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Designing a Helical Coil Heat Exchanger

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ABSTRACT

Heat exchangers are the important engineering systems with wide variety of applications including power plants, nuclear reactors, refrigeration and air-conditioning systems, heat recovery systems, chemical processing , food industries and commonly used for heating of curde oil with steam during oil production. Helical coils have been used in wide variety of applications due to simplicity in manufacturing and its capacityaccommodate a large heat transfer area in a small space, with high heat transfer coefficients. 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. The aim of this work is to design a helical coil heat exchanger through a scientific methodology that includes many steps to obtain an experimental HCHE, calculating the number of turns needed to obtain the required amount of heat exchanged between the operating fluids and determining the rest of the design factors for this exchanger **.**

Keywords: Helical coil Heat exchanger, secondary flow.

1. INTRODUCTION

During the flow of fluid in a curved pipe, a secondary motion of the flow is developed and it is superimposed on its primary stream flow.The curvature of helical coil induces centrifugal force, causing the development of the secondary flow Fig.1.The intensity of the secondary flow is dependent on the radius of the bend curvature (Rc) and Reynolds number (Re) based on the pipe diameter (D) and velocity (U).

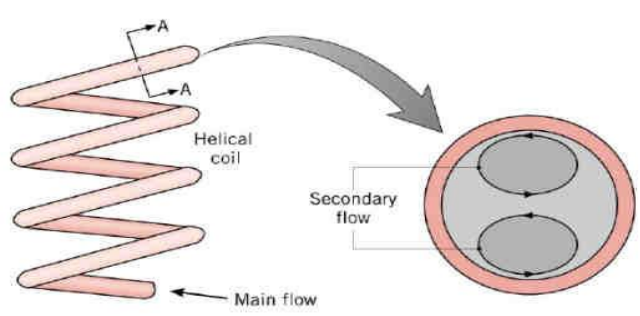

Fig 1. Secondary flow developed due to curvature

2. LITERATURE REVIEW

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It has been widely reported in literature that heat transfer rates in helical coils are higher as compared to a straight tube. The centrifugal force dueto the curvature of the tube results inthe secondary flow development which enhances the heat transfer. The first attempt has beenmade by Dean **[1,2]** to describe mathematically the flow in a coiled tube. A first approximation of the steady motion of incompressible fluid flowing through a coiled pipe with a circular cross-section is considered in his analysis. It was observed that the reduction in the rate of flow due to curvature depends on a single variable, K, which is equal to 2(Re)2r/R, for low velocities and small r/R ratio.

White **[3]** has continued the study of Dean for the laminar flow of fluids with different viscosities through curved pipes with different curvature ratios (δ). The result shows that the onset of turbulence did not depend on the value of the Re or the De. He concluded that the flow in curved pipes is more stable than flow in straight pipes. White also studied the resistance to flow as a function of De and Re. There was no difference in flow resistance compared to a straight pipe for values of De less than 11.6.

Prabhanjan et al.[4] reported an experimental investigation the purpose of this study was to determine the advantage of using a helically coiled heat exchanger versus a straight tube heat exchanger for heating liquids .The results showed that the heat transfer coefficient in helical coil is 1.16 times greater than that of straight tubes at 40 °C and the largest is 1.43 at 50 °C.

Rennie **[5]** studied the heat transfer characteristics of a double pipe helical heat exchanger for both counter and parallel flow. For dean numbers ranging from 38 to 350 the overall heat transfer coefficients were determined. The results showed that the overall heat transfer coefficients varied directly with the inner dean number but the fluid flow conditions in the outer pipe had a major contribution on the overall heat transfer coefficient. The study showed that during the design of a double pipe helical heat exchanger the design of the outer pipe should get the highest priority in order to get a higher overall heat transfer coefficient.

3.Nomenclature

A Area for heat transfer, m^2

B outside diameter of inner cylinder, m

C inside diameter of outer cylinder ,m

D inside diameter of coil , m

$$D_{Haveragediaof\ \ helix\ ,m}$$

$D_{H1}\ insidediameterofhelix, m$

$D_{H2}\ outsidediameterofhelix, m$

$d_0 outsidediameterofcoil, m$

$G_S massvelocityoffluidkg/(m^2)(h)$

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H height of cylinder , m

$h_i heattransfercoefficientinsidestraighttube$

$basedoninsidediameter$ w/m^2.k

$h_{ic} heattransfercoefficientinsidecoiledtube$

$basedoninsidediameter, w/m^2.k$

$h_{io} heattransfercoefficientinsidecoilbasedon$

$outsidediaofcoil, w/m^2.k$

$h_0 heattransfercoefficientoutsidecoil, w/m^2.k$

L length of helical coil needed to form N turns ,m

M Mass flowrate of fluid, kg/m

N Theoretical number of turns of helical coil

n Actual number of turns of coil needed for given process heat duty

q Volumetric flowrate of fluid , m^3/h

r Average radius of helical coil taken from the centerline of the helix to the centerline of the coil , m

