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Optimization Performance on Plate Fin Tube Heat Exchanger

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***Abstract*-The main objective of the present work is to investigation of optimum design of plate fin tube heat exchanger using Computational fluid dynamic approach and maximizing thermal performance. There are total five designs of plate fin and tube heat exchanger are used in present work and CFD analysis have been performed in it to get maximum heat transfer. It has been observed from CFD analysis that the maximum heat transfer can be achieved from plate fin and tube heat exchanger with elliptical tube arrangement inclined at 30º with 23.22% more heat transfer capacity as compared to circular tube plate pin heat exchanger. So that it is recommended that if the plate fins and tube heat exchanger with inclined elliptical tube used in place of circular tube arrangement, batter heat transfer can be achieved.**

***Keywords*: Plain fin; Turbulence; Friction factor; etc.**

I. INTRODUCTION

Plate-fin heat exchanger

A plate-fin heat exchanger is a type of heat exchanger design that uses plates and finned chambers to transfer heat between fluids. It is often categorized as a compact heat exchanger to emphasise its relatively high heat transfer surface area to volume ratio. The plate-fin heat exchanger is widely used in many industries, including the aerospace industry for its compact size and lightweight properties, as well as in cryogenics where its ability to facilitate heat transfer with small temperature differences is utilized.

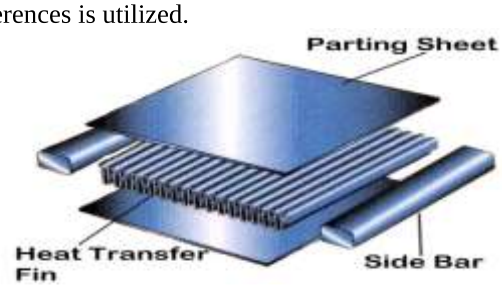


Figure 1 Plate fin heat exchanger

Plate fin-and-tube heat exchangers are used extensively in heating, ventilating, and air conditioning (HVAC), process engineering, and refrigeration applications such as compressor intercoolers, fan coils, and air-coolers. The governing thermal resistance for heat exchangers is typically located on the air side, accounting for 85% or more of the total resistance in practical applications. Consequently, the use of finned surfaces on the air side facilitates improvements to the overall thermal performance of heat exchangers.

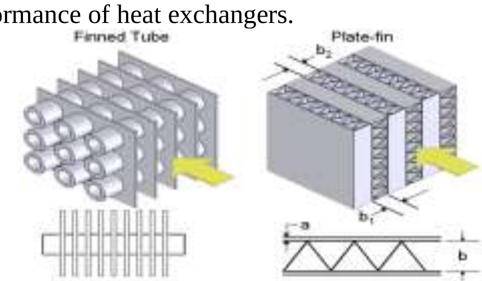


Figure 2 design of fin plate heat exchanger

Heat transfer principle

Fourier's law of heat conduction states that if temperature gradient is present in a body, then the heat will transfer from a high-temperature region to allow- temperature region. And, this can be achieved in three different ways, such as convention, radiation and conduction.

Whenever two objects with different temperature come in contact with each other, conduction occurs causing the fast-moving molecules of the high-heat object to collide with the slow-moving molecules of the cooler objects, and thus, transfers thermal energy to the cooler object, and this is termed as thermal conductivity.

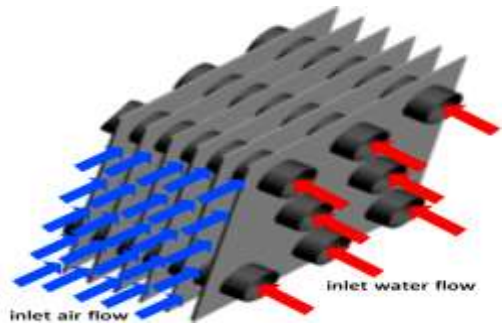


Figure 3 design of fin plate of air flow

II. LITERATURE REVIEW

Y Peng (2017) Air-cooled heat exchanger plays an important role in the field of industry like for example in thermal power plants. On the other hand, it can be used to remove core decay heat out of containment passively in case of a severe accident circumstance. Thus, research on the performance of fins in air-cooled heat exchangers can benefit the optimal design and operation of cooling systems in nuclear power plants.

Artur Rubcov (2017) Results of experimental tests of a wavy fin and tube heat exchanger used to heat (cool) air in a ventilation system when the wavy fin of the heat exchanger is dry and wet. The experimental tests, performed in the range of 1000<Re<4500 of the Reynolds number, determined the dependency of the heat transfer coefficient on the amount of supplied air with the varying geometry of the heat exchanger (the number of tube rows, the distance between fins, the thickness of the fin and the diameter of the tube). The experimental tests were performed on 9 heat exchangers in heating mode (dry fin) and 6 heat exchangers in cooling mode (wet fin).

R.Anbarasan (2017) The CFD simulations of the working fluid flow distribution in individual tubes of fin-andtube heat exchanger. For this purpose, the CFD simulations have been conducted for the design of the inlet and outlet manifolds of the heat exchanger tube elliptical, and the results compared with the values determined empirically, by measuring the mass flow flowmeter installed in the lower part of the heat exchanger tube. A comparison of the results of numerical calculations with the measurement results is presented. The turbulence model k-ε, k-ω and Shear Stress Transport model SST was considered in the computations.

