


**Figure 8:** variation of Height of segment vs moment at each section

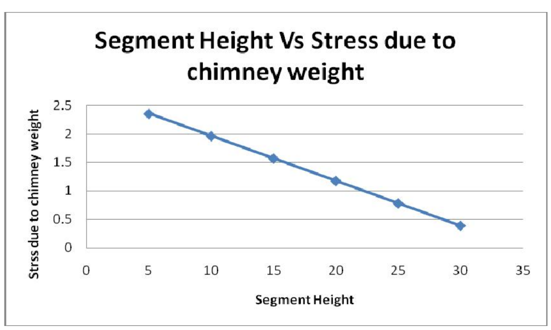


**Figure 9:** variation of Height of segment vs stress of chimney weight

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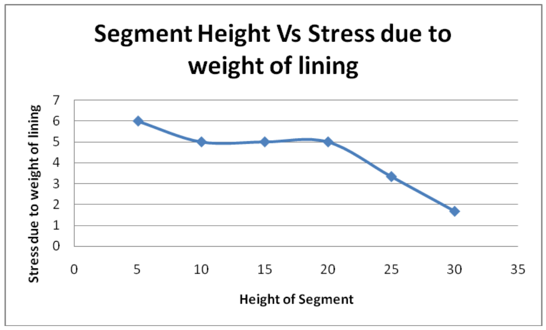


**Figure 10:** Variation of Height of segment vs stress due to weight of lining

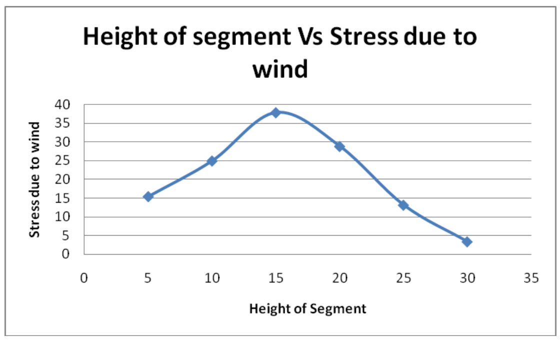


**Figure 11:** variation of Height of segment vs stress due to wind

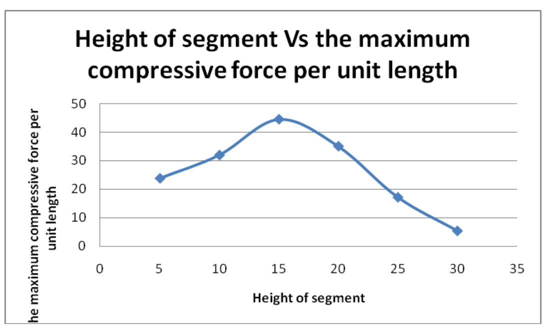


**Figure 12:** variation of Height of segment vs maximum compressive force

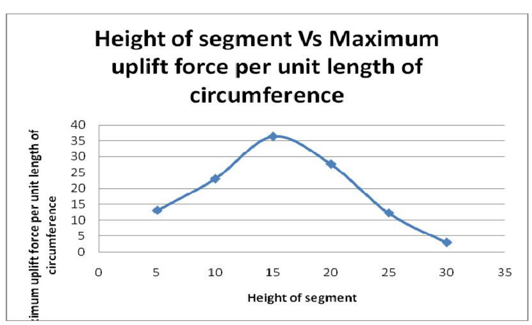


**Figure 13:** variation of Height of segment vs maximum uplift force

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## IV. EXPERIENTIAL ANALYSIS

The modification in design and further tests carried out as follows,

1. Introduction of flappers and its analysis using CAE for varying pressure and velocities to check effects of stresses generated on boiler chimney surface.
2. Forced convection test with varying air flow
3. Transient test

**Forced Convection Test for Different Air Flow Rates.**

1. The heat exchanger was connected to the air inlet fan and the furnace.
2. The air flow control flap was set at 750.
3. Room temperature was measured and recorded as Tr.
4. Air inlet fan was switched on and the air velocity was measured by use of an air velocity meter.
5. The furnace was fired and temperatures of the gas at inlet and outlet were measured and recorded.
6. The air control damper was then changed to 600, 450, 300, 150 and 00 and their respective temperature readings and air velocities taken and recorded.
7. The results were recorded in table 5. Transient Tests

The objective here was to determine the time it took for the exit temperature to reach a constant value. (Time response).

