## Example 1: Pump of condensate

How is supplied power of a condensate pump? The pump pumps flow of condensate $\dot{m}_k = 100 \cdot 10^3$ kg.h^{-1} from the condenser with pressure $p_k = 4$ kPa to the degasser with pressure $p_{dg} = 0.16$ MPa through two low pressure heaters (LPH). Specific loss energy is done by each LPH $Y_{L\,LPH} = 80$ J.kg^{-1}, pipeline and fittings $Y_{L\,P} = 130$ J.kg^{-1} and input to the degasser $Y_{L\,DG} = 90$ J.kg^{-1}. Reserve of specific energy of the pump is considered 20 %. Geodetic height of the pump is input $z_{ig} = -3$ m and output $z_{og} = 25$ m. Pump efficiency is $\eta_p = 0.74$.

Solution:
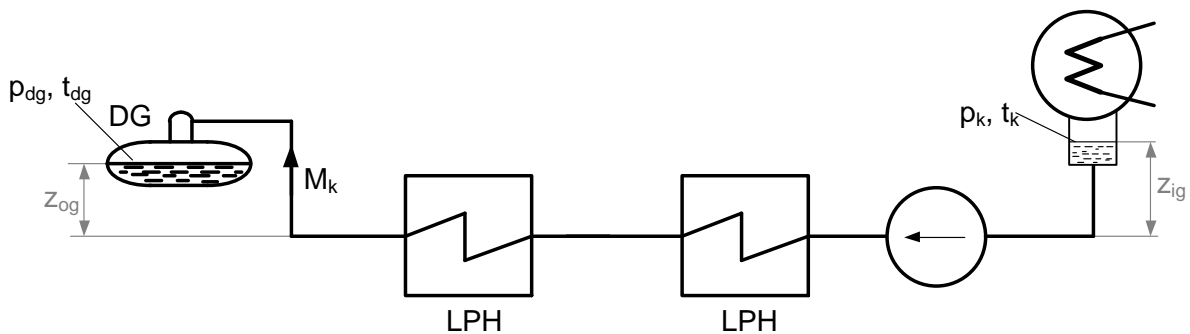
Temperature and density of condensate at the dryness line are $t_k = 28.5$°C and $\rho = 10^3$ kg.m^{-3} for pressure of condenser $p_k = 4$ kPa.

Specific energy of the pump device:

$$Y_a = g \cdot \left(z_{ig} + z_{og}\right) + Y_{L\,P} + Y_{L\,DG} + 2 \cdot Y_{L\,LPH} + \frac{p_{dg} - p_k}{\rho}$$

$$= 9.81 \cdot (-3 + 25) + 130 + 90 + 2 \cdot 80 + \frac{(1.6 - 0.04) \cdot 10^5}{10^3} = 751.82\, J \cdot kg^{-1}$$

Specific energy of the condensate pump with considered reserve:

$$Y = 1.2 \cdot Y_a = 1.2 \cdot 751.82 = 902.2\, J \cdot kg^{-1}$$

Condensate flow:

$$Q = \frac{\dot{m}_k}{3600 \cdot \rho} = \frac{100 \cdot 10^3}{3600 \cdot 10^3} = 0.028\, m^3 \cdot s^{-1}$$

Supplied power of the condensate pump:

$$P_s = Q \cdot Y \cdot \rho \cdot \frac{1}{\eta_p} = 0.028 \cdot 902.2 \cdot 10^3 \cdot \frac{1}{0.74} = 34.14 \cdot 10^3\, W$$

Example 2: Pump of feed water

How is supplied power of a feed water pump? The pump pumps flow of feed water $\dot{m}_{fw}$ = 150·10³ kg.h⁻¹ from the degasser with pressure p_{dg} = 0.16 MPa to the boiler with pressure p_b = 9.3 MPa through high pressure regenerative heater (HPH). Reserve of feed water flow is considered 20 % and reserve of specific energy of the pump is considered 25 %. Specific loss energy is done by HPH $Y_{L\,HPH}$ = 90 J.kg⁻¹, pipeline and fittings Y_{LP} = 120 J.kg⁻¹ and input to the boiler Y_{LB} = 140 J.kg⁻¹. Geodetic height of the pump is input z_{ig} = -17 m and output z_{og} = 27 m. Pump efficiency is η_p = 0.76. Temperature of feed water is t_{fw} = 190°C.

