HEAT TRANSFER IN AGITATED VESSEL

AIM

(a) To determine coil side overall heat transfer coefficient \((h)\) for different agitation speeds in given agitated vessel.

(b) Determination of coil side heat transfer coefficient while transferring heat from an agitated liquid in a vessel to cold water flowing through the coil, submerged in the vessel under steady state conditions.

APPARATUS

1. An agitated vessel fitted with an electrical heater, a cooling coil and a variable speed agitator with a suitable blade for agitating liquid in the vessel.
2. Two digital thermometers with 0.1 °C accuracy for measuring the inlet and outlet temperatures of the cooling water circulating through cooling coil.
3. Liquid in glass thermometer to measure the bath temperature.
4. Variable speed-pump to circulate cooling water through cooling coil at a constant flow rate.
5. Stopwatch and a bucket to measure the flow rate of cooling water.
6. Tachometer to measure the speed of agitator

PROCEDURE

1. Fill the given agitated vessel with the given test liquid to about 85-90 % of its capacity.
2. Start the agitator motor and set its speed at the desired r.p.m. by manipulating its speed regulator.
3. Connect the inlet of the cooling water circulation pump to cooling water supply line, and start the pump. Adjust the flow rate of the cooling water at the desired level by adjusting its speed regulator.
4. Start the heaters in the agitated vessel and set the desired temperature on the thermostat, so as to keep temperature in the agitated vessel at a constant level. Throughout the given set of readings keep this temperature at this level.
5. Allow sufficient time for the steady state to be attained. After steady state is attained note down inlet and outlet temperatures of the cooling water. Also measure the flow rate of the cooling water.

6. Repeat step (5) for different flow rates of the cooling water keeping the agitation speed constant. [Alternatively the experiment can be carried out keeping flow rate of cooling water constant and changing the speed (r.p.m.) of the agitator motor.]

(* Note: Students must ensure that a ‘steady state’ (in terms of temperatures as well as flow rate) is attained before noting the observation readings)

THEORY

Tube coils afford one of the cheapest means of obtaining heat transfer surface. They are usually made by rolling lengths of copper, steel or alloy tubing into helixes or double helix coils in which inlet and outlets are conveniently located side by side. Helical coils of either type are frequently installed in vertical cylindrical vessels with or without an agitator, although free space is provided between the coil and the vessel wall for circulation. When such coils are used with mechanical agitation, the vertical axis of the agitator usually corresponds to the vertical axis of the cylinder. However very limited data are available for predicting heat transfer coefficient from submerged coil to the surrounding fluid in natural convection although the coefficients are undoubtedly lower. A mechanical agitation can improve the heat transfer coefficient between fluid in the agitated vessel and the coil. Chilton, Drew and Jebens have published an excellent correlation on both jacketed vessels and coils under batch and steady-state conditions and employing ‘j’ factor with a Reynolds number modified for mechanical agitation. Although much of the work was carried out on a vessel 1.0 feet in diameter, checks were also obtained on vessels five times those of experimental setup. 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 vessel with mechanical agitation heated or cooled by submerged coils is as follows,
\[
\frac{h_c}{D_j K} = 0.87 \left[ \frac{L^2 N \rho}{\mu} \right]^{2/3} \left[ \frac{C_p \mu}{K} \right]^{1/3} \left( \frac{\mu}{\mu_w} \right)^{0.14}
\]  

where \( D_j \) = inside diameter of the agitated vessel \([m]\)

\( h_c \) = coil side heat transfer coefficient \([Kcal/hr m^2 \circ C]\)

\( L \) = agitator diameter \([m]\)

\( N \) = agitator speed \([\text{rev/sec}]\)

\( \rho \) = density of fluid in the vessel \([\text{kg/m}^3]\)

\( K \) = thermal conductivity of fluid in the vessel \([\text{Kcal/hr m} \circ C]\)

\( \mu \) = viscosity of fluid in the vessel \([\text{kg/m hr}]\)

\( \mu_w \) = viscosity of fluid in the vessel at coil wall temp. \([\text{kg/m hr}]\)

It can be noticed from equation [1] that for the given vessel with the given fluid and coil the heat transfer coefficient will be proportional to \( N^{2/3} \).

As far as the inside coefficient for the coil is concerned because of the increased turbulence due to circulatory path the heat transfer coefficient will be greater than those calculated for straight pipes. For ordinary use McAdams suggests that straight tube equations such as Dittus-Boelter equation or Sider-Tate equation can be used, when the value of ‘h’ so obtained is multiplied by \( 1 + 3.5 \left[ \frac{D}{D_C} \right] \) where \( D \) is the inside diameter of the tube and \( D_C \) is the diameter of the coil helix.

**GRAPHS**

Plot the graph of \( \frac{1}{U} \) versus \( \frac{1}{V^{0.8}} \) on the linear scale. Intercept of this graph will give the value of \( \frac{1}{h_0} \) in case of constant agitator speed experiment. The intercept of this graph will give the value of \( 1/h_0 \). For the experiment with constant cooling water flow rate and variable agitator speed plot the graph of \( \frac{1}{U} \) versus \( \frac{1}{N} \) on a log-log graph. Slope of this graph should be around 2/3.
RESULTS

Comment on the nature of the graph obtained.

CONCLUSION
OBSERVATIONS

1) Temperature of liquid in the agitated vessel (T) ________ °C

2) Length of the coil immersed in the agitated vessel (L) ________ m

3) Inside diameter of the coil tube (d₁) ________ m

4) Outside diameter of the coil tube (d₀) ________ m

5) Area of coil available for heat transfer = π x d₀ x L = ________ m²

6) Coil helix diameter ________ m

7) Specific heat of water \((C_p)\) ________ Kcal/kg °C

OBSERVATION TABLE

<table>
<thead>
<tr>
<th>Obs. No.</th>
<th>Inlet temperature cooling of water (t_1[^\circ C])</th>
<th>Outlet temperature cooling water (t_2[^\circ C])</th>
<th>Weight of water collected (W) [Kgs]</th>
<th>Time of collection (t) [Sec]</th>
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CALCULATIONS

Specimen Calculation for Reading No. : ________.

1. Mass flow-rate of water (m) = (W/t) x 3600 = _________ kg/hr.
2. Δt = t₂ – t₁ = ___________ °C
3. Q = m x C_p x Δt = ___________ Kcal/hr
4. ΔT₁ = T – t₁ = ___________ °C
5. ΔT₂ = T – t₂ = ___________ °C
6. LMTD (ΔT_{lm}) = (ΔT₁ - ΔT₂)/[ln(ΔT₁/ΔT₂)] = ___________ °C
7. U = Q/(A x ΔT_{lm}) = ___________ Kcal/hr. m². °C

RESULT TABLE

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<tr>
<th>Obs. No.</th>
<th>Amount of heat transferred Q [Kcal/hr]</th>
<th>Log mean temperature difference [°C]</th>
<th>Overall heat transfer coefficient [Kcal/hr m² °C]</th>
<th>1/U</th>
<th>1/V^{0.8}</th>
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