III.OBJECTIVES

- ❖ The main objective of the present work to perform computational Fluid Dynamics simulations to predict the effect of inlet air flow maldistribution on the design and thermal hydraulic performance of heat exchanger.
- ❖ To create new model of plate fin and tube heat exchanger with different tube pitches for batter heat transfer.
- ❖ To perform computational fluid dynamics simulations to predict the effect of inlet air flow maldistribution on the new design and thermal hydraulic performance of heat exchangers.
- ❖ To compare the results from both computational fluid dynamic analysis and validate with base paper.

IV.METHODOLOGY

Steps Of Expected Methodology

1. Acquiring the design dimensions of Plate fin-and-tube heat exchangers .
2. Preparing the CAD model of Plate fin-and-tube heat exchangers .
3. Assigning the selected material to the Plate fin and tube heat exchangers in ANSYS Software.
4. Assigning the suitable boundary conditions.
5. Further CFD analysis will be perform for base paper model and proposed model of Plate fin and tube heat exchangers .

CFD model details

Geometrical parameters for the plain-fin-and-tube heat exchanger models.

Parameters	Values
Tube diameter fin collar outside diameter, *D* (mm)	9.97
Longitudinal tube pitch, Ll (mm)	27.50
Transverse pitch, Lt (mm)	31.75
Fin pitch, Fp (mm)	3.21
Fin thickness, Ft (mm)	0.20
Number of tube row, N	4
Fin-and-tube arrangements	In-line, staggered

FEM analysis:

The use of finite element method as a tool to solve various engineering problems in industrial applications is quite a new concept. ANSYS is generally used in general purpose finite element analysis program. The construction of solution to engineering problems using FEM requires development of computer program based on FEM formulation or commercially available FEM program like ANSYS .

Steps of computational fluid dynamics Analysis:

The different analysis steps involved in computational fluid dynamics Analysis are mentioned below.

1. Preprocessor

A. Creation of CAD Model:
B. Generation of Meshing:
C. Define Materials:

2. Solution Processor: In this phase of analysis the computer takes over and solves the instantaneous equation which is generated by finite element method.

Postprocessor: Reviewing analysis results over the entire model is done in the general postprocessor.

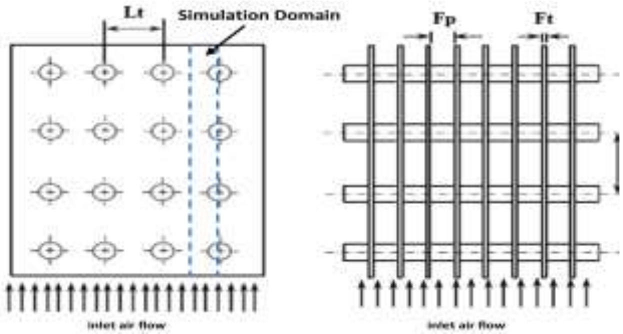


Figure: 4 Physical model with staggered arrangement

Because of the symmetry of the tube bank geometry, only a portion of the domain needs to be modeled. The computational domain is shown in outline in Figure

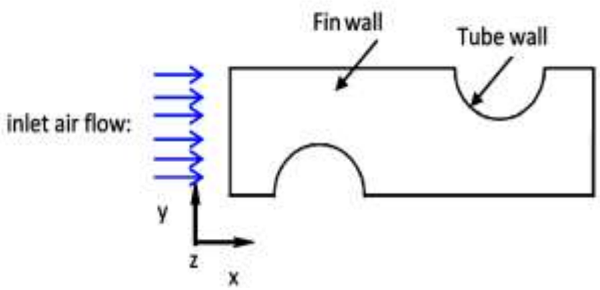


Figure:5 Model heat exchangers: computational domain with boundary conditions.

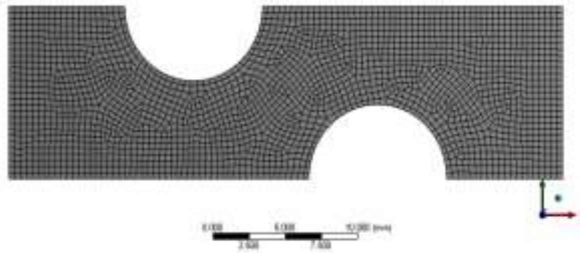
CFD Analysis of plate fin with circular tube heat exchanger

CAD geometry:

In the present work a two dimensional CAD model of plate fin with circular tube heat exchanger is created with the help of design modular of ANSYS workbench.

Meshing

After completing the CAD geometry of plate fin with circular tube heat exchanger is imported in ANSYS workbench for further computational fluid dynamics analysis and the next step is meshing. CAD geometry is divided into large numbers of small pieces called mesh. in the present work is 2406 and total No. of Elements is 2275. Types of elements used are rectangular which is a rectangular in shape with four nodes on each element.



Meshing: Total Nodes 2406 Total elements 2275

Different boundaries of Plate fin with circular tube heat exchangers

Governing Equations

Conservation of mass or continuity equation:

The equation for conservation of mass, or continuity equation, can be written as follows

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho\,\vec{v}) = S_m$$

Where

S_m = mass added to the continuous phase or any user defined sources. For 2D axisymmetric geometries, the continuity equation is given by

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho v_x) + \frac{\partial}{\partial r}(\rho v_r) + \frac{\rho v_r}{r} = S_m$$

Where x is the axial coordinate, r is the radial coordinate, Vx is the axial velocity, and Vr is the radial velocity.

