

Thermal Analysis Validation for Different Design Tubes in a Heat Exchanger

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Abstract- Shell and Tube Heat exchanger are the basic types of heat exchanger one of the fluids flow through a bundle of tubes enclosed by a shell. The outer fluid is forced through a shell and it flows over the outside surface of the tubes. Such an arrangement is employed where reliability and heat transfer effectiveness. In order to achieve the maximum heat transfer rate an analysis is made on single tube with two different fluids (Water and Al₂O₃-water based Nano fluid) in a shell and tube heat exchanger. With relate to same to have a maximum heat transfer rate this paper gives various optimal design solutions using computational techniques. To measure the performance of different designs, its model is suitably designed and fabricated so as to perform experimental tests. Thermal analysis has been carried out for different design with two fluids and on the basis of comparative results is made which one give the best heat transfer rates.

Keywords : Heat Exchanger, Water, Al₂O₃-water based, Optimal Design, Thermal analysis, Computational Techniques

1.Introduction

In a Heat Exchanger, consists of bundle of tubes. One fluid flows through the tubes while the second fluid flows space between the tubes and shell. Tubes plays an important role while exchanging heat from hot fluid to cold fluid. Although they are not specially compact, their robustness and shape make them well suited for high pressure operations. They have larger heat transfer surface area to volume ratio than the most of common types of heat exchangers, and they are manufactured easily for a large variety of sizes and flow configurations. The main design objectives here are to accommodate thermal expansion, to furnish ease of cleaning, or to provide the least expensive construction.

To get robust, least expensive and technically sound design, we will be dealing with four different designs viz. "Circular Tube", "Elliptical type(Oval)", "Twisted type" and "Coil type" Along with construction issue we too come across the difficulties in improving heat transfer rates, which means to have high effectiveness, we were in flow to compromise the design and robustness. In order to achieve the maximum heat transfer rate an analysis is made on single tube for different designs with two different fluids (Water and Al₂O₃-water based Nano fluid) in a shell and tube heat exchanger. This paper shows how maximum heat transfer rate has been achieved by comparing four different designs and getting optimal design solutions using computational techniques. To measure the performance of different designs, its model is suitably designed and fabricated so as to perform experimental tests. Thermal analysis has been carried out for four different designs with two fluids and on the basis of comparative results is made which one give the best heat transfer rates. After the modification of design an experimental validation is carried out to validate the results from analysis.

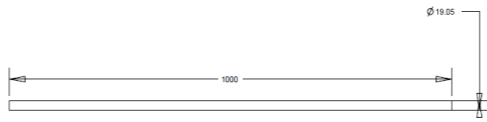
2. Literature Review

Ala Hasan [1] experimentally investigated five oval tubes and compared with that for a circular tube in a cross-flow way and concluded that oval tube gives higher heat transfer results. The outcome was taken for comparing results of oval and circular tubes which helped for optimized design. Abdul Kareem Abbas *et al* [2] shows heat transfer augmentation due to twisting parameter was investigated in a twisted tube of rectangular/square cross sectional area. Also swirling increases internal mixing process which enhances internal thermal equilibrium. The heat transfer coefficient also increases as Reynolds number increased as velocity components are increased. This relation shown was used as function and one of the parameter in design. Su Thet Mon Than *et al* [3] In this paper data is evaluated for heat transfer rate having spiral tubes and pressure drop and checking whether the assumed design satisfies all requirement or not by using computational techniques. Satisfied design found was used for coil type tubes for analysing the heat transfer rate. Jay J. Bhavsar *et al* [4] objective of this paper is to design and analyze of spiral tube heat exchanger. In this newly proposed design hot fluid flows in axial path while the cold fluid flows in a spiral path. The presented work was used in spiral tube design and has high heat transfer rate compared with helical coil heat exchanger and spiral plate heat exchanger. P. M. Deshpande *et al* [5] They studied horizontal spiral coil tube (HSTC) for various forces (viscous, buoyancy and centrifugal force) acting on fluid element in coil; of which the centrifugal force is predominant and results in secondary flow. This phenomenon also depends on the physical properties of fluid at a given temperature. They also concluded that as the coil diameter reduces the curvature ratio increase that increases the pressure drop. Relation was used for designing coil type tubes.

