DWSIM Modelling Project

Modelling Helical Coil Heat Exchanger

by

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The custom model for the Helical Coil Heat Exchanger was created by keeping the following paper as reference: *R. K. Patil, B. W. Shende, and P. K. Ghosh, "Designing a helical-coil heat exchanger." pp. 1–8, 1984.*

The paper was replicated as it is and the results were completely matched.

For the calculation of h_i the term for wall temperatures are required if the Reynolds Number > 10000. Note: If wall temperature of coil and annulus aren't available, input the material stream temperature as an approximation. It will turn mu/mu_w to 1 and its effect was negligible showing no effects on result.

For the calculation of "h" the equation from the book mentioned in the paper was used:

Equation 6.2, from "Process heat Transfer" by Donald Q. Kern. Copyright 1950 by McGraw-Hill Book Co.

Care should be taken to have pure compound amounts as the input to the shell and tube side.

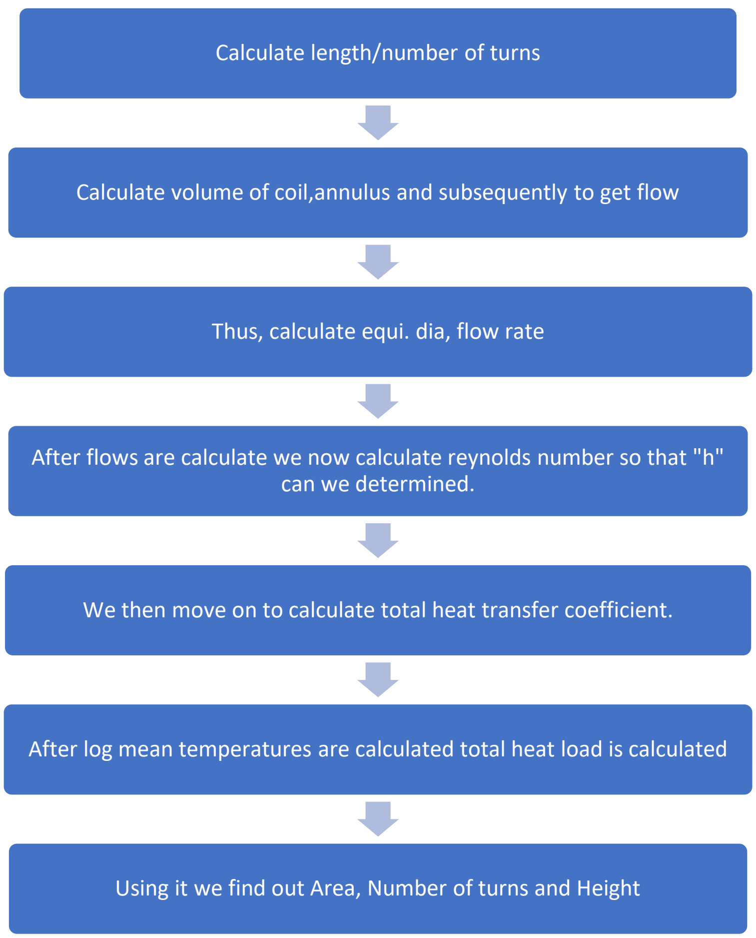
A is the liquid that flows inside the shell (annulus) and B is the liquid that flows through tube (coil).

Equations solved are:

1. Calculating model parameters from the variables:
   a. $Dh = (B + C)/2$
   b. $Dh1 = Dh - do;\ Dh2 = Dh + do$
   c. $p = 1.5 * do;\ r = Dh/2$
   d. $x = \frac{do-D}{2}$
2. Calculating length/number of turns, Volumes, equivalent diameter and flow rates:
   a. $L\_N = \sqrt{(2\pi r)^2 + p^2}$
   b. $V\_coil = \frac{\pi}{4} * do * do * L\_N$
   c. $V\_annulus = \frac{\pi}{4} * (C^2 - B^2) * p$
   d. $Vflow = Vannulus - Vcoil$
   e. $Deqv = 4 * V\frac{flow}{\pi * do * LN}$
3. Calculating Reynolds number, h, U and LMTD:
   a. Prandtl and Reynolds Number: $N_{Pr} = Cp * \frac{mu}{k}$; $N_{Re} = D * u * \frac{rho}{mu}$
   b. Calculating h for shell side:
      i. $N_{Re} < 10000 : 0.06 * \left(N_{Re}^{0.5}\right) * (N\_Pr^{0.31}) * (\frac{k}{D})$
      ii. $N_{Re} > 10000 : 0.36 * \left(N_{Re}^{0.55}\right) * (N\_Pr^{0.33}) * \left(\frac{k}{D}\right) * \left(mu_A/mu_{w_A}\right)^{0.14}$
   c. Calculating h for tube side:
      i. $N_{Re} < 10000 : 0.06 * \left(N_{Re}^{0.5}\right) * (N\_Pr^{0.31}) * (\frac{k}{D})$
      ii. $N_{Re} > 10000 : 0.027 * (N_{Re}^{0.8}) * (N\_Pr^{0.33}) * \left(\frac{k}{D}\right) * \left(\frac{mu_B}{mu_{w_B}}\right)^{0.14}$
   d. Calculating U: $\frac{1}{U} = \frac{1}{ho} + \frac{1}{hic} + \frac{x}{kc} + Rt + Ra$, where $hic = h * (1 + \frac{3.5D}{Dh})$

