

Renewable Energy: Solution (Geothermal)

1. (a) The mass of the air to be heated is :

$$m_{air} = V \cdot \rho_{air} = 8000m^3 \cdot 1.29 \text{ kg/m}^3 = 10320 \text{ kg}$$

The required energy change:

$$\Delta \dot{E} = m_{air} \cdot c_{air} \cdot \Delta T / \Delta t = 10320kg \cdot 1000 \frac{J}{kgK} \cdot 7.3 \cdot 10^{-3} K/s = 75336 J/s$$

$$\text{Installed heating capacity: } P_n = 75.3 \text{ kW}$$

- (b) COP of heat pump = 4.2

E = Electrical energy (for pump)

Q_n = Useful heat

Q_u = Ambient heat

$$Q_n = Q_u + E$$

Coefficient of power for heat pump is defined as $COP = \frac{Q_n}{E} = \frac{P_n}{P_{el}}$

This implies electrical power $P_{el} = 75.3 \text{ kW} / 4.2 = 17.9 \text{ kW}$

Heating power of the probe corresponds to the Q_n and hence $P_n = P_u + P_{el}$ implying
 $P_u = 75.3 \text{ kW} - 17.9 \text{ kW} = 57.4 \text{ kW}$

- (c) l is the length of the probe. Using P_u from part b we get: $l \cdot 52 \frac{W}{m} = 57.4 \text{ kW}$ implies
 $l = 1104m$

$$\text{we also have : } \frac{Q_u}{l} = \frac{Q_n - E}{l} = \frac{Q_n - \frac{Q_n}{COP}}{l}$$

Insertion of annual heating demand $Q_n = 135000 \text{ kWh}$ gives:

$$\frac{Q_u}{l} = 93.5 \frac{kWh}{m} < 110 \frac{kWh}{m}$$

- (d) $E = \frac{Q_n}{COP} = 32143 \text{ kWh}$

implies the electricity cost = $32143 \text{ kWh} \cdot 0.13 \text{ Fr./kWh} = 4178.59 \text{ Fr.}$

- (e) Oil heating:

Annual heating demand in MJ equal to $135000 \text{ kWh} = 486000 \text{ MJ}$

Volume of oil required is $V_{oil} = \frac{486000 MJ}{42.6 MJ/kg \cdot 0.86 kg/l} = 13266 \text{ litres}$

The price of the oil would be $13266 \text{ litres} \cdot 0.86 \text{ Fr./litre} = 11408 \text{ Fr.}$

$$(f) \text{ CO}_2 \text{ emission geothermal heat pump : } E \cdot 0.13 \frac{\text{kg}}{\text{kWh}} = \frac{Q_n}{COP} \cdot 0.13 = 4179 \text{ kg}$$

$$\text{CO}_2 \text{ emission oil heating : } 486000 \text{ MJ} \cdot 0.074 \frac{\text{kg}}{\text{MJ}} = 35964 \text{ kg}$$

$$\text{Hence reduction in CO}_2 \text{ emission is } \frac{(35964 - 4179)}{35964} = 88.4\%$$

2. (a) Available heat in the geothermal source: $\dot{Q} = \dot{m}c_p(T_{in} - T_{out}) = 50 \cdot 4180 \cdot (190 - 85) = 21.945 \text{ MW}$

Exergy available in the geothermal source:

$$T_{\logmean} = \frac{T_{h,in} - T_{h,out}}{\ln \frac{T_{h,in}}{T_{h,out}}} = \frac{463 - 358}{\ln \frac{463}{358}} = \frac{105}{0.2572} = 408.25 \text{ K}$$

$$Ex_{source} = \dot{Q} * \left(1 - \frac{T_a}{T_{\logmean}}\right) = 21.945 * \left(1 - \frac{287}{408.25}\right) = 21.945 * (1 - 0.703) = 6.52 \text{ MW}$$

Exergy for district heating:

$$T_{\logmean} = \frac{T_{h,in} - T_{h,out}}{\ln \frac{T_{h,in}}{T_{h,out}}} = \frac{333 - 313}{\ln \frac{333}{313}} = \frac{20}{0.06194} = 322.9 \text{ K}$$

$$Ex_{heating} = \dot{Q} * \left(1 - \frac{T_a}{T_{\logmean}}\right) = 12 * \left(1 - \frac{287}{322.9}\right) = 12 * (1 - 0.889) = 1.334 \text{ MW}$$

Energy Efficiency:

$$\text{- summer: } 3.2 \text{ MW}_e / 21.945 \text{ MW} = 14.6\%$$

$$\text{- winter: } (2.4 \text{ MW}_e + 12 \text{ MW}_{th}) / 21.945 \text{ MW} = 65.6\%$$

Exergy Efficiency:

$$\text{- summer: } \epsilon = \frac{Ex_{electrical} + Ex_{heating}}{Ex_{source}} = \frac{3.2 + 0}{6.52} = 49.1\%$$

$$\text{- winter: } \epsilon = \frac{Ex_{electrical} + Ex_{heating}}{Ex_{source}} = \frac{2.4 + 1.334}{6.52} = 57.3\%$$

(b) The marginal electrical efficiency in winter is the elec. production from the residual heat (21.945 MW - 12 MW DH = 9.945 MW), thus 2.4/9.945=24.1%