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DEVELOPMENT OF A SOFTWARE FOR DESIGNING OF PARALLEL FLOW HEAT EXCHANGER

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Abstract The purpose of this paper is to develop a software for calculating design parameters of counter and parallel flow heat exchanger. The parameters are, Heat Exchanger Effectiveness, Overall Heat Transfer Co-efficient, Heat Transfer rate, Length of Heat Exchanger, Heat Exchanger surface area. The software is very useful for calculating such parameters accurately and easily. Other types of heat exchanger, e.g. shell & tube heat exchanger, crossflow heat exchanger, designing can not be possible with this software. Only two types of fluid have been considered for designing of Heat Exchanger, however the software can be easily expanded for other types of fluid. No phase change of the fluid is considered for designing of heat exchanger. Only two types of Heat Exchanger materials are used for designing heat exchanger but also other materials can be used for designing heat exchanger. Language "C" is used to develop software for design of parallel flow heat exchanger. Manual calculation for a particular problem is done & then the calculated values are compared with the output of the software for that particular problem for validation of the software.

INTRODUCTION

All heat transfer process involves the transfer and conversion of energy. They must therefore obey the first law as well as second law of thermodynamics.

A Heat exchanger is a device, which effects the transfer of heat from one fluid to another. The transfer of heat between the two fluids is carried out either by direct contact or by transmission through a separating wall. The transfer process consists of convection between one fluid and the wall, conduction through the wall, and convection between the wall and other fluid. When the temperature difference between the wall and the fluid is large, radiation takes place in addition to convection, in the present situation radiation has been neglected.

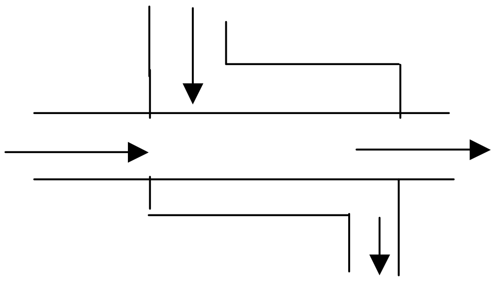

Fig.1 Parallel flow heat exchanger

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DESCRIPTION OF THE PROBLEM

To develop a software we have solved various problems. In every problem analysis initially we have given definition of the problem, then we have given the solution of the problem.

In some problems several iterations have been done. One of those problems for Parallel Flow Heat Exchanger among them are given below,

A parallel flow, concentric tube heat exchanger is used to cool the lubricating oil for a large industrial gas turbine. The flow rate of cooling water (cold fluid) through the inner tube is 0.2(kg/s), while the flow rate of oil (hot fluid) through the outer annulus is 0.1(kg/s).

The oil and water inlet temperature is 100 degree Celsius(c) & 30 degree Celsius(c) respectively. Heat Transfer Surface area is 5.22 square meter. To find the heat exchanger effectiveness, the Length of the tube, the heat transfer rate, the outlet temperature of cold fluid, the outlet temperature of hot fluid, overall heat transfer coefficient, whether the flow is laminar or turbulent, whether the flow fully developed or not. The inner diameter is 25 millimeter & the outer diameter 45 millimeter. The material of the heat exchanger is steel.. The problem has been solved by the following way,

In the problem the following parameters are given: T_{hi} = 100 (C); T_{ci} = 30 (C); m_h = 0.1 (kg/s); m_c = 0.2 (kg/s); A=5.22(m^2); D_o=45(mm); D_i=25(mm).

Schematic

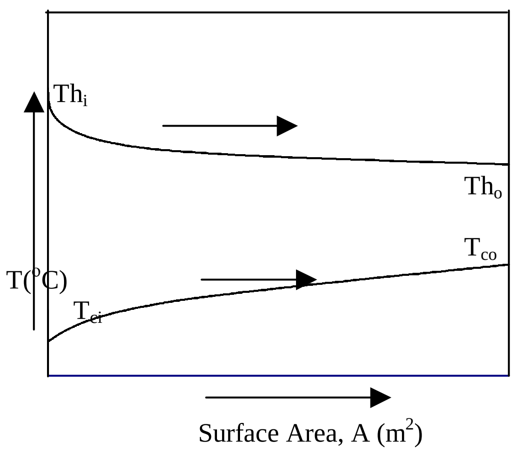

Fig.2: Temperature (T) vs. Heat Exchanger (H/E) surface area (A) curve.

