Automation of Optimal Design of Air Preheater's Corrugated Heating Elements using CFD

Mousumi Roy
Former faculty, *Department of Mechanical Engineering*
CVSR Engg. College, Hyderabad. , Telangana state ,India

A.S Panwalkar
*CFD consultant, Hyderabad. , Telangana state,*India

Abstract - The Ljungstrom Air Preheater is more widely used than any other type of heat exchanger for comparable service. The basic component of Air Preheater is a continuously rotating cylinder having matrix (consisting of corrugated steel plates i.e. heating elements), called the rotor. As the rotor revolves, waste heat is absorbed by the matrix from the hot exhaust gas passing through one half of the structure. This accumulated heat is released to the incoming air as the same surfaces enter the other half of the structure. Thus heat energy is captured and transferred to incoming air for combustion before it is lost to the stack. The result is a substantial saving in fuel that would otherwise be required to bring the air up to combustion temperature. The development of optimal design of corrugated sheets of Profile shape (heating elements) is significantly important. The dimensional variation can be stimulated directly by using CFD techniques to optimize the Pressure drop and heat transfer rate.

In this work the corrugated sheets of notched-flat type are designed. The whole process is automated. This consists of profile shape generation using Bezier Curve techniques, creating profiled fluid domain surfaces and subsequent mesh generation. Automation is possible as ICEM-CFD uses TCL/TK as a script language. The automation code is written in TCL/TK language along with ICEM-CFD commands embedded in it. The code is run as a script file in ICEM-CFD. First code's GUI (Heating Element Profile Design-HEPD) is created apart from ICEM-CFD GUI. Different Profile shapes (of Heating Elements) are obtained by moving the interactive Bezier knots of the Bezier curve in HEPD GUI. With Pull-Down menu option of HEPD-GUI, finalized profile shape is drawn and visualized directly in the ICEM-CFD GUI. Another pull down menu of HEPD-GUI can be used to create mesh in ICEM-CFD. Subsequent CFD analysis is made in Fluent solver using this mesh. CFD heat transfer analysis is carried out in ANSYS Fluent software with constant temperature boundary conditions for the heating element. The solution is converged to RMS residual level of 1.0E-04 Critical analysis of the converged results is made. Sample test cases are presented.

***Keywords*— Lungstorm Air Preheater, Heating Element of Corrugated Shapes, Bezier Curve, Tcl/Tk code, Design Automation, Heat Transfer Coefficient, Friction factor, and Temperature Distribution Plots.**

I. INTRODUCTION

Heating combustion air can raise boiler efficiency by about 1% for every 40F (22°C) in temperature increase. The most common way to preheat the air is with a heat exchanger by high temperature exhaust flue gases.

Modern high capacity boilers are always provided with an air preheater. Air pre-heater is an important boiler auxiliary which primarily preheats the air for combustion. Serving as the last heat trap for the boiler system, a regenerative air preheater typically accounts for over 10% of a plants thermal efficiency on a typical steam generator. Regenerative air heaters are relatively compact and are the most widely used type for combustion air pre heating in electric utility steam generating plants.

The automation in developing heating element profiled surfaces is carried out in this work. Using TCL/TK script code under ICEM-CFD platform designing from Bezier interpolated shapes of (Flat-Notched) heating elements to mesh generation has been automated. Further many profiled shapes have been analyzed by CFD to obtain high heat transfer rate with low frictional losses.

A. LJUNGSTORM AIRPREHEATER

The Ljungstrom rotary air pre-heater is a regenerative heat exchanger used for preheating the combustion air, mainly in steam boiler plant. The hot gas and cold air ducts are arranged to allow both the flue gas and the inlet air to flow simultaneously through the machine (*figure.1*).The hot flue gas heats the rotor material and as the rotor rotates, the hot rotor section moves into the flow of the cold air and heats it. The major component of the Ljungstrom air preheater is a continuously rotating cylinder, called the rotor, which is packed with thousands of square feet of specially formed sheets of heat transfer surface which are commonly called elements. The preheater structure consists of hot and cold end center sections, connected by two main pedestals on either end. The Rotor revolves with low speed of rotation, typically between 1 to 2 rpm. As the rotor revolves, waste heat is absorbed from the hot exhaust gas passing through one-half of the structure. This accumulated heat is released to the incoming air as the same surfaces pass through the other half of the structure. The heat transfer cycle is continuous as the surfaces are alternately exposed to the outgoing gas and incoming air streams. The speed of rotor rotation is low, so that sufficient duration is allowed for the heat to be transferred from or to the heating surfaces. The reasons for worldwide acceptance are due to its high thermal effectiveness, proven performance and reliability.