3. Design of Tubes :

3.1 Circular type tube :

$D_i=16.65\text{mm}$
 $D_o=19.05\text{mm}$
Thickness= $t=18\text{BWG}$
Length= 1000mm



Source:

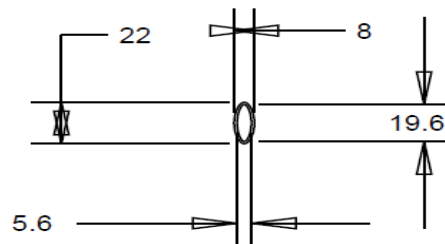
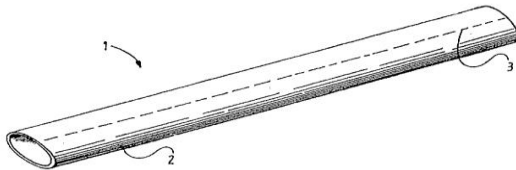
- 1) Design of Heat Exchange equipment.
- 2) Design shell and tube heat exchanger [Rajiv Mukherjee Engineers India Ltd.]
- 3) Handbook of TEMA.

3.2 Elliptical Type Tube(Oval):

Axis Ratio = $R_a=3$
Major Axis = $2a=22\text{ mm}$
Minor Axis = $2b=8\text{mm}$

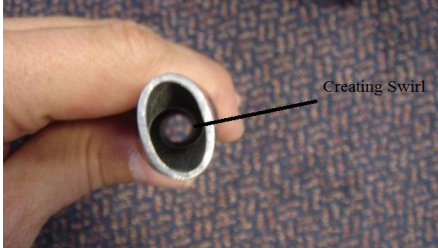
Source:

- 1) Thermal-Hydraulic performance of oval tubes in a cross-flow air- ALA-HASAN
- 2) Structural and Thermal Analysis of Heat Exchanger with Tubes of Elliptical Shape -Nawras H. Mostafa Qusay R. Al-Hagag



3.3 Twisted Type Tube:

Length(L)=1000mm
 Thickness(t)=1.2mm
 Breadth of rectangular tube(b)=22 mm
 Depth of rectangular tube(d)=8mm
 No. of twists(Nt)=05(Each at 200mm)



Source:

- 1) Twisted Tube Heat Exchanger Technology-R. Donald Morgan
- 2) Twist parameter influence on heat transfer coefficient augmentation for a square twisted tube- A. Kareem

3.4 Coil Type Tube:

Diameter (D_0) = 3/4" = 19.05mm
 Length(L)=1000mm
 Number of turns(n)=6
 Thickness(t)=1.2mm
 Effective coil diameter(D)=52mm
 Pitch(p) for helical it is taken as $1.5D_0=30$ mm
 To know the unknown parameter, D (Coil Diameter)

Equation is given by,

$$L = N\sqrt{(2\pi R)^2 + (p)^2}$$

$$1000 = 6\sqrt{(2\pi R)^2 + (1.5 \times 19.05)^2}$$

$$\frac{1000}{6} = \sqrt{(2\pi R)^2 + (1.5 \times 19.05)^2}$$

$$\frac{1000}{6} = \sqrt{(2\pi R)^2 + 816.53}$$

$$\frac{26961.24}{4\pi^2} = R^2$$

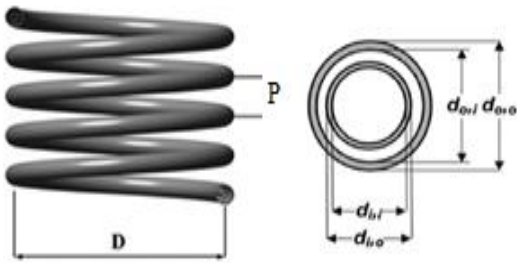
Therefore,

$$R = 26.13\text{mm}$$

$$D \cong 52 \text{ mm}$$

Source:

