HEAT PUMPS

DIDACTIC MATERIALS

- In heat pump system does not use gas, it uses substance, named the service medium.
- Service medium is characterised by the fact that it can be in all three aggregate states.
- Aggregate, phase transition has an extremely high energy density, it relatively easily allow the process to be approximated to the Carnot process.
- High energy density allows more compact heat pump systems to be produced.
- Approximation to the Carnot process is because substances as a phase transition is always an isothermic process.

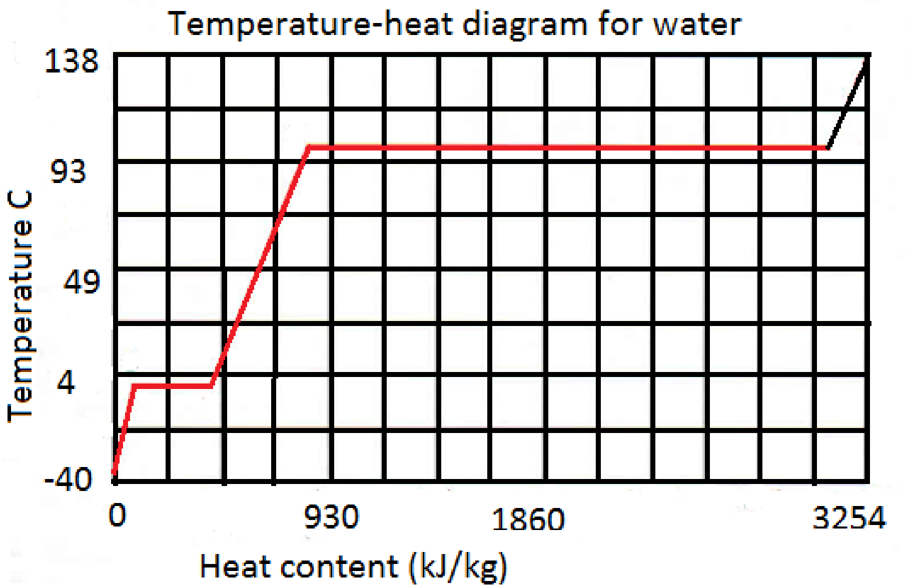


Fig.1. Temperature-heat diagram for water

The heat pump in the log p, h diagram

- In heat pump engineering, it is simple to represent the cycle in a log p, h diagram.
- In log p, h diagram energy differences easily identified.
- Every service medium (refrigerant) has its own diagram depending on its thermodynamic characteristics.

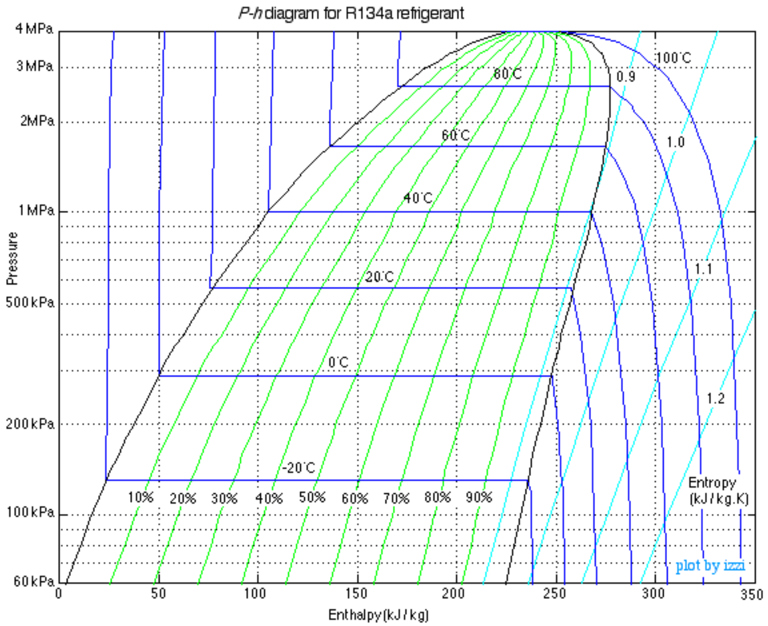


Fig.2. P-h diagram for R134a refrigerant

Operating principle of the heat pump

- The fundamental principle of the heat pump cycle is the dependency of the boiling temperature on pressure.

