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Design &Analysis of Helical Coil Heat Exchanger

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***Abstract---* Heat exchanger are important engineering system with wide variety of application including power plants, refrigeration and air conditioning system, heat recovery system, nuclear reactors, chemical processing and food industries Working towards the goal of saving energies and to make concise design for mechanical and chemical devices and plants, heat transfer play major role in design of heat exchangers. In this research its aims to perform a numerical study of helical coil Shell heat exchanger with water as both hot and cold fluid. To improve the effectiveness, D/d geometrical parameter will be varied for different boundary conditions. The impact of this modification on Cold water temperature, Hot water temperature, Cold water velocity, Hot water velocity, Reynolds number, with respect to D/d will also be studied.**

***Index Terms*— Helical coil heat exchanger, Heat transfer, Nusselt number, LMTD, Reynolds number**

I. INTRODUCTION

Heat exchange between flowing fluids is one of the most important physical process of concern, and a variety of heat exchangers are used in different type of installations, as in process industries, compact heat exchangers nuclear power plant, HVACs, food processing, refrigeration, etc. The purpose of constructing a heat exchanger is to get an efficient method of heat transfer from one fluid to another, by direct contact or by indirect contact. The heat transfer occurs by three principles: conduction, convection and radiation. The purpose of constructing a heat exchanger is to get an efficient method of heat transfer from one fluid to another, by direct contact or by indirect contact. The Helical coils of circular cross section have been used in wide variety of applications due to easy to manufacture. Flow in curved tube is different from the flow in straight tube because of the presence of the centrifugal forces. These centrifugal forces generate a secondary flow, normal to the primary direction of flow with circulatory effects that increases both the friction factor and rate of heat transfer coefficients

II. DESIGN PROCEDURE OF HELICAL COIL HEAT EXCHNGER

- Mass flow rate **:** $Q = mc\ cp\ (Tco – Tci)$
- Average diameter of helix
- $Dh = (B+C)/2$
- Average radius of helix
- $r = Dh /2$
- Inside Diameter of helix:
- Dh1 = Dh – do
- Outside Diameter of helix:
- $Dh2 = Dh + do$
- Pitch of the coil :$p = 1.5\times do$
- $L = p + \sqrt{(2□r)2}$
- Volume occupied by one turn of coil
- $Vc = \pi/4\times do2\times L$
- Volume of annulus (1 turn coil)
- $Va = \pi/4(C2 - B2) \times p$ (13)
- Volume in annulus = Vf = Va - Vc
- DE = 4VF ⁄ □DOL
- Clearance = (C−B)^2− do) ⁄ 2
- Using LMTD method: LMTD depends on the hot and cold fluid temperature differences at the inlet and exit of the heat exchanger.
- ΔTm =(Thi − Tco) − (Tho − Tci)ln (Thi − Tco)/(Tho − Tci)
- Prandtl number = Pr =Cpμ/K
- Re = (ρ×vc×D) ⁄ μ
- The mass flow rate of hot fluid in the annulus is given by energy balance for annulus as:
- Q = ma cp (Thi – Tho)
- Mass flow rate in the annulus = ma = Q / cp (Thi – Tho)
- Area of flow in annulus = Aa =π/4[(C2 - B2) – (Dh22 – Dh12)
- Velocity at the annulus side (va) can be found from eq. as: ma = ρ × va × Aa
- Re = (ρ×va×De) ⁄ μ
- Nusselt number Nu =hd/K
- Heat transfer coefficient on Coil Side:
- As Re > 10000 so, the following co-relation is used for turbulent flow: hido ⁄ K = 0.023 Re0.8Pr0.4
- Heat transfer coefficient on Shell Side:
- hodo ⁄ K = 0.6 Re0.5Pr0.31
- Fouling factor of shell side (For distilled water) = Ra= 0.0005 h.m2.Ko ⁄ kcal
- OverallHeatTransferCoefficient**:**1/U=1/hi+1/ho+x/kc+