- 1) ASME German AD-Merkblatt
- 2) European pressure equipment directive (PED)
- 3) Designing a helical-coil heat exchangers- *K. Ramchandra*



4. Experimental Work:

We achieved temperature range by placing thermocouple at 250 mm apart for four design tubes.

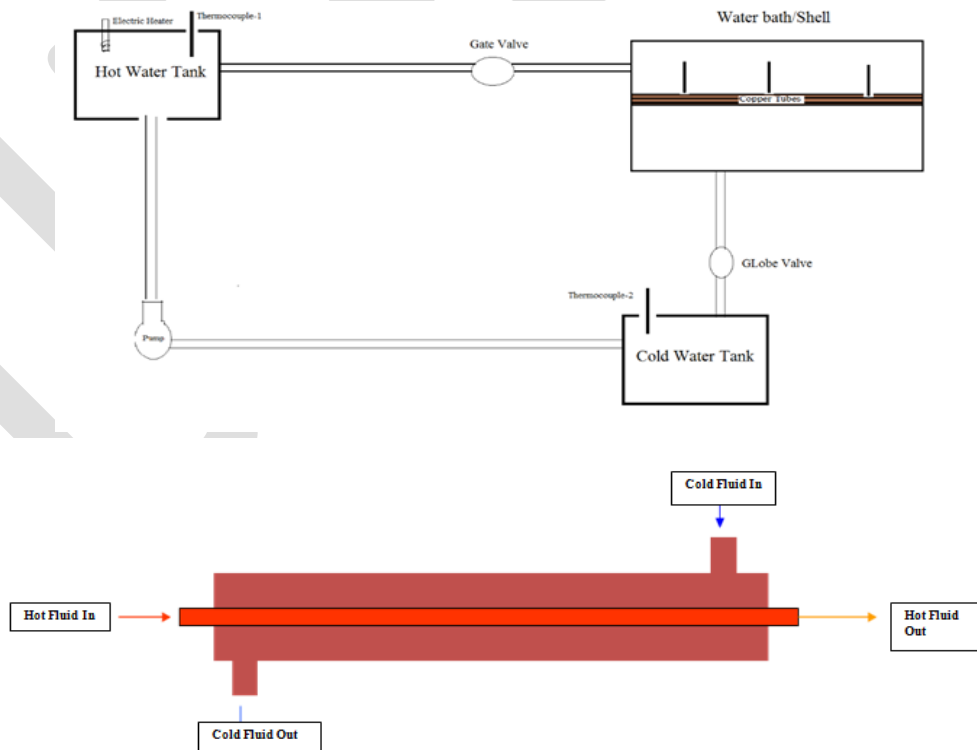
T_1 = Temperature at inlet of tube.

T_2 = Temperature at a distance of 250mm from inlet.

T_3 = Temperature at a distance of 500mm from inlet.

T_4 = Temperature at a distance of 750mm from inlet.

T_5 = Temperature at outlet of tube.



4.1 For (Water –Water as a fluid)

4.1.1 For circular type:

Sr. No	Mass rate(Kg/sec)	flow	Temperatures at different points of tube (°C)				
			T1(At start 0mm)	T2(At 250 mm)	T3(At 500mm)	T4 (At 750mm)	T5(At 1000mm)
1	0.14		67	66.5	65.5	65	64
2	0.12		67	66.5	66.5	65	64
3	0.05		66.5	66	65	64.5	63.5