   e. Calculating LMTD:
      i. Co-current: $delta_{t_{lm}} = \frac{(Tin_A - Tin_B) - (Tout_A - Tout_B)}{\log(\frac{Tin_A - Tin_B}{Tout_A - Tout_B})}$
      ii. Counter current: $delta_{t_{lm}} = \frac{(Tin_A - Tout_B) - (Tout_A - Tin_B)}{\log(\frac{Tin_A - Tout_B}{Tout_A - Tin_B})}$
      iii. Correction factor: $delta_{t_c} = 0.99 * delta\_t_{lm}$
4. Calculating final result parameters:
   a. $Q = M_A * Cp_A * (Tin_A - Tout_A)$
   b. $A = Q/(U * delta\_t_c)$
   c. $N = \frac{A}{\pi * do * L\_N}$
   d. $H = (([N] + 1) * p) + do$

Algorithm for the calculation of heat load and hence the number of turns and height is as follows:



Following are the results, given the properties are as specified as in the paper. Since the material properties were specific, they were simulated on python. It can be replicated by providing/creating a material of the given specifications in DW-SIM, if possible.

$N = 31.52$	$H = 1.47$	$A = 3.734$	$delta_{t_{lm}} = 72.79$
$delta_{t_c} = 72.069$	$U = 135.43$	$x = 0.00249$	$h_{io} = 3381$
$h_{ic} = 4057$	$h_i = 3329.61$	$Nre_{tube} = 36378.27$	$Nre_{shell} = 833.719$
$Gs = 56791.78$	$D_{eqv} = 0.084$	$V_{flow} = 0.002504$	

List of variables used (Pay special attention to the units used else the results will change accordingly)

A	Area for heat transfer **(m²)**
A_a	Area for fluid flow in annulus **(m²)**
A_f	Cross-sectional area of coil **(m²)**
B	Outside diameter of inner cylinder **(m)**
C	Inside diameter of outer cylinder **(m)**
Cp	Fluid heat capacity **(kcal/kg*°C)**
D	Inside diameter of the coil **(m)**
D_eqv	Shell-side equivalent dimeter of the coil **(m)**
Dh	Average diameter of helix **(m)**
Dh1	Inside dimeter of helix **(m)**
Dh2	Outside diameter of helix **(m)**
Do	Outside diameter of the coil **(m)**
Gs	Mass velocity of fluid **(kg/m²*h)**
H	Height of cylinder **(m)**
hi	Heat-transfer coefficient inside straight tube **(kcal/h*m²*°C)**
hic	Heat transfer coefficient inside coiled tube based on inside diameter **(kcal/h*m²*°C)**
hio	Heat transfer coefficient inside coil based on outside diameter of coil **(kcal/h*m²*°C)**
ho	Heat transfer coefficient outside coil **(kcal/h*m²*°C)**
k	Thermal conductivity of fluid **(kcal/h*m*°C)**
kc	Thermal conductivity of coil wall **(kcal/h*m*°C)**
L	Length of helical coil needed to form N turns **(m)**
M	Mass flow rate of fluid **(kg/h)**
N	Theoretical number of turns of helical coil
n	Actual number of turns of coil needed for given process heat duty (N rounded to the next highest integer)
Npr	Prandtl number
Nre	Reynolds number
Q	Heat Load **(kcal/h)**
q	Volumetric flow rate of fluid **(m³/h)**
r	Average radius of helical coil taken from centerline of the helix to the centerline fo the coil **(m)**
Ra	Shell-side fouling factor **(h*m²*°C /kcal)**
Rt	Tube side fouling factor **(h*m²*°C /kcal)**
delta_t_c	Corrected log mean temperature difference **(°C)**
delta_t_lm	Log mean temperature difference **(°C)**
u	Fluid velocity **(m/h)**
U	Overall heat transfer coefficient **(kcal/h*m²*°C)**
V_annulus	Volume of annulus **(m³)**
V_coil	Volume occupied by N turns of coil **(m³)**
V_flow	Volume of compound available for fluid flow in the annulus **(m^3)**