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Ra + Rt

- Area of Heat Transfer: A =Q*U×ΔTm
- Turns =Aπdo×L
- Height:H = (N × p) + do

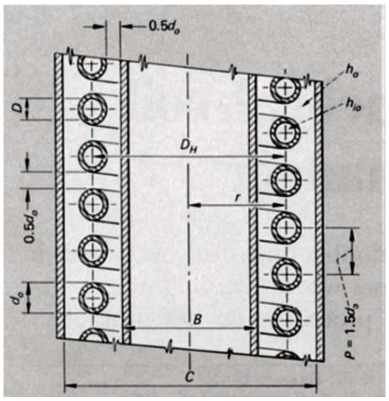

Fig 1

The design of a helical coil tube in tube heat exchanger has been facing problems because of the lack of experimental data available regarding the behaviour of the fluid in helical coils and also in case of the required data for heat transfer, unlike the Shell & Tube Heat exchanger. So to the best of our effort, numerical analysis was carried out to determine the heat transfer characteristics for a helical-shell heat exchanger by varying the different parameters like different temperatures and different material and also to determine the fluid flow pattern in helical coiled heat exchanger. The objective of the paper is to obtain a better and more quantitative insight into the heat transfer process that occurs when a fluid flows in a helically coiled tube The material used for the coil are as follows: Material selection of coil :copper (cu) ,Aluminium (Al) ,Stainless steel (ss-)

Due lack of research data on helical coil diameter have been assumed & taken from the research paper which contains companies standard parameters for example: sentry company. Those are taken into consideration.

Ranges of geometrical parameters.

Parameters	Values (m)
d_t	0.007, 0.008, 0.01, 0.011, 0.013, 0.016
d_c	0.06, 0.07, 0.08, 0.10
d_{sh}	0.10, 0.12, 0.14, 0.16, 0.22
d_v	0.01, 0.015, 0.02, 0.025, 0.03
H_c	0.12, 0.14, 0.16, 0.18, 0.20
H_{sh}	0.24, 0.28, 0.32, 0.36, 0.40
p	0.0154, 0.02, 0.022, 0.025, 0.033, 0.04
f	0.12, 0.144, 0.20, 0.22, 0.251

III. MODEL ANALYSIS

(NUMERICAL ANALYSIS)

- MASS FLOW RATE :
- *Q = mc cp (Tco – Tci)*

q= 0.0169 ⁄ [4183 (33.4 – 22.103)]

- Qc= 911.303 KW
- Average diameter of helix
- *Dh = (B+C)/2*
- Dh= 0.103 m
- Average radius of helix is calculated as:
- Average radius of helix
- *r = Dh /2*
- r= 0.0515 m
- Inside Diameter of helix:
- Dh1 = Dh – do
- Dh1= 0.103-0.016= 0.087 m
- Outside Diameter of helix:
- *Dh2 = Dh + do*
- *Dh2*= 0.119 m
- Pitch of the coil
- *p* = 1.5×*do*
- p= 0.024
- *L = p + √ (2□r)2*
- *L=0.019 + √ (2×3.1415×0.1524)2*
- *L* = 0.347m
- Volume occupied by one turn of coil= *Vc* =π/4×*do2*×*L*
- *Vc* =0.000069768 m3
- Volume of annulus (1 turn coil) = *Va* =π/4(*C2 - B2*) × *p* (13)
- Va =π/4(0.35562-0.2542) × 0.019 =
- Va= 0.000132022 m3
- Volume in annulus = Vf = Va - Vc
- Vf = 0.000062322 m3
- **DE** = 4VF ⁄ □DOL=0.019056
- Clearance = (C−B)^2− do) ⁄ 2 =C=0.0074225m
- Using LMTD method:
- LMTD depends on the hot and cold fluid temperature differences at the inlet and exit of the heat exchanger.
- ΔTm =(Thi − Tco) − (Tho − Tci)ln (Thi − Tco)/(Tho − Tci)
- ΔTm =(33.4− 22.30) − (22.103– 10.9) In(22.103-22.30)/(22.103-10.9)
- **ΔTm=11.24 c**