Momentum Conservation Equations

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla.(\rho\vec{v}\vec{v}) = -\nabla p + \nabla.(\bar{\bar{\tau}}) + \rho\vec{g} + \vec{F}$$

For 2D axisymmetric geometries, the axial and radial momentum conservation equations are given by

$$\frac{\partial}{\partial x}(\rho v_x) + \frac{1}{r}\frac{\partial}{\partial x}(r\rho v_x v_x) + \frac{1}{r}\frac{\partial}{\partial r}(r\rho v_r v_x)$$
$$= -\frac{\partial p}{\partial x} + \frac{1}{r}\frac{\partial}{\partial x}\left[r\mu\left(2\frac{\partial v_x}{\partial x} - \frac{2}{3}(\nabla.\vec{v})\right)\right] + \frac{1}{r}\frac{\partial}{\partial r}\left[r\mu\left(\frac{\partial v_x}{\partial r} + \frac{\partial v_r}{\partial x}\right)\right] + F_x$$

Energy Equation:

The energy equation for the mixture takes the following form:

$$\frac{\partial}{\partial t}\sum_{k=1}^{n}(\alpha_k\rho_k E_k) + \nabla.\sum_{k=1}^{n}(\alpha_k\vec{v}_k(\rho_k E_k + p)) = \nabla.(k_{eff}\nabla T) + S_E$$

where k_{eff} = effective conductivity

S_E = volumetric heat sources

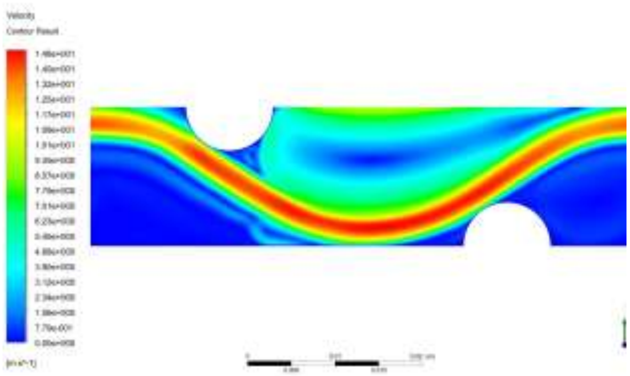
$$E_k = h_k - \frac{p}{\rho k} + \frac{v_k^2}{2}$$

$E_k = h_k$ for an incompressible phase and h_k = sensible enthalpy f

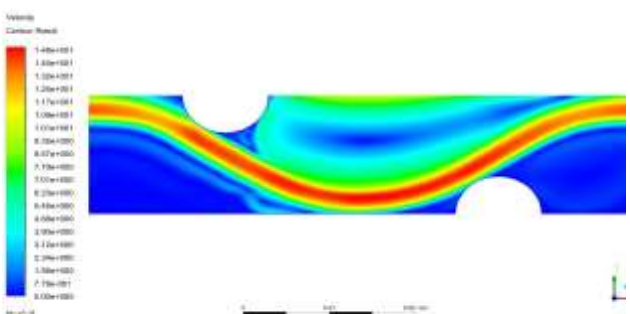
Boundary condition

- To determine the maximum temperature Plate fin-and-tube heat exchangers need to on energy equation.
- Select Second Order Upwind for the Momentum and Energy equation.

Velocity distribution over the plate fin with circular tube heat exchanger. The maximum velocity at Plate fin-and-tube heat exchangers has been recorded is 14.8 m/sec.

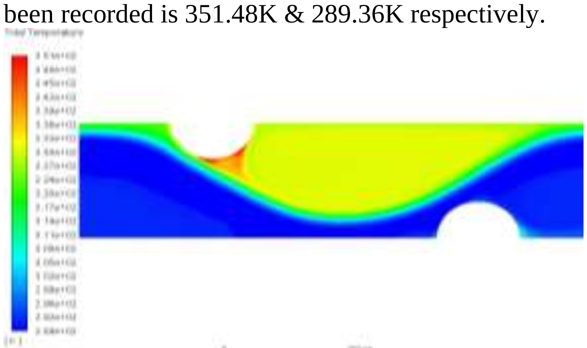


VELOCITY DISTRIBUTION



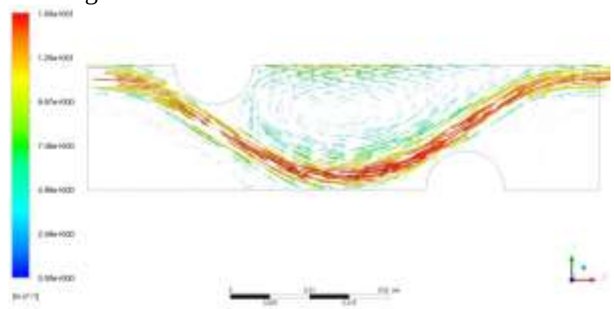
PRESSURE DISTRIBUTION

Temperature distribution over the plate fin with circular tube heat exchanger. The maximum & minimum temperature at Plate fin-and-tube heat exchangers has been recorded is 351.48K & 289.36K respectively.