- Heat absorption must be at a lower temperature and heat emission at a higher temperature.

- This is reached by evaporating the refrigerant at a low temperature to take the necessary heat flow from the heat sources.

- To make this process, the pressure must be reduced so that the evaporation temperature is below the desired heat sources temperature.

Operating principle of the heat pump

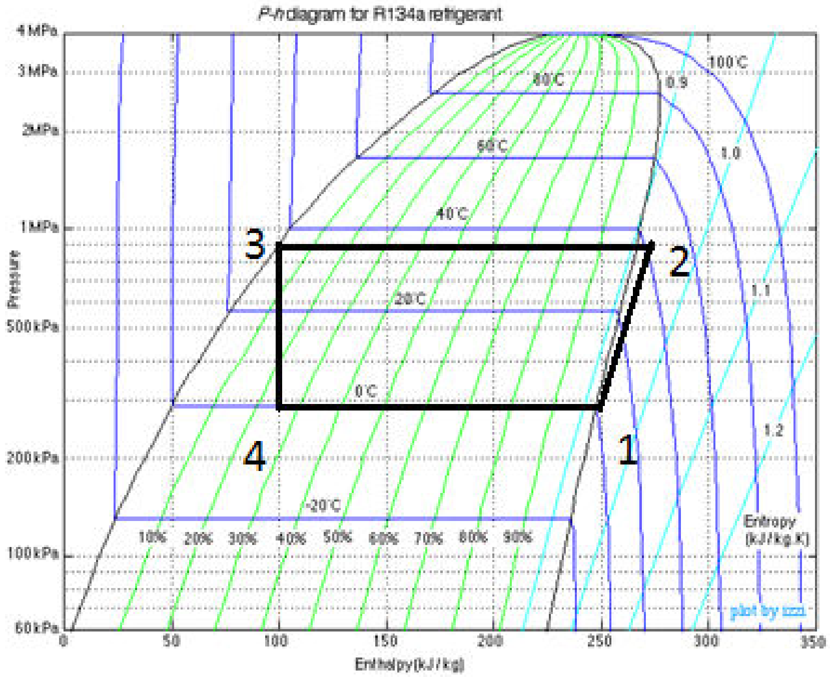


Fig.3. The heat pump cycle in a p-h diagram

- Line 1-2 Fig.3, compressing the refrigerant to a higher pressure, at which the boiling temperature is above the user's temperature.
- Line 2-3 Fig.3 condensation of the refrigerant in the condenser, the heat flow Qout is discharged to the user.

Qout- heat pump heat supplied to the user.

- Line 3-4 Fig.3 throttling, an expansion valve is used for throttling .
- Line 4-1 Fig.3 Evaporation. During evaporation, the refrigerant absorbs the heat flow Qin from the heat sources.

Qin- heat pump heat supplied from heat source.

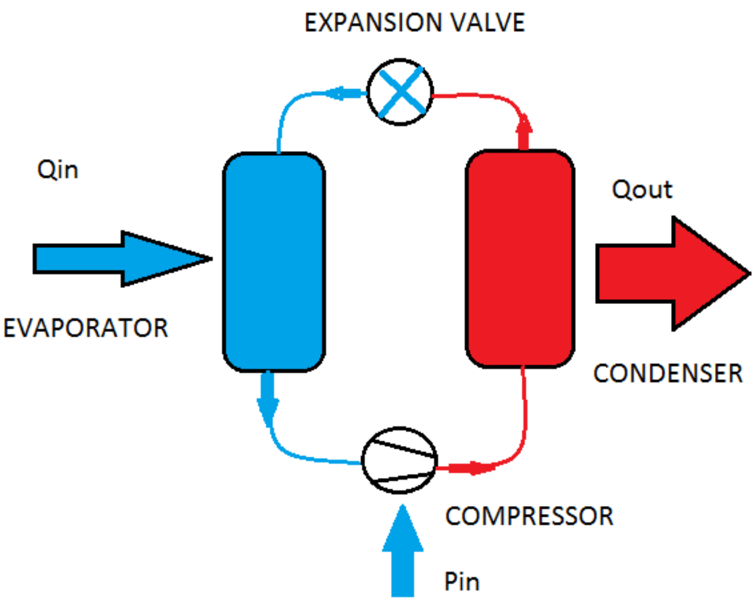


Fig.4. The heat pump four main components

- **Compressor** – used to raise refrigerant temperature.
- **Condenser** – used to transfer heat from refrigerant to the heat user.
- **Expansion valve** – used to reduce refrigerant temperature.
- **Evaporator** – used to transfer heat from the heat source to refrigerant.

