International Journal of Innovation and Scientific Research
ISSN 2351-8014 Vol. 16 No. 1 Jun. 2015, pp. 225-238

http://www.ijisr.issr-journals.org/

CFD PREDICTION OF PRESSURE DROP & THERMAL PERFORMANCE IN 36 SOLID CIRCULAR FINNED TUBE BUNDLES POSITIONED AT INLINE ARRANGEMENT, STAGGERED ARRANGEMENT & CRINKLED 45° ARRANGEMENT

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ABSTRACT: The aim of this present work is to find out, which arrangement for finned tube bundles is better for achieving higher heat transfer rate and better pressure drop and other turbulent effects. All of work is done only on two Arrangements (i.e. inline and staggered Arrangement). In this paper a new Arrangement (i.e. Crinkled 45^0 Arrangement) is developed for 36 solid circular finned tube bundles. This paper investigates the problems of heat transfer, pressure drop and thermal hydraulic performance of inline and staggered arrangement of finned tube bundles. To minimize these problems Author gives a new finned tube bundle arrangement named as CRINKLED 45^0 Arrangement. A Steady State approach, with a two-equation turbulence model, is employed to examine the prediction of results and analysis. A Computational Fluid Dynamics FLUENT 14.5 is used for Performance Analysis of Arrangements. The modeling of arrangements is done on CATIA V5 and it is imported into the FLUENT 14.5 and in this a steady state pressure based solver and standard k-epsilon turbulence model was used. The proposed method based on a finite volume method and integral averaging of gas temperature across 36 tube row is appropriate for modeling of plate fin and tube heat exchangers, especially for exchangers in which substantial gas temperature differences in one tube row occur. Analysis was done on Modelled 36 solid circular finned tube bundles in cross flow positioned at Inline Arrangement, Staggered Arrangement and Crinkled 45^0 Arrangement.

KEYWORDS: CFD Fluent14.5 Finned Tube, Forced Convection, Thermal Performance, Inline, Staggered & Crinkled 45^0 Arrangements.

1 INTRODUCTION

Tube bundles in cross flow are found in many industrial heat transfer applications, from air conditioning and cooling, to boiling and heat-recovery operations. Finned tube bundles in cross flow are used both for waste heat recovery and steam production. For steam generation in cross flow, air is played an important role for steam generation. In this, air is a primary source or primary fluid. Commonly, wound fins are located on the external tube surface, improving the rate of heat transfer by increasing the surface area and improving convection at the surface. Finned tube heat exchangers are used in a variety of household applications and as industrial heat exchanger. An air heat exchanger like the evaporator coil for an air conditioning unit is typically a fin tube exchanger. An application of finned tube heat exchanger has seen in wide spread expansion recently is 'dry-cooling' for steam power. This consists of using an air cooled condenser. A finned tube heat exchanger will typically have tubes with fins attached to the outside of them. There will usually be a liquid flowing through the inside of the tubes and air or some other gas flowing outside of the tubes, where the additional heat transfer surface area due to the finned tubes increases the heat transfer rate. For a cross flow fin tube exchanger, the fins will typically be radial fins either circular or square. Finned-tube heat exchangers have been used to exchange heat between gases and liquids, which are single- or two-phase, for many years. The performance of the finned-tube heat exchanger is limited by the air side heat transfer resistance because the air side heat transfer coefficient is significantly lower than the refrigerant side heat transfer coefficient. Much research has been conducted to develop enhanced design techniques to improve the air side heat transfer performance of the finned-tube heat exchanger. Generally, air-conditioning systems use finned-tube heat exchangers with small fin pitches, while refrigerators or freezers use those with large fin pitches to obtain high performance and reliability during the frosting and defrosting processes. The finned-tube heat exchangers used in refrigerator and freezers adopt either discrete or continuous plate fins. The finned-tube heat exchanger with continuous fins has better heat transfer performance and has slightly simpler manufacturing process than that with discrete fins. Zhang et al. [1] evaluated theoretically the performance of a finned tube evaporator designed to recover the exhaust waste heat from an internal combustion engine.web and Kim [2] Recently, a variety of techniques of enhancing air and water side heat transfer in cross-flow tube heat exchangers has been developed. Mon and Gross [3] studied the effects of fin pitches on four-row annular finned-tube bundles in staggered and inline alignments. They found that the boundary layer and horseshoe vortices between the fins were substantially dependent on the Reynolds number and the ratio of fin pitch to height. Bayat et al. [4] found that the cam-shaped tubes in the staggered arrangement perform better compared with the circular tubes. Xie et al. [5] Studied air side heat transfer and friction characteristics of continuous finned-tube heat exchangers for 1–6 tube rows. In addition, Mon [6] conducted a numerical investigation on the air side heat transfer coefficient and pressure drop in circular plain finned-tube heat exchangers with discrete circular fins for inline and staggered tube alignments. Yang et al. [7] studied fin pitch optimization of a continuous finned-tube heat exchanger under frosting conditions for fin pitches greater than 5 mm. Ranganayakulu et al. [8] and Ranganayakulu and Seetharamu [9,10] investigated the combined effects of wall longitudinal heat conduction, inlet flow uniformity and temperature nonuniformity on the thermal performance of a two fluid cross-flow plate-fin heat exchanger using finite element method. The results showed that the performance may be reduced by 30% under non-uniform operating conditions. Lalot et al. [11] used CFD to study the gross flow maldistribution in an electrical heater. They presented the effect of flow non-uniformity on the performance of heat exchangers, based on the study of flow maldistribution in an experimental electrical heater. They found that reverse flows would occur for the poor header design and the perforated grid can improve the fluid flow distribution. Their results indicated also that the flow maldistribution leads to a loss of effectiveness of about 25% for cross-flow exchangers.

In previous studies all of the investigations are carried out on inline arrangement and staggered arrangement and from the studies it was found that the changes in finned tube arrangement it can give better heat transfer and pressure drop results and more effective thermal hydraulic performance.

This paper investigates the problems of thermal performance and pressure drop effects and developed the new solid circular finned tube arrangement named as 'crinkled 45^0 arrangement' for achieving better results.