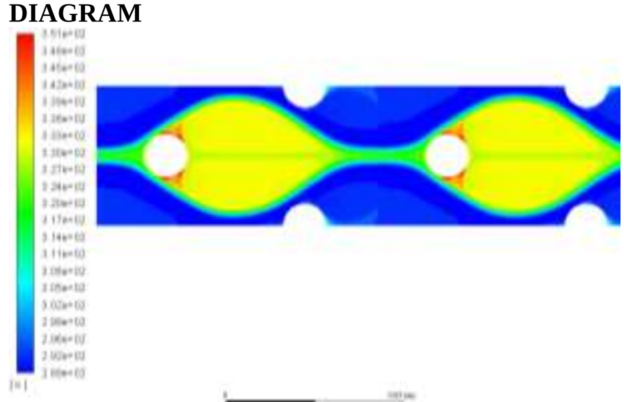


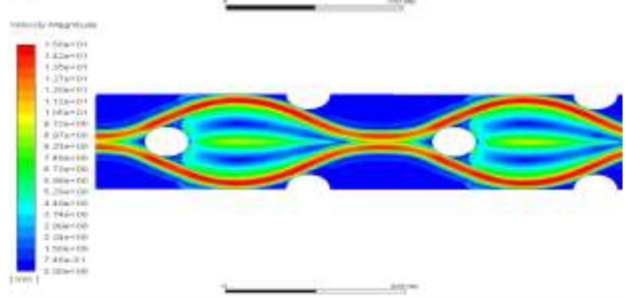
TEMPERATURE DISTRIBUTION

Figure shows the schematic wind velocity vector diagram of air flowing through the plate fin with circular tube heat exchanger .



VELOCITY VECTOR DIAGRAM





CAD geometry

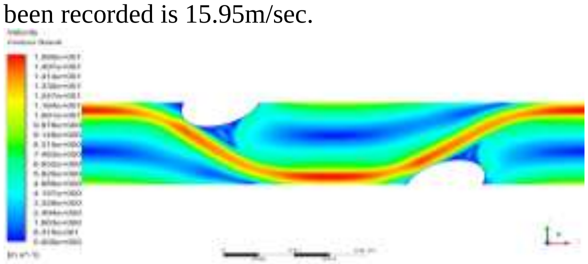
In the present work a two dimensional CAD model of plate fin tube heat exchanger with elliptical tube inclined at 30° is created with the help of design modular of ANSYS workbench.

Meshing

After completing the CAD geometry of Plate fin with inclined elliptical tube heat exchangers is imported in ANSYS workbench for further computational fluid dynamics analysis and the next step is meshing. in the present work is 15944 and total No. of Elements is 15586. Types of elements used are rectangular which is a rectangular in shape with four nodes on each element.

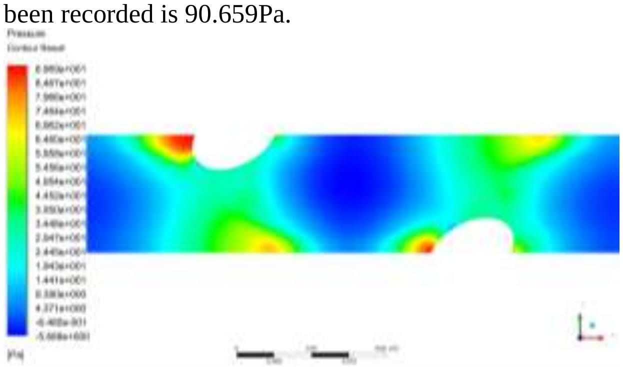
Meshing: Total Nodes 15944 Total elements 15586
Different boundaries of Plate fin with inclined elliptical tube heat exchangers

Velocity distribution over the Plate fin with inclined elliptical tube heat exchangers. The maximum velocity at Plate fin with inclined elliptical tube heat exchangers has been recorded is 15.95m/sec.



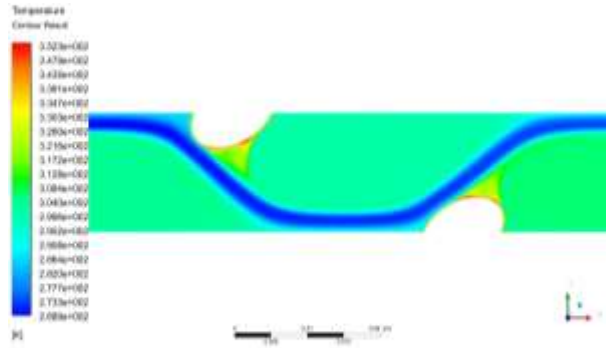
PRESSURE DISTRIBUTION

Pressure distribution over the Plate fin with inclined elliptical tube heat exchangers. The maximum pressure at Plate fin with inclined elliptical tube heat exchangers has been recorded is 90.659Pa.