Solution:
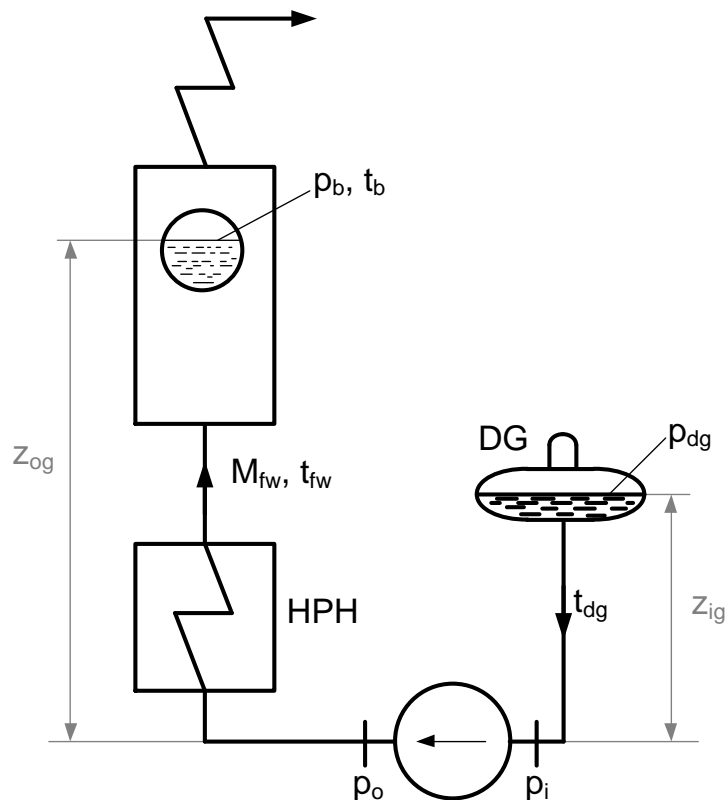
Temperature differences of feed water are large and then water density is not considered constant in pipeline route from the degasser to the boiler.

Degasser temperature and density are t_{dg} = 113°C and ρ_{dg} = 949 kg.m⁻³ for water with pressure p_{dg} = 0.16 MPa at dryness line. (The density is the reciprocal of the specific volume.)

Large temperature difference of pumped water is possible simplified replace to average temperature (of temperature at the degasser and temperature at the boiler). Boiler temperature is t_b = 305°C for boiler pressure p_b = 9.3 MPa.

$$t_{AVG} = \frac{t_b + t_{HPH}}{2} = \frac{305 + 113}{2} = 209°C$$

Average density of feed water is ρ_{AVG} = 853 kg.m⁻³ for this average temperature.

Determination of specific energy of pump device is suitable of pressure difference at input and output of the pump.

Output pressure of the pump:

$$p_o = p_b + \rho_{AVG} \cdot (g \cdot z_{og} + Y_{L\,b} + Y_{L\,HPH} + Y_{L\,P}) = 93 \cdot 10^5 + 853 \cdot (9.81 \cdot 27 + 140 + 90 + 120)$$
$$= 98.245 \cdot 10^5 \, Pa$$

Input pressure of the pump:

$$p_i = p_{dg} - \rho_{dg} \cdot z_{ig} \cdot g = 1.6 \cdot 10^5 - 949 \cdot (-17) \cdot 9.81 = 3.183 \cdot 10^5 \, Pa$$

Pressure difference of the pump:

$$\Delta p = p_v - p_s = 98.245 \cdot 10^5 - 3.183 \cdot 10^5 = 95.062 \cdot 10^5 \, Pa$$

Specific energy of the pump device:

$$Y_a = \frac{\Delta p}{\rho_{dg}} = \frac{95.062 \cdot 10^5}{949} = 10017.1 \, J \cdot kg^{-1}$$

Specific energy of the feed water pump with reserve 25 %:

$$Y = 1.25 \cdot Y_a = 1.25 \cdot 10017.1 = 12251.4 \, J \cdot kg^{-1}$$

Volume flow rate of feed water with reserve 20 % through the pump:

$$Q = \frac{1.2 \cdot \dot{m}_{fw}}{3600 \cdot \rho_{dg}} = \frac{1.2 \cdot 150 \cdot 10^3}{3600 \cdot 949} = 0.0525 \, m^3 \cdot s^{-1}$$