$R_a shellsidefoulingfactor(h)(m^2)(°C)/kal$

$R_t tubesidefoulingfactor(h)(m^2)(°C)/kal$

$v_a volumeofannulus , m^3$

$v_c volumeoccupiedbyNturnsofcoil , m^3$

$v_f volumeavailableforfluidflowintheannulus , m^3$

x thickness of coil wall , m

$\mu fluidviscosity , kg/(m)(h)$

$\rho fluiddensity , kg/m^3$

Nu Nusselt number

Re Reynolds number

Q heat load , kcal/h

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4.Experimental model:

Liquid A flows inside a 316 stainless-steel pipe coil, liquid Bin the annulus. The flowrates, the inlet and outlet temperatures, and the physical properties of the fluids are given in the table . The geometry of the HCHC is that shown in Fig 2, where B = 0.04 m , C = 0.06 m ,

D = 0.004 m , d_0=0.006 m

Table 1: Fluid properties			
property	Unit	Liquid A	Liquid B
Mass flowrate	Kg/h	36	36
Inlet temperature	℃	130	30
Outlet temperature	℃	97	50
Heat capacity	kcal/(kg)(℃)	1.00	1.00
Thermal conductivity	Kcal/(h)(m)(℃)	0.419	0.4075
Viscosity	Kg/m.h	1.89	5.76
Density	Kg/m3	870	935

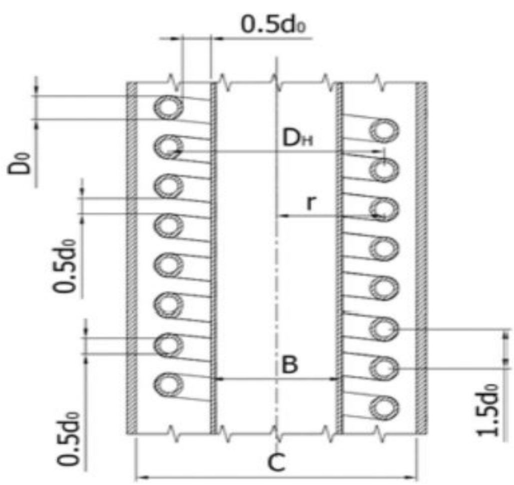

Fig 2 :Geometrical assumptions for designed helical coil heat exchanger

A. calculate the shell-side heat transfer coefficient h_0

1- The length of coil $L = \sqrt{(2\pi r)^2 + P^2}$

$P = 1.5 \times 0.006 = 0.009m$

$r = \frac{B}{2} + d_0$

r = 0.026m

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$L = \sqrt{2\pi(0.026)^2 + (0.009)^2}$

L = 0.164N

2-The volume available for fluid flow in the annul v_f is:

$V_f = V_a - V_c$

Vc =(π/4)d0^2 P

Va = (π/4)(C^2 –B^2)PN

Va =(π/4)(0.062 -0.042)×0.009×N

= 1.413×10^{-5} N

Vc =(π/4)(0.006)20.164 N

=4.635×10-6 N

$$V_f = 1.413 \times 10^{-5}N - 4.635 \times 10^{-6}N$$

=9.495×10^{-6} N

3-The shell-side equivalent diameter is :

D_e = 4V_f /πd0L

D_e =(4)(9.495×10^{-6} N)/(π)(0.006)(0.164N)

=0.0123m

4-The mass velocity of the fluid is :

Gs = M/{(π/4)((C^2 –B^2) – (DH_2^2-DH_1^2))}

D_{H1} = B + d0

= 0.04 + 0.006 = 0.046m

D_{H2} = C - d0

=0.06-0.006 = 0.054m

Gs =36/{(π/4)((0.062-0.042) – (0.0542-0.0462))}

=38216.561 kg/(m^2)(h)

5- The Reynolds number is :

Re = (38216.561)×(0.0123)/(5.76)

=82

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6-The heat transfer coefficient based on the outside the coil :

$h_0\ D_e/k = 0.6\ N_{Re}^{0.5}\ N_{Pr}^{0.31}$

Pr = (1×5.76)/(0.4075) = 14.135

$h0 = (0.6)(0.4075)(82)^{0.5}(14.135)^{0.31}/(0.0123)$

=410 kcal/(h)(m^2)(°C)

