Analysis of Heat Transfer Coefficients for Helical Coil Heat Exchanger

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Abstract—Helical coil has better heat transfer rate as compared to shell and tube heat exchanger, Because of development of secondary flow. Helically coiled tubes are used frequently in heating, refrigeration, HVAC applications, steam generator, condenser designs in power plants because of their large surface area per unit volume. In the presented work the inside heat transfer coefficient (h_i) and outside heat transfer coefficient (h_o) from the different research paper were compared. For the calculation of heat transfer coefficient MATLAB code is developed for the same. The values of heat transfer coefficient for inner side has agreement between each other, however outside heat transfer coefficient has no agreement is found.

Key words- Helical Coil, Matlab, Heat Transfer Coefficient.

NOMENCLATURE

d_i	Tube inner diameter (=2*r) in m
d_o	Tube outerdiameter in m
$D_{c,b}$	Coil bottom diameter(=2*$R_{c,b}$)in m
$D_{c,t}$	Coil top diameter(=2*$R_{c,t}$) in m
D	Diameter of straight helical coil(=2* R) in m
D_{ave}	Average diameter (=$D_{c,b}$ +$D_{c,b}$/2) in m
$D_{s,o}$	Outer shell diameter in m
$D_{s,i}$	Inner shell diameter in m
L	Length of coil in m
H	Height in m
P	Pitch of coil in m
N	Number of turns
B	Clearance in m
k_t	Thermal conductivity of tube material in W/m °K
k_c	Thermal conductivity of tube fluid in W/m °K
k_s	Thermal conductivity of shell fluid in W/m °K
β_c	Coefficient of volumetric thermal expansion of tube fluid in 1/°K
β_s	Coefficient of volumetric thermal expansion of shell fluid in 1/°K
ρ_c	Mass density of tube fluid in (kg/m^3)
ρ_s	Mass density of shell fluid in (kg/m^3)
μ_c	Dynamic viscosity of tube fluid in m/kgS
μ_s	Dynamic viscosity of shell fluid in m/kgS
$T_{c,i}$	Inlet temperature of tube fluid in °K
$T_{c,o}$	Outlet temperature of tube fluid in °K
$T_{s,i}$	Inlet temperature of shell fluid in °K
$T_{s,o}$	Outlet temperature of tube fluid in °K
$C_{p,c}$	Specific heat of tube fluid in J/Kg°K
$C_{p,s}$	Specific heat of shell fluid in J/Kg°K
$C_{p,mn}$	Minimum specific heat in J/Kg°K
PF	Parallel flow arrangement
CF	Counter flow arrangement
m_c	Mass flow rate of tube fluid in Kg/ S
m_s	Mass flow rate of shell fluid in Kg/ S
$(mC_p)_{min}$	Minimum value of product of m and C_p
De	Dean Number
D_{eq}	Equivalent Diameter
D_{hx}	Hydraulic Diameter
DR	Diameter Ratio
PR	Pitch Ratio
HCCHE	Helical cone coil heat exchanger
HCCSS	Helical cone coil straight shell
HCCCS	Helical cone coil cone shell
θ	Cone angle of conical coil
N	Velocity exponential
R_{th}	Thermal Resistance
Z	drag coefficients
	SUBSCRIPTS
C	Cold water
H	Hot water
I	Inner, tube side
S	Shell
T	Tube
C	Coil
O	Outer, outside
Ov	Overall
Ave	Average
W	Wall

I. INTRODUCTION

Straight helical coil heat exchanger

"Heat exchanger is a device which is use to transfer the heat from one fluid to another fluid through the same device". In helical coil heat exchanger the helical coils are used for the heat transfer. Helically coiled tubes are used frequently in heating, refrigerating, HVAC applications, steam generator, condenser and power plants because of their large surface area per unit volume. In spite of their widespread use there in no information available on natural convection from such coils however correlation in the literature for natural convection from vertical and horizontal plates are available. The foregoing consideration provided motivation for the present research to fill the gap in the literature. [1]

