HEAT TRANSFER THROUGH A SUBMERGED HELICAL COIL IN AN AGITATED VESSEL STEADY STATE

AIM

The objective of the experiment is to determine coil side overall heat transfer coefficient as a function of agitator speed (R.P.M.).

APPARATUS

- An insulated cylindrical vessel fitted with an electrical heater, a cooling coil and a variable speed fractional horse power motor with an agitator for agitation of liquid in the vessel
- Cold fluid circulations pump with speed variation mechanism; Cold fluid circulation pipe line containing a rotameter to measure the flow rate of the cold fluid
- Digital temperature indicators to measure inlet and outlet temperatures of cooling water with accuracy of 0.1°C
- Digital temperature indicator cum controller to measure as well as control temperature of liquid in the vessel in which cooling coil is immersed

THEORY

Coils afford one of the cheapest means of obtaining heat transfer surface in the reactors. The advantage of the coils is its surface can be adjusted as per requirement. Coils are usually made by rolling lengths of copper, stainless steel or alloy tubing into helix or double helix. Inlet and outlet connections for these coils are conveniently located side by side. Helical coils of either type are frequently installed in vertical cylindrical vessel with or without an agitator. Free space is generally provided between the coil and the vessel wall which makes the entire surface of the coil available for heat transfer. When such coils are used with mechanical agitation agitator, the vertical axis of the agitator usually coincides with the axis of the cylindrical vessel in which the coil is installed. Very limited data are available in literature for prediction of heat transfer coefficient from submerged coil to the surrounded fluid in natural convection. However, the heat transfer coefficients in natural convection are undoubtedly lower. A mechanical agitation can improve the convective heat transfer coefficients in agitated vessel and coil. Chilton, Drew and Jebems have published an excellent correlation on both jacketed vessel and coils under batch and steady state conditions with modified Reynolds number for mechanical agitation. The deviations on runs with water were highest for the fluids tested, which included lube oils and glycerol, and were in some instances off by 17.5%. Their correlation for heat transfer to fluids in the vessel with mechanical agitation heated or cooled by submerged coils is

$$\frac{h_c * d_c}{K} = 0.87 * (L^2 * N * \rho/\mu)^{2/3} * (C_p * \mu/K)^{\frac{1}{3}} * (\mu/\mu_W)^{0.14} \qquad [1]$$

Where

h_c = Heat transfer coefficient between fluid and coil surface $\frac{\text{KJ}}{\text{sec}*\text{m}^2*\text{K}}$

d_c= Coil diameter (m)

L= Agitator diameter (m)

