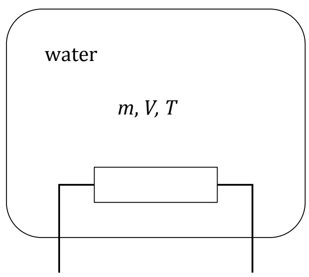
1 Thermal processes: heat accumulation

$$\begin{bmatrix}\text{the rate of energy}\\ \text{accumulation}\end{bmatrix} = \begin{bmatrix}\text{rate of energy}\\ \text{by inflow}\end{bmatrix} - \begin{bmatrix}\text{rate of energy}\\ \text{by outflow}\end{bmatrix} + \begin{bmatrix}\text{rate of heat}\\ \text{added}\end{bmatrix} + \begin{bmatrix}\text{rate of work}\\ \text{done on system}\end{bmatrix}$$

1.1 Special case #1. No transfer into environment and mass exchange



- mass of liquid $m = 30$ kg,
- power $P = 2$ kW,
- water heat capacity $c_p = 4185.5\ \dfrac{\text{J}}{\text{kg}\cdot\text{K}}$

What is temperature changing rate $\dfrac{\mathrm{d}T}{\mathrm{d}t}$?

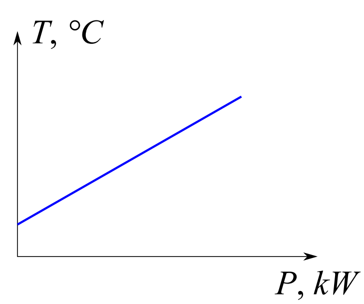
No mass exchange $\Longrightarrow F_{in} = F_{out} = 0$.
No transfer into environment $\Longrightarrow K_l = 0$.

$$\begin{bmatrix}\text{the rate of energy}\\ \text{accumulation}\end{bmatrix} = [0] - [0] + [Q] + [0]$$

or

$$\rho V c_p \frac{\mathrm{d}T}{\mathrm{d}t} = Q, \quad (1)$$

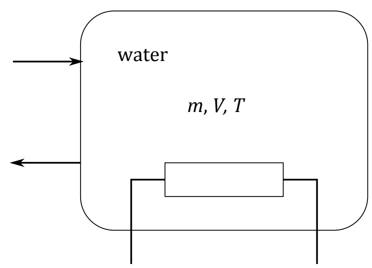
where Q is the power P of the boiler.



$$W(s) = \frac{K_p}{s} \text{ - integrator} \quad (2)$$

Answer: $57,3$ °C/h.

1.2 Special case #2. No transfer into environment, but heating of the running water



- if volumetric flow $F = 200$ ml/s,
- power $P = 2$ kW,
- final temperature in the boiler $T = 20$ °C.

What is the temperature of inflow T_{in}?

Assume, that volume of the liquid inside boiler does not change $\Longrightarrow q_{in} = q_{out} = q$.
No transfer into environment $\Longrightarrow K_l = 0$.

$$\begin{bmatrix} \text{rate of energy} \\ \text{by inflow} \end{bmatrix} - \begin{bmatrix} \text{rate of energy} \\ \text{by outflow} \end{bmatrix} = q_{in}c_pT_{in} - q_{out}c_pT = -qc_p(T - T_{in})$$

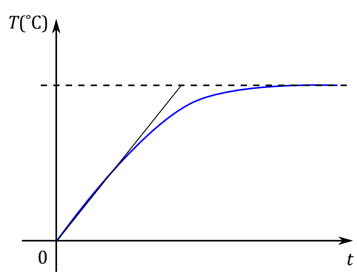
$$\begin{bmatrix} \text{the rate of energy} \\ \text{accumulation} \end{bmatrix} = -[qc_p(T - T_{in})] + [Q] + [0]$$

or

$$\rho V c_p \frac{\mathrm{d}T}{\mathrm{d}t} = -qc_p(T - T_{in}) + P.$$

Questions:

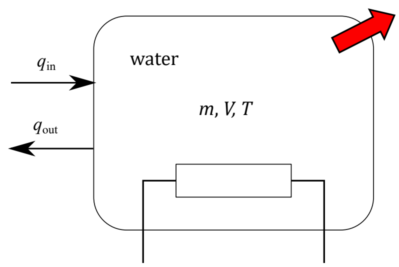
1. What is the steady-state of the given process?



$$W(s) = \frac{K_p}{1 + \tau_p s} \tag{3}$$

Answer: $T_{in} = 17.6$ °C.

1.3 Special case #3. Heat transfer into environment and mass exchange



To heat running water (q and $T_{in} = 10$ °C) upto T boiler is used ($V = 10$ l, $P = 1,5$ kW). Temperature of the environment is $T_e = 20$ °C.

If water is heated upto $T = 80$ °C, then boiler is turned off (no flow, no heater). In that case temperature changing rate is $\frac{\mathrm{d}T}{\mathrm{d}t} = -30$ °C/h.

$$\begin{bmatrix} \text{rate of energy} \\ \text{by inflow} \end{bmatrix} - \begin{bmatrix} \text{rate of energy} \\ \text{by outflow} \end{bmatrix} = -\,[\text{looses}] - \begin{bmatrix} \text{mass} \\ \text{exchange} \end{bmatrix} =$$
$$-K_l(T - T_e) - qc_p(T - T_{in}),$$

$$\begin{bmatrix} \text{rate of heat} \\ \text{added} \end{bmatrix} = P.$$

$$V\rho c_p \frac{\mathrm{d}T}{\mathrm{d}t} = P - K_l(T - T_e) - qc_p(T - T_{in}) \tag{4}$$

Steady-state: $\frac{\mathrm{d}T}{\mathrm{d}t} = 0$.

Questions:

1. What is the differential equation describing the process?
2. What is the cooling rate K_l?
3. Steady-state?
4. What should be q_s if water temperature is $T_s = 100$ °C?

Answer:

- $K_l = 5.8$ W/°C;
- $q_s = 9.9$ kg/h.

2 Heat transfer

1 *Copper pot*

A copper pot of radius 12 cm and thickness 5 mm sits on a burner and boils water. The temperature of the burner is 115 °C while the temperature of the inside of the pot is 100 °C. Copper thermal conductivity is $\lambda = 400 \; \left[\frac{\mathrm{W}}{\mathrm{m \cdot K}}\right]$

Questions:

1. What is the power needed?
2. What mass of water is boiled away every minute?

Heat transfer with conduction

$$\frac{\mathrm{d}Q_{contuction}}{A\mathrm{d}t} = -\lambda\frac{\Delta T}{\Delta x}$$

or

$$q = \lambda A\frac{\Delta T}{x}.$$

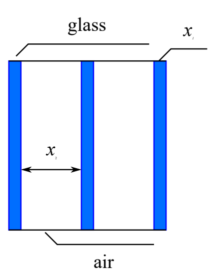
Phase changes:

$$Q = m \cdot L,$$

where L is Latent Heat of Vaporization.
Answer:

- $P = 54,3$ kW;
- $m = 1.44$ kg.

2 *Three panes glass*



Consider three panes of glass, each of thickness 5 mm. The panes trap two 2.5 cm layers of air in a large window. How much power leaks through a 2.0 m^2 glass window if the temperature outside is −10 °C and the temperature inside is 20 °C?

Answer: $q = 28.6$ W.

3 *Kettle cooling*

What is the heat loss from the heated stainless steel kettle surface ($h = 15$ cm, $r = 6$ cm) from 100 °C if room temperature is $T_e = 20$ °C due to radiation effect?

$$q_{rad} = \epsilon\sigma A(T_1^4 - T_2^4).$$

1. What is the heat radiation area?

Answer: $q = 7.6$ W.