Nomenclature

A	area (m2)
Acin; Aco	inner and outer cross section area of the tube (m2)
A_f	heat transfer area of the fin (m2)
Amf	area of the bare tube between two adjacent fins (m2)
Am	mean surface of the tube,
Amin	minimum free flow frontal area on the air side (m2)
Cp	specific heat (J/ (kg K))
Ain; Ao	inner and outer surface of the bare tube (m2)
dh	hydraulic diameter of air flow passages (m)
dr	hydraulic diameter on the liquid side,
h	convective heat transfer coefficient (W/ (m2 K))
ha; hw	air- and water-side heat transfer coefficient (W/(m2 K))
ho	effective heat transfer coefficient
k	thermal conductivity (W/ (m K))
kt	thermal conductivity of the tube material (W/ (m K))
Ki	integral or reset gain (1/s)
Kp	controller gain
Lch	length of the heat exchanger (m)
m_	mass flow rate (kg/s)
m_g	gas mass flow rate per tube (kg/s)
Nua	air-side Nusselt number,
p1	pitch of tubes in plane perpendicular to flow (height of the fin) (m)
p2	pitch of tubes in the direction of flow (width of the fin) (m)
Pin; Po	inner and outer perimeter of the oval tube, respectively (m)
Pr	Prandtl number,
Q_	heat transfer rate (W)
Rea	air-side Reynolds number,
Rew	liquid-side Reynolds number,
s	fin pitch (m)
t	time (s)
T	temperature (_C or K)

2 CFD MODEL DETAILS

3D modelling of inline, staggered and crinkled 45^0 tube arrangements is done on CATIA V5 software and imported into the CFD FLUENT 14.5. For modelling 2GB ram, Pentium dual core processor system configurations were used and for thermal analysis and analysis of different parameters 3GB ram, intel i3 processor system configurations were used.

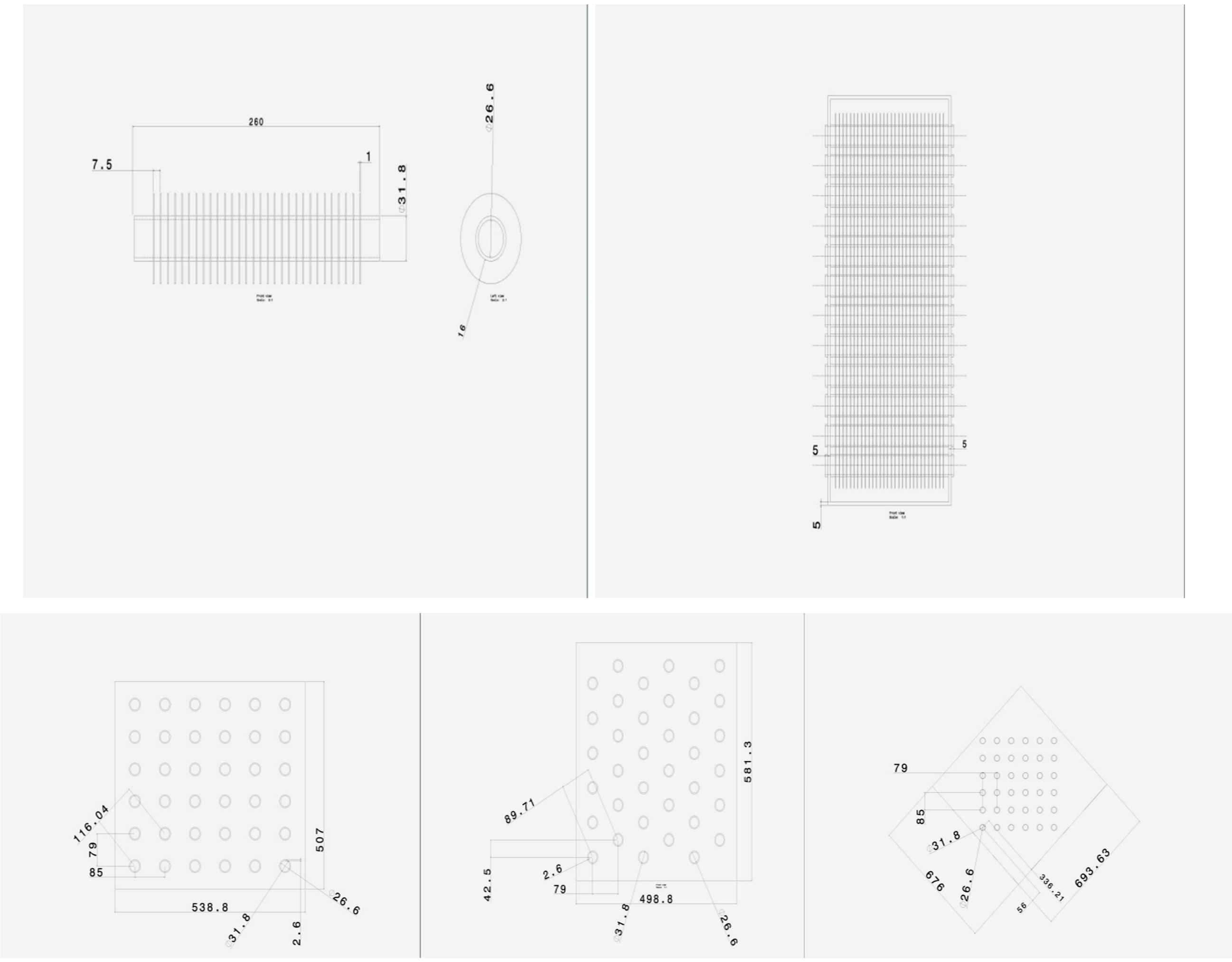
2.1 GEOMETRY DETAILS

The geometry details for arrangements is shown in table 1

Table 1. Geometry Table

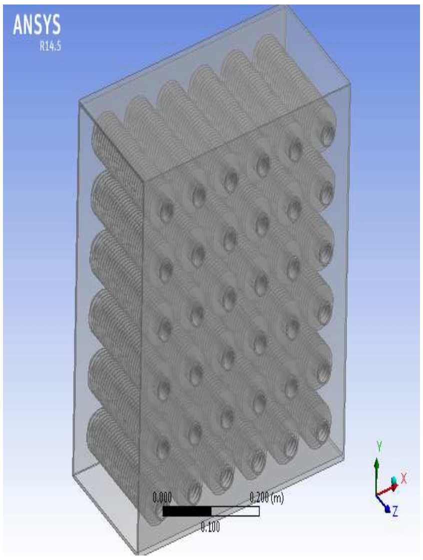
	Inline Arrangement	Staggered arrangement	Crinkled45^0 arrangement
No. of tubes	36	36	36
No. of fins	30	30	30
Fin pitch(mm)	7.5	7.5	7.5
Inner dia. of tube(mm)	26.6	26.6	26.6
Outer dia. of tube(mm)	31.8	31.8	31.8
Tube material	Al	Al	Al
Tube length (mm)	260	260	260

Geometry of arrangements: Geometries of arrangement is shown below.