It has been long recognized that heat transfer characteristics of helical tubes is much better than straight one because of the occurrence of secondary and fluid flow in planes normal to the main flow inside helical tubes show great performance in heat transfer enhancement while the uniform curvature of spiral conical structure inconvenient in pipe installation in heat exchanger.[2]

In this type of heat exchanger, the secondary flow is generated by centrifugal action and acts in a plane perpendicular to the primary flow. Since the velocity is maximum at the centre, the fluid at the centre is subjected to the maximum centrifugal action, which pushes the fluid towards the outer wall. The fluid at the outer wall moves in ward along the tube wall to replaces the fluid ejected outwards. This results in the formation of two vortices symmetrical about a horizontal plane through the tube center.

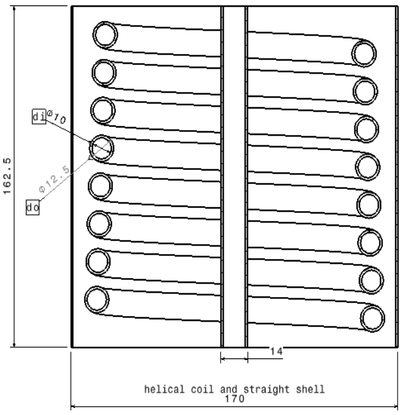

Fig 1.1 Straight Helical Coil Heat Exchanger

Inside heat transfer coefficient for helical coil and curved tube are greater than inside heat transfer coefficient of straight tube because of secondary flow (Dean Vortex) in curved tube and it is characterized by Dean Number which is equal to

$$De = Re \times ((d_i/D)^{0.5}) \qquad (1.1)$$

In this type the curvature ratio is constant. Secondary flow become intensive, which in turn increases (hi).

For calculation of outside heat transfer coefficient (h_0) correlations are found only for typical applications and specified ranges of Re, Ra study by researchers.

Generally correlations for h_0, covering entire range of Re, di/D is not found due to this we have used the available correlations of straight tube.

It has been widely observed that the flow inside coiled tube remains in the viscous regime up to much higher Reynolds number than that for straight tubes. Helical coils are known to have better heat and mass transfer compared to straight tube the reason for that is the formation of a secondary flow superimposed on the primary flow. [3]

II. LITERATURE SURVEY

The Mohamed Ali[1] was performed the experimental investigation of Natural convection made to study, steady type Natural Convection was obtained from turbulent natural convection to water. The experiment have been carried for four coil diameter to tube diameter ratio for five and ten coil tubes and for five pitch outer diameter ratio.

He correlated Rayleigh Number for two different coil sets and the heat transfer coefficient decreases with coil length for tube diameter do =0.012m but increases with coil length for do=0.008m. For tube diameter of 0.012 m with either five or ten coil turns, critical $D/d_0$is obtained for a maximum heat transfer coefficient.

Yan ke [2] investigated numerical simulation of conical tube bundles. He observed the effect of structural parameters on heat transfer characteristics. fluid flow characteristics inside tube of different cross section also investigated result shows that cone angle cross section have been significant effect inside heat transfer. Also helical pitch has little influence on heat transfer enhancement. He also includes that the secondary fluid become intensive along the tube due to increase of tube curvature. Secondary fluid flow contains four contours and flow direction of each contour are different due to this heat transfer rate increases.

J.S Jaykumar[3]after validating the methodology of CFD analysis of a heat exchanger, the effect of consideringthe actual fluid properties instead of a constant value is established. Various boundary conditions are compared to calculate heat transfercharacteristics inside a helical coil. It is foundthat the specification of a constant temperature or constant heat flux boundary conditionfor an actual heat exchanger does not give satisfactory result through modelling. For this problem the heat exchangerisanalysed with considering conjugate heat transfer and properties ofheat transport fluid which are temperature dependent. An experimentation was carried out for the calculation of the heattransfer characteristics. Experimental results and CFD calculationresults using the CFD package FLUENT 6.2 are compared. Finally the correlationis developed by using the experimental result obtained. The inner heat transfer coefficient of the helical coil is thus obtained.CFD code FLUENT is used for finding Heat transfer characteristics of the heat exchangerwith helical coil.The CFD predictions are in good agreement with theexperimental results within experimental error limits.