1. The air control valve was set at 00 and the air inlet fan switched on.
2. Stop watch was set at 0.
3. The air inlet fan was switched on and the furnace lit.
4. Temperature readings in each duct were taken at 2minutes interval until the temperatures reached a steady value.

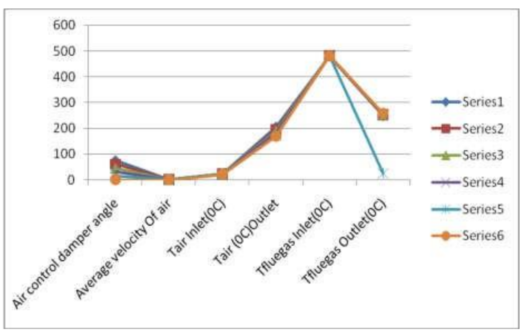


**Figure 14:** Effect of Flow rate against temperatures

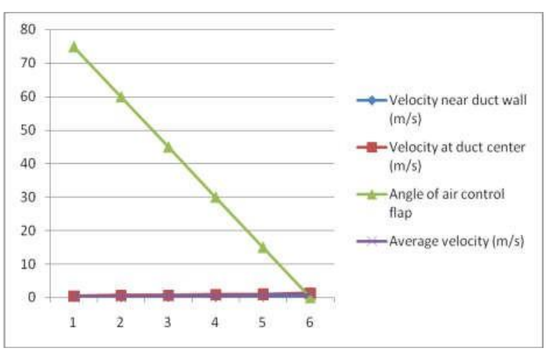


**Figure 15:** Effect of Air Flow rate

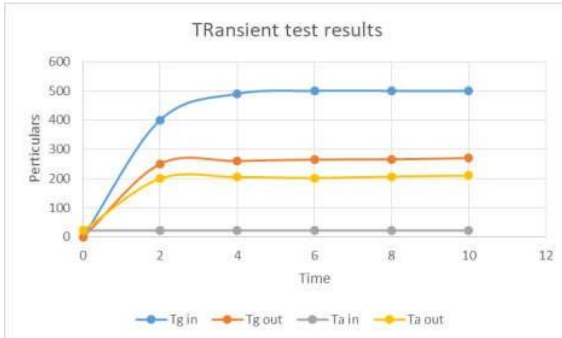


**Figure 16:** Transient test Results

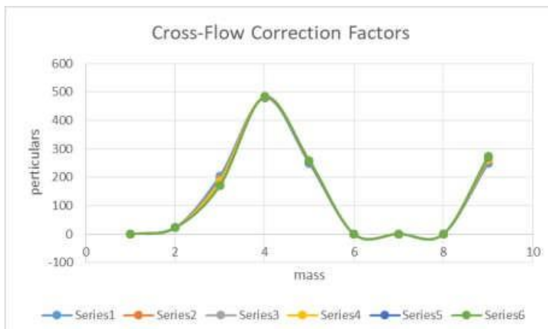


**Figure 17:** Cross flow correction factors

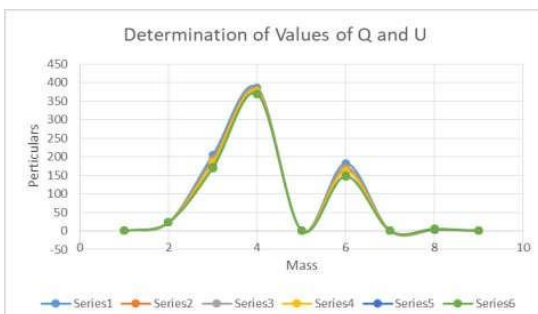


**Figure 18:** Determined Values of Q and U.

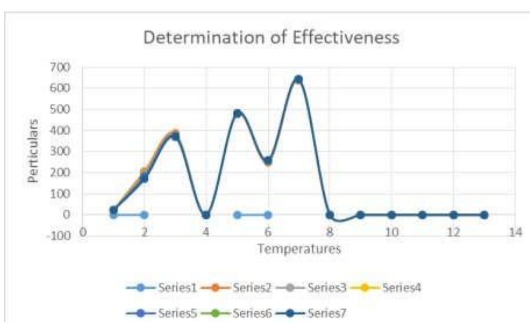


**Table 19:** Determination of Dwell Time and Normalized Time

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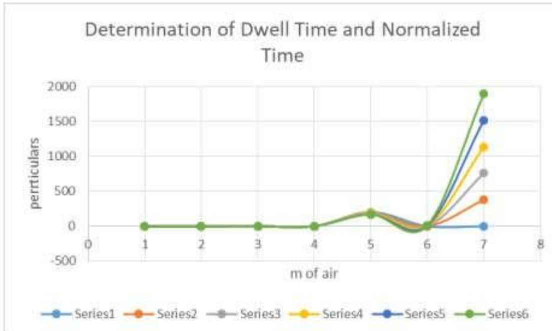