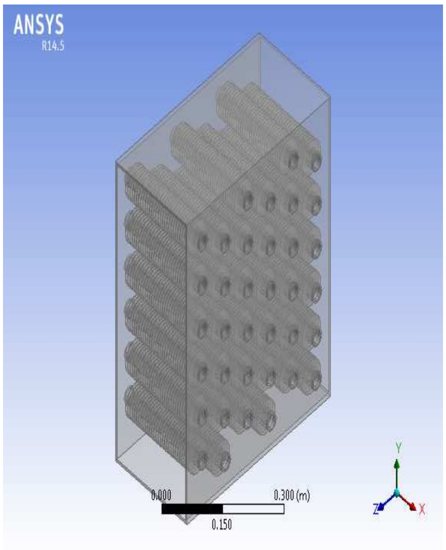


2.2 MODELLING DETAILS

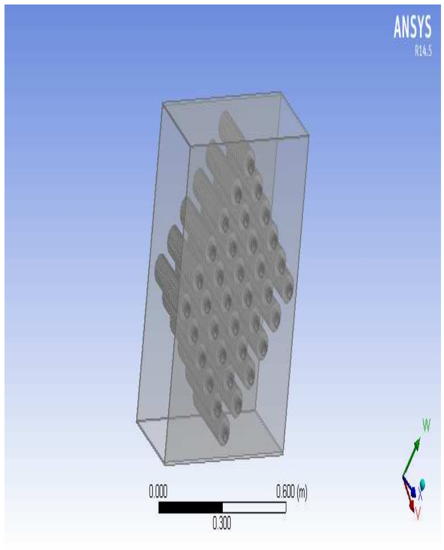
The modelling of Solid circular finned tube bundles positioned at inlined, staggered and crinkled 45^0 arrangements was done in CATIA V5. The modeled 3D geometries were imported into CFD FLUENT 14.5 for further procedures and for done meshing operation.



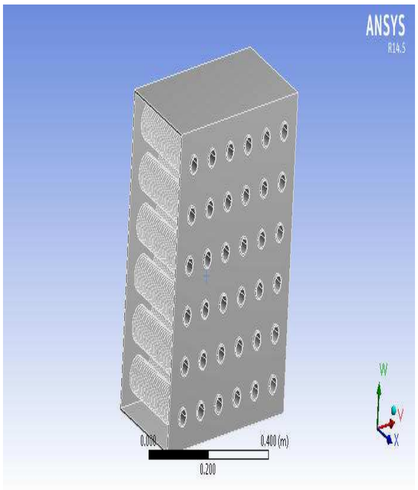
Inline arrangement of Finned tube bundles

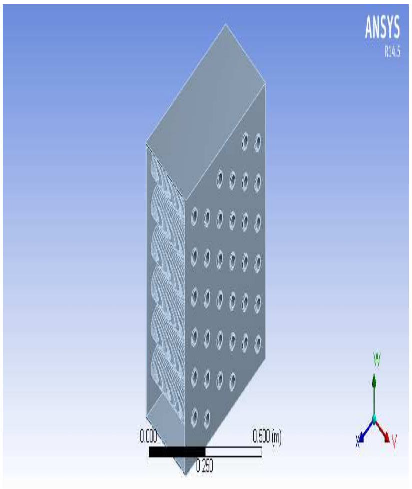


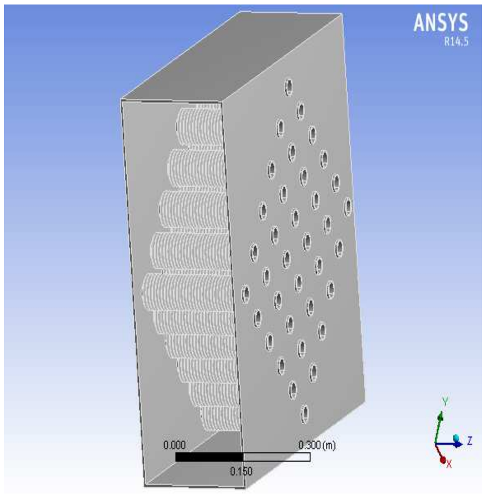
Staggered arrangement of Finned tube bundles



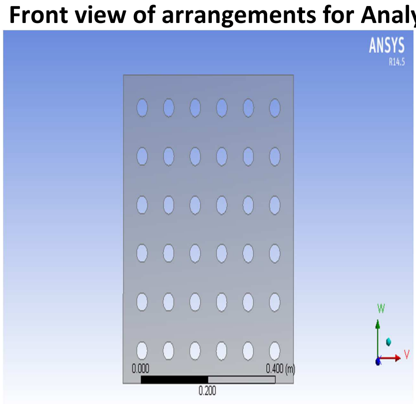
Crinkled 45^0 arrangement of Finned tube bundles