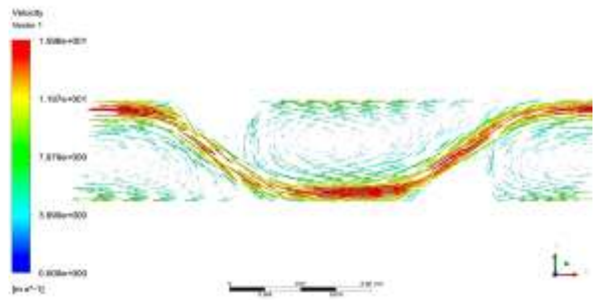
TEMPERATURE DISTRIBUTION

Temperature distribution over the Plate fin with inclined elliptical tube heat exchangers. The maximum & minimum temperature at Plate fin with inclined elliptical tube heat exchangers has been recorded is 349.78K & 268.87K respectively

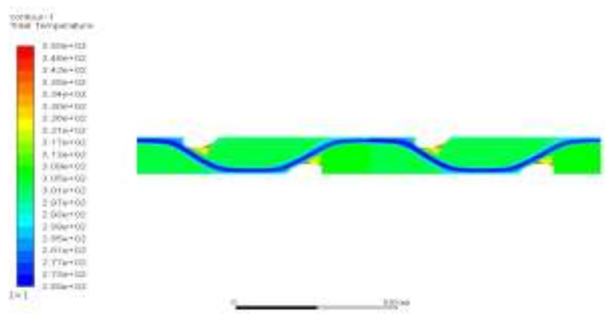


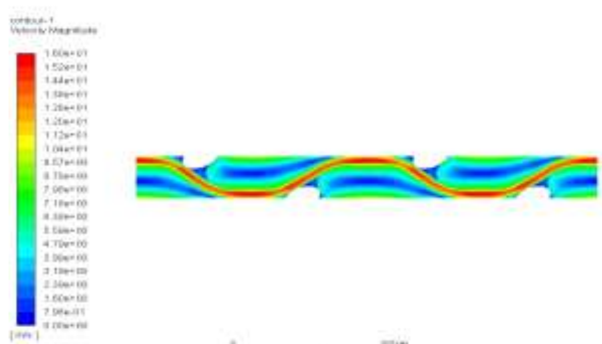
VELOCITY VECTOR DIAGRAM

Figure shows the schematic velocity vector diagram of air flowing through the Plate fin with inclined elliptical tube heat exchangers .



Velocity and temperature contour for plate fin and tube heat exchanger having tube inclined at 30º





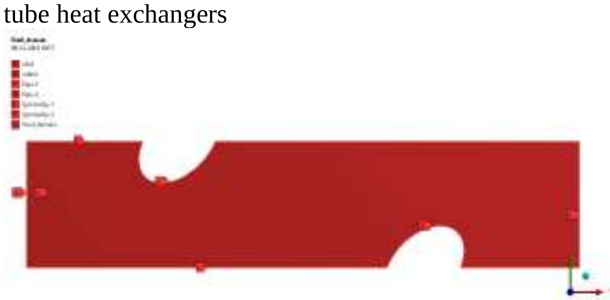
CAD geometry

In the present work a two dimensional CAD model of plate fin tube heat exchanger with elliptical tube inclined at 45° is created with the help of design modular of ANSYS workbench.

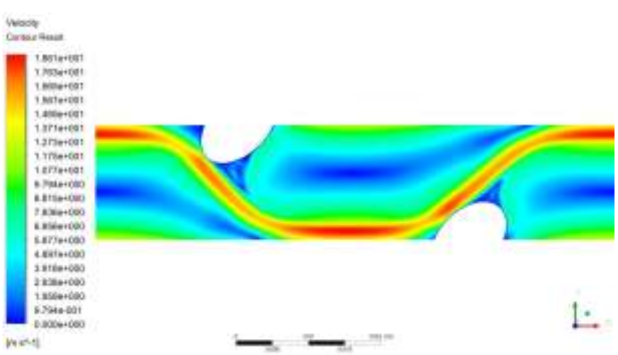
Meshing

After completing the CAD geometry of Plate fin with inclined elliptical tube heat exchangers is imported in ANSYS workbench for further computational fluid dynamics analysis and the next step is meshing. in the present work is 16601 and total No. of Elements is 16247. Types of elements used are rectangular which is a rectangular in shape with four nodes on each element

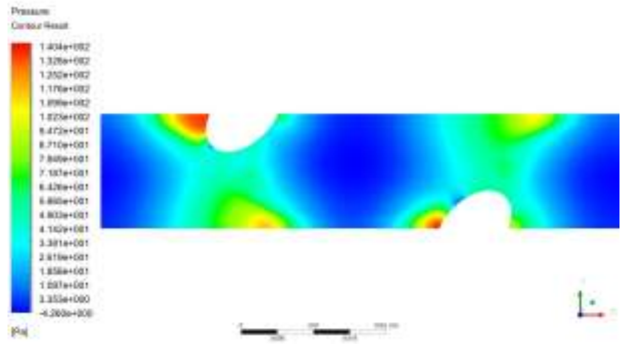
Different boundaries of Plate fin with inclined elliptical tube heat exchangers



Velocity distribution over the Plate fin with inclined elliptical tube heat exchangers. The maximum velocity at Plate fin with inclined elliptical tube heat exchangers has been recorded is 18.79m/sec.



Pressure distribution over the Plate fin with inclined elliptical tube heat exchangers. The maximum pressure at Plate fin with inclined elliptical tube heat exchangers has been recorded is 90.659Pa.



Temperature distribution over the Plate fin with inclined elliptical tube heat exchangers. The maximum & minimum temperature at Plate fin with inclined elliptical tube heat exchangers has been recorded is 349.2K & 270.30K respectively.