.

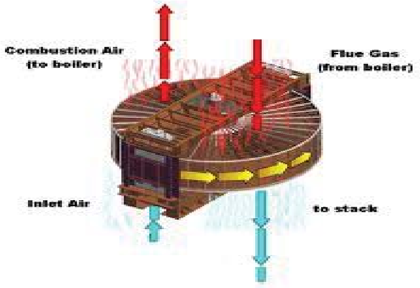


Figure.1 Ljungstorm Air Preheater

B. HEATING ELEMENT PROFILES

Heat transfer surface, also known as heating element, are the heart of an Air Preheater. They are the compact arrangement of specially formed metal plates (*figure.2*) contained in retaining baskets, which are installed in the rotor compartments. There are normally two to four layers of heating element in the rotor. At the cold end, where the cold air enters and the cooled flue gas exits, metal temperatures are lowest and corrosion, fouling and plugging potential are the highest. In each consecutive layer toward the hot end, metal temperatures increase, corrosion potential decreases and temperature related fouling and plugging potential decreases. The function of the heating element is to absorb heat from the flue gas and release heat to the combustion air.

(a) (b)

Figure.2 (a) & (b) Heating Element Profiles

II.LITERATURE SURVEY

In a pioneering paper, Savostin and Tikhonov [1] presented heat transfer and pressure drop results for Reynolds numbers ranging from 200 to 4000, corrugation angles θ from 0º to 144° and pitch by height ratio P/H, = 2.2. Measurements were also taken for θ = 30° and P/H ranging from 0.8 to 2.3. The average heat transfer coefficient was determined by measuring the temperature variation of the air flowing across the test section, which was cooled by water and included about l0-20 unitary cells in the downstream direction. The authors observed that the Nusselt number increased significantly with θ, especially at Reynolds numbers above 600 (for which they assumed that turbulent flow was established). The highest values of both Nu and friction factor were attained for the highest values of P/H tested as 2, while heat transfer rates and hydraulic resistances decreased by15% as P/H, decreased from 2 to 1. Correlations for Colburn Factor and Nu were proposed and were applied to an optimization study of a rotary regenerator. The authors concluded that for given plate geometry, thermal power and overall frictional losses- increasing θ from 0° to 35°- 45° makes it possible to reduce significantly the heat transfer surface and depth of the exchanger, while keeping practically constant its front area ; this results in a 30-40% saving in weight and cost. In a paper Gaiser and Kottke [2] investigated the dependence of Nu and, friction factor on the corrugation angle θ (in the range - 60-160˚) for P/H of 1.78-7.12 and a Reynolds number of 2000. Their test section included over 100 unitary cells, so that practically fully developed conditions were attained, and the working fluid was air. Local mass transfer coefficients were measured by using a chromo chemical reaction between a reactant added in gaseous form to the air and a second one absorbed in wet paper coated in one of the walls; they were then converted into values of Nu by using the analogy between mass and heat transfer. Pressure drops were also measured by wall Pressure tappings.The authors reported the distribution of local heat transfer coefficient and proposed correlation between the average Nusselt Number and the friction factor with respect to the various corrugated angles θ. In a paper J. Stasteik**,** M. W. Collins and M. Ciofalo [3] discussed about the experimental and numerical study of flow and heat transfer for a crossed corrugated geometry under transitional and weakly turbulent conditions. Different computational approaches were used for numerical simulation for various geometries. Three dimensional numerical predictions were obtained by a finite volume method using a variety of approaches ranging from laminar flow assumptions to standard and low Reynolds number **k-ε** turbulence models, direct simulation and large eddy simulation. The influence of Reynolds number included angle and pitch to height ratio was investigated and alternative turbulence modeling approaches were tested. The authors concluded that the standard k-ε model with wall functions was acceptable at high Reynolds number but it failed to produce correct values of friction factor and Nusselt Number. While the simple laminar flow assumptions yielded acceptable results only for Re < 3000 and moderate angles. The best overall agreement with measured friction factors and average or local heat transfer coefficients on the whole range of the parameters was obtained by using a low-Reynolds number **k-ε** model.