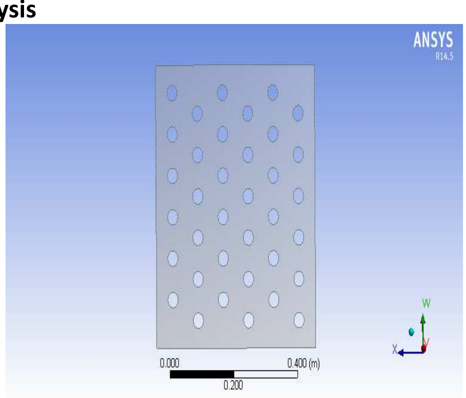


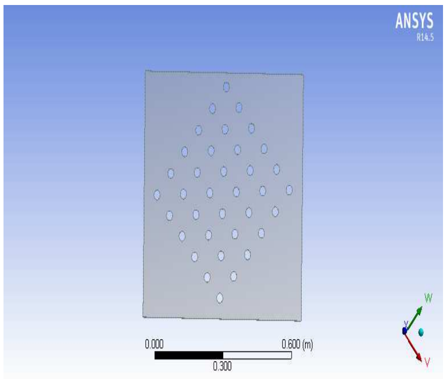




Front view of arrangements for Analysis





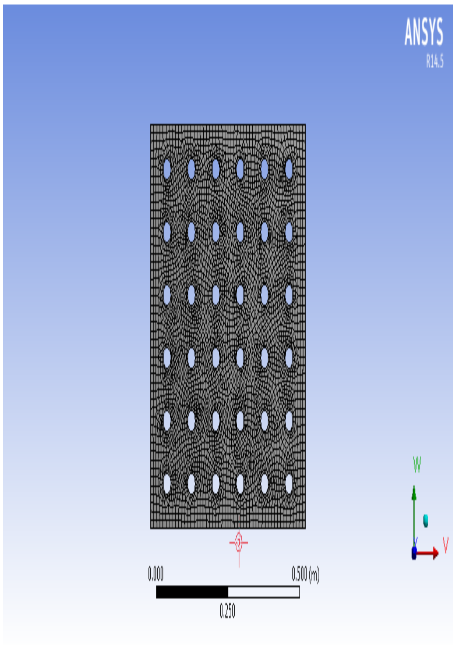


2.3 Meshing Details

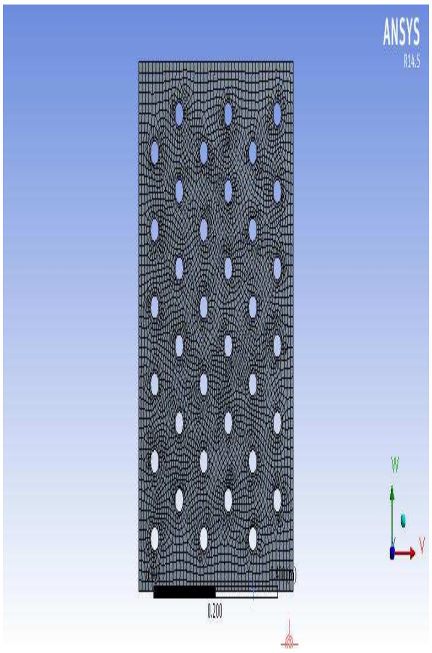
Meshing details of these arrangements are shown in meshing table 2.

Table 2. Meshing table

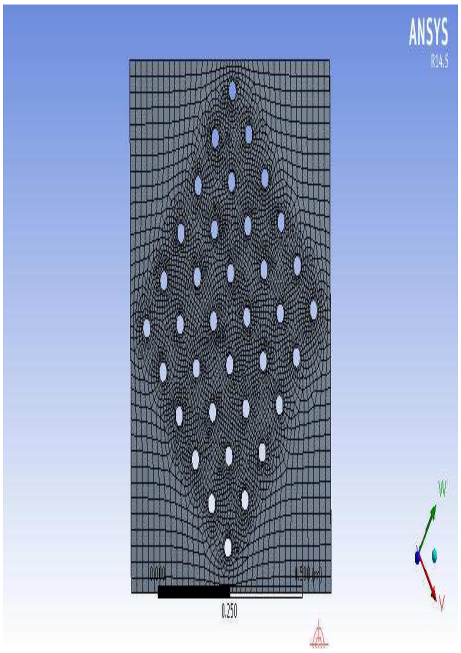
	Inline arrangement	Staggered arrangement	Crinkled45^0 arrangement
Relevance center	Fine	fine	fine
Smoothing	Medium	Medium	Medium
Transition	Slow	Slow	Slow
Transition ratio	0.272	0.272	0.272
Maximum layers	5	5	5
Growth rate	1.2	1.2	1.2
Nodes	11240	11706	11936
Elements	5216	5454	5602
Minimum edge length	$2.e^{-003}$m	$2.e^{-003}$m	$2.e^{-003}$m
Curvature normal angle	18.0^0	18.0^0	18.0^0



Front view of meshed inlined Arrangement



Front view of meshed staggered Arrangement



Front view of crinkled 45^0 Arrangement

Meshing was done in these arrangements and it was found that the number of nodes and elements in crinkled 45^0 arrangements is larger than other two arrangements, if relevance center is fine, smoothing is medium and transition ratio is same for all the arrangements. Large number of nodes and elements gives excellent convergence results for evaluation and for getting accurate results.

3 GOVERNING EQUATIONS

When analyzing heat transfer from a tube bank in cross flow, we must consider all the tubes in the bundle at once. The outer diameter is taken as the characteristic length. The arrangement of the tubes in the tube bank is characterized by transverse pitch S_T, longitudinal pitch S_L, and the diagonal pitch S_D between tube centers. The diagonal pitch is determined from

$$S_D = [S^2_L + (S_T/2)]^{1/2}$$

In tube banks, the flow characteristics are dominated by the maximum velocity V_{max} that occurs within the tube bank rather than the approach velocity V. The Reynolds number is defined on the basis of maximum velocity as

$$Re_D = \rho V_{max} D/\mu \quad \& \quad V_{max} = S_T.V/S_{T-D}$$

Here, the average Nusselt number for cross flow over tube banks is

$$Nu = 0.036\ Re^{0.8}.Pr^{1/3}$$

And skin friction coefficient for cross flow tube bundles is

$$C_{fx} = 0.455/\ [\ln (0.06\ Re_x)]^2$$

The heat equation was used to model heat conduction in the solid bodies (i.e. find tubes).

Fluid flow was modelled using continuity and Reynolds-Averaged Navier-Stokes (RANS) equation; mass and momentum source terms have been omitted.

$$\Delta\rho/\delta t + \delta\ (\rho U_i)/\delta x_i = 0$$

Pressure drop: Pressure drop correlation in cross flow finned tube are expressed as

$$\Delta P = N_L\, f_x\, \rho\, V^2_{max}/2$$

Where f is the friction factor and X is the correction factor.

4 METHODOLOGY

CFD Fluent14.5 was used to analyze and to validating the results of solid circular finned tube bundles positioned at inlined, staggered and crinkled 45^0 arrangements. Standard k-epsilon turbulence model and pressure based solver was used where air is taken as primary fluid. The detailed method configuration and parameters is mentioned below:

(A) Solution setup:

(i) General - Solver – pressure based
Time – steady

(ii) Models - Energy Equation – on
Standard K- epsilon model
C_1- epsilon = 1.44
C_2- epsilon = 1.92
Energy Prandtl no. = 0.85
Wall prandtl no. = 0.85

(iii) Materials - Fluid – air
Solid – aluminium

(iv) Boundary Conditions - velocity at inlet = 0.5 m/s
Pressure outlet (gauge pressure) = 0
Temperature = 300k
Wall heat flux = 800 w/m^2

(B) Solution:

(i) Discritization scheme

Variable	**Scheme**
Pressure	Standard
Pressure-Velocity Coupling	Simple
Density	First Order Upwind
Gradient	Least Squares Cell Based
Momentum	Second Order Upwind
Turbulent Kinetic Energy	First Order Upwind
Turbulent Dissipation Rate	First Order Upwind
Energy	Second Order Upwind

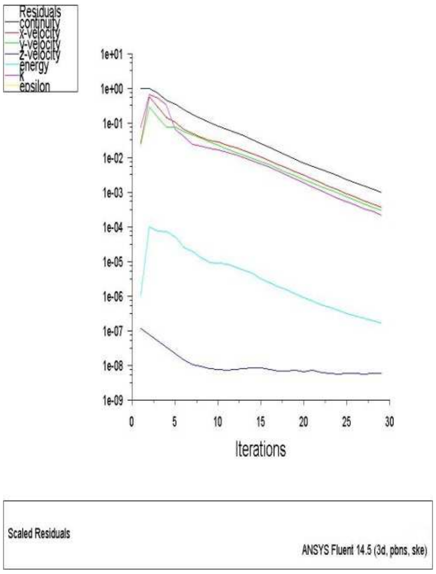
(C) Solution Control: **(i) Under-Relaxation Factors**