**Table 20:** Determination of Percentage Heat Recovered

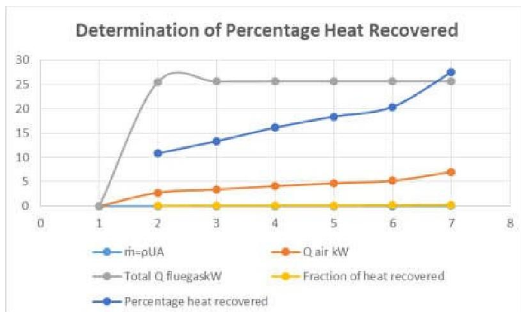


**Table 21:** Transient test

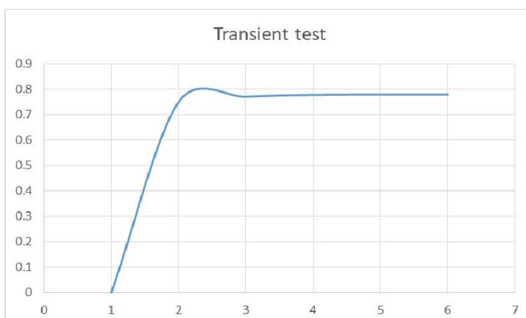


**Table 22:** Transient test

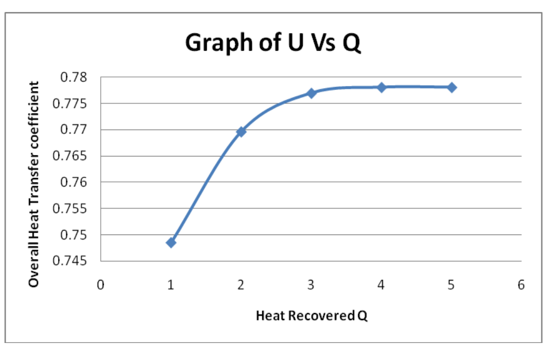


**Figure 23:** Overall heat transfer coefficient vs Heat recovered.

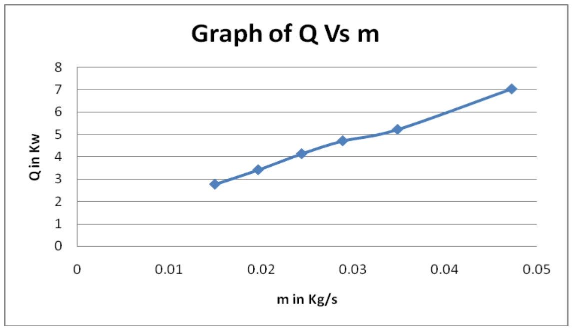


**Figure 24:** Heat recovered vs mass flow rate

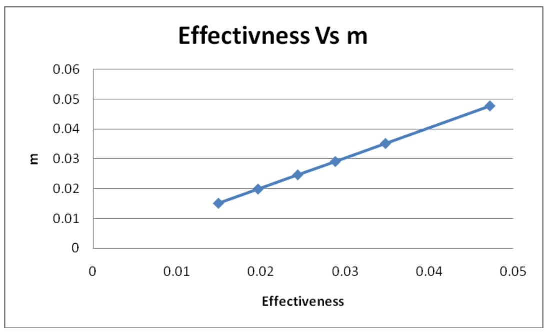


**Figure 25:** Mass flow rate vs Effectiveness

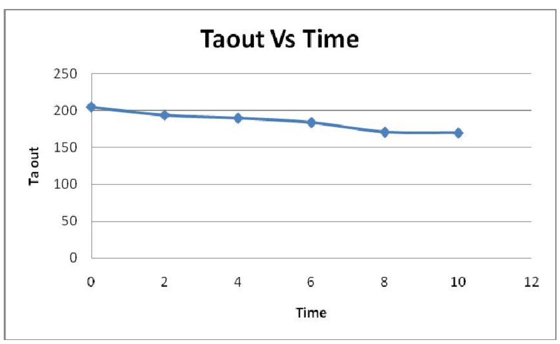


**Figure 26:** Taout Vs Time

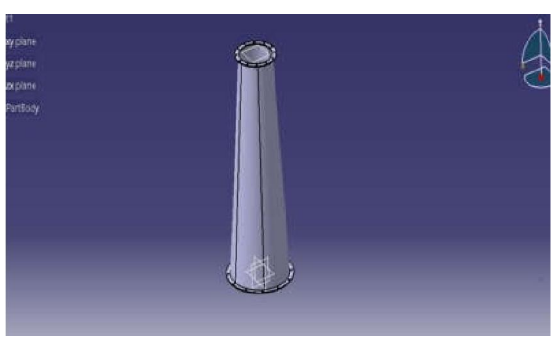

**Figure 27:** CAD model of segment II

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**Observations:**

1. The amount of heat recovered Q increased linearly with the overall heal transfer coefficient.
2. Heat recovered increased with increased mass flow rate.
3. For the mass flow rate of 0.02kg the corresponding effectiveness is 0.37 or 37%, the maximum effectiveness possible was taken as 40%.