  Prandtl number = Pr =Cpμ/K
- The thermal conductivity of water at the mean bulk temperature of secondary fluid i.e. 11.24^{O} C, flowing through the tube is given as:
- Thermal Conductivity = k = 0.549 W/m.K

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- Pr = (4071*0.1503) ⁄ 0.61590 =**pr= 9.93**
- **On shell Side**:T= Tci+Tco/2; T=16.6
- Pr = (40799×0.0529*10^-3) ⁄ 0.59938 **pr = 7.238**
- Reynolds number for the fluid flowing through the tube is given as:
- Re = (ρ×vc×D) ⁄ µ
- Re = (73.58×0.000069768 ×0.019056) ⁄ (0.1503×10-3)
  Re = 43304
- The mass flow rate of hot fluid in the annulus is given by energy balance for annulus as:
- Q = ma cp (Thi – Tho)
- Q = 0.0169 ⁄ 4182(33.4 – 22.103)
- Q=798.424 KW
- Area of flow in annulus = Aa =π/4[(C2 - B2) – (Dh22 – Dh12)
- Aa=π/4[(0.12-0.086) – (0.119^2 – 0.087^2)]
- Aa= 0.0215m2
- Velocity at the annulus side (va) can be found from eq. as: ma = ρ × va × Aa (21)
- va = ma ⁄ ρA = 0.019 ⁄ (9.9849E^2×0.0215) =
- Va=0.011958 m/s
- Re = (ρ×va×De) ⁄ µ = (73.77×0.011958 × 0.019056⁄ (0.05227×10-3)
  Re =6152.690(cold)
  Nusselt number Nu =hd/K
  Heat transfer coefficient on Coil Side:
- As Re > 10000 so, the following co-relation is used for turbulent flow:
- hido ⁄ K = 0.023 × 4330.4 × 5.399
- hi = 118.97 × (K ⁄ do)=118.97 × (0.609 ⁄ 0.0127)
- hi 1350.731 W⁄m2K
- Heat transfer coefficient on Shell Side:
- Ho=4341.96w/m^2k
- Fouling factor of shell side (For distilled water) = Ra= 0.0005 h.m2.Ko⁄ kcal = 4.3×10-4 m2Ko/W
- Fouling factor of shell side (For tap water) = Rt
- = 0.002 h.m2.Ko⁄ kcal = 1.72×10-3 m2Ko/W
- Overall Heat Transfer Coefficient:
- 1/U=1/hi+1/ho+x/kc+ Ra + Rt
- = U =996.9 W ⁄ m2Ko
- Area of Heat Transfer:
- A =Q*U×ΔTm
- A=3.9524 m2
- Turns:N =Aπdo×L
- N=68
- Height:
- H = (N × p) + do
- H=1.648m
- Effectiveness =Qact/Qmax
- Qmax= mhcph(thi-tci)=1590.2055
- Qact =mcp(thi-tho)=882.77
- E=0.58

Effectiveness	copper	aluminium	stainless-steel
	0.59	0.58	0.57
Overall heat coefficient	996.9	761.147	986.7
Q avg	855.1229	850.0655	845.2639
LMTD	11.24	10.88	11.1167

(CFD ANALYSIS)

Computational fluid dynamics (CFD) study of the system starts with the construction of desired geometry and mesh for modeling the dominion. Generally, geometry is simplified for the CFD studies.

Meshing is the discretization of the domain into small volumes where the equations are solved by the help of iterative methods.

Modeling starts with the describing of the boundary and initial conditions for the dominion and leads to modeling of the entire system. Finally, it is followed by the analysis of the results, conclusions and discussions

PROCEDURE OF CFD MODEL:

1) GEOMETRY : Heat exchanger is built in the ANSYS workbench design module By using ANSYS R2021 we are going to design the helical coil heat exchanger.