Variable	Value
Pressure	0.3
Density	1
Body Forces	1
Momentum	0.7
Turbulent Kinetic Energy	0.8
Turbulent Dissipation Rate	0.8
Turbulent Viscosity	1
Energy	1

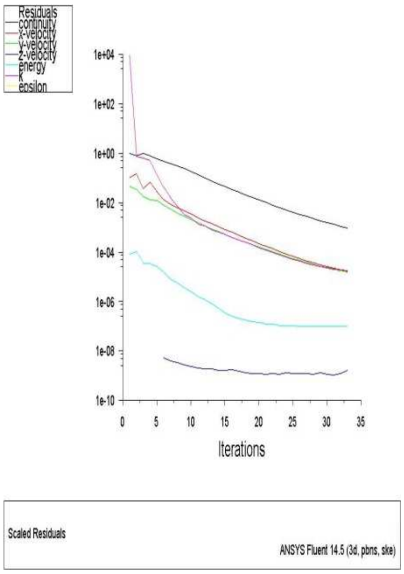
(ii) Solution Initialization – Hybrid Initialization

(iii) No. of Iterations = 500
(For Run Calculation)

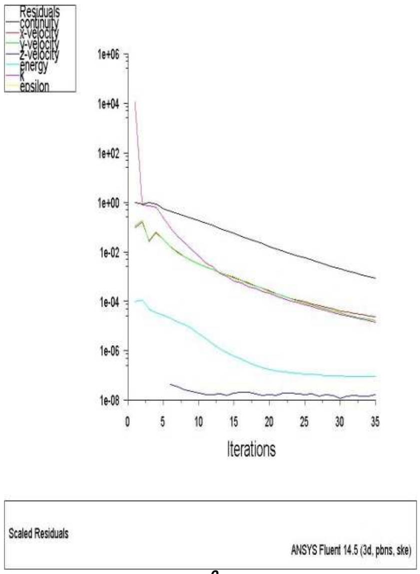
After Iterations the solution was converged and the converged arrangements is mentioned below-