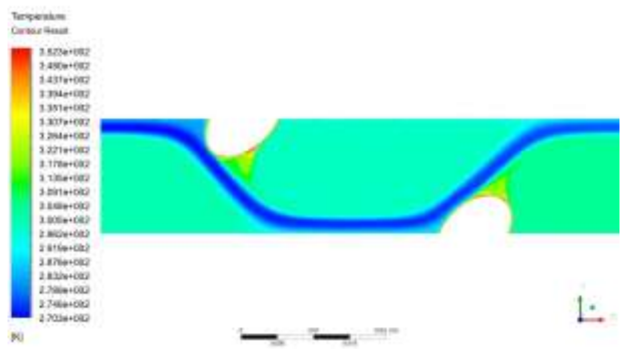
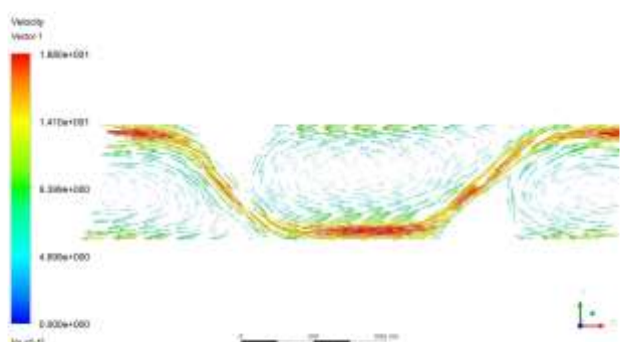
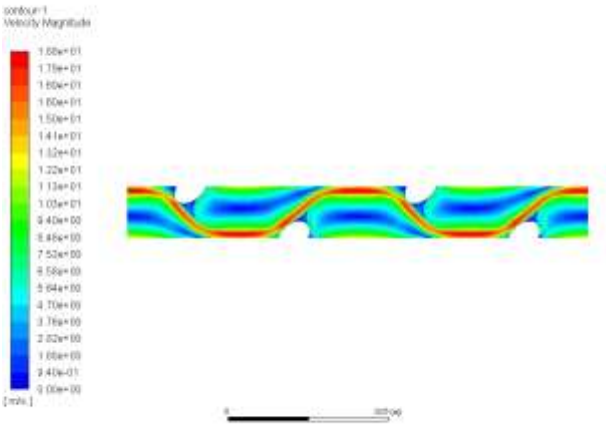
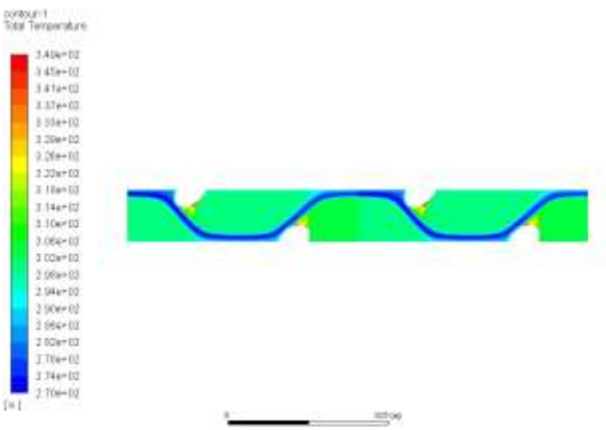


Figure shows the schematic velocity vector diagram of air flowing through the Plate fin with inclined elliptical tube heat exchangers







CAD geometry

In the present work a two dimensional CAD model of plate fin tube heat exchanger with elliptical tube inclined at 60° is created with the help of design modular of ANSYS workbench.

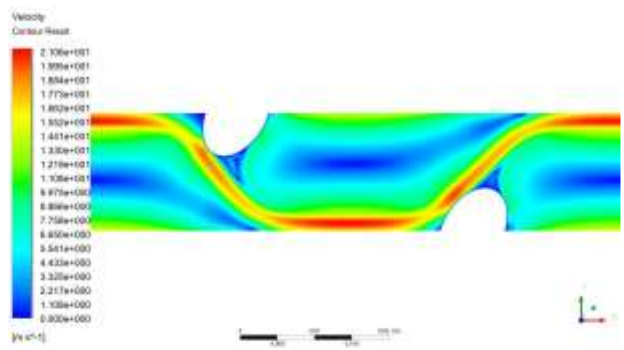
Meshing

After completing the CAD geometry of Plate fin with inclined elliptical tube heat exchangers is imported in ANSYS workbench for further computational fluid dynamics analysis and the next step is meshing. in the present work is 16698 and total No. of Elements is 16339. Types of elements used are rectangular which is a rectangular in shape with four nodes on each element.

Different boundaries of Plate fin with inclined elliptical tube heat exchangers

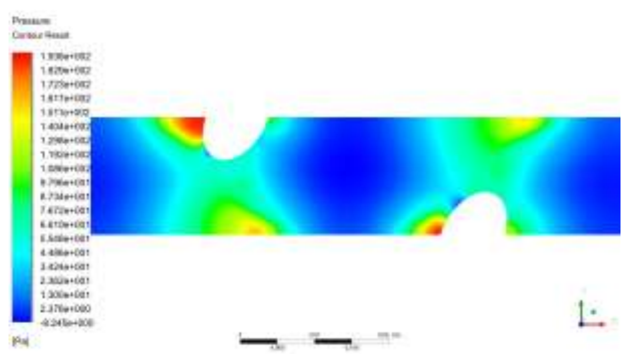
VELOCITY DISTRIBUTION

Velocity distribution over the Plate fin with inclined elliptical tube heat exchangers. The maximum velocity at Plate fin with inclined elliptical tube heat exchangers has been recorded is 21.27m/sec.