CFD is an established technique for determining the heat transfer performance of heating elements. Detailed 3D CFD analysis gives visual and quantitative predictions of flow and heat transfer behavior of a given heating element.

III. MESH AUTOMATION PROGRAM ‘HEPD’

Heating Element Profile Design (HEPD) is code in TCL/TK developed for designing different Corrugated shapes starting with the Existing design of a Profile which is used in Air-Preheater in Thermal Power Plant based on Bezier Curve Technique. In this work the corrugated sheets of notched-flat type are designed. The whole process is automated. This consists of profile shape generation using Bezier Curve techniques, creating profiled fluid domain surfaces and subsequent mesh generation. Automation is possible as ICEM-CFD uses TCL/TK as a script language. The automation code in TCK/TK language embeds ICEM-CFD commands for geometry creation mesh generation.

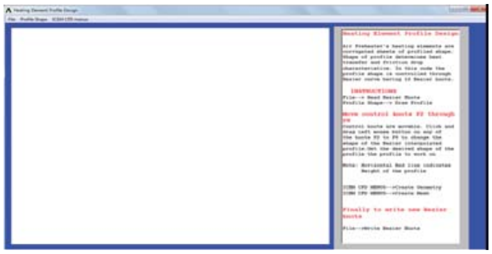
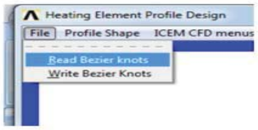


Figure.3 Graphics User Interface for Heating Element Profile

The code is run as a script file in ICEM-CFD. First code’s GUI (Heating Element Profile Design-HEPD) (*figure.3*) is created apart from ICEM-CFD GUI. Different Profile shapes (of Heating Elements) are obtained by moving interactively Bezier knots of the Bezier curve HEPDGUI.



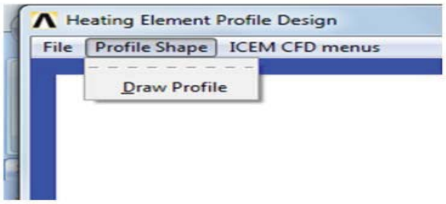


Figure.4 File Menu Reading Bezier Knots

Figure.5 Drawing Profile shape

The red horizontal line in the figure (*figure.6*) below shows the profile height.

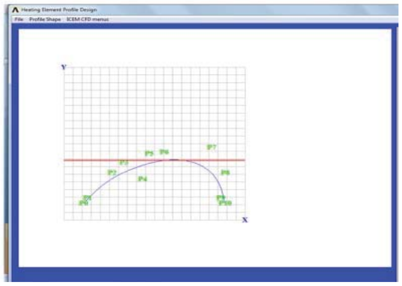


Figure.6 Basic Bezier Curve

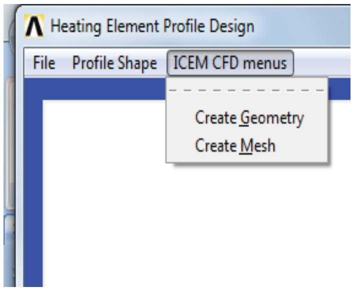


Figure.7 ICEM CFD MENUS creating geometry and mesh generation

With Pull-Down menu option of HEPD-GUI, finalized profile shape is drawn and visualized directly in the ICEM-CFD'S GUI. Another pull down menu of HEPD-GUI can be used to create geometry and mesh in ICEM-CFD (*figure.7*).