Functioning of a compression heat pump system

- The task of a compression heat pump system, is to transport heat energy Qin from a low temperature level to a high temperature level (Qout).

- In the picture Fig.4 of a heat pump, (Pin) supplied mechanical energy to the system from outside by a compressor.

Functioning of a compression heat pump system

- System must satisfy the 1st law of thermodynamics

$$Qout=Qin+Pin$$

Where:

Qout – output of the evaporator (heat pump heat supplied to the user).

Qin – output of the condenser (heat pump heat supplied from heat sources).

Pin – compressor output (supplied compressor mechanical energy).

CALCULATIONS USING THE (p-h) DIAGRAM

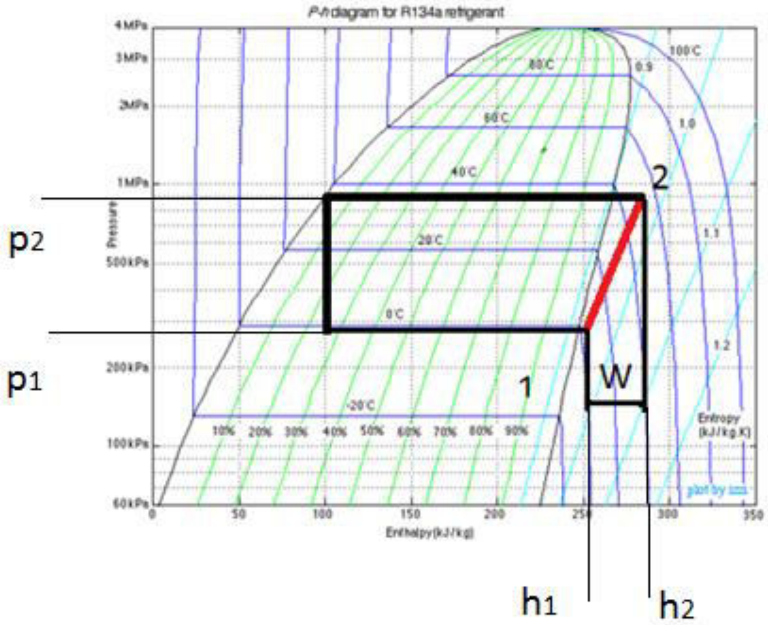


Fig. 5. The compressor work in p-h diagram

1st stage – Fig. 5 Isentropic compression (1-2) – the refrigerant gaseous taken in by the evaporator is compressed from the evaporation pressure **p1** to the condensation pressure **p2** by a compressor.

p1 – compressor inlet pressure.

p2 – outlet pressure of the compressor.

- In ideal conditions, compression is isentropic.
- In real compression process heat caused by friction.
- Heat will be transferred through the cylinder wall.
- The enthalpy increase equivalent to the amount of work used by compressor.

- The compressor output:

$$P_v = (h_2 - h_1) \cdot m_R \quad (kW)$$

- The specific compressor work:

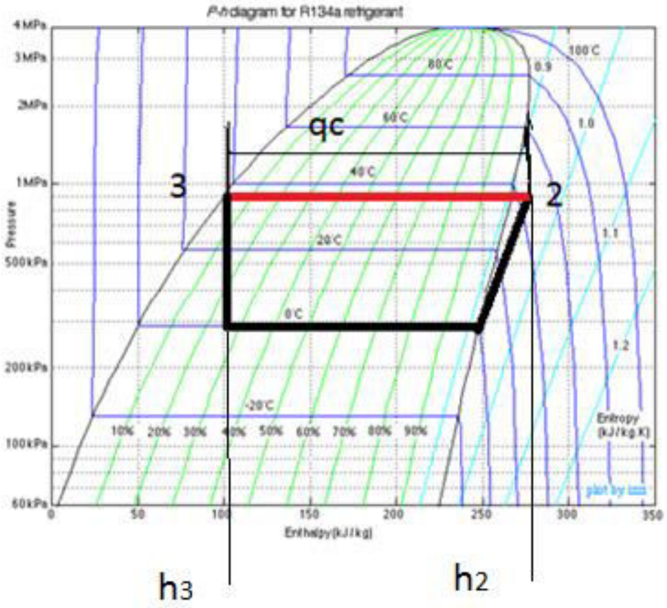
$$W = P_v / m_R = h_2 - h_1 \quad (kJ/kg)$$

