<u>Step 1:</u> Determine the Specific Gravity and Density of the Fuel Oil

The American Petroleum Institute (°API) gravity scale relates a petroleum fluid's density to that of water at standard conditions:

$$°API = \frac{141.5}{SG_{15.6°C}} - 131.5$$

Substituting 28°API:

$$28°API = \frac{141.5}{SG_{15.6°C}} - 131.5$$

$$SG_{15.6°C} = 0.8871$$

Using standard water density (ρ_{water} = 1000 kg/m^3), the absolute density (ρ_{oil}) of the fuel oil is:

$$\rho_{oil} = (0.8871)\left(1000\ \frac{kg}{m^3}\right) = 887.1\ \frac{kg}{m^3}$$

<u>Step 2:</u> Convert Volume Flow Rate to Mass Flow Rate (m)

The fuel oil enters at a volumetric rate of 1100 gal/hr. Using standard conversions (1gal = 3.785 L = 3.785 x 10^{-3} m^3)

$$V = \left(1100 \frac{gal}{hr}\right)\left(\frac{3.785\ x\ 10^{-3}\ m^3}{1\ gal}\right)\left(\frac{1\ hr}{3600\ s}\right) = 0.0011566\ \frac{m^3}{s}$$

Now, compute the mass flow rate (m):

$$m = \rho_{oil}V = \left(887.1\ \frac{kg}{m^3}\right)\left(0.0011566\ \frac{m^3}{s}\right) = 1.026\ \frac{kg}{s}$$

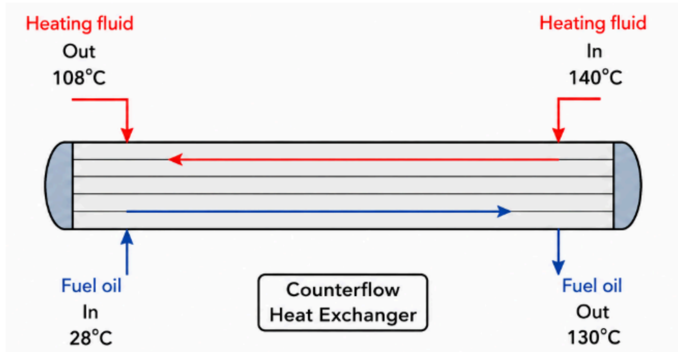
<u>Step 3:</u> Calculate the Heat Transfer Rate Required (Q)

The total thermal capacity rate absorbed by the fuel oil to raise its temperature from 28°C to 130°C is:

$$Q = mC_p\left(T_{oil,\ out} - T_{oil,\ in}\right) = \left(1.026\ \frac{kg}{s}\right)\left(2.4 \frac{kJ}{kg-K}\right)(130 - 28)°C$$

Q = 251.16 kW

Step 4: Compute the Log Mean Temperature Difference (LMTD)



For a counterflow heat exchanger, we define the terminal temperature differences at both ends:

- **End 1:** $\theta_1 = T_{hot,\,in} - T_{cold,\,out}$ = 140°C - 130°C = 10°C
- **End 2:** $\theta_2 = T_{hot,\,out} - T_{cold,\,in}$ = 108°C - 28°C = 80°C

Applying the integrated LMTD equation:

$$LMTD = \frac{\theta_2 - \theta_1}{ln\left(\frac{\theta_2}{\theta_1}\right)} = \frac{80 - 10}{ln\left(\frac{80}{10}\right)} = 33.66°C$$

Step 5: Convert Overall Heat Transfer Coefficient (U) to Compatible Units

Convert U from imperial-metric hybrid units to standard SI units (kW/m^2-K):

$$U = \left(430\ \frac{kcal}{hr{-}m^2{-}K}\right)\left(\frac{4.1868\ kJ}{1\ kcal}\right)\left(\frac{1\ hr}{3600\ s}\right) = 0.500\frac{kW}{m^2{-}K}$$

Step 6: Compute the True Required Surface Area (A)

$$Q = UA(LMTD)$$

$$251.16\ kW = \left(0.500\frac{kW}{m^2{-}K}\right)A(33.66°C)$$

A = 14.92 m^2

The terminal temperature difference at the hot end is tight (θ_1 = 10°C). A counterflow arrangement handles these tight approaches smoothly. In a parallel flow layout, heating a cold fluid up to 130°C using a hot fluid that exits at 108°C is thermodynamically impossible. Counterflow configurations bypass this limitation, maximizing thermal efficiency.