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Effect of Perforation in Tube to Improve the Thermal Performance of Circulating Fluidized Bed Boiler

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Abstract- Circulating Fluidized Bed plays an important role in thermal distribution in conversion of steam its operating condition which is used to dissipate the heat gained from transformation of steam from water inside the boiler. The simulation of the optimized model gives higher value of temperature distribution with respect to heat transfer coefficient and thermal conductivity with constant temperature of 673K, 773K and 873K. It is also observed from present analysis that CFB boiler tube with elliptical perforation at 673K gives higher thermal distribution also as increase in constant temperature of 873K maximum heat transfer coefficient is observed, Hence CFB boiler tube with circumferentially elliptical shaped perforation enhances maximum thermal performance. The configuration of elliptical perforated profile gives maximum convergence on all parameters amongst all the configurations used.

Keywords: Circulating Fluidized Bed, Temperature Distribution, Perforations, Heat Transfer Coefficient, And Thermal Conductivity.

I. ITRODUCTION

The Mercury and Air Toxic Standards (MATS) enacted in December 2011 by the EPA have forced all the countries in Europe and America to strictly adhere to this policy. This means that emissions such as metals, acid gases, organic compound, flue gas acids and other pollutants from power plants or industrial facilities have to meet the requirements set by EPA and upgrades have to be done for facilities that do not meet the standards. As a result, the demand for circulating fluidized bed technology is predicted to sky rocket [21].

In 1923, Winkler's coal gasifier represented the first significant large-scale industrial application of fluidized bed. CFB combustion technology continues to grow strongly in large utility power plant applications as CFB boiler technology has grown from small-scale industrial applications to large ultra-supercritical power plants in less than 20 years. Prime examples, both provided by Sumitomo SHI FW are the 460 MW supercritical CFB power plant operating since 2009 in Lagisza, Poland and 2200 MW ultra-super critical Samcheok (Korea) Green Power Plant successfully running since 2016 [Wikipedia].

The circulating fluidized bed (CFB) is a developing technology for coal combustion to achieve lower emission of pollutants. By using this technology, up to 95% of pollutants can be absorbed before being emitted to the atmosphere.

Circulating fluidized bed is a relatively new technology with the ability to achieve lower emission of pollutants. Extensive research has been conducted on this technology within the past 15 years due to increasing concerns over pollution caused by traditional methods of combusting coal and its sustainability. The importance of this technology has grown recently because of tightened environmental regulations for pollutant emission [19].

II. RELATED WORK

[1] Yuge yao et al: In this study, a new method for tube-wall temperature measurement in CFB boilers was proposed. In this method, thermocouples are embedded on the heating surface in deposited metal and three different designs of deposition shapes were also provided. To theoretically prove the reliability of this method, the temperature increase of the measuring point was numerically estimated by means of FEM simulation and the effect of influencing factors on the tube-wall temperature field were assessed.

[2] Artur Blaszczuk et al: This work investigates heat transfer characteristics in a bubbling fluidized bed with a submerged super-heater tube bundles under conditions of an integrated fluidized bed heat exchanger (Integrated Recycle Heat Exchanger, Intrex^{tm}) of a large-scale circulating fluidized bed boiler. The effect of mean bed particle size, normalized suspension density, and fluidizing number on the average heat transfer co-efficient between the immersed horizontal tubes and the bed was evaluated.

[3] G. Song et al: In order to investigate the heat transfer uniformity of fluidized bed heat exchangers (FBHEs), a series of experimental tests were carried out in a commercial 300 MW CFB boiler. The test results indicate that there is a good linear correspondence between the FBHEs conical valve openings and circulating ash flow rate, the average heat transfer coefficient of different heat exchangers takes on a monotonically increasing trend with the increase of the boiler loads.

[4] Y. Chen et al: The temperature distribution on the backside of the water-wall tubes in the first 600 MW CFB boiler operating at 60%, 80% and 100% of the boiler Maximum Continuous Rating (MCR) loads was experimentally determined and the thermal-hydrodynamic performance of water-wall system based on the mass and energy equations using the measured temperature was calculated. The results showed that the temperature of the water-wall tubes increased as the furnace height increased, showing a positive response characteristic in the water-wall system.

