Design of agitated Heat transfer vessel
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The Dual Shaft Mixer includes an Anchor agitator and a High Speed Disperser. The anchor feeds product into the high speed disperser blade and ensures that the mixture is constantly in motion. The anchor can be provided with scrapers to remove materials from the interior vessel walls to enhance the heat transfer capabilities of the mixer. Both agitators are available for variable speed operation.
Dual Shaft Paste Mixer
Jacked and coil heat transfer agitator vessel
Heat transfer coil in side vessel
Use of baffles
Applications

- Mixing tanks are typically used in the production of viscous fluids such as petroleum, plastics, paints, paper, cosmetics, and food. The mechanical agitation of fluid in these vessels can significantly increase the rate of heat transfer between the process and cooling fluids. Since the 1950s, a number of authors have explored heat transfer for Newtonian fluids in a variety of agitated vessel configurations. There has been a limited amount of research performed, however, for heat transfer to non-Newtonian (power law) fluids.
chemical, food, drugs dyes and other industries
Use for Pharmaceutical Application

S.S. LIMPETD REACTOR - 10 KL
used in chemical and pharmaceutical industries
Petro-Chemical, Polymers, Coatings & Adhesives, Agricultural & General Chemicals, Plastics & Rubber, Food & Beverage Industry.
Homogeneous Batch/Semi-batch Reactions

- Homogeneous batch/semi-batch are the most common reaction type. They can be as simple as adding measured quantities of two or more reactants to a vessel and mixing. Heat is normally removed or added through a jacket, heating mantle or external heat exchanger.
STATEMENT
Calculate the time required to heat 1268 gal. of liquid from 80°F to 180°F in a jacketed, agitated vessel conforming to standard configuration as shown in the figure. The vessel is assumed to be clean, free of fouling films and heated with 212°F steam.
Data Given

Liquid Properties:
\[ \text{Cp} = 0.6 \text{ Btu/(lb) (°F)} \]
\[ k = 0.1 \text{Btu/(hr)(sq.ft)(°F/ft)} \]
\[ \mu = 1000 \text{cp (at80F)} \]
\[ \rho = 60 \text{lb/ft}^3 = 8.02 \text{lb/gal} \]

\text{Cp, k and } \rho \text{ are assumed to be constant}
Steam properties:
\[ h_s = 1000 \text{ Btu/(hr)(sq.ft)(°F)} \]

Vessel Properties:
Wall thickness = 0.125 in
\[ K \text{ of vessel} = 9.4 \text{ Btu/(hr)(sq.ft)(°F/ft)} \]

Eq used for calculating heat transfer coefficient
\[ N_{NU} = 0.73 (N_{RE})^{0.65} (N_{PR})^{0.33} \left( \frac{\mu_w}{\mu_b} \right)^{0.14} \]
Vessel, baffle and impeller ratios for the standard tank configuration—Fig. 10

\[
\frac{D_T}{10}\]

Liquid

surface

Baffle

Driving shaft

Tank wall

\[
H_L = D_T
\]

\[
H_i = D_i
\]

\[
D_i = \frac{1}{3} D_T
\]

6-blade flat-blade turbine impeller
**STEP 1:**

Diameter of the vessel $D_T = 6$ ft.

6-ft diameter agitated vessel conforming to standard configuration as shown in the figure. The vessel is equipped with the 2 ft diameter 6-blade, flat-blade turbine impeller running at 100 rpm.

- Diameter of impeller = 2 ft
- Impeller blade width = 0.5 ft
- Impeller blade height = 0.4 ft
- Baffle width = 0.6 ft
STEP 2:
Inside area of the vessel = \( \pi DL \) (L=D)

\[ = 3.14(6)(6) \]
\[ = 113 \text{ ft}^2 \]
STEP 3: Reynolds number evaluation at 80F, 130F, 180F by using,

\[ \text{N}_{\text{RE}} = \rho N D_i^2/\mu \]

Here, we assume density to be constant over the temperature range.

Viscosity values at different temperatures is;

\[ \mu(80F) = 1000 \text{cp} \] (from table)
\[ \mu(130F) = 270 \text{ cp} \]
\[ \mu(130F) = 84 \text{cp} \]
Viscosity of the liquid for problem as a function of temperature—Fig. 11
Diameter of impeller, \( D_i = 2 \text{ ft} \)

From these values, the Reynolds number is,

\[
N_{RE}(80F) = \frac{(60)(6000)(4)}{(2420)} = 595
\]

\[
N_{RE}(130F) = 2200
\]

\[
N_{RE}(130F) = 7080
\]
STEP 4:
The Prandtl number calculations at 80F, 130F, 180F are,

\[ N_{PR} = \frac{C_p \mu}{k} \]

\[ N_{PR} \text{ (80F)} = (0.6)(2420)/(0.1) = 14500 \]

\[ N_{PR} \text{ (130F)} = 3920 \]

\[ N_{PR} \text{ (180F)} = 1220 \]
**STEP 5:** Approximate the value of inside heat transfer coefficient from given equation;

\[ N_{NU} = h_i \frac{D_T}{k} = 0.73(N_{RE})^{0.65}(N_{PR})^{0.33} \]

substituting the appropriate values into this relationship gives:

- \( h_i(80\text{F}) = 18.4 \frac{\text{Btu}}{\text{F} \cdot \text{hr} \cdot \text{sq.ft}} \)
- \( h_i(130\text{F}) = 27.6 \frac{\text{Btu}}{\text{F} \cdot \text{hr} \cdot \text{sq.ft}} \)
- \( h_i(180\text{F}) = 40.4 \frac{\text{Btu}}{\text{F} \cdot \text{hr} \cdot \text{sq.ft}} \)
**STEP 6:**

The wall temperature from the above heat transfer coefficients are calculated and used to evaluate the viscosity of liquid at vessel wall.