N= Agitator speed $\frac{\text{Rev}}{\text{sec}}$

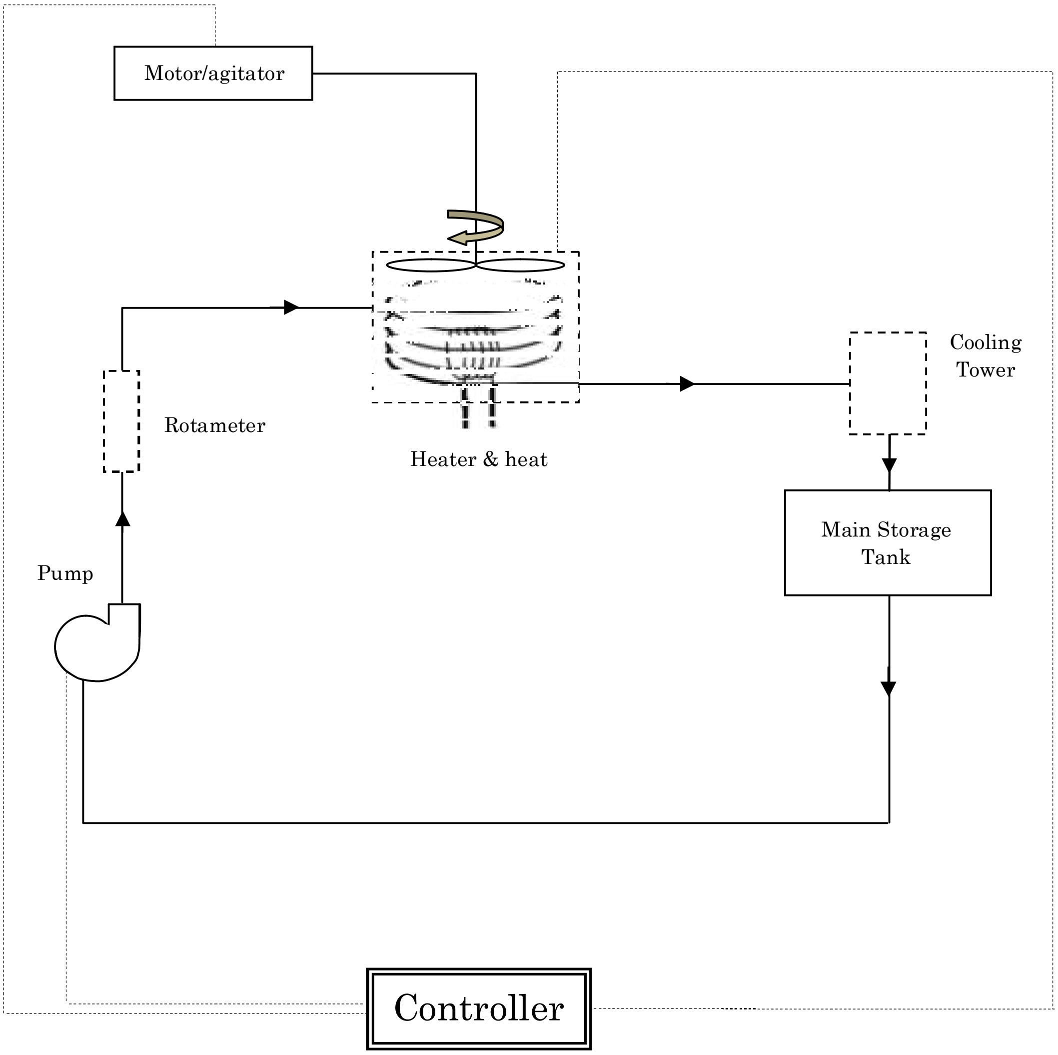
ρ= Density of fluid in the vessel ($\frac{\text{Kg}}{\text{m}^3}$)

K= Thermal conductivity of fluid in vessel($\frac{\text{KJ}}{\text{sec}*\text{m}^2*\text{K}}$)

PROCEDURE:

1) Fill the cylindrical vessel with given oil till the cooling coil is completely covered.
2) Start the agitator motor and adjust the speed at desired level by making use of its speed regulator.
3) Connect the inlet of the cooling water circulation pump to cooling water supply and start the pump. Adjust the flow rate of cooling water using rotameter and speed regulator of the pump. Keep hot and cold fluid flow rate constant throughout the entire experiment.
4) Switch on the heater and set the desired temperature on the controller so as to keep temperature of liquid in the vessel at the constant level. Throughout the given set of readings keep this temperature constant.
5) Due to heating, the outlet temperature of water flowing through coil would rise. At steady state inlet and outlet temperature of cooling water and the temperature of the liquid in the vessel (outside the cooling coil) would attain a constant value. After steady state is attained note down inlet and outlet temperatures of cooling water as well as its flow rate. Also note down the temperature of liquid in the vessel.
6) Repeat step (5) for at least 10 different speeds of the agitator.
7) Repeat whole experiment for different flow rates also.

SCHEMATIC FLOWSHEET



Heat transfer in agitated vessel

OBSERVATIONS

1) Length of the coil immersed in the agitated vessel (L)	1.6	m
2) Inside diameter of the coil tube (d_i)	9.45	mm
3) Outside diameter of the coil tube (d_o)	12.7	mm

4) Outside area of coil available for heat transfer=(π*d_o*L) = 1.156 mm^2

5) Temperature of fluid in the vessel during the test run (T) = 60-70 °C

6) Coil Diameter = 19.05cm

7) Conductivity of tube (Stainless Steel) = 43.5 W/m-k

OBSERVATION TABLE

Obs. No.	**Inlet temperature of cold fluid T_1(°C)**	**Output temperature of cold fluid T_2(°C)**	**Flow rate of cold fluid Q_{Water}(LPH)**	**R.P.M. of agitator motor N**
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				