4.1.2 For Elliptical type:

Sr. No	Mass rate(Kg/sec)	flow	Temperatures at different points of tube (°C)				
			T1(At start 0mm)	T2(At 250 mm)	T3(At 500mm)	T4 (At 750mm)	T5(At 1000mm)
1	0.14		67.5	65	64.5	64	63.5
2	0.12		63	62.5	62	61	59.5
3	0.05		63	62	62	61.5	60

4.1.3 For Twisted type:

Sr. No	Mass rate(Kg/sec)	flow	Temperatures at different points of tube (°C)				
			T1(At start 0mm)	T2(At 250 mm)	T3(At 500mm)	T4 (At 750mm)	T5(At 1000mm)
1	0.14		64	62	60	58.5	56.5
2	0.12		56	54	53	52	51
3	0.05		58	57	56	54	53

4.1.4 For Coil type:

Sr. No	Mass rate(Kg/sec)	flow	Temperatures at different points of tube (°C)				
			T1(At start 0mm)	T2(At 250 mm)	T3(At 500mm)	T4 (At 750mm)	T5(At 1000mm)
1	0.14		68	68	67	65	63
2	0.12		65.5	65	64.5	62	58
3	0.05		61	60	60.5	58	56.5

5 .Calculations for heat transfer coefficient

5.1 For case I(water-water):

Fluid properties for water are:

$$\mu=0.467 \times 10^{-3} \text{Ns/m}^2$$

$$\rho=1000 \text{ kg/m}^3$$

$$C_p=4.18 \text{ kJ/kg}^\circ\text{K}$$

$$k_w=0.625 \text{ W/m}^\circ\text{K}$$

For Circular type :

$$A_{c/s} = (\pi[d_o^2 - d_i^2])$$

$$= (\pi[0.01905^2 - 0.01665^2])$$

$$= 6.73 \times 10^{-5} \text{ m}^2$$

As Reynolds number for circular tube is given by,

$$Re = \rho v d / \mu \dots\dots\dots (1)$$

to find V,

We know continuity equation,

$$Q = A \times V$$

As density = mass/volume ($\rho = m/\text{vol.}$)

$$\text{Therefore, } m = A \times \rho \times V \dots \dots \dots (1a)$$

For mass flow rate $m = 0.14 \text{ kg/sec}$

$$0.14 = V \times 1000 \times 6.73 \times 10^{-5}$$

$$V = 2.08 \text{ m/s}$$

$$V = 2.08 \text{ m/s}$$

So,

$$Re = 74158.45$$

From Reynolds number, flow is turbulent. ($Re > 2000$)

Correlation used for turbulent flow is;

$$Nu = C Re^a Pr^{b-m} \dots \dots \dots (1b)$$

where $C = 0.021$ for gases,

$= 0.023$ for non-viscous liquids,

$= 0.027$ for viscous liquids

$$Nu = C Re^a Pr^{b-m}$$

$$= 0.023 \times Re^{0.8} Pr^{(1/3)} \times 1$$

$$= 0.023 \times (74158.45)^{0.8} \times (Pr)^{(1/3)} \dots \dots \dots (1c)$$

$Pr = \mu Cp/k \dots \dots \dots$ (Depend only on fluid properties)

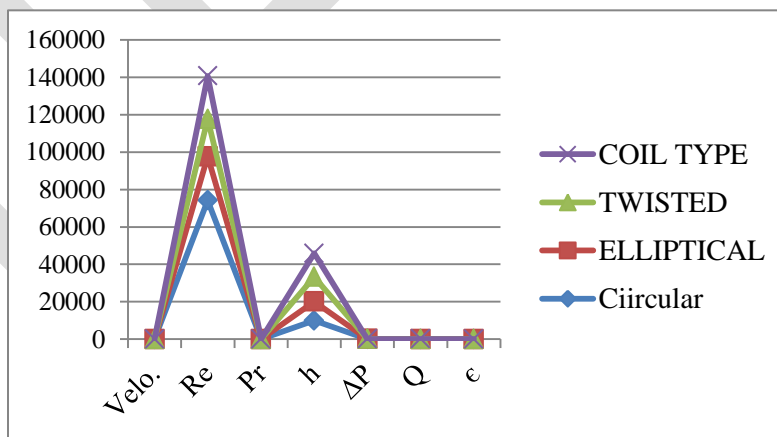
$$= 3.12$$

$$\text{Equation 1c, } \rightarrow = 0.023 \times (74158.45)^{0.8} \times (3.12)^{(1/3)}$$