where:

h1 – compressor inlet enthalpy (kJ/kg)

h2 – compressor outlet enthalpy (kJ/kg)

mR – freon mass flow rate (kg/s)



- **2nd stage** – Fig.6 Isobaric condensation (2-3) - heat energy is released to the environment by condensation of the refrigerant.
- There are the heat flow absorbed on the evaporator and the power intake of the compressor.

Fig.6. The condensation process in p-h diagram

- The total output of the condenser:

$$Q_c = (h_2 - h_3)\cdot m_R \ \ (kW)$$

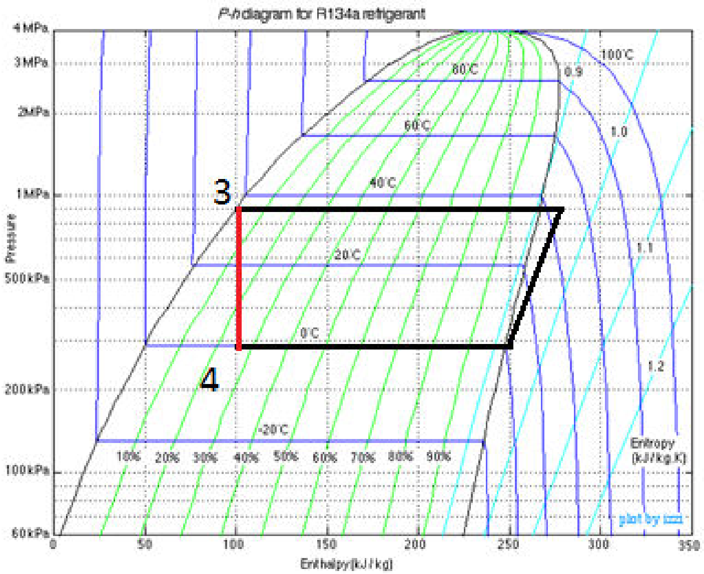
- The specific condenser output:

$$q_c = Q_c/m_R = h_2 - h_3 \ (kJ/kg)$$

where:

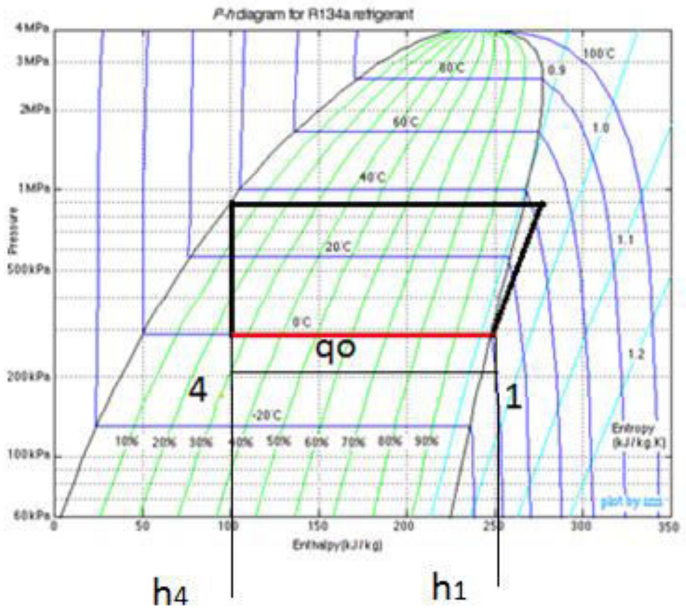
h2 – condenser inlet enthalpy (kJ/kg)

h3 – condenser outlet enthalpy (kJ/kg)



- **3rd stage-** Fig.7. Isenthalpic throttling (3-4).
- Completely condensed refrigerant is supplied to the evaporator at low pressure.
- This take place during an isenthalpic throttling.
- During process neither heat nor work is exchanged with the environment.