The wall temperature is estimated from the approximate equation:

\[ T_w = T_s - \left[ \frac{(T_s - T_B)}{1 + (h_s A_o / h_i A_i)} \right] \]

here, \( A_o = A_i \)
Solving wall temperature

\[ T_w (at \ T_B = 80F) = 209.6 \ F \]
\[ T_w (at \ T_B = 130F) = 209.8 \ F \]
\[ T_w (at \ T_B = 180F) = 210.7 \ F \]

Viscosity values at different temperatures is;

\[ \mu(209.6F) = 47 \text{cp} \quad \text{(from table)} \]
\[ \mu(209.8F) = 47 \text{cp} \]
\[ \mu(210.7F) = 46 \text{ cp} \]
Viscosity of the liquid for problem as a function of temperature—Fig. 11

Viscosity, $\mu$, cp.

Temperature, $T$, °F.
Calculate the viscosities ratios equals to \( \frac{\mu_w}{\mu_b} \)

- At \( T_B = 80F \) and \( T_W = 209.6F \)
  \( V_{IS} = \frac{47}{1000} = 0.047 \)

- At \( T_B = 130F \) and \( T_W = 209.8F \)
  \( V_{IS} = \frac{47}{270} = 0.174 \)

- At \( T_B = 80F \) and \( T_W = 209.6F \)
  \( V_{IS} = \frac{46}{85} = 0.541 \)
**STEP 7:**

\[ N_{NU} = 0.73(N_{RE})^{0.65}(N_{PR})^{0.33}(\mu_w/ \mu_b)^{0.14} \]

As

\[ N_{NU} = h_i \frac{D_T}{k} \]

\[ h_i(80F) = 38.4 \text{ Btu/(F) (hr) (sq.ft)} \]

\[ h_i(130F) = 42.2 \text{ Btu/(F) (hr) (sq.ft)} \]

\[ h_i(180F) = 46.7 \text{ Btu/(F) (hr) (sq.ft)} \]
**STEP 8:**

\[
\frac{1}{U_i} = \frac{1}{h_i} + \frac{x}{k} + \frac{1}{h_s}
\]

- \(h_i\) = as calculated in step 7
- \(x\) = 1/8 in = 0.0104 ft
- \(K\) = 9.4 Btu/(hr)(sq.ft)(F/ft) for the vessel wall
- \(h_s\) = 1000 Btu/(F)(hr)(sq.ft)
- \(U_i(T_b=80\ \text{F})\) = 0.0281 Btu/(F)(hr)(sq.ft)
- \(U_i(T_b=130\ \text{F})\) = 38.7 Btu/(F)(hr)(sq.ft)
- \(U_i(T_b=180\ \text{F})\) = 42.5 Btu/(F)(hr)(sq.ft)
Ui at different time intervals

Tb(F)

Ui
Evaluate heat-transfer coefficients for problem at the several temperature intervals—Fig. 12

Over-all heat-transfer coefficient, \( U_i \) (Btu.)/(hr.)(sq. ft.)(°F./ft.)

\[
\begin{align*}
&\text{Batch temperature, } T_b, \degree F. \\
&80 \quad 100 \quad 120 \quad 140 \quad 160 \quad 180 \quad 200
\end{align*}
\]

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STEP 9:
Time taken to heat the liq over each temp increment is calculated by this formula

\[ T_{hr} = \left( \frac{MC_P}{U_i A_i} \right) \ln \left[ \frac{T_s - T_i}{T_s - T_f} \right] \]

Liquid mass = \( \pi \left( \frac{D_t^2}{4} \right) (H_t) (\rho) \)
\[ = \pi \left( \frac{36}{4} \right) (6)(60) \]
\[ = 10180 \text{ lb} \]
Time reqd to heat the nass from 80 to 100 F is calculated as

\[ t(80-100F) = \frac{(10180)(0.6) \ln (212-80)}{(36.15)(113)} \left( \frac{212-100}{212-100} \right) \]

\[ = 0.242 \text{ hr} \]

\[ t(100 -120F) = 0.283 \text{ hr} \]
\[ t(120 -140F) = 0.340 \text{ hr} \]
\[ t(140-160F) = 0.439 \text{ hr} \]
\[ t(160-180F) = 0.630 \text{ hr} \]

Total Time = 1.934 hr
Approximate method:

\[ T_{hr} = \left( \frac{M C_p}{U_i A_i} \right) \ln \left[ \frac{T_s - T_l}{T_s - T_f} \right] \]

\[ T_{hr} = \left( \frac{10180 \times 0.6}{38.7 \times 113} \right) \times \ln \left[ \frac{212 - 80}{212 - 180} \right] \]

\[ T_{hr} = 1.981 \text{ hr} \]

Value differ by only 2.4%