$$\dot{h} = 9932.08 \text{ w/m}^2\text{K}$$

Likewise, calculated heat transfer rate for other three tubes are:

Sr. No.	Type of Design	V	Re	Pr	h	ΔP	Q	ϵ
1	Circular	2.08	74158.4	3.12	9932.08	31.18	19.6	0.35
2	Elliptical	1.7	23516.1	3.12	10213.7	54.91	19.22	0.24
3	Twisted	2.11	19952.4	3.12	13100.6	29.3	19.83	0.53
4	Coil	2.09	23032.5	3.12	12625.1	36.72	21.91	0.34



5.2 Calculated outcome of Case-II (AL₂O₃-Water as a Nano fluid):

Fluid properties for Al₂O₃- water (0.1 % concentration) are:

$$\mu = 0.35 \text{ cp} = 3.5 \times 10^{-4} \text{ Ns/m}^2$$

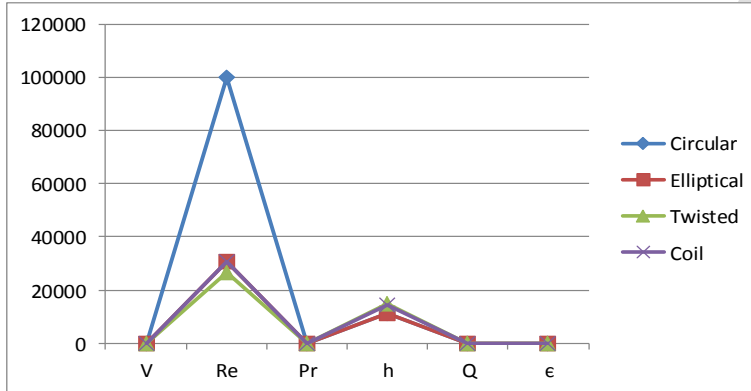
$$\rho = 1022 \text{ kg/m}^3$$

$$C_p = 3.1 \text{ kJ/kg}^\circ\text{K}$$

$$k = 0.72 \text{ W/m}^\circ\text{K}$$

Prandtl number obtained from calculation is common for all type of design as fluid properties are common, viz 1.5

Sr. No.	Type of Design	V	Re	h	Q	ε
1	Circular	2.06	100153.08	11399.20	20.63	0.38
2	Elliptical	1.63	30761.90	11427.08	20.16	0.30
3	Twisted	2.07	26563.12	14864.54	23.18	0.60
4	Coil	2.04	30617.95	14307.87	24.01	0.40



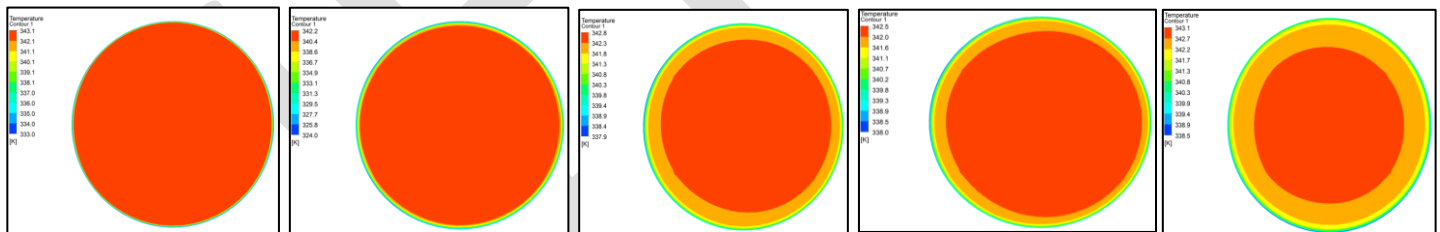
6. Thermal Analysis of Tubes with two different media:

6.1 CFD-Results of Case-I :

Mass flow rate : 0.14 kg/s

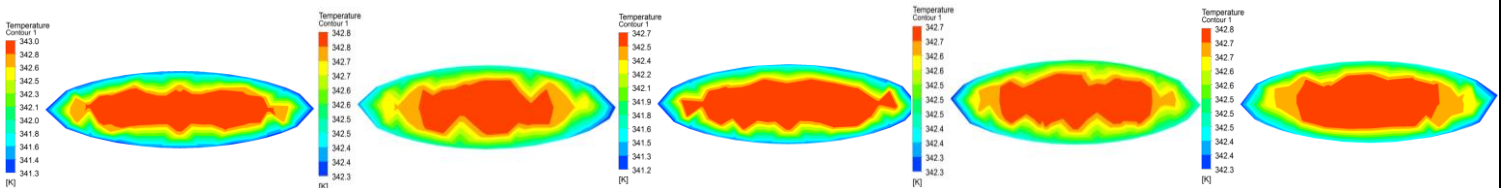
Temperature Contours

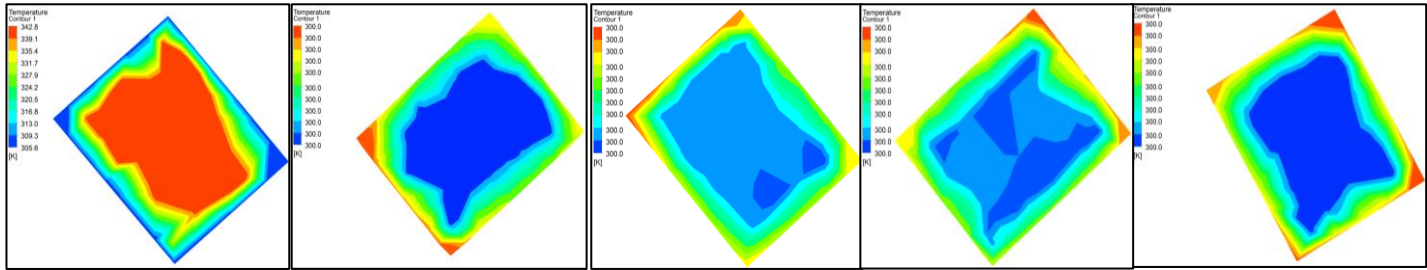
1. For Circular tube



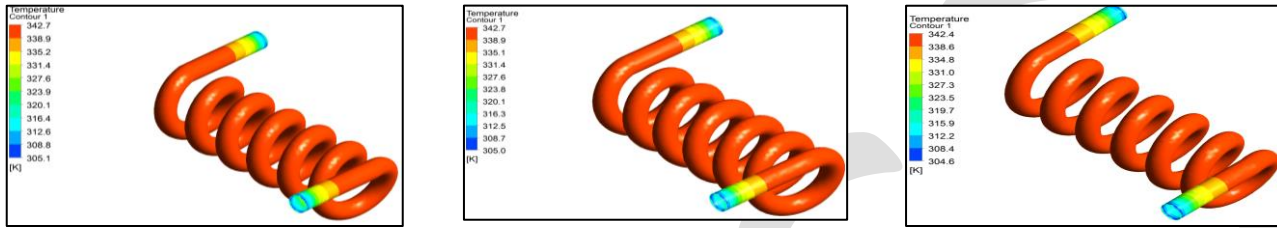
2. Elliptical Tube :