Here

T_{ho} = Outlet temperature of hot fluid (Kelvin or K);
T_{co} = Outlet temperature of cold fluid (Kelvin or K);

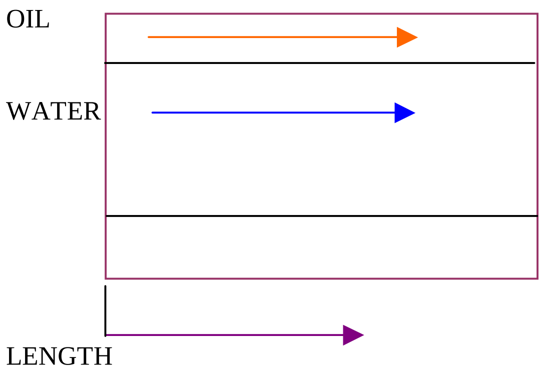

Fig.3 Flow through concentric tube Heat Exchanger

We have followed the following procedure to solve the above problem,

From properties table for unused engine oil[$(T_{hi} + T_{ci})/2.0 = 65(^oc)$ let, $T_{ho}= 65(^oc)$ so ,$T_h = (T_{hi} + T_{ho})/2.0 = (100+65)/2.0 = 82.5(^oc) = 355.5(K)$] , C_{ph} = 2.14 (kJ/kg-K).[By linear interpolation] , $\mu_h = 4.16*10^{-8}$(kg/m-s).[By linear interpolation] , ρ_h = 850.52 (kg/m^3).[By linear interpolation] , k_h =0.1379 (w/m-k).[By linear interpolation] , Pr_h =463.25. [By linear interpolation] , T_h = Average temperature of hot fluid.

From Properties Table For water [Let, $T_{co} = T_{ho}-0.1$,or T_{co} =65.0-0.1, T_{co} =64.90; $T_c = (T_{ci} + T_{co})/2.0 = (30+64.9)/2.0 = 47.45(^oc)$], C_{pc} = 4.174 (kJ/kg-K). [By linear interpolation], $\mu_C = 5.62*10^{-4}$(kg/M-s).[By linear interpolation], ρ_C = 989.25(kg/m^3).[By linear interpolation], k_C =0.642 (w/m-k).[By linear interpolation], Pr_C =3.74 .[By linear interpolation], T_c = Average temperature of cold fluid.

Analysis:_The capacity rate of hot fluid = The mass flow rate of hot fluid* specific heat of hot fluid;

$C_h = m_h * C_{ph}$

$C_h = 0.1$(kilogram/second)$*2.14*10^3$(Joule/kilogram-Kelvin) $=0.214*10^3$(Watt/Kelvin)

Similarly, the capacity rate of cold fluid = The mass flow rate of cold fluid* specific heat of cold fluid;

$C_c = m_c*C_{pc} = 0.2$(kilogram/second)$*4.174*10^3$(Joule/kilogram-Kelvin) $=0.8348*10^3$(Watt/Kelvin)

Since, $C_c > C_h$ So, here C_h is the minimum heat capacity rate and engine oil (Hot fluid) is the minimum fluid.