As shown in the fig 2. in which geometry is drawn where xy plane is taken and a circle is drawn of diameter i.e. the diameter of coil .the height is horizontal & vertical from origin. Second stage another xy plane is taken a line is drawn and sweep command is used . Outer tube is formed in this cold fluid will flow Third stage other xy plane is created and a diameter circle is formed . & sweep command is used this is inner tube in which hot fluid will flow

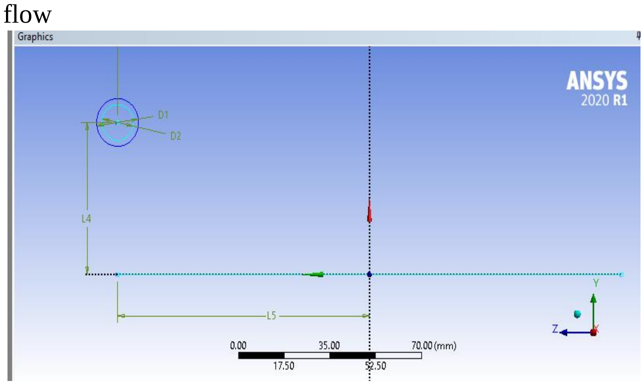

Fig 2

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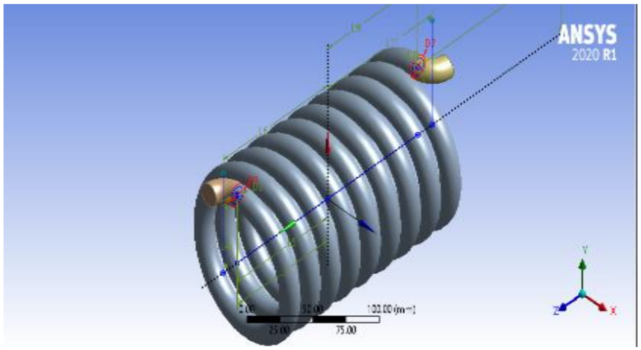

Fig 3.

Use boolean operation for both coil to unite the part into 1 solid body as the inlet & outlet of the hot fluid .Now, we are going to construct the shell in which cold fluid will flow . As shown in fig 4. Creating a plane 4 at xy plane & then using the command extrude we can create the inlet of cold fluid later using mirror option we can create outlet of cold fluid this will create the shell

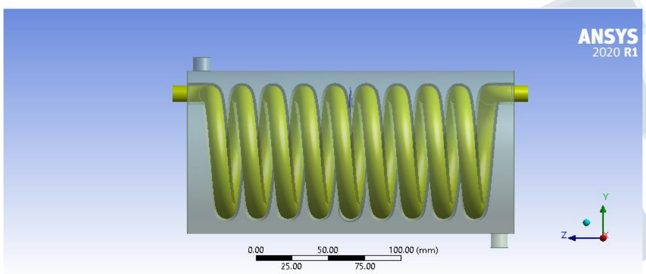

Fig 4.

2) MESHING : Meshing of the model consists of the discretization of the body into small parts known as elements. The meshing done for heat exchanger is volume meshing. As the fluid flows through the pipe the domain used for the analysis of the flow should be the volume in which the fluid is flowing. Hence the meshing done is of the parts which are in contact of the fluid or the volume in which the fluid is flowing. Meshing we will generate mesh updating with parameter such as relevance max face ratio transition named selection will give particularize the name of the inlet ,outlet of pipe ,the wall .