15				

CALCULATIONS

1) Mass flow rate of water ($\dot{m}$) = (Volumetric flow rate in LPH*ρ_{water})=………..…..=………….$\frac{Kg}{sec}$

2) Amount of heat transferred $Q=\dot{m}*C_p*(T_2-T_1)$=………………….…=……………..………..…$\frac{KJ}{sec}$

3) Log mean temperature difference(LMTD) ΔT_{lm}= $\frac{(T-T_1)-(T-T_2)}{\ln\frac{(T-T_1)}{(T-T_2)}}$=………………………………°C

4) Overall heat transfer coefficient (U)
$U = \frac{Q}{A*\Delta T_{lm}}$=……………..=…………………………$\frac{KJ}{sec*m^2*K}$

5) Velocity of water through tube of coil
$V=\frac{Q_{water}*1000}{3600*\frac{\pi}{4}(d_i)^2}$=…………………=………………………$\frac{m}{sec}$

6) Reynolds number of water through tube $N_{Re}=\frac{d_i*V*\rho}{\mu_{water}}$=………………..=…………………..

7) Prandtl number of water $N_{Pr}=\frac{C_p*\mu}{K}$=……………………………….=………………………………

8) Coil inside heat transfer coefficient $h_i=0.023(N_{Re})^{0.8}(N_{Pr})^{0.4}[1+3.5*\left({d_i}/{d_{coil}}\right)]\frac{K}{d_i}$
=…………………………………………=…………………………………………………$\frac{KJ}{sec*m^2*K}$

9) Outside film heat transfer coefficient $\frac{1}{h_o}=\frac{1}{U}-\frac{d_o}{d_i*h_i}-\frac{\Delta x}{K}$
=……………..=………………………………..
Or h_o=………………………..=……………………………….$\frac{KJ}{sec*m^2*K}$

μ = Viscosity of fluid in the vessel $\frac{Kg}{m*sec}$

μ_w= viscosity of fluid in vessel at coil wall temperature $\frac{Kg}{m*sec}$

CALCULATION TABLE

Obs. No.	**Amount of heat transferred** Q $\frac{KJ}{sec}$	**LMTD** ΔT_{lm} °C	**Overall heat transfer coefficient** U $\frac{KJ}{sec*m^2*K}$	**Inside heat transfer coefficient** $h_i \frac{KJ}{sec*m^2*K}$	**Outside heat transfer coefficient** $h_o \frac{KJ}{sec*m^2*K}$
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It can benoticed from equation [1] that for the given coil and given fluid in the vessel heat transfer coefficient from liquid in the vessel to the coil wall will be proportional to $N^{2/3}$. As far as the inside film heat transfer coefficient for the coil is concerned because of increased turbulence due to circulatory path the film heat transfer coefficient will be greater than that calculated for straight pipe. McAdams suggests that $h_{coil}=h_{straight\ tube}\ [1+(\frac{3.5\ d_{tube}}{d_{coil}})]$ where $h_{straighttube}$is given by Dittus-Boelter or Sieder-Tateequations depending upon the flow regime in the tube. Once the inside heat transfer coefficient of the coil is calculated, the outside heat transfer coefficient can be calculated from the equation given below.

$$\frac{1}{U_o} = \frac{1}{h_o} + \frac{R_o}{K} Ln(\frac{R_o}{R_i}) + \frac{1}{h_i}(\frac{R_o}{R_i}) \qquad [2]$$

Since outside heat transfer coefficient is proportional to $N^{2/3}$ graph of log (N) vs log (h_o) should have a slope of 2/3

GRAPHS: Plot graph of log (h_i) vslog (N)

Plot graph of log (h_i) vslog (Flow Rate)

RESULTS:

CONCLUSION

FURTHER READING

Fundamental of Heat and Mass Transfer by Frank P. Incropera and David P. Dewitt, Chapter 3.

TEACHING ASSISTANT