$C_{min} = 0.214*10^3$(Watt/Kelvin)
$C_{max} = 0.8348*10^3$(Watt/Kelvin)
From table ,for D_i=25 mm, t=3.4mm;
ID=D_i=25 mm and OD= D_i+t=25+3.4=28.4mm;
$M_C = M_{CT}$=o.2 (kg/s) and $M_h = M_{hT}$=o.1 (kg/s);
As cold fluid h_C is not given;
$Re_C = (4*M_C)/(\mu_C*D_i*\pi)$
$=(4*0.2)/(5.62*10^{-4}*25*10^{-3}*3.14) =18198.36$;
$L=A/(\pi*OD) =5.22/(\pi*28.4*10^{-3})=58.51$m
$l_C = L/D_i = 58.51/(25*10^{-3})=2340.25$m
So, Re_C>6000(Turbulent Flow) and l_C>60(Long Duct)
$Nu_C = 0.023*R_{ec}^{0.8}* Pr^{0.33} = 90.70$
$h_c = (Nu_C* k_c)/ D_i = 2328.23$(W/m^2-k)
As hot fluid h_h is not given,
$Re_h = (4*M_h)/(\mu_h*(D_o + D_i) *\pi) = 2925.5$
As, Re_h>6000 and l_h>60
$Nu_h = 0.023*R_{eh}^{0.8}* Pr^{0.33} = 335.94* 10^3$
Now, $T_f = (T_h + T_c)/ 2.0 = 65(^0C)$
As Material is steel, from table for T_f= 65(^{0}C),
k= 43(W/mk)
$h_u = (Nu_h* k_h)/ (D_o - D_i) = 1.56*10^6$ (W/m^2-k)
For Water, Fouling Factor, R_i =0.002 (m^2-k/W)
For Engine Oil, Fouling Factor, R_o =0.0009 (m^2-k/W)
$U=1/(1/ h_h)+R_o +(OD/k)*\ln(OD/ID)+ (R_i*OD)/ID+OD/(h_c *ID)$
U=174.07(W/m^2-k)
Now, $NTU=(U*A)/ C_{min} = 4.25$
$\varepsilon=(1-e^{[-NTU(1-c)]})/ ((1-c)*e^{[-NTU(1-c)]})=96.81\%$
$q=\varepsilon\, C_{min} (T_{hi} - T_{ci})=14.50*10^3$ (Watt)
$T_{ho} = T_{hi} - (q/(m_h *C_h))=77.23$(Degree Celsius)
$T_{co} = T_{ci} + (q/(m_c *C_c))=47.37$(Degree Celsius)
Now, $T_{h(N)} = (T_{hi} + T_{ho})/2.0=38.69$(Degree Celsius)
$T_{c(N)} = (T_{ci} + T_{co})/2.0=66.15$(Degree Celsius)
As, $|T_{h(Present)} - T_{h(Previous})>1$ and $|T_{c(Present)} - T_{c(Previous})>1$

So we can approach to the final value by following the above procedure taking $T_h = T_{h(N)}$ and $T_c = T_{c(N)}$

Assumptions

In problem solving we have assumed that Negligible heat loss to the surroundings, Negligible kinetic energy (K.E.)& potential energy (P.E.) changes, Constant properties, Negligible tube wall thermal resistance & fouling factors and Fully developed condition (Overall heat transfer coefficient (U) independent of length (x).

FLOWCHART

The general approaches taken in the mathematical problem solving are summarized in the flow chart given below,