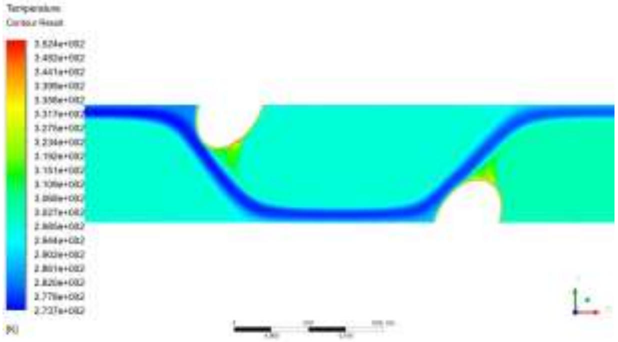
PRESSURE DISTRIBUTION

Pressure distribution over the Plate fin with inclined elliptical tube heat exchangers. The maximum pressure at Plate fin with inclined elliptical tube heat exchangers has been recorded is 195.59Pa.



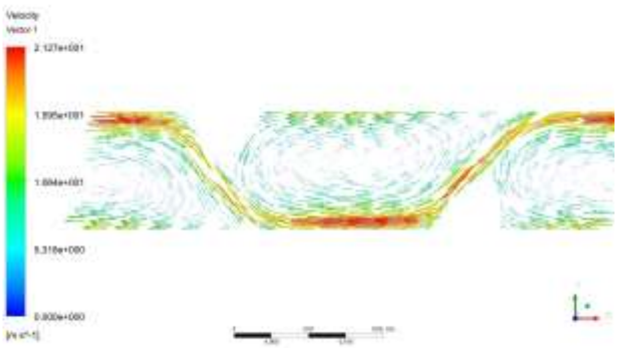
TEMPERATURE DISTRIBUTION

Temperature distribution over the Plate fin with inclined elliptical tube heat exchangers. The maximum & minimum temperature at Plate fin with inclined elliptical tube heat exchangers has been recorded is 349.14K & 273.68K respectively.

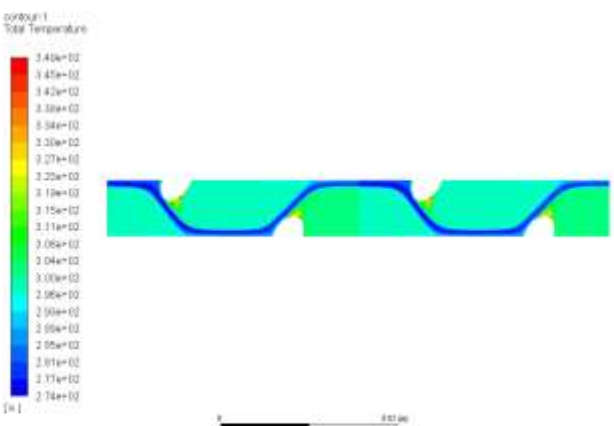


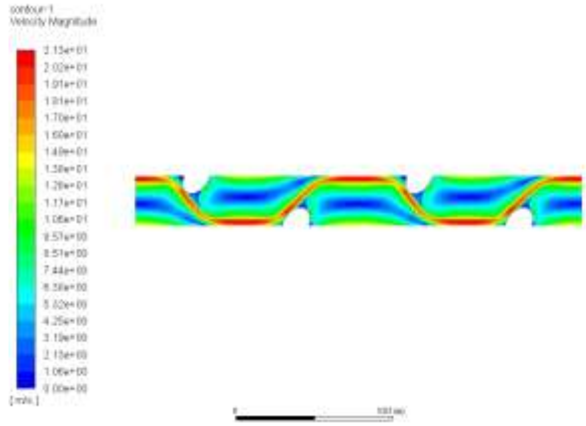
VELOCITY VECTOR DIAGRAM

Figure shows the schematic velocity vector diagram of air flowing through the Plate fin with inclined elliptical tube heat exchangers .



Velocity and temperature contour for plate fin and tube heat exchanger having tube inclined at 45º





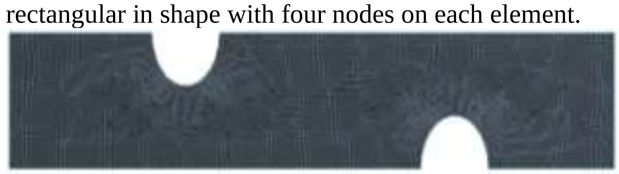
CFD Analysis of plate fin with vertical elliptical tube heat exchanger

CAD geometry:

In the present work a two dimensional CAD model of Plate fin with vertical elliptical tube heat exchangers is created with the help of design modular of ANSYS workbench.

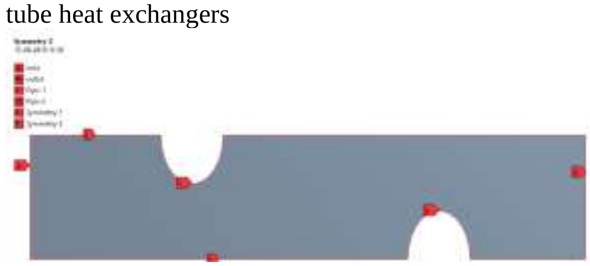
Meshing

After completing the CAD geometry of Plate fin with vertical elliptical tube heat exchangers is imported in ANSYS workbench for further computational fluid dynamics analysis and the next step is meshing. in the present work is 17435 and total No. of Elements is 17059. Types of elements used are rectangular which is a rectangular in shape with four nodes on each element.