[5] A. Blaszczuk et al: The interrelation between fuzzy logic and cluster renewal approaches for heat transfer modeling in a circulating fluidized bed (CFB) has been established based on a local furnace data. The furnace data have been measured in a 1296 t/h CFB boiler with low level of flue gas recirculation. In the present study, the bed temperature and suspension density were treated as experimental variables along the furnace height. The measured bed temperature and suspension density were varied in the range of 1131–1156 K and 1.93–6.32 kg/m3, respectively.

[6] Jaroslaw Krzywanski et al: The purpose of this paper is to first present the key features of the fuzzy logic (FL) approach as a cost-effective technique in simulations of complex systems, and then demonstrate the formulation and application of the method.

Design/methodology/approach: The fuzzy logic approach is employed as an alternative method of data handling, considering the complexity of analytical and numerical procedures and high costs of empirical experiments. The distance from gas distributor, the temperature and voidage of the bed, flue gas velocity and the load of the boiler are input parameters, whereas the overall heat transfer coefficient for membrane-walls constitutes the output. Five overlapping sigmoid and constant linguistic terms are used to describe input and output data. The Takagi-Sugeno inference engine and the weighted average defuzzification methods are applied to determine the fuzzy and crisp output value, respectively.

[7] Hong Xu et al: A single tube model based on the finite volume method and measured temperature of inlet and outlet steam is proposed to evaluate the wall temperature profiles of the high temperature surface tubes in power plant. The model permits the consideration of oxide scales in the inner wall, which can leading to the overheating of material. With the increasing of outer oxide scale thickness under the same condition, the temperature of the outer wall will be rapidly increasing more than inner wall. In the same condition without oxide scale, steam is more easily leading to the increased of the wall temperature than flue gas. The higher mass flow rate will increase the convection coefficient and decrease the heat flux from the tube metal to the steam.

[8] L. Xu et al: To install multi-stage anti-wear beams on water-wall is an effective method to protect against the erosion in a CFB boiler. However, it changes the gas–solid flow and heat transfer on the water-wall. For a clear understanding, this paper used a numerical method to analyze the effect of anti-wear beams on the wall heat transfer in a 330 MW CFB boiler. The gas–solid hydrodynamics in furnace was simulated based on the TFM and EMMS drag model, and the heat transfer characteristic was obtained by cluster renewal model.

[9] A. Blaszczuk et al: In the present work, the heat transfer study focuses on assessment of the impact of bed temperature on the local heat transfer characteristic between a fluidized bed and vertical rifled tubes (38mm-O.D.) in a commercial circulating fluidized bed (CFB) boiler. A heat transfer analysis of CFB boiler with detailed consideration of the bed-to-wall heat transfer coefficient and the contribution of heat transfer mechanisms inside furnace chamber were investigated using mechanistic heat transfer model based on cluster renewal approach. The predicted values of heat transfer coefficient are compared with empirical correlation for CFB units in large-scale.

[10] P. Madejski et al: In modern utility boilers, characterized by high values of steam pressure and temperature, the individual super-heater stages and also the individual passes are made of different low alloy steel grades. The use of tubes having a complex shape of cross section allows the building of the platen with smooth side sur- faces, which are arranged in the upper part of the combustion chamber. This avoids the erosion of the super-heater tubes and deposition of slag and ash in the spaces between adjacent tubes. The super-heaters of this type are widely used in CFB boilers. To select the appropriate steel for each pass and each stage, the maximum wall temperature of tube need to be determined

[11] G. Sankar et al: Computation of metal temperatures in a furnace water-wall of a boiler is necessary for the proper selection of tube material and thickness. An adequate knowledge of the heat flux distribution in the furnace walls is a pre-requisite for the computation of metal temperatures. Hence, the measurement of heat flux in a boiler water-wall is necessary to arrive at an optimum furnace design, especially for high ash Indian coal fired boilers. Also, a thoroughly validated furnace model will result in a considerable reduction of the quantum of experimentation to be carried out. In view of the above mentioned scenario, this paper reviews the research work carried out by various researchers by experimentation and numerical simulation in the below mentioned areas:

- Furnace modeling and heat flux prediction,
- Heat flux measurement techniques and
- Applications of heat flux measurements.