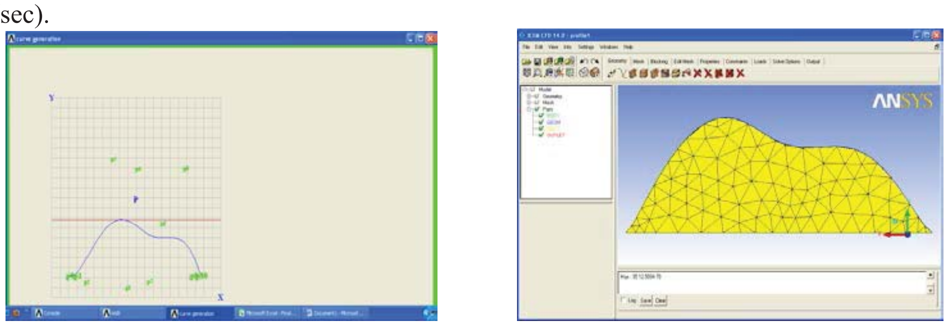
(a) (b)

Figure.8 (a) & (b) Mesh generation of the Heating Element Profile

The mesh is then reviewed (*figure. 8)* with standard ICEM-CFD menu options for Quality. If required, mesh may be created again manually to meet quality aspects. Finalized mesh is then exported to the CFD solver. Subsequent CFD analysis is made in fluent solver.

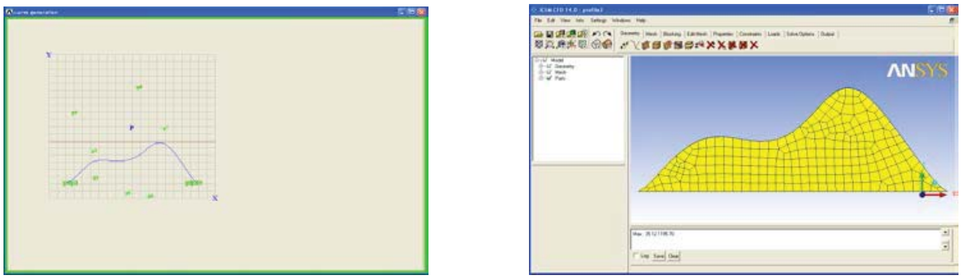
IV. HEAT TRANSFER ANALYSIS USING CFD

CFD heat transfer analysis is carried out in Fluent software with constant temperature boundary conditions for the heating element. For turbulence, k-ε model was used. The solution is converged to RMS residual level of 1.0E-04. Critical analysis of the converged results is made. Few test cases are presented. Different Profiles are compared for selecting the best profile which will give the optimized design and can be used as an efficient heating element by giving highest rate of heat transfer and heat transfer coefficient, lowest pressure drop & friction factor at the highest velocity(25m/sec).



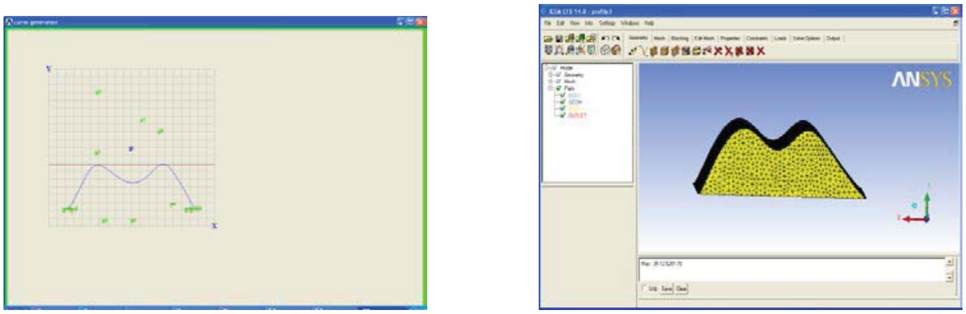
(a) (b)