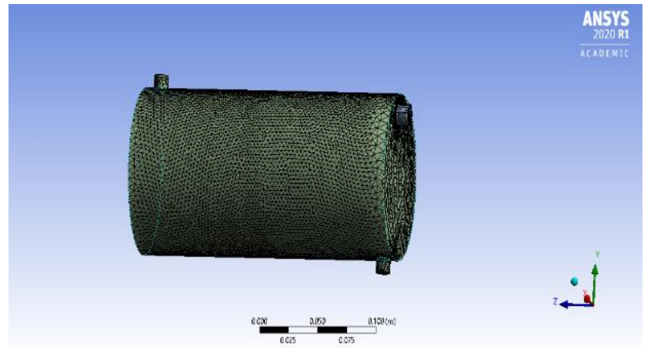

Fig .5

3) SOLUTION: Solution is the next process in which we apply boundary conditions, energy equation the materials are applied the turbulence model, viscous etc.

Models :Energy is set to ON position. Viscous model is selected as “k-ε model.

Materials :The create/edit option is clicked to add water-liquid and copper to the list of fluid and solid respectively from the fluent database.

Cell zone conditions: The parts are assigned as water and copper as per fluid/solid parts.

Boundary Conditions: Boundary conditions are used according to the need of the model. The inlet and outlet conditions are defined as velocity inlet and pressure outlet. As this is a counter-flow with two tubes so there are two inlets and two outlets. The walls are separately specified with respective boundary conditions. No slip condition is considered for each wall. Except the tube walls each wall is set to zero heat flux condition.

Run Calculation: The number of iteration is set to 500 and the solution is calculated and various contours, vectors and plots are obtained.

4) RESULT: The result is been calculated.A s shown in the Fig .6,Fig 7 shows cold inlet temperature,

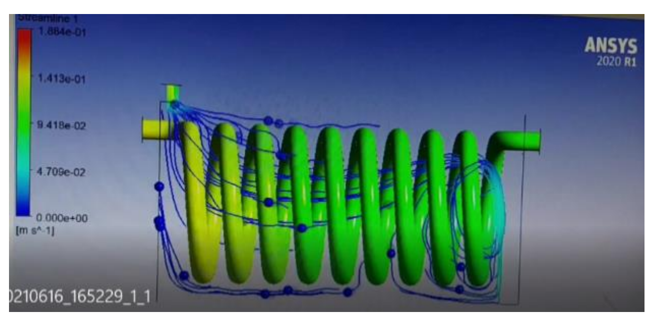

Fig 6

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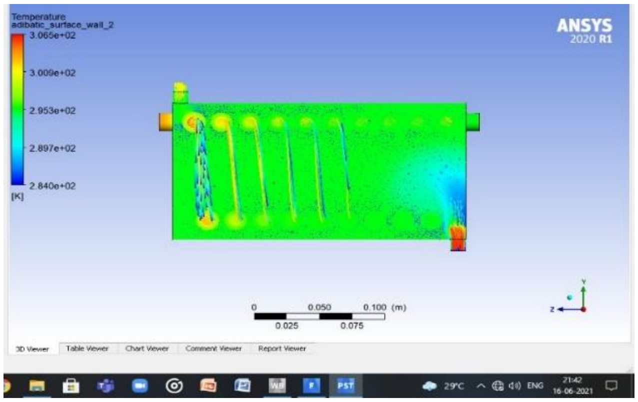

Fig7.

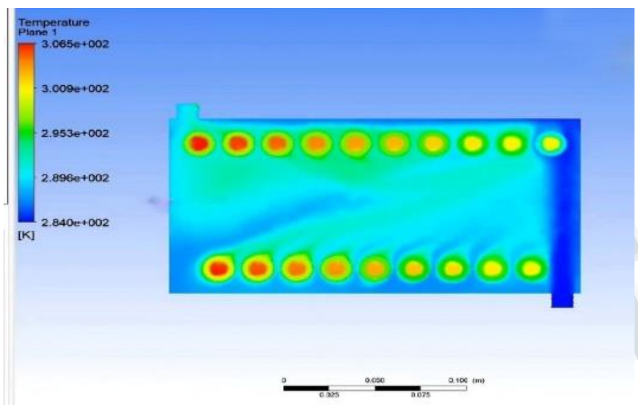

Fig 8.