Converged inline Arrangement



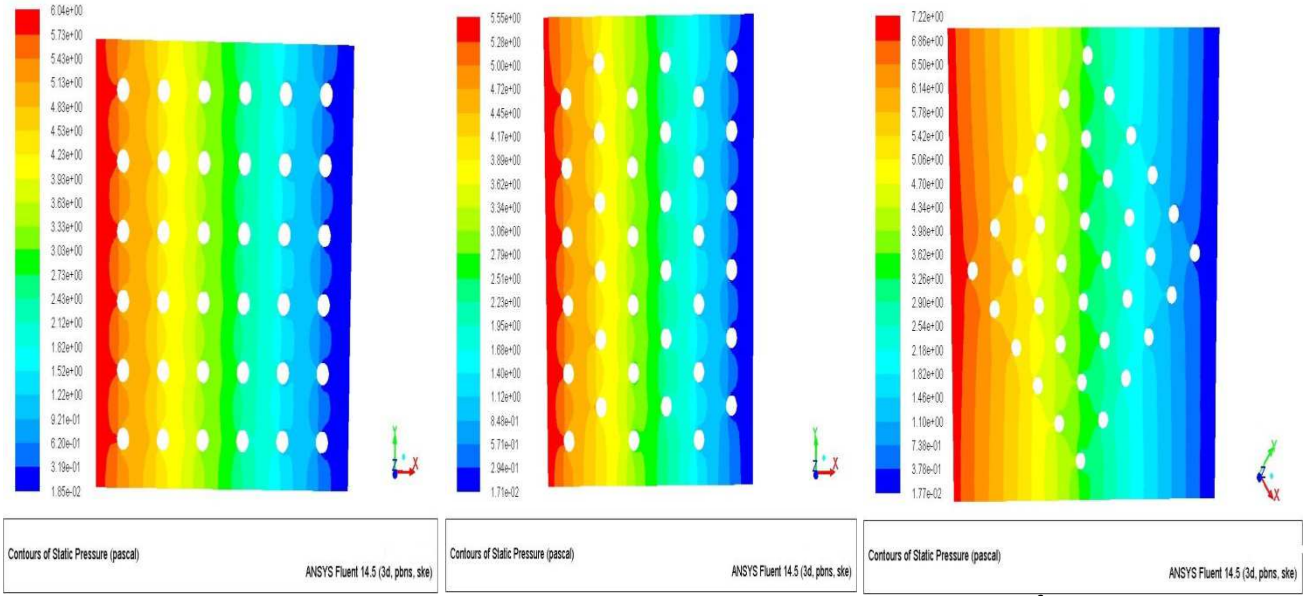
Converged staggered Arrangement



Converged crinkled 45^0 Arrangement

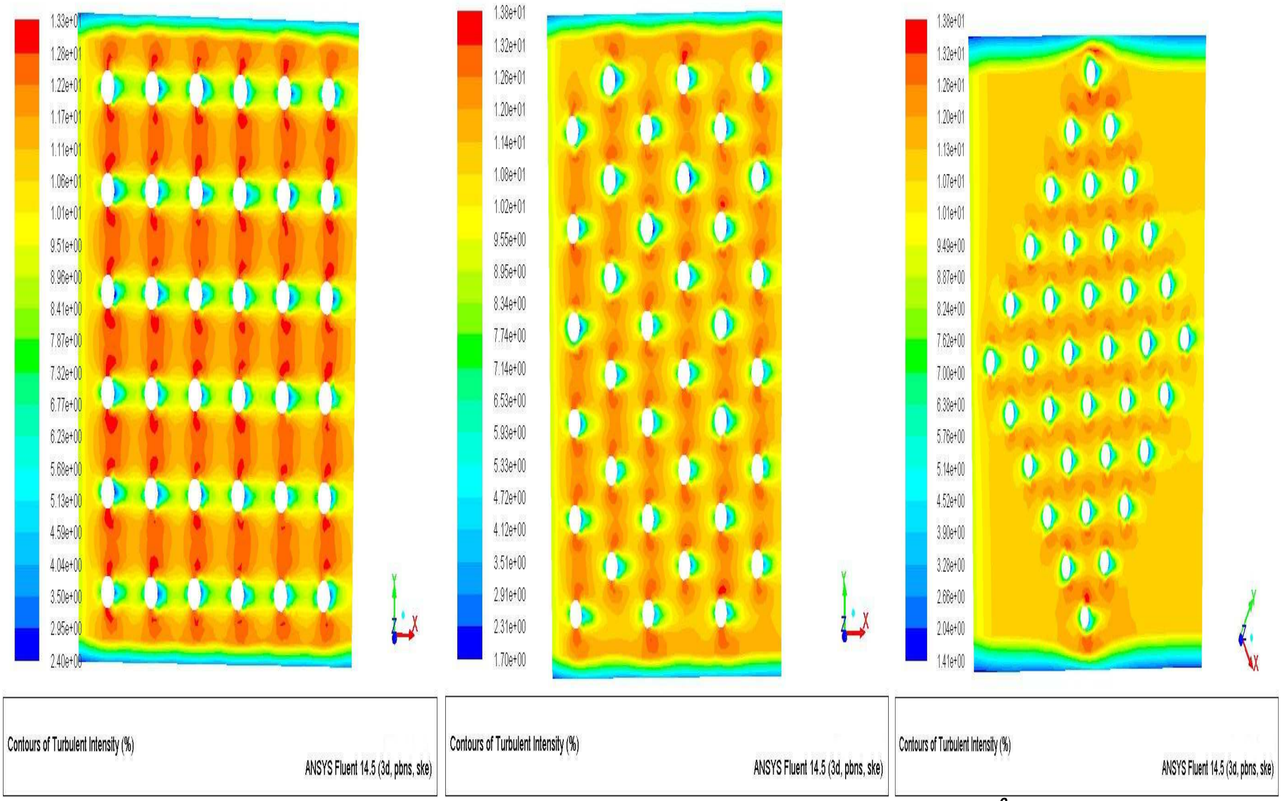
5 RESULTS & DISCUSSIONS

(i) Contour of Static Pressure



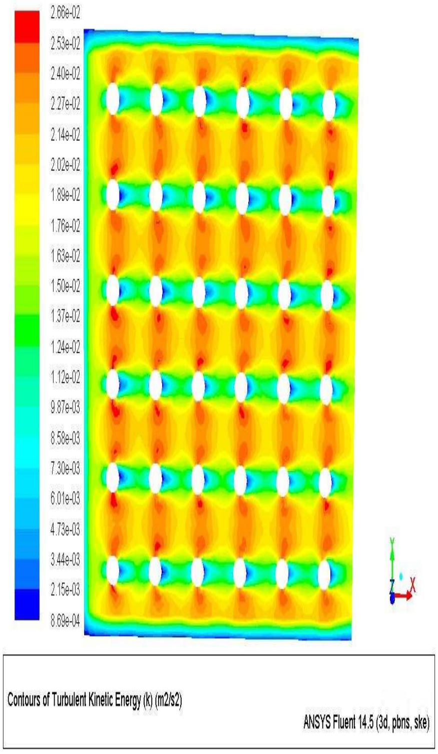
Inlined Arrangement *Staggered Arrangement* *Crinkled 45^0 Arrangement*

(ii) Contour of Turbulent Intensity (%)

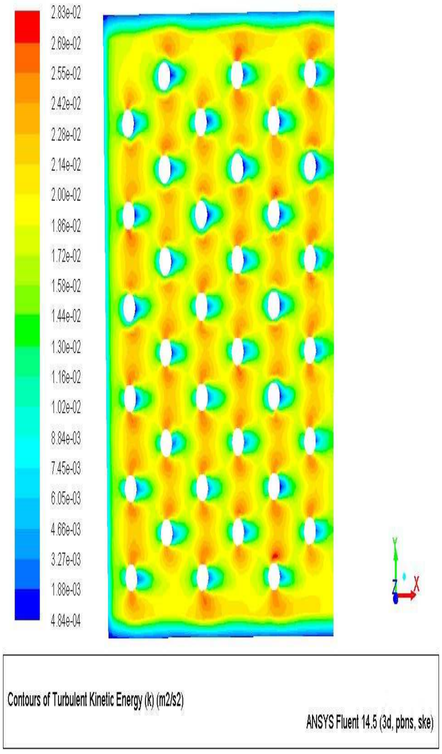


Inline Arrangement *Staggered Arrangement* *Crinkled 45^0 Arrangement*

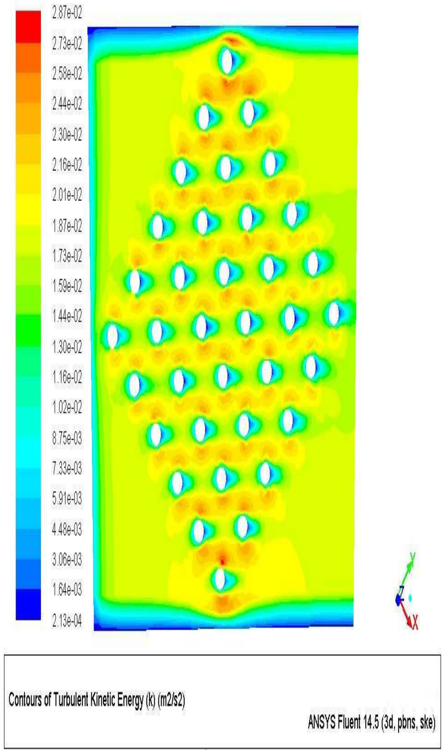
(iii) Contour of Turbulent Kinetic Energy (k)