Figure.9 (a) Design of 1st corrugated Profile (b) Meshing of the profile



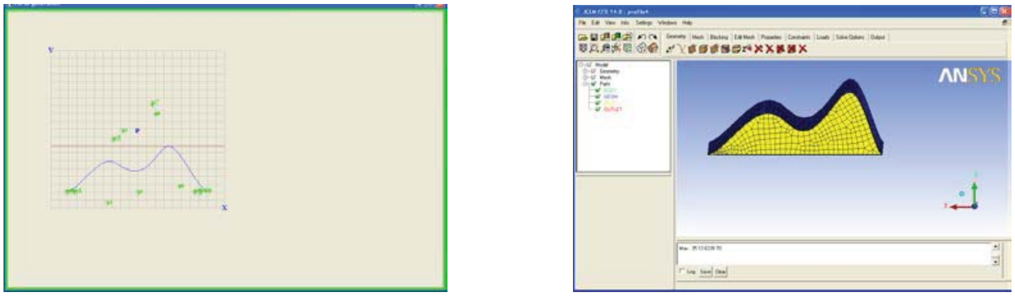
(a) (b)

Figure.10 (a) Design of 2nd corrugated Profile (b) Meshing of the profile



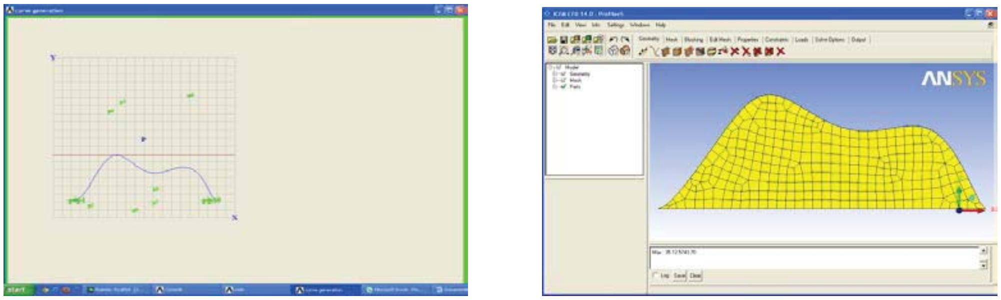
(a) (b)

Figure.11 (a) Design of 3rd corrugated Profile (b) Meshing of the profile



(a) (b)

Figure12. (a) Design of 4th corrugated Profile (b) Meshing of the profile



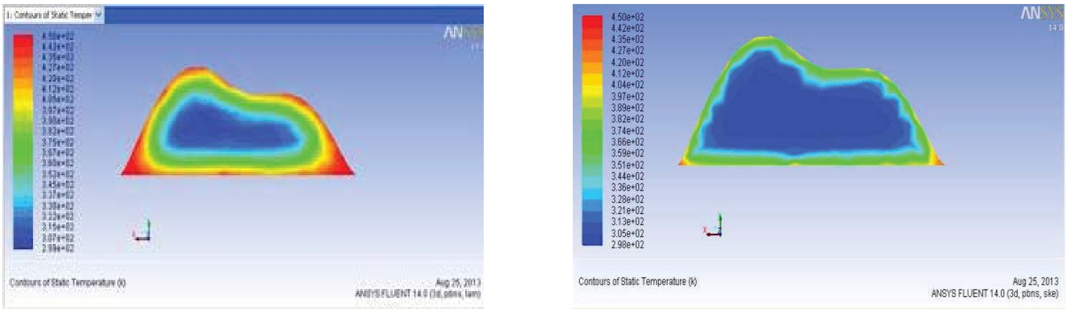
(a) (b)