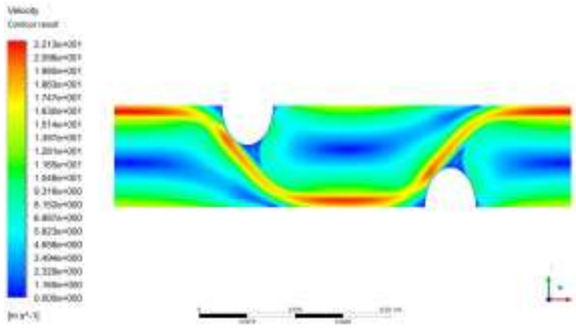
Meshing: Total Nodes 17435 Total elements 17059

Different boundaries of Plate fin with vertical elliptical tube heat exchangers



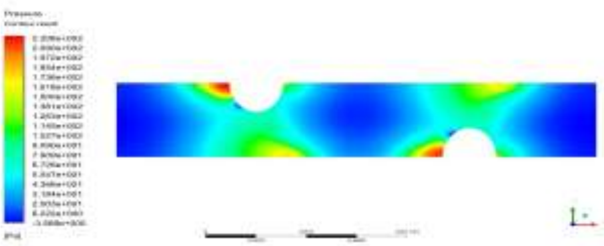
VELOCITY DISTRIBUTION

Velocity distribution over the Plate fin with vertical elliptical tube heat exchangers. The maximum velocity at Plate fin with vertical elliptical tube heat exchangers has been recorded is 22.35 m/sec.



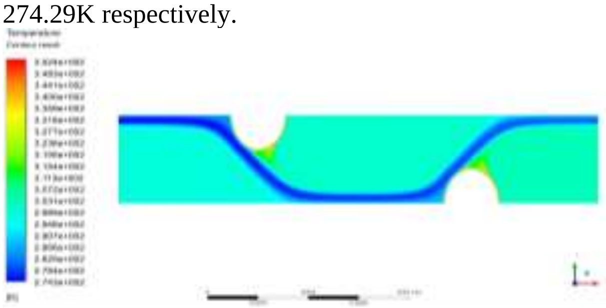
PRESSURE DISTRIBUTION

Pressure distribution over the Plate fin with vertical elliptical tube heat exchangers. The maximum pressure at Plate fin with vertical elliptical tube heat exchangers has been recorded is 223.09Pa.



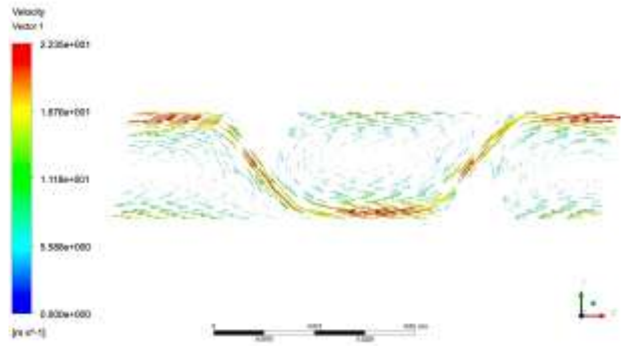
TEMPERATURE DISTRIBUTION

Temperature distribution over the Plate fin with vertical elliptical tube heat exchangers. The maximum & minimum temperature at Plate fin with vertical elliptical tube heat exchangers has been recorded is 347.49K & 274.29K respectively.



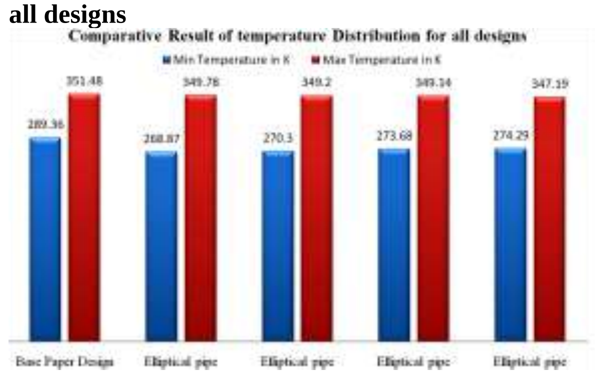
VELOCITY VECTOR DIAGRAM

Figure shows the schematic velocity vector diagram of air flowing through the Plate fin with vertical elliptical tube heat exchangers



V. RESULT AND DISCUSSION

Comparative Result of temperature Distribution for all designs



VI. CONCLUSION

After performing computational fluid dynamics analysis on various design of plate fin tube heat exchanger following conclusion have been drawn.

- Maximum and minimum temperature for base paper design (plate fin tube heat exchanger with circular tube arrangement) was observed as 351.48K and 289.36K, hence the temperature difference is 62.12 degree
- Maximum and minimum temperature for plate fin tube heat exchanger with elliptical tube arrangement inclined at 30^o was observed as 349.78K and 268.87K, hence the temperature difference is 80.91 degree and heat transfer performance improved as compared with base paper design is 23.22%.
- Maximum and minimum temperature for plate fin tube heat exchanger with elliptical tube arrangement inclined at 45o was observed as 349.2K and 270.3K, hence the temperature difference is 78.9 degree and heat transfer performance improved as compared with base paper design is 21.26%.

REFERENCES

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