Tutorial 2

1.An evaporator is to be fed with 10,000 kg/hr of a solution having 1% solids. The feed is at 38°C. It is to be concentrated to 2% solids. Steam is freezing at a total enthalpy of 640 kcal/kg and the condensate leaves at 100°C. Enthalpy of feed are 38.1 kcal/kg, product solution is 100.8 kcal/kg and that of the vapour is 640 kcal/kg. Find the mass of vapour formed per hour and the mass of steam used per hour.

Ans:

Mass of vapour

Feed = 10,000 kg/hr @ 1% solids Solids = 10,000 x 1/100 = 100 kg/hr Mass_liquor = 10,000/2 = 5000 kg/hr *(Note: This likely represents the mass of the final thick liquor)* Vapour formed = 10,000 - 5000 = 5000 kg/hr Thick liquor = 5000 kg/hr

Steam consumption:

Enthalpy of feed = 10,000 x 38.1 = 38.1 x 10^4 kcal Enthalpy of the thick liquor = 5000 x 100.8 = 5.04 x 10^5 kcal Enthalpy of the vapour = 5000 x 640 = 32,00,000 kcal

Heat Balance:

Heat input by steam + Heat in feed = Heat out in vapour + Heat out in thick liquor [M x (640-100) + 38.1 x 10,000] = (32,00,000 + 5,04,000) M x 540 = 3,323,000 Mass of steam required = 3,323,000 / 540 = 6153.7 kg/hr

2.The Energy-production data (for Jan–June, 2011) of an industry follows a relationship:
Calculated energy consumption = 0.5 P + 220
A Waste heat recovery system was installed at end of June 2011 and further data was gathered up to December 2011. Using CUSUM technique, calculate energy savings in terms of ton of oil equivalent (toe) and the reduction in specific energy consumption achieved with the installation of waste heat recovery system.
The plant data is given in the table below:

2011-Month	Actual Energy Consumption, toe/month	Actual production, ton/month
Jan	620	760

Feb	690	760
Mar	635	960
Apr	598	790
May	628	830
June	600	830
July	590	760
Aug	605	820
Sep	670	840
Oct	582	920
Nov	512	750
Dec	540	670

Ans:

The table below gives values of actual energy consumption vs. calculated (predicted) energy consumption from July – Dec. 2011.

Specific energy consumption monitored vs. predicted for each month. The variations are calculated and the Cumulative sum of differences is calculated from Jan–June-2011.

2011-Month	**Eact.**	**Ecal (0.5P + 220)**	**Eact - Ecal**	**CUSUM**
July	590	600	-10	-10
Aug	605	630	-25	-35

Sept	670	690	-20	-55
Oct.	582	595	-13	-68
Nov.	512	525	-13	-81
Dec.	540	555	-15	-96

Energy savings achieved = 96 toe

Reduction in specific energy consumption = 96 / 4550 = 0.021 toe/tonne of production

(Production for 6 months = 760 + 820 + 840 + 750 + 610 + 670 = 4550 tonnes)

3.An industrial facility operating 24 hours a day throughout the week consumes 2.8 million kWh of electricity in April. The demand varied between 3000 kW and 5500 kW during that month. The electrical load supplied by the utility has fluctuated between 2000 kW and 6400 kW during the previous 11 months. The demand billing for a given month is based on 50 percent of peak demand in the previous 11 months. The unit price of electricity is \$0.12/kWh, and the demand charge is \$13/kW. Determine:

(a) the load factor

(b) the consumption charge

(c) the demand charge for the month of April.

Solution

(a) The total operating hours in the month of April is:

Operating hours = (24 h/day)(30 days/month) = 720 h

The average load (demand) during this month is:

Average demand = Amount of electricity consumed / Operating hours

$= (2.8 \times 10^6 \text{ kWh}) / 720 \text{ h} = 3889 \text{ kW}$

The load factor is defined as the ratio of the average load to the peak load. Therefore,

Load factor = Average demand / Peak demand

= 3889 kW / 5500 kW = 0.707

(b) The amount of money the facility pays for electricity consumption is:

Electricity charge = Electricity consumption × Unit price of electricity

$= (2.8 \times 10^6 \text{ kWh}) \times (\$0.12/\text{kWh})$

= $336,000

(c) The demand billing for a given month is based on 50 percent of peak demand in the previous 11 months. The peak demand for this period is 6400 kW, and 50 percent of this value is 3200 kW. The amount of money the facility pays for its demand profile becomes:

Demand charge = Demand value × Unit price

= (3200 kW) × ($13/kW) = $41,600

This is 12.4 percent of the consumption charge, which is significant

4. Comparison of Three Projects Based on Their Net Present Values

An electric motor is to be purchased, and there are three options. Compare the total costs of standard motor, high-efficiency motor, and premium-efficiency motor. Use the net present value method for the comparison, and consider the following data:

- All three motors provide the same mechanical output of 45 kW.
- The efficiencies of the standard, high-efficiency, and premium-efficiency motors are 88%, 91%, and 94%, respectively. Efficiency is defined as the actual mechanical power output over the electricity input.
- Initial costs:
    - Standard motor: $11,000

    - High-efficiency motor: \$13,000
    - Premium-efficiency motor: \$14,500
- Lifetime: 10 years
- Operating hours: 4000 hours/year
- Load factor: 0.65
- Price of electricity: \$0.10/kWh
- O&M costs: \$500/year
- Interest rate: 8%
- No salvage value at the end of the lifetime.

Ans.

Standard Motor (Efficiency = 88%)

Initial Cost:
P_1 = \$11,000

Present Value of O&M Costs:
$P_2 = \$500 \times [(1 - (1 + 0.08)^{(-10)}) / 0.08] = \$3355$

Electricity Consumption:
$= 45 \times 0.65 \times 4000 \times (1 / 0.88) = 132{,}955$ kWh/year

Electricity Cost:
$= 132{,}955 \times 0.10 = \$13{,}296$/year

Present Value of Electricity Cost:
$P_3 = \$13{,}296 \times [(1 - (1 + 0.08)^{(-10)}) / 0.08] = \$89{,}216$

Total Net Present Value:
$NPV = P_1 + P_2 + P_3 = 11{,}000 + 3355 + 89{,}216 = \$103{,}600$

High-Efficiency Motor (Efficiency = 91%)

Initial Cost:
P_1 = \$13,000

Present Value of O&M Costs:
P_2 = \$3355

Electricity Consumption:
$= 45 \times 0.65 \times 4000 \times (1 / 0.91) = 128{,}572$ kWh/year

Electricity Cost:
$= 128{,}572 \times 0.10 = \$12{,}857$/year

Present Value of Electricity Cost:
$P_3 = \$12{,}857 \times [(1 - (1 + 0.08)^{(-10)}) / 0.08] = \$86{,}270$

Total Net Present Value:
$NPV = P_1 + P_2 + P_3 = 13{,}000 + 3355 + 86{,}270 = \$102{,}600$

Premium-Efficiency Motor (Efficiency = 94%)

Initial Cost:
P_1 = \$14,500

Present Value of O&M Costs:
P_2 = \$3355

Electricity Consumption:
$= 45 \times 0.65 \times 4000 \times (1 / 0.94) = 124{,}469$ kWh/year

Electricity Cost:
$= 124{,}469 \times 0.10 = \$12{,}447$/year

Present Value of Electricity Cost:
$P_3 = \$12{,}447 \times [(1 - (1 + 0.08)^{(-10)}) / 0.08] = \$83{,}519$

Total Net Present Value:
$NPV = P_1 + P_2 + P_3 = 14{,}500 + 3355 + 83{,}519 = \$101{,}400$

Motor	Present Value of Costs	Total Cost

Standard (88%)	Initial: \$11,000 O&M: \$3355 Electricity: \$89,216	\$103,600
High-Efficiency (91%)	Initial: \$13,000 O&M: \$3355 Electricity: \$86,270	\$102,600
Premium-Efficiency (94%)	Initial: \$14,500 O&M: \$3355 Electricity: \$83,519	\$101,400

5. Furnace Efficiency with and without APH

In a crude distillation unit of a refinery, a furnace is operated to heat 500 m^3/hr of crude oil from 255°C to 360°C by firing 3.4 tons/hr of fuel oil having GCV of 9850 kcal/kg. As an energy conservation measure, the management has installed an air preheater (APH) to reduce the flue gas heat loss. The APH is designed to pre-heat 57 tonnes/hr of combustion air to 195°C.

Objective:
Calculate the efficiency of the furnace before and after the installation of APH.