4. In transient test, the air exit temperature rose sharply with time within the first two minutes from 22.70C to about 2000C. It then rose to a maximum of 2100C in the next one minute then dropped to 2050C at the end of four minutes. This temperature then remained constant.
5. The maximum time to allow temperatures to reach maximum was 4 minutes.
6. Normalizing this time with the dwell time the maximum normalized time was found to be 750.

In the designing of the exchanger following factors were put to consideration.

1. The surface has to be the most efficient and suitable.
2. The design has to consider the fouling effect of the flue gases.
3. The design has to allow for quick maintenance without interfering with the boiler operations.
4. The ducting design has to conform to the boiler chimney design.

Based on the above points, flapper provided at various angles in chimney convergent duct to check the velocity increase of flue gases in chimney area.

**FEA Results**

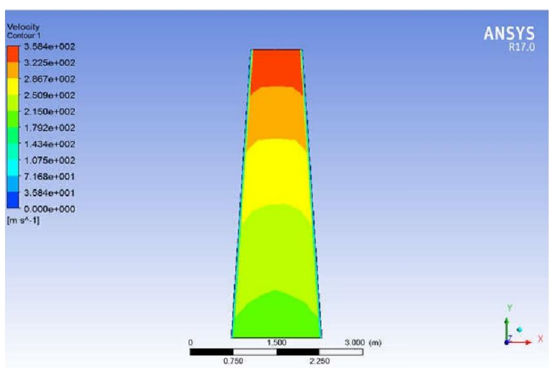


**Figure 28:** Velocity obtained in without modification

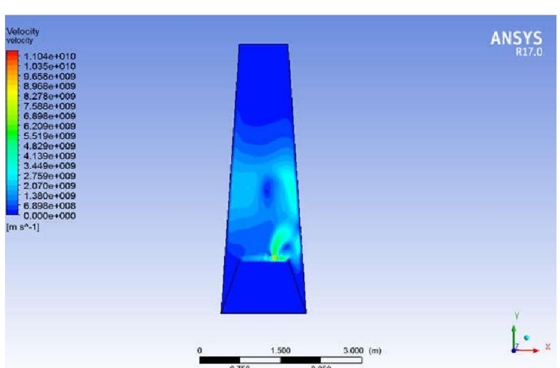


**Figure 29:** Velocity obtained in with modification

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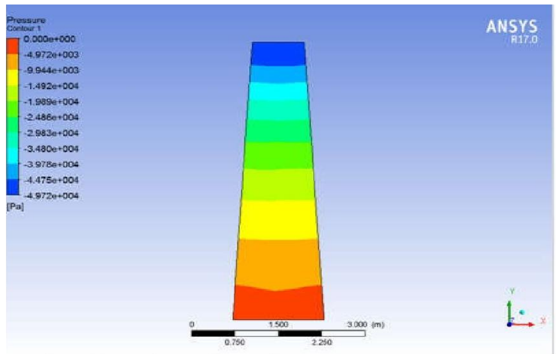