[12] A. Arjunwadkar et al: Circulating Fluidized Bed (CFB) technology has emerged as the most favored steam generation technology in recent times. The use of CFB boilers is growing exponentially, due to its attractive features such as fuel flexibility, stable operation and low acid gas emissions, to name a few. The design of CFB boilers has developed over the years to meet the demanding availability expectations of the utilities. Proactive operation and maintenance (O&M) helps improve availability and reduce operating costs, which form a crucial component of the final steam cost of the boiler plant.

[13] Artur Blaszczuk et al: The effect of bed particle size on the local heat transfer coefficient between a fluidized bed and vertical rifled tubes (38 mm-O.D.) has been determined in a large-scale circulating fluidized bed (CFB) reactor. Bed particles with different Sauter mean particle diameter within the range of 0.219–0.411 mm and particle density in the range of 2650–2750 kg/m3 were used as bed material in this heat transfer study.

[14] L. Xu et al: A heat flux determination method of combined thermal-hydraulics inside the water-wall tubes and thermal process on the furnace gas–solid side (HFW) is presented in this study, for the purpose of a detailed understanding of heat transfer characteristics on heating surface. The method consists of three main steps: 1. gas–solid hydrodynamic simulation by means of the Eulerian–Eulerian model; 2. bed-to- wall heat transfer coefficient calculation based on cluster renewal model; and 3. coupling thermal- hydraulic calculation at supercritical condition.

[15] Y. Xia et al: Anti-wear beams installed on water walls of circulating fluidized bed (CFB) boilers are one of the most effective ways to protect against water-wall erosion. Beam effects from, for example, beam size and superficial gas velocity were investigated on gas–solid hydrodynamics in a CFB test rig using CFD simulations and experimental methods.

[16] P. Oclon et al: This study presents a novel, simplified model for the time-efficient simulation of transient conjugate heat transfer in round tubes. The flow domain and the tube wall are modeled in 1D and 2D, respectively and empirical correlations are used to model the flow domain in 1D. The model is particularly useful when dealing with complex physics, such as flow boiling, which is the main focus of this study. The tube wall is assumed to have external fins. The flow is vertical upwards.

[17] A. Blaszczuk et al: The role of bed particle size in the heat transfer to membrane walls of a supercritical circulating fluidized bed (CFB) combustion system was studied. In this work, values of the heat transfer coefficient between the membrane walls and the bed include contributions of particle convection, gas convection, cluster convection, gas conduction and also radiation. The heat transfer conditions in the CFB combustor were analyzed for five sizes of bed inventory, with Sauter mean particle diameters of 0.219, 0.232, 0.246, 0.365 and 0.411 mm (Geldart group B).

[18] J. Taler et al: Three different tubular type instruments (flux tubes) were developed to identify steady-state boundary conditions in water wall tubes of steam boilers. The first meter is constructed from a short length of eccentric smooth tube containing four thermocouples on the fire side below the inner and outer surfaces of the tube. The fifth thermocouple is located at the rear of the tube on the casing side of the water-wall tube. The second flux tube has two longitudinal fins which are welded to the eccentric smooth tube. In the third solution the fins are attached to the water wall tubes not to the flux tubes as in the second variant of the flux tubes.

III. RESEARCH METHODOLOGY

1. Procedure for Solving the Problem

The system procedure for solving the problem processes consist several steps describe as follows;

- Create the geometry.
- Meshing of the domain.
- Steady state thermal solver.
- Set the material properties and boundary conditions.
- Obtaining the solution.
- Results.

2. Finite Element Analysis of Circulating Fluidized Bed Boiler Tube Profile

For finite element analysis of circulating fluidized bed boiler tube profile using Steady state thermal domain.