Given Data:

- Specific heat of crude oil = 0.6 kcal/kg°C
- Specific heat of air = 0.24 kcal/kg°C
- Specific gravity of crude oil = 0.85
- Ambient temperature = 28°C

Before the Installation of APH

Heat gain by the crude:

$= 500 \times 1000 \times 0.85 \times 0.6 \times (360 - 255)$
$= 26{,}775{,}000$ kcal/hr

Heat input to the furnace:

$= 3.4 \times 1000 \times 9850$
$= 33{,}490{,}000$ kcal/hr

Efficiency of the furnace:

$= 26{,}775{,}000 / 33{,}490{,}000$
$= 80\%$

After the Installation of APH

Heat gain by the crude:

$= 500 \times 1000 \times 0.85 \times 0.6 \times (360 - 255)$
$= 26{,}775{,}000$ kcal/hr

Heat gain by air preheater:

$= 57 \times 1000 \times 0.24 \times (195 - 28)$
$= 2{,}284{,}560$ kcal/hr

Heat reduction in the furnace input:

= Heat gain by air preheater
$= 2{,}284{,}560$ kcal/hr

New heat input to the furnace:

$= 33{,}490{,}000 - 2{,}284{,}560$
$= 31{,}205{,}440$ kcal/hr

Efficiency of the furnace after installation of APH:

$= 26{,}775{,}000 / 31{,}205{,}440$
$= 85.8\%$

6. A counterflow double pipe heat exchanger using hot process liquid is used to heat water, which flows at 10.5m3/hr. The process liquid enters the heat exchanger at 180◦C and leaves at 130◦C. The inlet and exit temperature of water are 30◦C and 90◦C respectively. Specific heat of water is 4.18kJ/kg◦C.

a) Calculate the heat transfer area, if overall heat transfer coefficient is 814 W/m2◦C. b) What would be the percentage increase in are, if the fluid flows were parallel?

Ans:

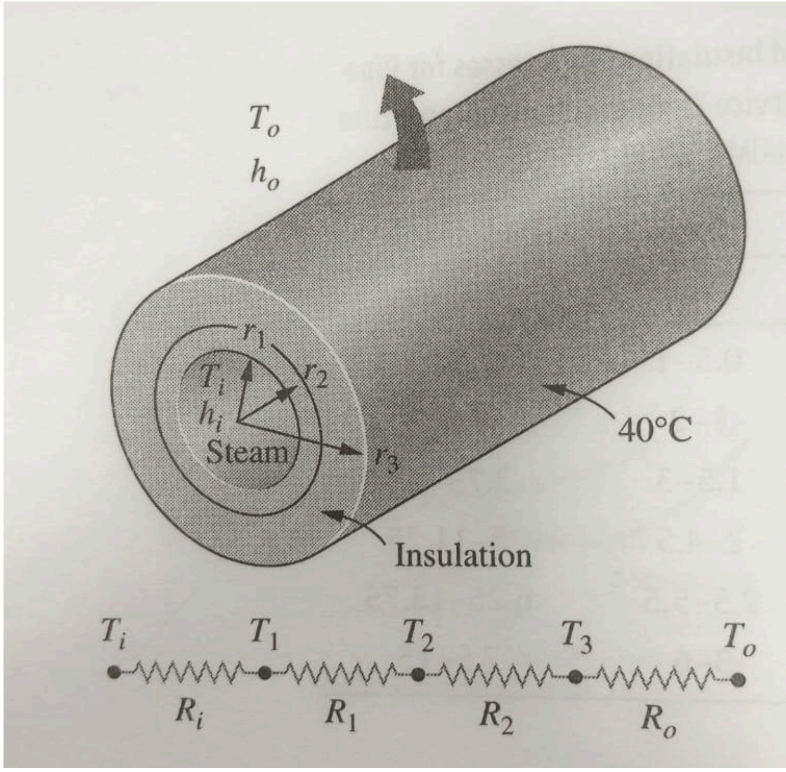
Water flow rate =10.5×1000=10500 kg/hr

Heat content in water =m×Cp×ΔT =10500×4.18×(90−30) =2633400kJ/hr =2633400/3600 =731.5kW

For Counter current flow: triangle T * 1 = 180 - 90 = 90 deg * C triangle T * 2 = 130 - 30 = 100 deg * C
LMTD of counter flow = (100 - 90) / (ln(100/90)) = 95 deg * C
Overall heat transfer coeff. = 814 W/m²°C
Area of heat exchanger for counter flow = 731.5 x 1000 / (814x 95) = 9.5 m²
For Parallel flow:
Delta*T * 1 = 180 - 30 = 150 deg * C Delta*T * 2 = 130 - 90 = 40 deg * C
LMTD of parallel flow = (150 - 40) / (ln(150/40)) = 83 deg * C
Overall heat transfer coeff. = 814 W/m²°C
Area of heat exchanger for parallel flow = 731.5 x 1000 / (814 x 83) = 10.8 m²
Increase in the area for parallel flow = [(10.8 - 9.5) / 9.5] * 100 = 14%