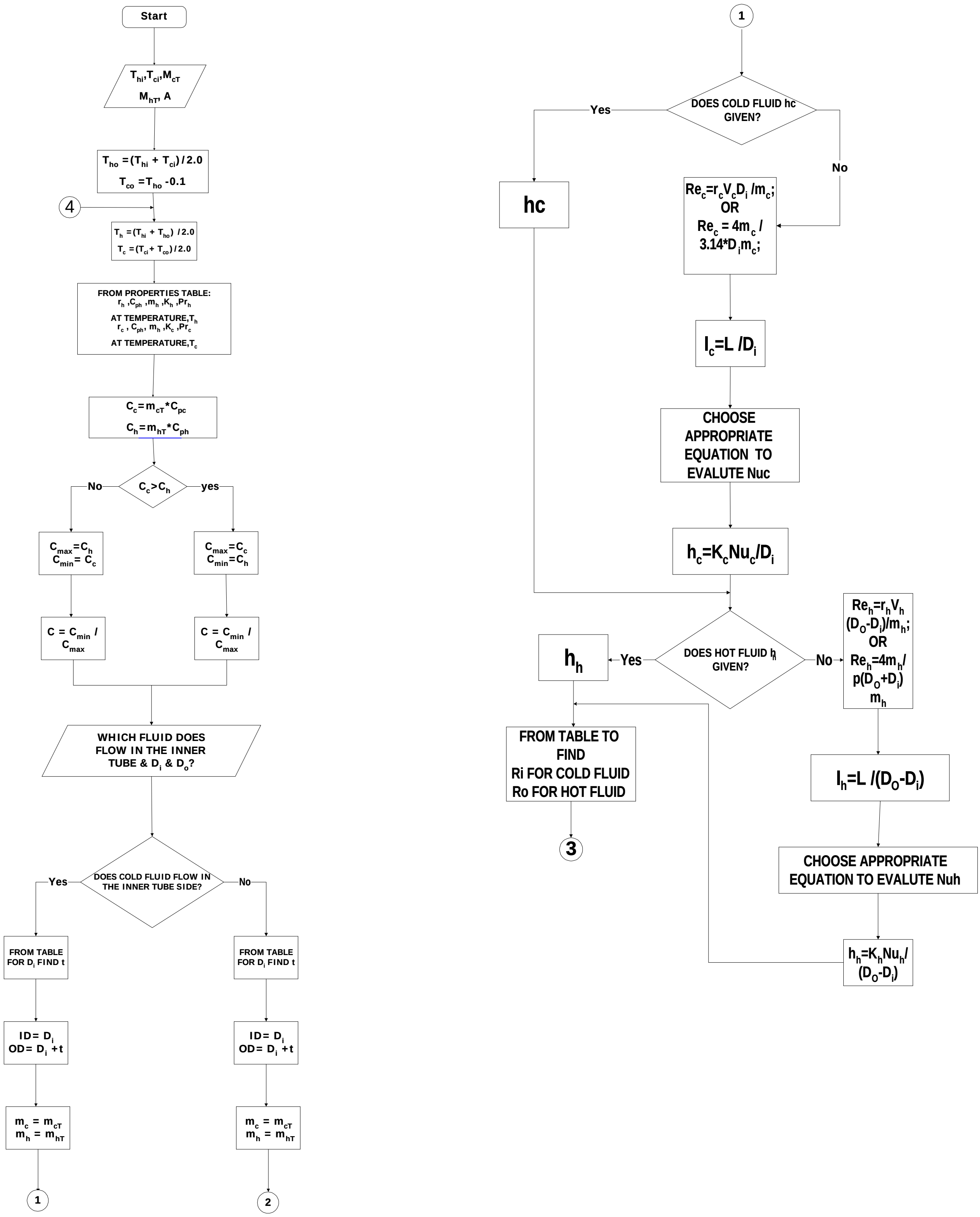

Fig. 4 Flow Chart (I)