3. Type of Element

For finite element analysis of circulating fluidized bed boiler tube profile using Quadrahedral type of element.

4. Preparation of the CAD models

Table 1: Basic Geometry Parameters of CFB Boiler Tubes

Geometric Parameter	Value × 10^3
Inner Diameter of the Tube (di)/m	38
Outer Diameter of the Tube (do)/m	50
Thickness of membrane fin (lm)/m	6
Tube Pitch (lp)/m	60
Thermocouple Diameter (dt)/m	2
Characteristics deposition thickness (ld)/m	1.5

The dimensions of the computational domain of CFB boiler tube were based on the work done by Yuge Yao [1] author of base paper that was considered for present simulation of CFB boiler tube model. After this process the constraints were applied and this way the model was created in modelling software UNI - GRAPHICS NX-8.0 The following table 1 show basic geometric parameters of CFB boiler tube.

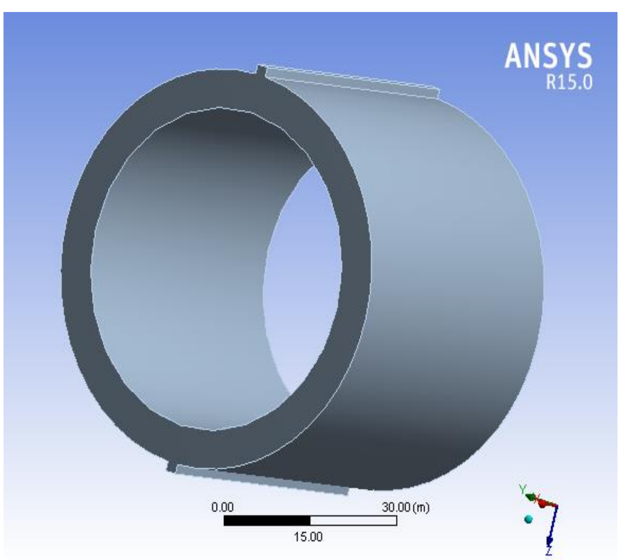

Figure 1: 3D model of CFB boiler tube with fin (Validation model)