Figure13. (a) Design of 5th corrugated Profile (b) Meshing of the profile

V. ANALYSIS OF HEATING ELEMENT

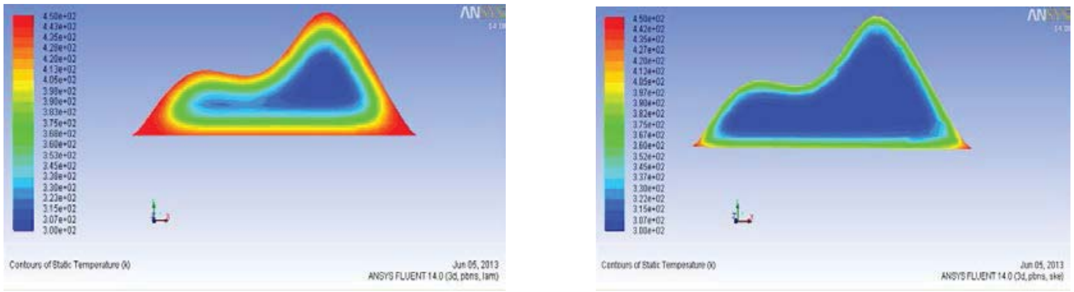
After the generation of Mesh files of fluid flow passages of different heating element profiles in ANSYS ICEM CFD, the complete analysis of the profiles is done by FLUENT (Solver) to calculate different parameters such as Pressure Drop, Friction Factor, Heat transfer rate and heat transfer coefficient with constant Temperature Boundary conditions for different velocities ranging from 1m/sec to 25m/sec.

The type of modeling which is used for the analysis of the Profile is Turbulence Modeling**.** In this work k-έ model of turbulence is used for the analysis of Profiles. The analysis is being done at constant temperature at inlet, and 0 gauge pressures at outlet and the geometry. Temperature at inlet. is taken as *300K*, Backflow temperature at outlet is taken as *310K* and the wall i.e. heating surface, temperature is taken as *450K.* Temperature Contours *(figure.14 to 18)* are drawn for different velocities on the outlet surface of the heating element profile which shows the distribution of temperature on the outlet surface of the Profile at different velocities. The red color represents the largest scale value and the blue color represents the smallest scale value. For least velocity 1m/sec(*a*) on the outlet surface for different heating element profiles the red color appears to be more near the corners and the edge of the profile and the blue color appears to be less on the surface. As for less velocity the mass flow rate of the fluid is less so more amount of heat is required for heating of the fluid so the temperature increases. So, the red color appears to be more. For highest velocity 25m/sec (*b*) the red color appears to be very less near the corners and the blue color appears to be more in the surface as for higher velocities the mass flow rate of the fluid is more so it requires less amount of heat for heating of the fluid for which the temperature gradually decreases. In 4th profile for the velocity of 1m/sec (*figure.17a*) it is observed that the due to small gap in the middle zone of the profile the temperature is percolated and the middle zone of the heating element is heated up so green color appears to be in the middle zone and the blue color is not visible at the middle zone while due to less mass flow rate and high temperature the red color appears to be more at the corners and the edge of the profile.



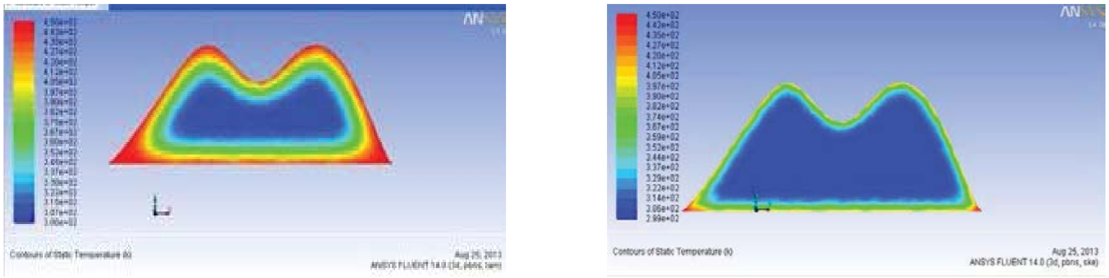
(a) *(U=1m/sec)* (b) *(U=25m/sec)*

Figure14. Distribution of temperature contour plots at the Outlet for different velocities for 1st Profile