3. Twisted Tube :





4. Coil Tube: (For three planes)
i. Temperature Contours

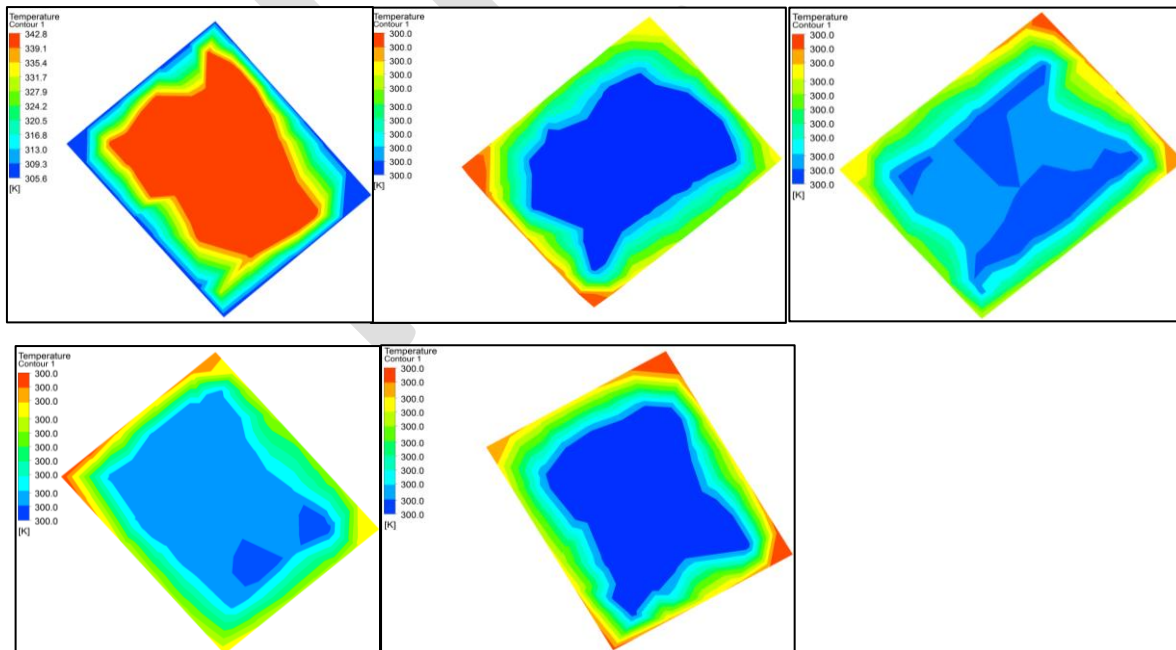


ii. h-Contours for inner wall



6.2. CFD-Results of Case-II (Al_2O_3 as a Nano fluid) :

We have focused only on twisted type tube as in above sequence of calculations we are getting high heat transfer rate and high effectiveness by calculation.



In above colourful diagram, if we compare d the twisted tube temperature contours with water as base fluid, an CFD analyst may observe that for 4th and 5th plane we are getting blue colour contours as compared to case 1, which directly shows the temperature gradient in above case is high along with effectiveness.

7. Conclusion:

This study shows the design and thermal analysis of different tubes. Experimentally, same designs are made and results are evaluated. With relate to same design tubes are thermally analysed in ANSYS software and compared both the results. After comparing the result for both water-water(Case-I) and water-Al₂O₃(Case-II) for four different tubes we are in conclusion that twisted type of tube is giving high heat transfer coefficient as compared to other i.e 1.14 more. Along with effectiveness, twisted tube is at higher side by 1.17. So according to my research one should go for twisted tube.

However, a good understanding of the underlying principles of exchanger design is needed to use this software effectively. The possibility to increase in these characteristics using the latest technology and various methods has raised application range of these designs. Modified design tubes are having great applications due to their large heat transfer area and high heat transfer coefficients. They are used in many industrial processes like waste water treatment, refrigeration, wine and beer making, petroleum refining

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