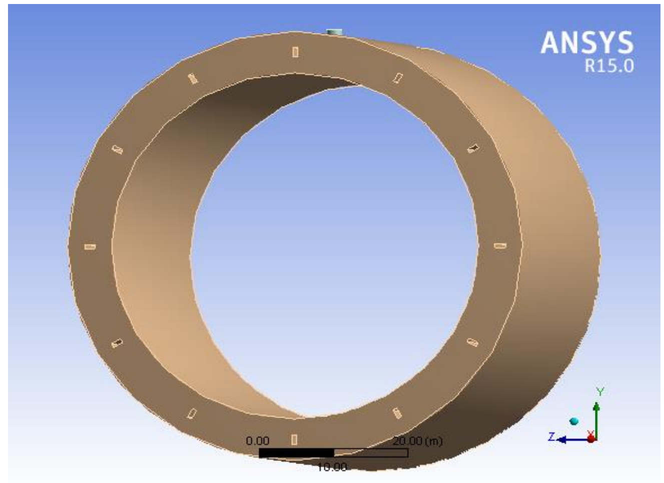

Figure 2: 3D model of CFB boiler tube with square shaped perforations

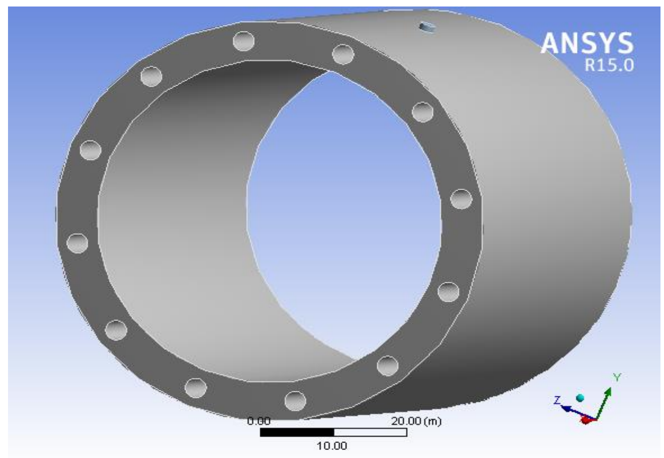

Figure 3: 3D model of CFB boiler tube with circular shaped perforations

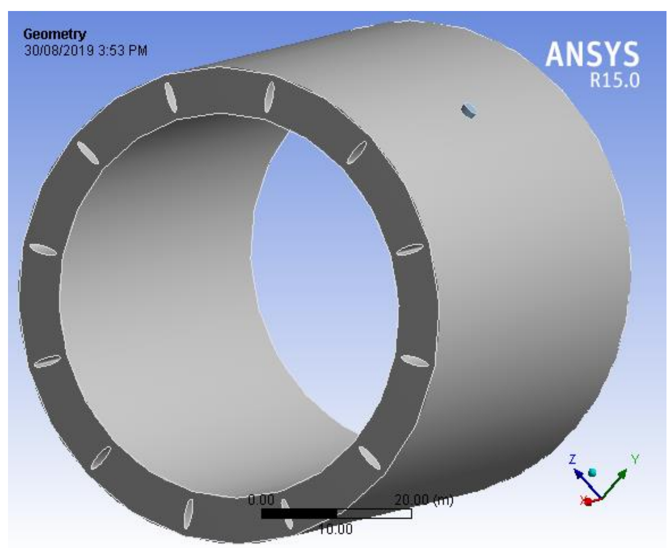

Figure 4: 3D model of CFB boiler tube with elliptical shaped perforations

As above depicted figures 1, 2, 3 and 4 shows that the three dimensional model CFB boiler tube for validation, square shape, circulating shape and elliptical shape respectively.

5. Meshing of the Domain

The total number of elements of 58200 & nodes of 266169 were employed to assess the grid independence in the CFB boiler tube case. The total number of elements higher than above mesh was employed in the CFB boiler tube (Elliptical perforation) case. It is clear that the present results have good agreement with the available data in the literature. The results of the grid refinement study showed that the simulation based on the CFB boiler tube case and CFB boiler tube (Elliptical perforation) case mesh provide satisfactory numerical accuracy, and are the essentially grid independent in this case.

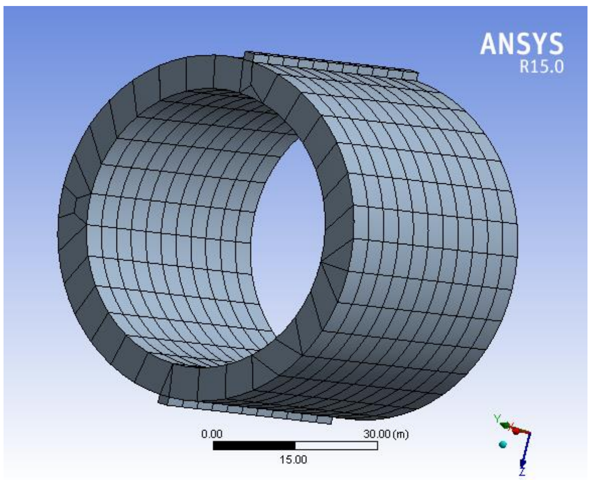

Figure 5: Mesh of CFB boiler tube with fin (Validation model)