Fig.7. The throttling process in p-h diagram



- **4th stage-** Fig.8. Isobaric evaporation.
- The liquid refrigerant enters the evaporator after throttling, where it evaporates.
- Evaporation consumes heat source heat.

Fig.8. The evaporation process in p-h diagram

- The total output of the evaporator can be calculated:

$$Q_o = (h_1 – h_4)\cdot m_R \quad (kW)$$

- The specific freon capacity is calculated as:

$$q_o = Q_o/m_R = h_1 – h_4 \quad (kJ/kg)$$

where:

h4 – evaporator inlet enthalpy (kJ/kg)

H1– evaporator outlet enthalpy (kJ/kg)

- The heat pump output coefficient:

$$\varepsilon = q_c/w = q_c/(q_c - q_o) = Q_c/P_v$$

where:

ε – coefficient of performance

qc – specific condense capacity (kJ/kg)

qo – specific evaporator capacity (kJ/kg)

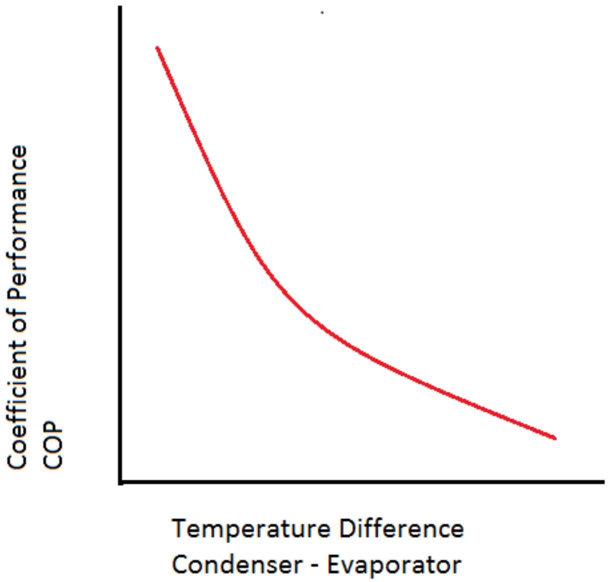


Fig. 9. Coefficient of performance depending on evaporation and condensation temperature

- The coefficient of performance is determined by the evaporation and condensation temperature Fig. 9.
- The coefficient of performance is higher, the less the evaporation and condensation temperature difference.
- The maximum coefficient of performance is given by the Carnot process.

Components of a compression refrigeration system:

- **The compressor** – one of the four main components of a heat pump system. Its task is to supply circuit mechanical energy.
- The compressor takes gaseous refrigerant at low pressure, compresses and emits it at high pressure.
- During compression, the temperature of the gas increase.

There are two basic compressor types:

- **Displacement engines**, the working chamber is periodically filled and drained. The most widespread type of displacement engine is the piston compressor.

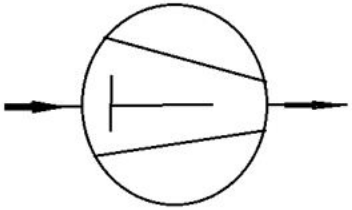


Fig. 10. Symbol for a piston compressor

Dynamic type compressors:

The working medium is supplied with kinetic energy, and this is then transformed into pressure energy.

- Dynamic type compressors allowing very large flow volumes.
- Dynamic type compressors are used for a compressor output of more than around 400kW.

Capacity of piston compressor

The capacity of a system depends on the evaporation temperature.

- The capacity decreases as the evaporation temperature falls.
- The lower evaporation temperature can be reached by decreasing pressure and the specific volume of the refrigerant will rise.