N.Ghorbani[4] conducted experimental study of thermal performance shell and coil heat exchanger in the purpose of this article is to access the influence of tube diameter , coil pitch , shell side and tube side mass flow rate on themodified effectivenessand performance coefficient of vertical helical coiled tube heat exchanger. The calculation has been performed for the steady state and the experiment was conducted for both laminar and turbulent flow inside coil. It was found that the mass flow rate of tube side to shell ratio was effective on the axial temperature profiles of heat exchanger. He concluded that with increasing mass flow rate ratio the logarithmic mean temperature difference was decreased and the modified effective’s decreases with increasing mass flow rate.

R. Patil [5]suggested design methodology for helical coil heat exchanger. heat transfer coefficient based on the inside coil diameter hi, is obtained using method for a straight tube either one of Sieder –Tate relationships or plot of the Colburn factor ,JH vs Re. outside heat transfer coefficient is calculated using correlation for different range of Reynolds number. Helical coil heat exchanger is the better choice where space is limited and under the conditions of low flow rates or laminar flow.

III. RESEARCH REVIEW ON HEAT TRANSFER COEFFICIENTS:

3.1 Heat transfer coefficient based on **Churchill and Manplaz** Correlation**:**

Correlation used for inside and outside heat transfer coefficient given below

$$h_i = k_c \frac{\left((3.675+(\frac{4.343}{X_1}))^3 + (1.158\times(\frac{D_{eic}}{X_2})^{1.5})\right)^{0.33}}{d_i} \quad (3.1)$$

Where,

$$X_1=(1+\frac{957}{\frac{D_{eic}^2}{pr}})^2 \quad (3.2)$$

$$X_2=(1+\frac{0.477}{Pr}) \quad (3.3)$$

$$h_o = k_s \frac{(0.683\times R_{edo})^{0.446}\times(Pr)^{0.33}}{d_o} \quad (3.4)$$

For solving above equation we had developed Matlab code, which is given below

Matlab Program

```
ms=input(' enter the mass  flow rate for shell ms:');
mc=input(' enter the mass  flow rate for coil mc:');
Cps=input(' enter the spe heat  for shell Cps:');
Cpc=input(' enter the spe heat  for coil Cpc:');
tsi=input(' enter the shell inlet temp tsi:');
tso=input(' enter the shell outlet temp tso:');
tci=input(' enter the coil inlet temp tci:');
di=0.01;
do=0.0125;
Q=1.27409;
p=0.0125;
B=0.003;
Rhoc=input('enter the density of the coil fluid Rhoc :');
Rhos=input('enter the density of the shell fluid Rhos :');
Muc=input('enter the dy viscosity of coil fluid Muc :');
Mus=input('enter the dy viscosity of shell fluid Mus :');
Deic=input('enter the dean nu within the range 1000 to 5000 Deic :');
L=5;
Pr=input('enter the prandtl nu Pr:');
Kc=input('enter the th conductivity of coil fluid Kc :');
Ks=input('enter the th conductivity of shell fluid Ks :');
Vc=((4*mc)/(Rhoc*3.1416*(di)^2));
Reic=((Rhoc*Vc*di)/(Muc));
Dcb=(di/(Deic/Reic)^2);
Rcb=(Dcb /2);
Recrt=(2000*(1+13.2*(di/Dcb)^0.5));
X1=((1+957/((Deic)^2/Pr)))^2;
X2=(1+(0.477/Pr));
Nuic=((((3.675+(4.343/X1))^3)+(1.158*(Deic/X2)^1.5))^0.33);
hi=((Nuic*Kc)/(di));
 Rct=sqrt((Rcb)^2-(L*p)/(3.14*tan(Q)));
   Dct=2*Rct;
   Dso=(Dcb+do+(2*B));
   Dsi=(Dct-do-(2*B));
   Ais=(0.7854*((Dso)^2-(Dsi)^2));
   Vs=((4*ms)/(Rhos*Ais));
   Vmax=1.595*Vs;
   Redo=((Rhos*Vmax*do)/(Mus));
   Nudo=(0.683*(Redo)^(0.446)*(Pr)^(1/3));
   ho=((Nudo*Ks)/(do));
 fprintf('\n the hi=%f',hi);
 fprintf('\n the ho=%f',ho);
```