**Figure 30:** Pressure obtained in without modification

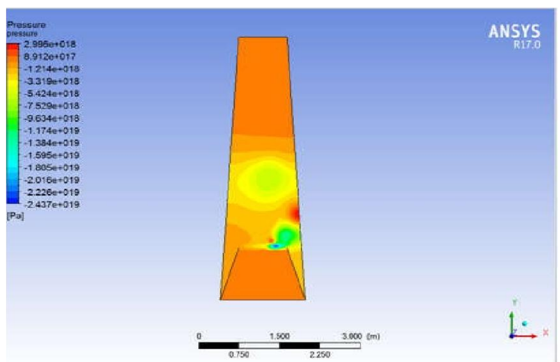


**Figure 31:** Pressure obtained in with modification.

**Observation Results:**

In above modification we have use convergent on the diverse aspects of the operation of boiler efficiently. In upcoming years to come Efficient operation of boiler is likely to play a very big role in following years, Industries all over the world are going through increased and powerful competition and increased automation of plants. To get away with this challenge, it is clearer by this paper. By using this technology, we have obtained change in velocity and pressure. In other word we can say that, velocity increases and pressure decrease due to modification. The difference between velocity and pressure of existing and modified design is as shown below graph.

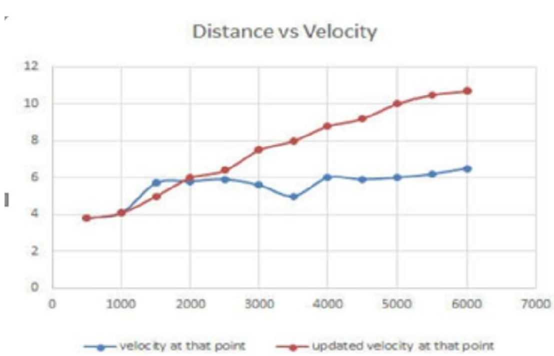


**Figure 32:** Graph 1- Distance vs Velocity.

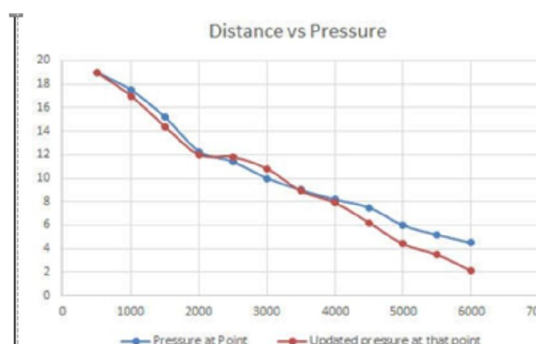


**Figure 33:** Graph - Distance vs Pressure.

## V. CONCLUSION AND FUTURE SCOPE

**Conclusions**

1. The objective of this project was completion and testing of boiler chimney heat recovery heat exchanger system that could be used to recover heat lost through flue gases and reduces the effects of fouling.
2. Design calculation with specified working parameters in order to reduce the fouling on boiler chimney surface were validated and implemented successfully.
3. The systems model was completed and tested under forced convection conditions. From the performance of the model the optimum operating conditions were obtained as:
    - Overall heat transfer coefficient U= 0.778kW/m2K
    - Amount of heat recovered Q =3.4 kW Effectiveness ε = 40%
    - T air in = 22.70C, T air out = 1940C, T g in = 4820C, T g out 2530C
4. Attempts were made to reduce fouling by introducing flappers in the fifth section of the chimney. Flappers were installed at various angles like 10°, 12°, 15° and analysis is done on the results by comparing all of them.
5. Analysis results showed that, the flappers installed at 15° is the best choice to reduce soot formation i.e., fouling which eventually increases the efficiency of the chimney and also the life of chimney.
6. The effects of pressure and velocities of flue gases on the boiler chimney surface are analysed through finite element method, the results of which were validated with the actual with satisfactory results.

**Future Scope**

1. The exchanger core plate spacing should be increased to improve on air flow.
2. An allowance for expansion of the plates should be provided at the ends of the plates.
3. The height of segment should be optimized, to increase the time for the flue gases to exchange heat with air.
4. Similar work can be done different heat exchanger surface which are affected by fouling or clogging on the heat transfer surface.
5. In this project Finite element analysis method were used to check the effect of pressure and velocities of flue gases due to design modifications. Computational Fluid dynamics can be applied to check the effects of flue gases due to shape optimization performed due to design modifications.

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