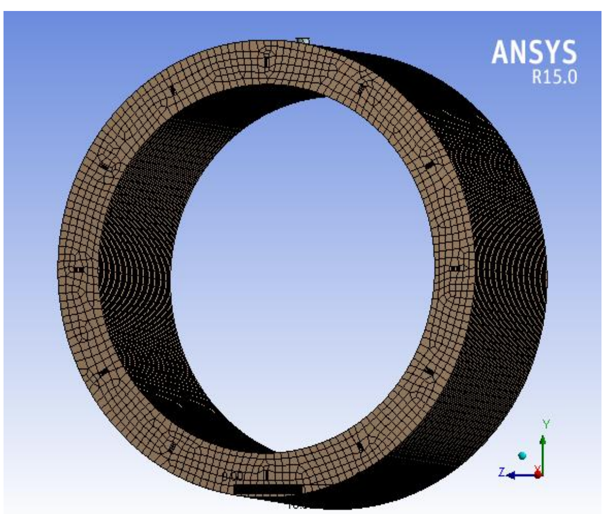

Figure 6: Mesh of CFB boiler tube with square shaped perforations

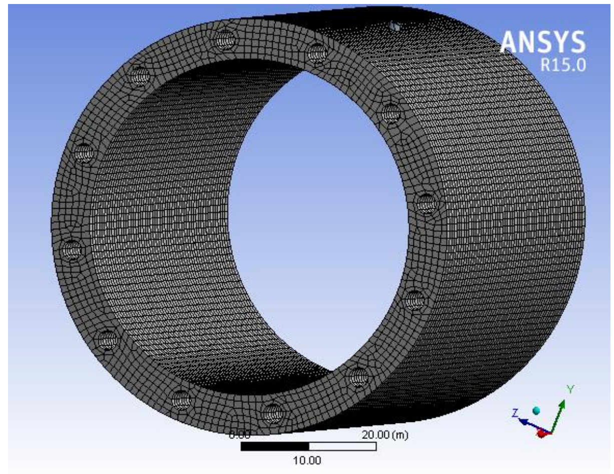

Figure 7: Mesh of CFB boiler tube with circular shaped perforations

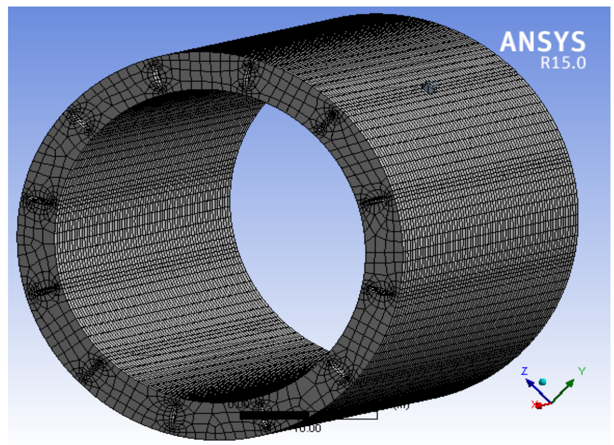

Figure 8: Mesh of CFB boiler tube with elliptical shaped perforations

As above depicted figures 5, 6, 7 and 8 shows that the meshing of three dimensional model CFB boiler tube for validation, square shape, circulating shape and elliptical shape respectively.

5. Set the material properties

Table 2: Materials Properties

Properties	15crmo	AISI304L
Thermal Conductivity,	20.46 – 24.33	38.70 – 31.00

6. Boundary conditions

Given the periodic structure of the CFB boiler tube, the two thermal parameter is investigated. Thermal domain employed. The material of the CFB boiler tube is 15crmo. The circumference of inside tube is heated at a constant heat transfer rate of 873K that is the and at different profiles of CFB boiler tube i.e. tube with square, circular, elliptical perforations. The temperature is assumed to be constant Radiation effect is ignored.

IV RESULTS ANALYSIS & DISCUSSION

The different CFB boiler tube model was developed on UNIGRAPHICS – 8.0 and analysis was done using the ANSYS software (Steady State Thermal domain) 15.0. The difference in temperature constant heating power 873K, thermal resistance decreases and by these effects of heat transfer coefficient increases, it is also observed as temperature increases the heat distribution is higher in elliptical perforated CFB boiler tube at each value of thermal conductivity. The simulations of CFD models of CFB boiler tube with different configurations show a good relation with base paper results presented in the literature and this also shown in the figure 8.