x	Thickness of coil wall **(m)**
mu	Fluid viscosity at the mean bulk-fluid temperature **(kg/m*h)**
mu_w	Fluid viscosity at the pipe wall temperature **(kg/m*h)**
rho	Fluid density **(kg/m^3)**

Example 2:

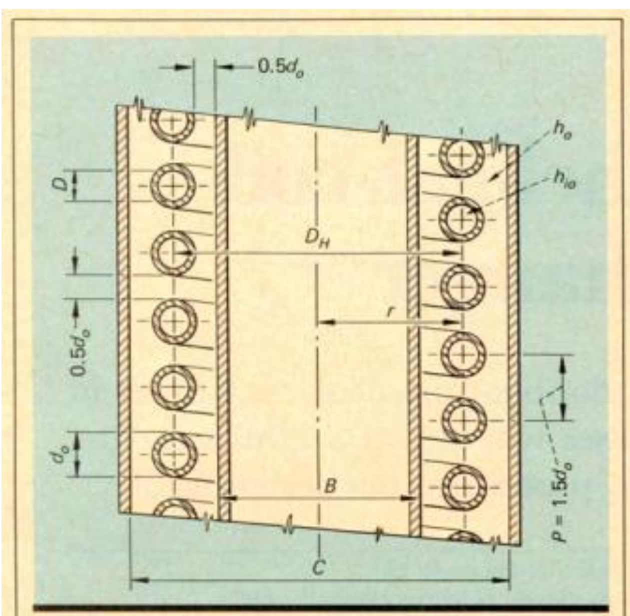
$N = 88.93$	$H = 1.707\, m$	$delta_{t_{lm}} = 54.388$	$delta_{t_c} = 53.844$
$U = 136.616 \frac{W}{m^2 K}$	$x = 0.00125\, m$	$Q = 24.998\, kW$	$h_{ic} = 7450.33 \frac{W}{m^2 K}$
$Nre_{tube} = 24668.27$	$Nre_{shell} = 667.54$	$D_{eqv} = 0.084\, m$	$V_{flow} = 0.00080\, m^3$
$A = 3.398\, m^2$	$h_i = 6669.19 \frac{W}{m^2 K}$		

The units used in the paper are SI, and the flow is anti-parallel and hence the LMTD formula changes. The changes in the values of N is majorly because of the high value of U. The value of U changes since the formula used for x is different in both the papers. However, I used the one that was originally published, i.e., x=(do-D)/2. If we change this value the results match. Rest minor differences are due to manual calculations, and slight difference in the correlations. In all such cases the relations form the previous papers is used.

It is also important to be consistent in units while giving input.

Input Variables Required:

Figure Reference: *R. K. Patil, B. W. Shende, and P. K. Ghosh, "Designing a helical-coil heat exchanger." pp. 1–8, 1984.*



Schematic cutaway view of an HCHE Fig. 2

B, C, D, do are the design parameters required in meters to the script

Ra, Rt, kc are the conductivity and the fouling factors required for the calculation of U

T_Wall_annulus, T_Wall_coil are the wall temperatures, T_out_A and T_out_B are the outlet temperature.

For co current flow keep zero_for_cocurrent_else_anything as 0.

For counter current flow change it's value from 0 to any number.

Bibliography:

1. R. K. Patil, B. W. Shende, and P. K. Ghosh, “Designing a helical-coil heat exchanger.” pp. 1–8, 1984.
2. M.Usman, Sikandar. (2019). Design of Helical Coil Heat Exchanger for a mini powerplant. International Journal of Scientific and Engineering Research. 10. 303-313. 10.14299/ijser.2019.12.
3. “Process heat Transfer” by Donald Q. Kern. Copyright 1950 by McGraw-Hill Book Co.