Inline Arrangement

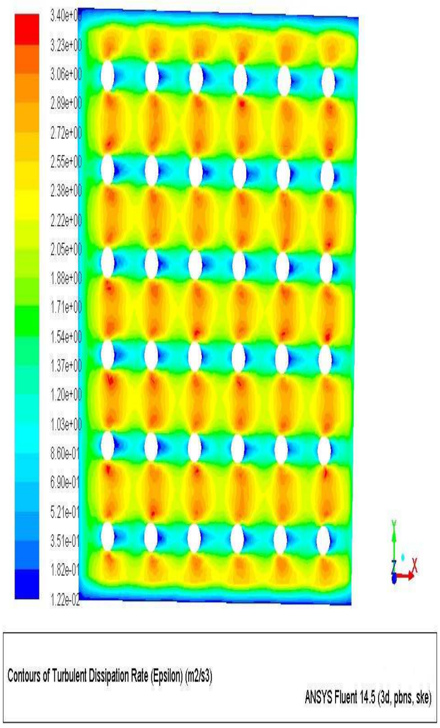


Staggered Arrangement

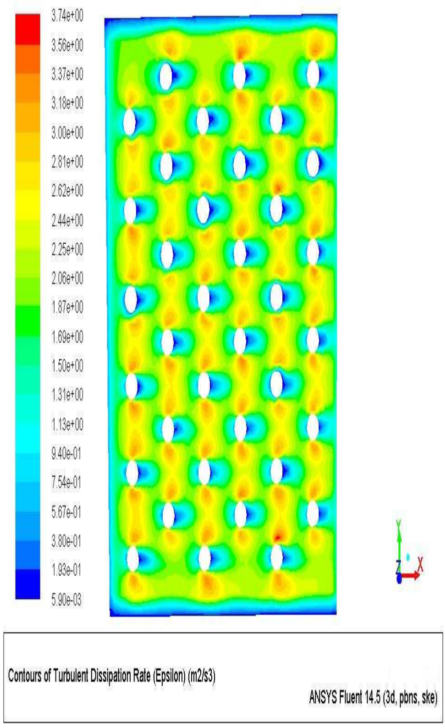


Crinkled 45^0 Arrangement

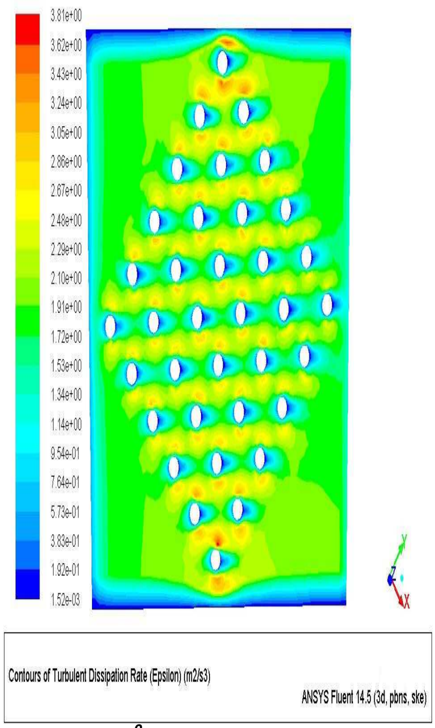
(iv) Contour of Turbulent Dissipation Rate (epsilon)



Inline Arrangement

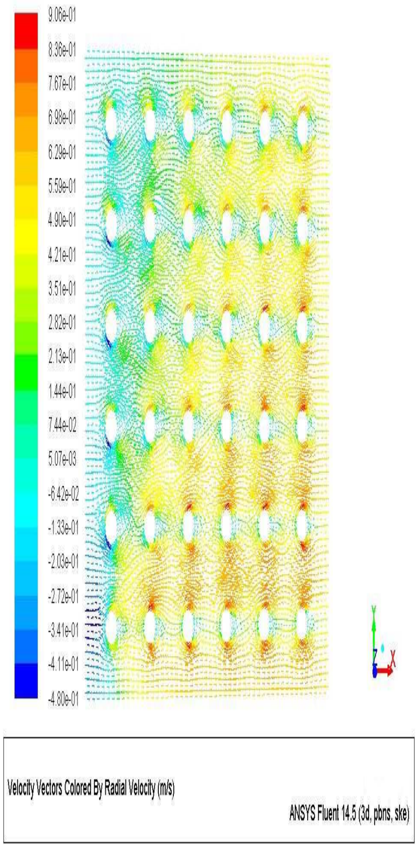


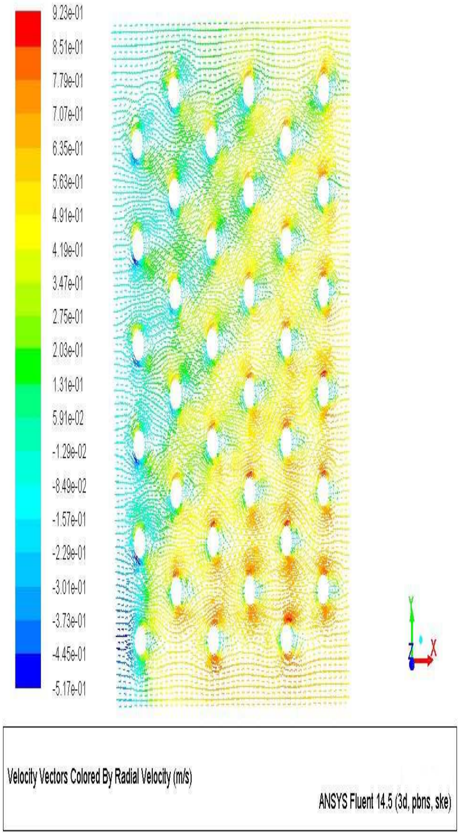
Staggered Arrangement

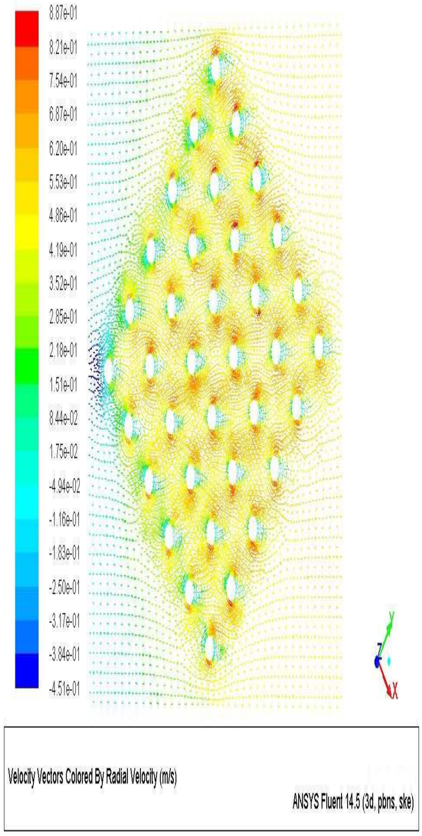


Crinkled 45^0 Arrangement

(v) Velocity Vector of Radial Velocity (m/s)