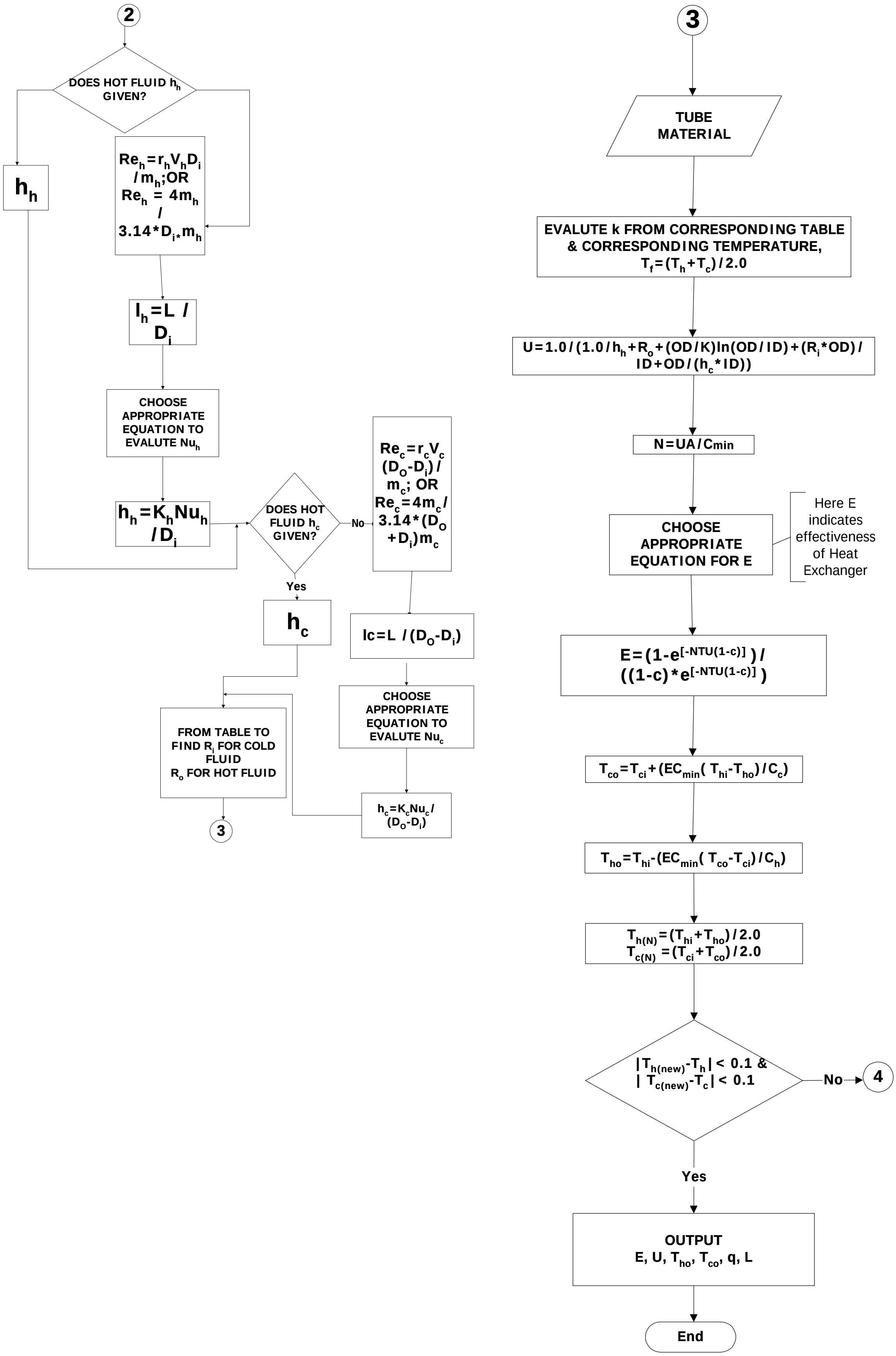

Fig. 5 Flow Chart (II)

COMPUTER PROGRAM

A computer program has written to find out the various parameter of parallel and counter flow heat exchanger. Language "C" is used to develop software for design of counter and parallel flow heat exchanger. Manual calculation for a particular problem is done & then the calculated value is compared with the output of the software for that particular problem for justification of the software.

RESULT AND CONCLUSION

For the problem described above, the following results can be found out by manual calculation and the calculated values are compared with the output of the software for that particular problem. The results are like that:

Parameter	Hand Calculation(for 1 Iteration)	Program Output(For 1 Iteration)
Overall Heat Transfer Co-efficient(W/m^2k)	147.07	203.16
Heat Exchanger Effectiveness	0.96	0.99
Heat Transfer rate(Watt)	14500	14990
Length of Heat Exchanger(meter)	58.51	58.54
Outlet Temperature of hot fluid(degree Celsius)	77.23	85.35
Outlet Temperature of cold fluid (degree Celsius)	47.37	41.23

By this Software it can be possible to approach to final value without doing minimum 5 to 7 steps iteration manually. The above problem has been solved without knowing the values of outlet temperature of oil and water and without knowing the Reynolds number and length of tube and Nusselt number and Heat Transfer Coefficient of both fluid and finally without knowing the values of overall heat transfer coefficient and values of fouling factor. The various fluid property values can be found out from table by liner interpolation. So it is not needed to provide various fluid properties values.