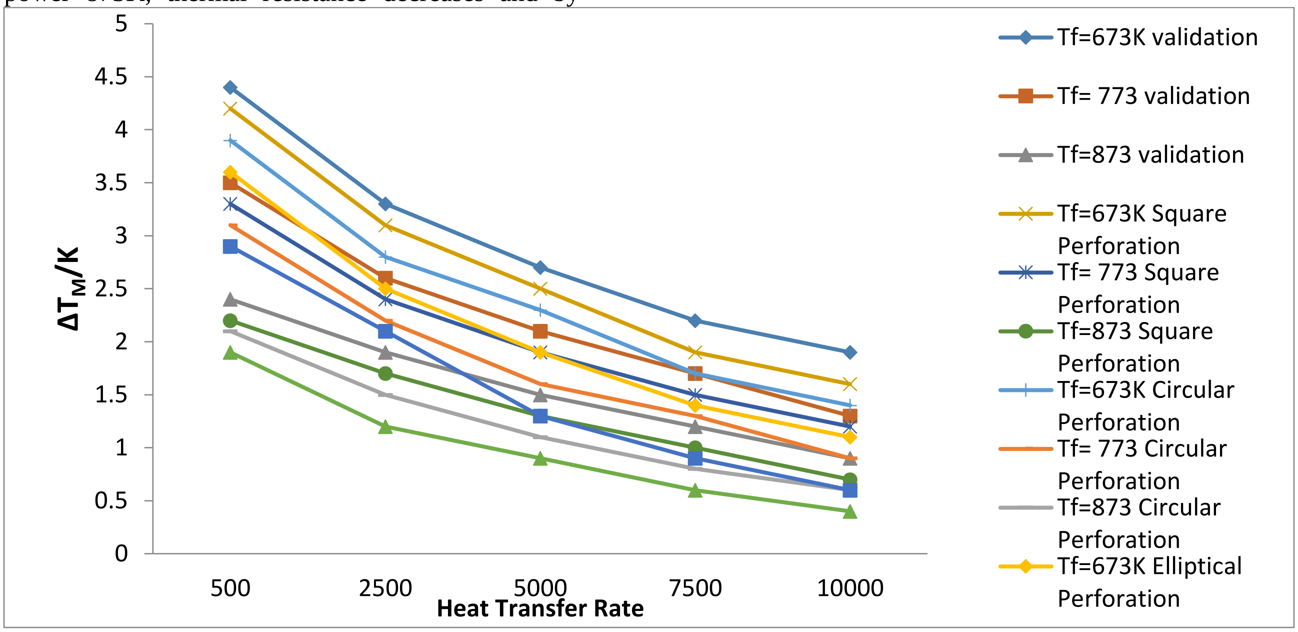

Figure 8: Overall comparison of temperature distribution and heat transfer coefficient in CFB boiler tube