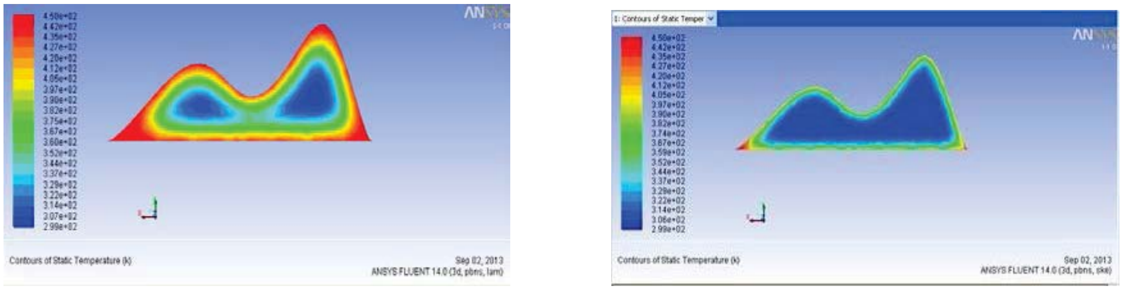
(a) *(U=1m/sec)* (b) *(U=25m/sec)*

Figure15. Distribution of temperature contour plots at the Outlet for different velocities for 2nd Profile



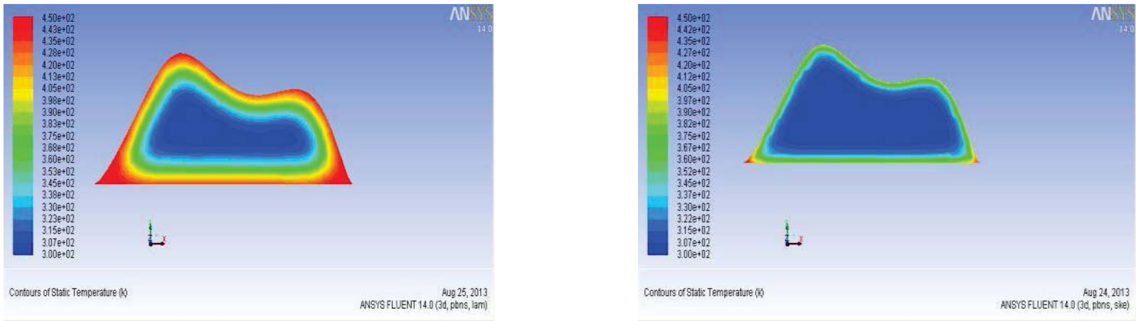
(a) *(U=1m/sec)* (b) *(U=25m/sec)*

Figure16. Distribution of temperature contour plots at the Outlet for different velocities for 3rd Profile



(a) (*U=1m/sec*) (b) *(U=25m/sec)*

Figure17. Distribution of temperature contour plots at the Outlet for different velocities for 4th Profile



(a) (*U=1m/sec*) (b) *(U=25m/sec)*

Figure18. Distribution of temperature contour plots at the Outlet for different velocities for 5th Profile

VI. RESULTS AND CONCLUSIONS

Different graphs *(figure. 19 to 22)* are plotted between velocity, Pressure drop, Friction factor, Heat transfer coefficient and Rate of heat transfer after the calculations of different Parameters of different corrugated profiles.