NOMENCLATURE

A = The heat exchanger (H/E) surface area (square meter or m^2);
C_{pc}= Specific heat of cold fluid (joule/kilogram-Kelvin or j/kg-k);
C_{ph}= Specific heat of hot fluid (joule/kilogram-Kelvin or j/kg-k);
C_h= The capacity rate of hot fluid= The mass flow rate of hot fluid * specific heat of hot fluid (watt/Kelvin or w/k);
C_c= The capacity rate of cold fluid = the mass flow rate of cold fluid * specific heat of cold fluid (watt/Kelvin or w/k);
C_{min}= Minimum heat capacity rate; C_{max}= Maximum heat capacity rate;
C= The ratio of minimum heat capacity rate & maximum heat capacity rate;
D_i= Diameter of the inner tube (meter or m);
ID= Inner diameter of the tube; incase of shell & tube heat exchanger (meter or m);
OD= Outer diameter of the tube; incase of shell & tube heat exchanger (meter or m);
ID= Inner diameter of the tube; incase of shell & tube heat exchanger (meter or m);
OD= Outer diameter of the inner tube; incase of parallel & counter flow heat exchanger (meter or m);
h_h= Heat transfer coefficient for hot fluid (watt/square meter-Kelvin or w/m^2-k);
h_c= Heat transfer coefficient for cold fluid (watt/square meter-Kelvin or w/m^2-k);
h_c= Average unit thermal convective conductance, (watts/m^2. K.);
K_h = Thermal conductivity of hot fluid (watt/ meter-Kelvin or w/m-k);
K_c = Thermal conductivity of cold fluid (watt/ meter-Kelvin or w/m-k);
K = Thermal conductivity of any material (watt/ meter-Kelvin or w/m-k);
L= Length of the inner tube or annulus (m);
$L_{(N)}$ OR $L_{(NEW)}$ = New length of the tube (m);
$L_{(N)}$ OR $L_{(NEW)}$ = New length of the inner tube or annulus (m);
Nu_c= Nusselt number for cold fluid; Nu_h= Nusselt number for hot fluid;
M_h= Mass flow rate of hot fluid (kilogram/second or kg/s);
M_{hT}= Total mass flow rate of hot fluid (kilogram/second or kg/s);
M_c= Mass flow rate of cold fluid (kilogram/second or kg/s);
M_{cT}= Total mass flow rate of cold fluid (kilogram/second or kg/s);
NTU OR N= The number of transfer unit;
q OR Q= The actual heat transfer rate (watt or w);
R_o= Fouling resistance for hot fluid (square meter-Kelvin/ watt/ or m^2-k/w);
R_i= Fouling resistance for cold fluid (square meter-Kelvin/ watt/ or m^2-k/w);
R_f= Fouling resistance (square meter-Kelvin/ watt/ or m^2-k/w);
T_{hi} = Hot fluid inlet temperature (Kelvin or k);
T_{ci} = Cold fluid inlet temperature (Kelvin or k);
T_{ho} = Hot fluid outlet temperature (Kelvin or k);
T_{co} = Cold fluid outlet temperature (Kelvin or k);
T_h = Average hot fluid temperature (Kelvin or k);
T_c = Average cold fluid temperature (Kelvin or k);
$T_{h(NEW)}$ OR $T_{h(N)}$= New average hot fluid temperature (Kelvin or k);
$T_{c\ (NEW)}$ OR $T_{c(N)}$= New average cold fluid temperature (Kelvin or k);

T_f= Film temperature of hot & cold fluid; (Kelvin or k);
t= Thickness of tube, incase of shell & tube heat exchanger (meter or m);
U OR U_h= Overall heat transfer coefficient (watt/square meter-Kelvin or w/m^2-k);
ε(Epsilon) or E= The effectiveness of the heat exchanger (H/E);
ρ_c or r_c =Density of cold fluid (kilogram/cubic meter or kg/ m^3);
ρ_h or r_h = Density of hot fluid (kilogram/cubic meter or kg/ m^3);
μ_c or m_c = Viscosity of cold fluid (kilogram/ meter-second or kg/m-s);
μ_h or m_h = Viscosity of hot fluid (kilogram/ meter-second or kg/m-s);
Δ_{min}= Temperature difference of the minimum fluid in the heat exchanger;
Δ_{max}[delta maximum]= Maximum temperature difference in the heat exchanger;
Pr_h= Prandtl number for hot fluid; Pr_c= Prandtl number for cold fluid;
Re_c= Reynolds number for cold fluid; Re_h= Reynolds number for hot fluid;

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