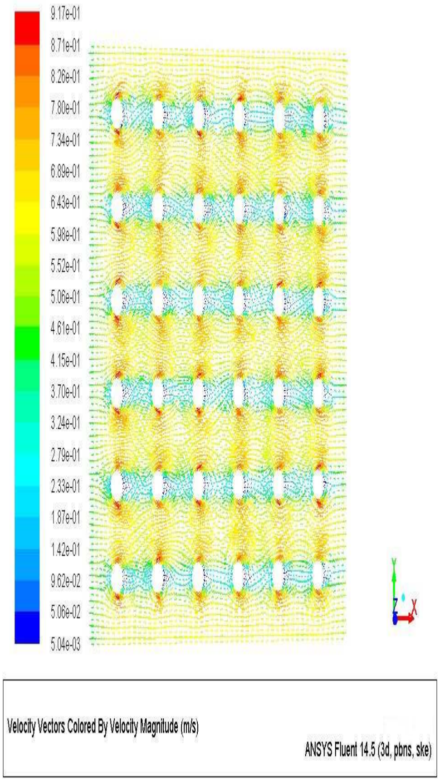


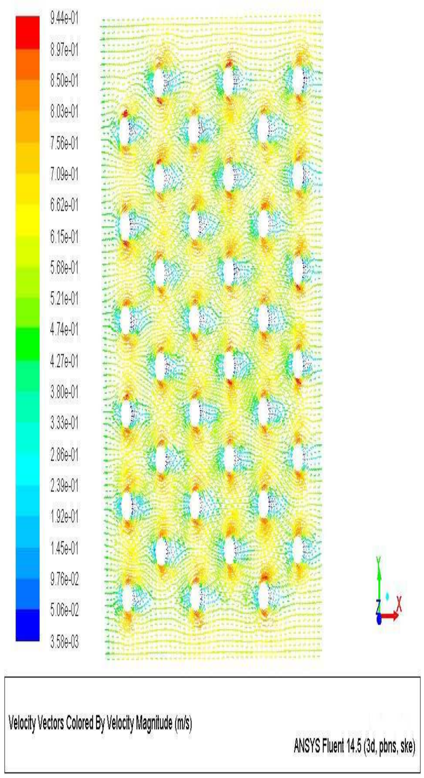


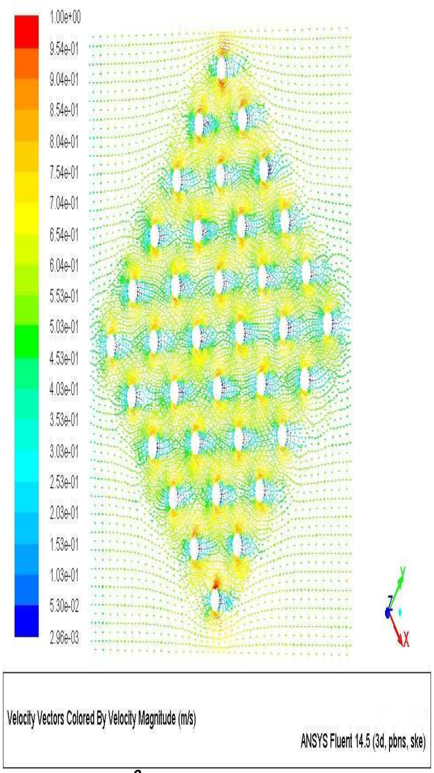


Inline Arrangement *Staggered Arrangement* *Crinkled 45^0 Arrangement*

(vi) Velocity Vector of Velocity Magnitude (m/s)

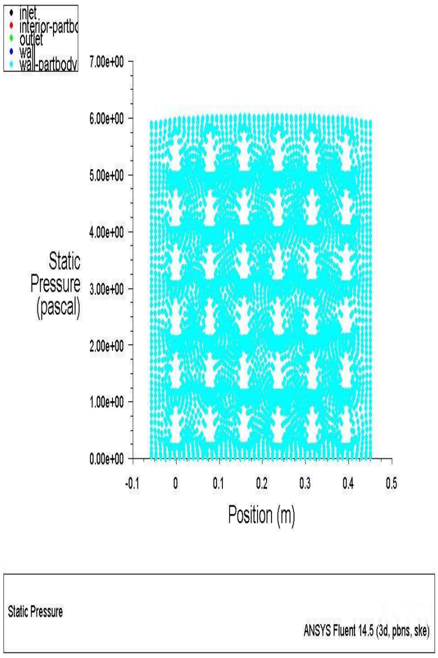




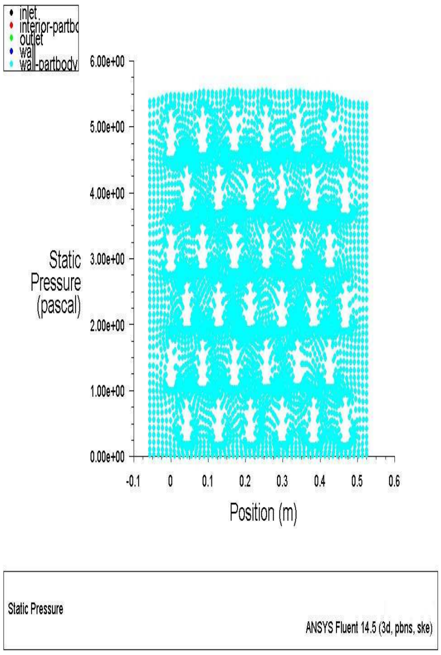


Inline Arrangement *Staggered Arrangement* *Crinkled 45^0 Arrangement*

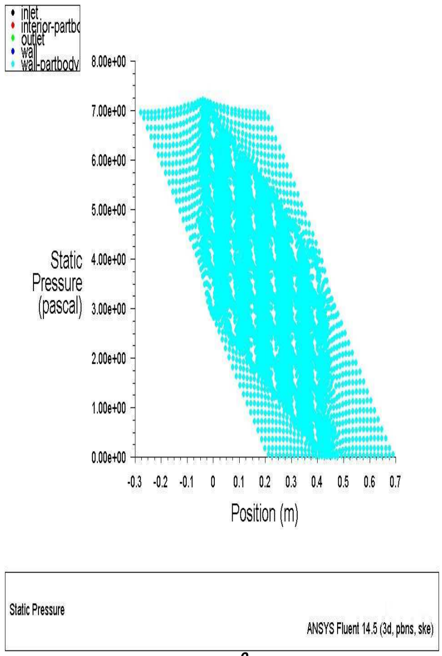
(vi) XY plot of Static Pressure along Y Direction



Inline Arrangement



Staggered Arrangement



Crinkled 45^0 Arrangement

From Comparative results on different parameters like static pressure, velocity vector of radial velocity etc. it is found that the Crinkled 45^0 Arrangement shows better results as compared to inline and staggered arrangement.

6 CONCLUSION

The arrangements for 36 solid circular finned tube bundles in cross-flow heat exchangers were presented. FLUENT 14.5 PRESSURE BASED SOLVER and Finite volume method approach were used for prediction and validation of results. A new Arrangement named as CRINKLED 45^0 Arrangement was developed and implemented in 36 solid circular finned tube bundles. When the method proposed in the paper is used for modeling cross-flow tubular heat exchangers, the temperature-dependent properties of fluids, the variable heat transfer coefficients along the liquid path flow, and a non-uniform gas velocity upstream the heat exchanger can be taken into account. Also, individual heat transfer correlations for determining the air-side heat transfer coefficients for each row of tubes can be used. After calculations of iterations, a converged solution was achieved for all of these three arrangements and that converged solutions and other results showed that Crinkled 45^0 arrangement gives better results than inline & staggered arrangement. The use of the CFD model offers particular benefits where the finned-tube geometry varies between adjacent rows within a tube bundle – a feature of Heat Recovery Steam Generators commonly used in power generation. To the best of the authors' knowledge, Crinkled 45^0 arrangement is the best arrangement than inline and staggered arrangement for 36 solid circular finned tube bundles.

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