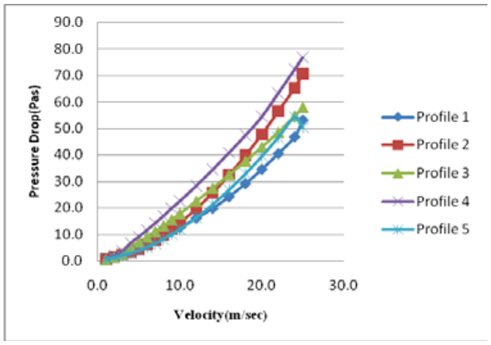


Figure19. Velocity Vs Pressure Drop

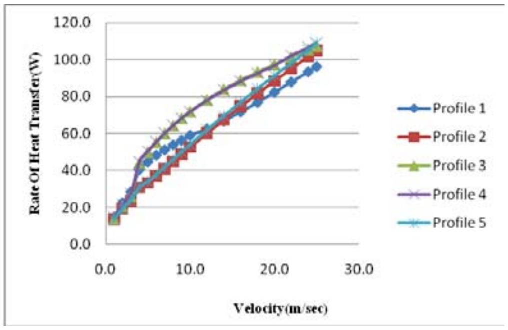


Figure 20. Velocity Vs Rate of Heat Transfer

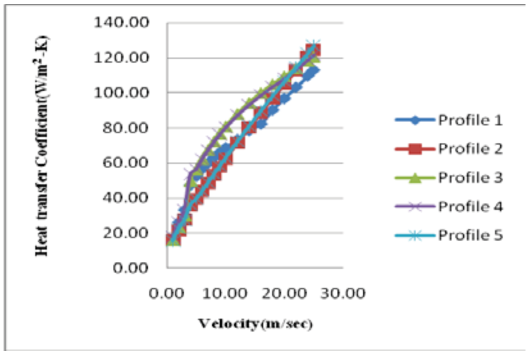


Figure21. Velocity Vs Heat transfer Coefficient

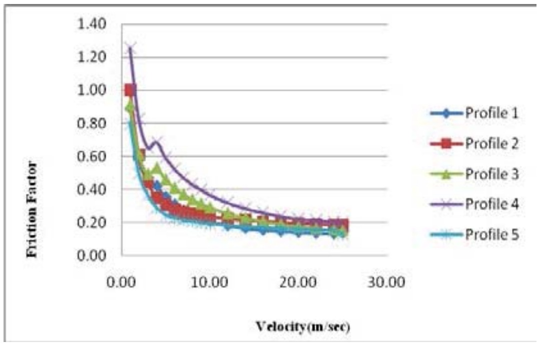


Figure22. Velocity Vs Friction Factor

. The Nusselt No., the Heat Transfer coefficient and the rate of heat transfer were found to increase with increase in Reynolds's no. with increased velocity. The Friction Factor was found to decrease with increase in Reynolds's number. A substantial increase in the Total rate of Heat Transfer, Heat Transfer Coefficient and substantial decrease in the Pressure Drop and Friction Factor is observed in different Heating Element Profiles with respect to the Existing Profile (Profile1), Comparing all the Profiles with the Existing Profile (Profile 1) PROFILE 5 Is Considered as The Best Profile as it gives the highest total rate of heat transfer of 109 W, highest heat transfer coefficient of *126.840W/m2 K*, Lowest Pressure Drop of *50.3N/m2(Pa)* and lowest Friction factor of 0.132 at the highest velocity *of 25m/sec*. Profile 5 can be used an efficient heating element as it enhances the rate of heat transfer by19.4% and heat transfer coefficient by 20% and decreases the friction factor by 22% and Pressure drop by27.7% which Optimizes the design of the heating element plate**.**

REFERENCES

[1] Asotin and.Tikhonov,1970 Investigation of the characteristics of the Corrugated plate type heating surfaces

[2] Focke,1985 The effect of the corrugation inclination angles on the thermohydraullic performance of the plate heat exchangers.

[3] Gaiser and Kottke,1989,Flow Phenomenan and local heat and mass transfer in Corrugated Passages

[4] Collins,-et al.,Ciofalo,.Chew, 1995,Investigation of flow and heat transfer in Corrugated Passages-Experimental Results.

[5] Collins,-et al .Ciofalo.Stasteik,.1996, Investigation of flow and heat transfer in Corrugated Passages- Numerical Simulations.

[6] Stasteik,1998 Experimental studies of heat transfer and fluid flow across corrugated-undulated heat exchanger surface.

[7] Michele Ciofalo,1998, A computational approach to conjugate heat transfer between two fluids in plate heat exchangers of arbitrary geometry.

[8] Focke and Knibbe,1986, Flow Visualization in Parallel plate ducts with Corrugated Walls.

[9] Akino-et al,.,Moffat, Simonich,Liguid Crystal mapping of local heat transfer in cross corrugated geometries.

[10] P.N.Sapkal, P.R.Baviskar, M.J.Sable, S.B.Barve,2011,Optimize air preheater Design for better Performance

[11] Rakesh Kmar, Sanjeev Jain,pp1-4 , Performance Evaluation of air pre heater at off Design condition.