The cut section of HCHE

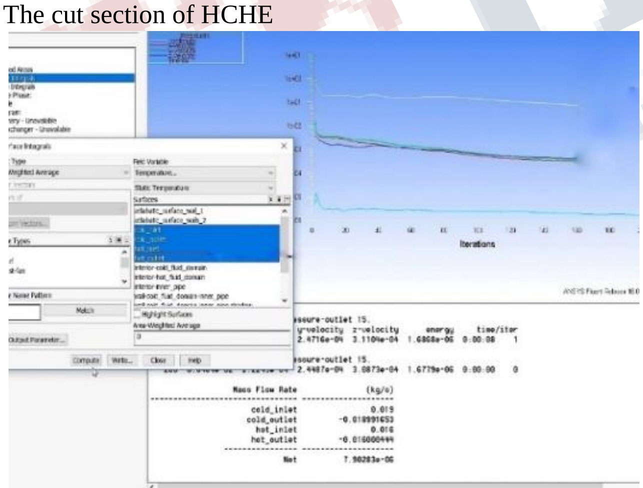

Fig9

COPPER	Q=855.129	E=0.589	U=996.9
ALUMINIUM	Q=850.0566	E=0.578	U=761.53
STAINLESSSTEEL	Q=845.2369	E=0.56	U=986.75

By calculating we found that the material copper is more effective than aluminum & stainless-steel. From the analysis we are able to see the heat rate mass flow rate & net temperature of the helical coil .As the ‘ dsh’ increases the heat transfer rate also decreases (it is because with increase of ‘dsh’ the existing gap between coil & shell increases).similarly the heat transfer also decrease with increases in ‘Hsh’ .From the analysis results with the increase of both ‘dv & f’ i.e. inlet &outlet diameters of shell ,heat transfer rate increases .the reason of enchantment of heat transfer rate with increasing of dv is that with increase of ‘dv’ ,mass flow rate of shell side increases keeping the inlet velocity constant with leads to high heat transfer rate .Also from numerical analysis the overall heat transfer coefficient of copper is more than the other two material its value is 996.9w/m^2K.

IV. CONCLUSION

This paper represents a comparative analysis of the studies of researchers like different materials, temperature, and temperature for helical heat exchanger. The various equations use different parameters for the analysis.

By using the different material the overall effect of these parameters on *Nu* and *hi* is presented in this project . The analysis shows that comparison of 3 materials Nu & hi effectiveness overall heat transfer coefficient values respectively; also the analysis done on ANSYS gives the comparatives results of temp & mass flow rate The overall effect of these parameters on *Nu* and *hi* is presented in this paper. The analysis shows that comparison of 3 materials copper, aluminum, stainless steel; also the analysis done on ANSYS gives the comparatives results of temp & mass flow rate When mass flow rate of cold water is maintained at lower value the effectiveness is maximum but, when mass flow rates of cold water increases effectiveness decreases correspondingly.

The overall heat transfer coefficient and Heat transfer rate increases with increase in mass flow rate of hot water .The temperature of hot water at outlet increases with increase in mass flow rate of hot water inside the tube. More amount of heat transfer takes place as mass flow rate of cold water on shell side increases.The effectiveness of helical coil heat exchanger gradually increases as flow rate of hot water increases. The overall heat transfer of heat exchangers depends on its LMTD. Nusselt Number is directly proportional to inner heat transfer coefficient (hi), So that Nusselt Number is increases with increasing inner tube flow rate, for constant Cold Water Flow Rate.

V. FUTURE SCOPE

In this paper CFD analysis is been carried out by various different diameter different material Future works required to be carried out for further improvement of helical heat exchangers are:CFD analysis and optimization of the curvature ratio using Dean number and Colburn factor for boundary conditions of constant wall temperature and constant wall heat flux for both laminar and turbulent flow. To analyse the results and optimize the heat transfer rate with varying the pitch of the helical coil.

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