B-Compute h_{io}, the heat transfer coefficient inside the coil:

1-The fluid velocity is :

$U = q/A_f$

Where $A_f = \Pi D^2/4 = \pi(0.004)^2/4 = 1.256\times10^{-5}\ m^2$

q = M/p=36/870=0.041 m^3/h

$u = (0.041)/(1.256\times10^{-5})$

u=3264.331 m/h

2-The Reynolds number (tube-side) is then :

Re=(3264.331)×(0.004) ×(870) /(1.89)

=6010.514 **3**- Using the Dittus-Boelter relationship, we calculate the heat transfer coefficient inside the straight tubes depending on the inside diameter:

$Nu_{DB} = 0.023 Re^{0.8}\ Pr^{0.4}$

$$h_i = \frac{(0.023)\times(0.419)\times(6015.514)^{0.8}\times(4.511)^{0.4}}{(0.004)}$$

=4642.162 kcal/(h)(m^2)(°C)

4-Corrected for a coiled tube , this becomes:

$h_{ic} = (4642.162)[1 + 3.5(0.004/0.05)]$

=5941.967 kcal/(h)(m^2)(°C)

5-The heat transfer coefficient based on the outside diameter of the coil is:

$$h_{io} = (5941.967)(0.004/0.006)$$

$$= 3961.311 \text{kcal}/(\text{h})(m^2)(°\text{C})$$

C- Calculate the overall heat transfer coefficient U:

The coil wall thickness x is :

x = (d0 – D)/2

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=(0.006 – 0.004)/2 =0.001m

Both R_t and R_a are 8.2×10^{-4}(h)(m^2)(℃)/kcal

$$\frac{1}{U} = \frac{1}{h_0} + \frac{1}{h_{io}} + \frac{x}{k_c} + R_t + R_a$$

1/U = 1/410 + 1/3961.311 + 0.001/14 + 0.00082+0.00082

$$U = 277.118(\text{h})(\text{m2})(℃)/\text{kcal}$$

D-Determine the required area:

-The log mean temperature difference is :

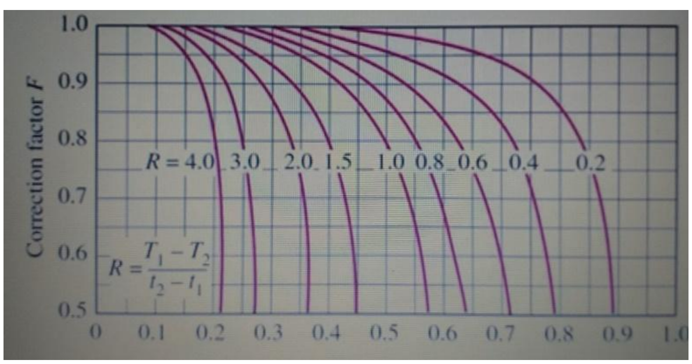
$$\Delta T_{tm} = \frac{[(130-50)-(97-30)]}{ln(130-50)/(97-30)}$$

= 73.3℃

To account for counter flow , the correction factor from Fig 3 is 0.99

Where $P = \frac{(50-30)}{(130-30)} = 0.2$

$$R = \frac{(130-97)}{(50-30)} = 1.65$$



Calculate the correction factor from Fig 3

So that, ΔT_c = (0.99)(73.3)= 72.567 ℃

The heat load is :

Q =(36)(1)(130-97) = 1188 kcal/h

The required area:

A = (1188)/(277.118)(72.567)

=0.059 m^2

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E-Calculate the number of turns of coil required :

$N = A/(\pi d0(L/N))$

$N = (0.059)/(\pi)(0.006)(0.164) = 19.11$

And: n=20

The height of the cylinder needed to accommodate 21 turns of coil is :

$H = 20\times0.009 + 0.006 = 0.186m$

5. Conclusions

1- The study showed that the heat transfer coefficient inside the helical coil is high, so the overall heat transfer coefficient is also high despite that the laminar flow of the working fluid inside coil . The fluid flowing through curved tubes induces secondary flow in the tubes. This secondary flow in the tube has significant ability to enhance the heat transfer due to mixing of fluid.

2- The low flow rate of the operating fluids on the coil side and shell side so the straight tube heat exchanger can't use because its low thermal efficiency.

3-The greatest advantage of the HCHE is that, the helical coil can accommodate greater heat transfer area in a less Space, with higher heat Transfer coefficients.

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