3.2 Heat transfer coefficient based on **R. K Patil's** correlation:

Correlation used for inside and outside heat transfer coefficient given below

$$h_i=105\frac{(\frac{k_c}{d_i})\times Pr^{0.33}}{4.18} \quad (3.5)$$

$$h_o = \frac{0.36\times(R_{edo}{}^{0.55})\times Pr^{0.33}\times(\frac{M_{us}}{M_{uw}})^{0.14}\times K_s}{D_{eq}} \quad (3.6)$$

Where,

$$R_{edo}=\frac{R_{hos}\times V_{max}\times d_o}{M_{us}} \quad (3.7)$$

3.3 Heat transfer coefficient based on **N. Ghorbani's** correlation:

Correlation used for inside and outside heat transfer coefficient given below

$$h_i=2(\frac{k_c}{d_i+d_o})\times Pr^{0.33}\times(0.137\times(R_{eic})^{0.7038}) \quad (3.8)$$

$$h_o = \frac{0.0175 \times R_a^{\ 0.3276} \times (R_{eic}^{\ 0.1}) \times Pr^{0.3} \times K_s}{D_{eq}} \quad (3.9)$$

Where,

$$R_a = \frac{9.81 \times beta \times L^3 \times d_t}{alpha \times neu} \quad (3.10)$$

IV. RESULTS:

Table 4.1:Inside and Outside Heat Transfer Coefficient Based on **Churchill and Manplaz** Correlation:

mc	ms	tsi	tso	tci	Output	
					hi	ho
0.01	0.01	20	22	29	4191.24	342.79
0.001	0.002	30	37	60	4369.14	113.26
0.012	0.03562	31	49	65	4334.344	344.198
0.0444	0.0356	30	35	51	4263.22	622.39

Table 4.2:Inside and Outside Heat Transfer Coefficient Based on **R.K. Patil's** Correlation:

mc	ms	tsi	tso	tci	Output	
					hi	ho
0.01	0.01	20	22	29	3861.122	14.048
0.001	0.002	30	37	60	4572.28	3.85
0.012	0.03562	31	49	65	4455.19	22.93
0.0444	0.0356	30	35	51	4581.48	37.83

Table 4.3:Inside and Outside Heat Transfer Coefficient Based on **N. Ghorbani** Correlation:

mc	ms	tsi	tso	tci	Output	
					hi	ho
0.01	0.01	20	22	29	4274.81	5640.55
0.001	0.002	30	37	60	3613.15	7895.84
0.012	0.03562	31	49	65	4283.68	18037.21
0.0444	0.0356	30	35	51	4398.93	10765.24

V. CONCLUSION

A good agreement is found for inside heat transfer coefficient calculated from the different correlations given by researchers. For outside heat transfer coefficient calculated from different correlation of researcher agreement is not found. Results obtained are different for ho by different correlations this is due to specified range of consideration and different characteristics lengths used for Nusselt number calculation. So the present study conclude the heat transfer coefficients correlation for the helical coil needs to be developed which gives satisfactory result over large range. Numerical simulation is the most efficient and economical way for the flow and thermal analysis for developing the correlation of heat transfer coefficients.

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