Supplied power of the feed water pump:

$$P = Q \cdot Y \cdot \rho_{dg} \cdot \frac{1}{\eta_p} = 0.0525 \cdot 12251.4 \cdot 949 \cdot \frac{1}{0.76} = 820.85 \cdot 10^3 \, W$$

Example 3: Pump of cooling water

How is supplied power of a cooling water pump? The pump pumps water to thermal turbine condenser with allowed warming $\Delta t_w = 8°C$ of cooling water. Enthalpy of condensed steam is $h_k = 2320$ kJ.kg^{-1} and mass flow of condensed steam is $\dot{m}_k = 10^5$ kg.h^{-1}. Pressure at condenser is $p_k = 4$ kPa. Pump station with water reservoir is placed 500 m from the condenser. Cooling water is pumped by pipeline with diameter 1 m (friction factor $\lambda = 0.03$). Geodetic height of the pump is $z_g = 5$ m and pump efficiency is $\eta_p = 0.8$. Losses of condenser flow are considered $Y_{LK} = 120$ J.kg^{-1}. Losses of pipeline flow are needed calculate.

Solution:
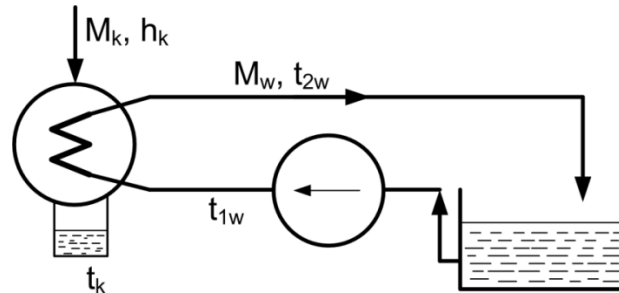
Cooling water flow is done of condenser energy balance. Temperature and density are $t_k = 28.5°C$ and $\rho = 10^3$ kg.m^{-3} for pressure $p_k = 4$ kPa at dryness line. (The density is the reciprocal of the specific volume.) Allowed warming of cooling water: $\Delta t_w = 8°C = t_{2w} - t_{1w}$.

$$\dot{m}_w \cdot c_w \cdot \Delta t_w = \dot{m}_k \cdot (h_k - c_w \cdot t_k)$$

$$\dot{m}_w = \frac{\dot{m}_k \cdot (h_k - c_w \cdot t_k)}{c_w \cdot \Delta t_w} = \frac{10^5 \cdot (2320 - 4.18 \cdot 28.5)}{4.18 \cdot 8} = 65.8 \cdot 10^5 \ kg \cdot h^{-1}$$

Volume flow rate of cooling water:

$$Q_w = \frac{\dot{m}_w}{3600 \cdot \rho} = \frac{65.8 \cdot 10^5}{3600 \cdot 10^3} = 1.83 \ m^3 \cdot s^{-1}$$

Speed of cooling water flow:

$$v_w = \frac{Q_w}{S} = \frac{4 \cdot Q_w}{\pi \cdot D^2} = \frac{4 \cdot 1.83}{\pi \cdot 1^2} = 2.33 \ m \cdot s^{-1}$$

Specific energy loss of loop pipeline with length l = 2 x 500 = 1000 m:

$$Y_{LP} = \lambda \cdot \frac{l}{D} \cdot \frac{v_w^2}{2} = 0.03 \cdot \frac{1000}{1} \cdot \frac{2.33^2}{2} = 81.4 \ J \cdot kg^{-1}$$

Specific energy of the cooling water pump:

$$Y = Y_a = g \cdot z_g + Y_{LP} + Y_{LK} = 9.81 \cdot 5 + 81.4 + 120 = 250.45 \ J \cdot kg^{-1}$$

Supplied power of the cooling water pump:

$$P = Q_w \cdot Y \cdot \rho \cdot \frac{1}{\eta_p} = 250.45 \cdot 1.83 \cdot 10^3 \cdot \frac{1}{0.8} = 572.9 \cdot 10^3 \ W$$