7. Hot water at Ti= 120 deg C flows in a stainless steel pipe (k= 15W / m C) whose inner diameter is 1.6 cm and thickness is 0.2 cm . The pipe is to be covered with adequate insulation so that the tem-perature of the outer surface of the insulation does not exceed 40°C when the ambient temperature is T = 25 deg * C . Taking the heat transfer coefficients inside and outside the pipe to be h i = 70W / (m ^ 2) *^ C and h o = 20W / (m ^ 2) *^ C, respectively, determine the thickness of fiberglass insulation (k= 0.038W / m *^ C) that needs to be installed on the pipe.

Ans.The thermal resistance network for this problem involves four resistances in series and is given in Fig. The inner radius of the pipe is r_{1} = 0.8 cm and the outer radius of the pipe and thus



T_o
h_o
r_1
r_2
T_i
h_i
Steam
r_3
40°C
Insulation
T_i
T_1
T_2
T_3
T_o
R_i
R_1
R_2
R_o

the inner radius of the insulation is $r_2 = 1.0$ cm. Letting r_3 represent the outer radius of the insulation, the areas of the surfaces exposed to convection for an $L = 1$-m-long section of the pipe become

$$A_1 = 2\pi r_1 L = 2\pi(0.008\text{ m})(1\text{ m}) = 0.0503\text{ m}^2$$

$$A_3 = 2\pi r_3 L = 2\pi r_3(1\text{ m}) = 6.28r_3\text{ m}^2$$

Then the individual thermal resistances are determined to be

$$R_i = R_{\text{conv},1} = \frac{1}{h_i A_1} = \frac{1}{(70\text{ W/m}^2\cdot{}^\circ\text{C})(0.0503\text{ m}^2)} = 0.284\ {}^\circ\text{C/W}$$

$$R_1 = R_{\text{pipe}} = \frac{\ln(r_2/r_1)}{2\pi k_1 L} = \frac{\ln(0.01/0.008)}{2\pi(15\text{ W/m}\cdot{}^\circ\text{C})(1\text{ m})} = 0.0024\ {}^\circ\text{C/W}$$

$$R_2 = R_{\text{insulation}} = \frac{\ln(r_3/r_2)}{2\pi k_2 L} = \frac{\ln(r_3/0.01)}{2\pi(0.038\text{ W/m}\cdot{}^\circ\text{C})(1\text{ m})} = 4.188\ln(r_3/0.01)\ {}^\circ\text{C/W}$$

$$R_o = R_{\text{conv},2} = \frac{1}{h_o A_3} = \frac{1}{(20\text{ W/m}^2\cdot{}^\circ\text{C})(6.28r_3\text{ m}^2)} = \frac{1}{125.6r_3}\ {}^\circ\text{C/W}$$

Noting that all resistances are in series, the total resistance is determined to be

$$R_{\text{total}} = R_i + R_1 + R_2 + R_o = \left[0.284 + 0.0024 + 4.188\ln(r_3/0.01) + \frac{1}{125.6r_3}\right]{}^\circ\text{C/W}$$

Then the steady rate of heat loss from the steam becomes

$$\dot{Q} = \frac{T_i - T_o}{R_{\text{total}}} = \frac{(120-25){}^\circ\text{C}}{\left[0.284 + 0.0024 + 4.188\ln(r_3/0.01) + \dfrac{1}{125.6r_3}\right]{}^\circ\text{C/W}}$$

Noting that the outer surface temperature of insulation is specified to be 40°C, the rate of heat loss can also be expressed as

$$\dot{Q} = \frac{T_3 - T_o}{R_o} = \frac{(40-25){}^\circ\text{C}}{\left(\dfrac{1}{125.6r_3}\right){}^\circ\text{C/W}} = 1883r_3$$

Setting the two relations above equal to each other and solving for r_3 gives $r_3 = 0.0170$ m. Then the minimum thickness of fiberglass insulation required is

$$t = r_3 - r_2 = 0.0170 - 0.0100 = 0.0070\text{ m} = \mathbf{0.70\ cm}$$

Insulating the pipe with at least 0.70-cm-thick fiberglass insulation will ensure that the outer surface temperature of the pipe remains at 40°C or below. ▲