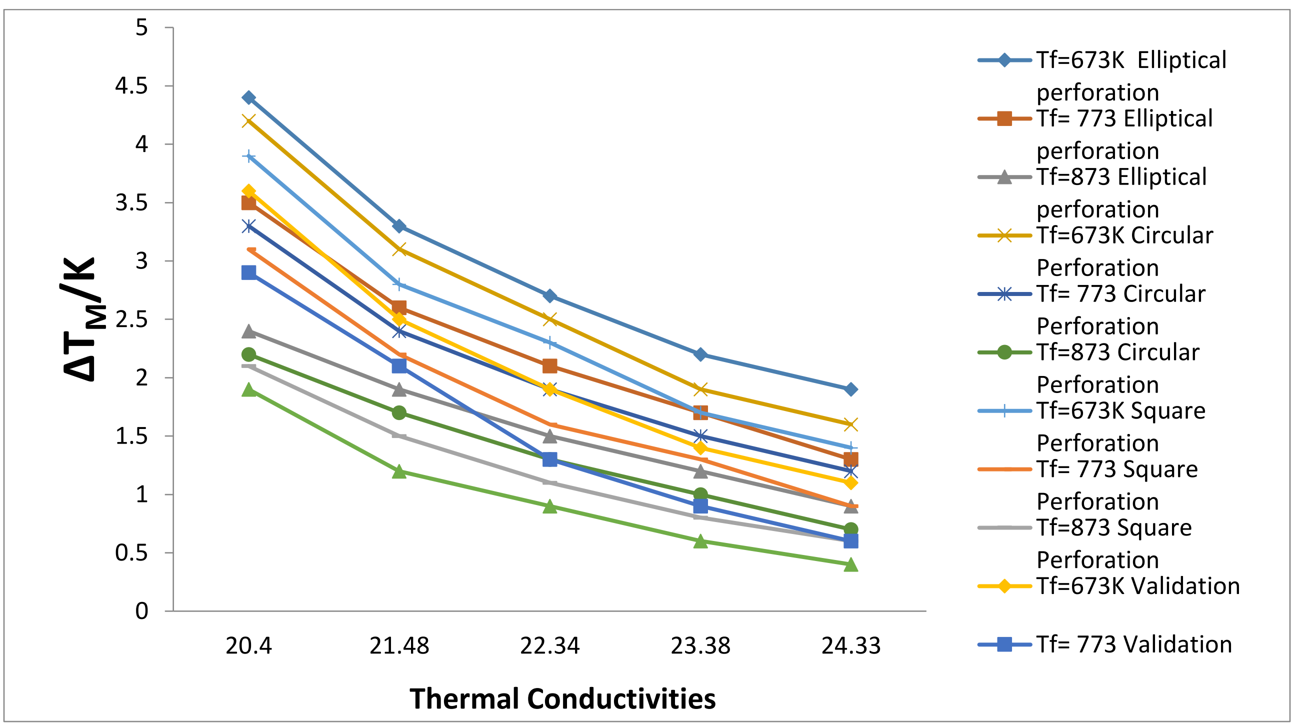

Figure 9: Overall comparison of temperature distribution and thermal conductivities in CFB boiler tube

The temperature distribution is the fundamental parameter in the performance of CFB boiler tube different optimized profile of tubes. The tube surface area is varied due effect of perforations of different profile the thermal resistance effect is observed to decrease significantly. In the study, CFB boiler tube i.e. tube with square, circular, elliptical perforations are the key geometric parameter on the performance of CFB boiler tube. With an implementation of elliptical perforation in circumference of tube of deposited material the effect of thermal conductivity at 673K of constant temperature enhances maximum temperature distribution in tube wall. The proposed three types of CFB boiler tube represented on results show that perforation increases surface area, and decreases the thermal barriers due to it can recognize that elliptical shaped perforation is the best configuration as shown in the figure 9.

V CONCLUSION

In this research, detailed analysis of the influences of temperature distribution, heat transfer coefficient and thermal conductivity of CFB boiler tube with different profiles has been conducted by simulations using the ANSYS software on steady state thermal domain 15.0. Work bench. The following conclusions are withdrawn:

- The different CFB boiler tube model was developed on UNIGRAPHICS – 8.0 and analysis was done using the ANSYS software (Steady State Thermal domain) 15.0.
- The temperature distribution is the fundamental parameter in the performance of CFB boiler tube different optimized profile of tubes. The tube surface area is varied due effect of perforations of different profile the thermal resistance effect is observed to decrease significantly.
- In the study, CFB boiler tube i.e. tube with square, circular, elliptical perforations are the key geometric parameter on the performance of CFB boiler tube. With an implementation of elliptical perforation in circumference of tube of deposited material the effect of thermal conductivity at 673K of constant temperature enhances maximum temperature distribution in tube wall.
- The proposed three types of CFB boiler tube represented on results show that perforation increases surface area, and decreases the thermal barriers due to it can recognize that elliptical shaped perforation is the best configuration.
- The difference in temperature constant heating power 873K, thermal resistance decreases and by these effects of heat transfer coefficient increases, it is also observed as temperature increases the heat distribution is higher in elliptical perforated CFB boiler tube at each value of thermal conductivity.
- The simulations of CFD models of CFB boiler tube with different configurations show a good relation with base paper results presented in the literature.

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