The capacity of a piston compressor is determined geometrically, the mass flow rate will fall and the capacity of the system decreases.

$$P_v = m_R \cdot (h_2 - h_1) \ (\mathrm{kW})$$

Where:

Pv – compressor output (kW)

mR – freon mass flow rate (kg/s)

h1– compressor inlet enthalpy (kJ/kg)

h2 – compressor outlet enthalpy (kJ/kg)

The volume conveyed the piston compressor depend on evaporation and condensation pressure. The pressure ratio can be calculated as follows:

$$\Pi = P_c / P_o$$

Where:

Π – Pressure ratio at compressor

Pc – The pressure in the condenser

Po – The pressure in the evaporator

- The higher the volumetric efficiency at a particular pressure ratio, the higher the quality of the compressor.
- The capacity also falls as the condensation temperature rise.
- Piston compressor can operate effective, reliable in a particular range.

The clear operating range is limited by the usage limits:

- Maximum pressure ratio.
- Maximum possible final compression temperature.
- Minimum evaporation temperature.
- Maximum power consumption of compressor.

Condenser – task is to transmission the heat flows absorbed on the evaporator.

- The surface temperature of the condenser must be over the surrounding temperature or the cooling water temperature.

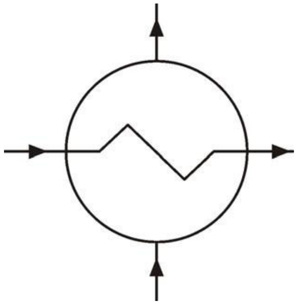


Fig. 11. Condenser symbol

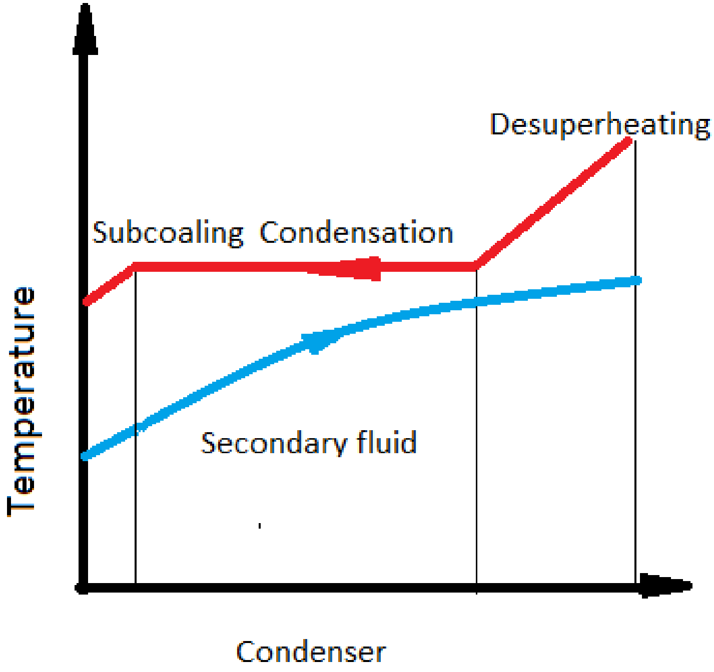


Fig.12. The condenser processes

- The refrigerant passes through three areas Fig.12.: desuperheating zone, condensation zone, supercooling zone.
- Heat desuperheating zone – superheated, gaseous freon cools at a constant pressure to the condensation temperature. The heat dissipation zone accounts for a 5% - 15% share of the total heat transmission of the condenser.

Isenthalpic throttling

- Condensed refrigerant, condensation stage, must be supplied to the evaporator at low pressure and temperature.
- This happen during an isenthalpic change of state in the throttle.
- During process neither heat nor work is exchanged with the environment.

- Entropy increases take place during regulation as energy is dissipated inside the throttle during the process.

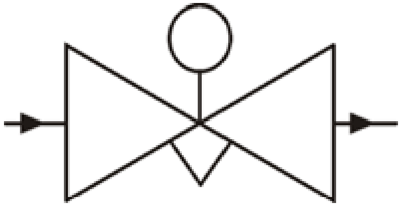


Fig. 13. Condenser symbol

- Proportion of the evaporated refrigerant during the throttling process can be identified from p,h diagrams. They contain lines that indicate the constant vapour content x in the wet steam area.

- This depends on the evaporation temperature and the supercooling of the refrigerant at the condenser.

Isobaric evaporation

- The liquid refrigerant enters the evaporator takes heat energy from the surroundings and boils.

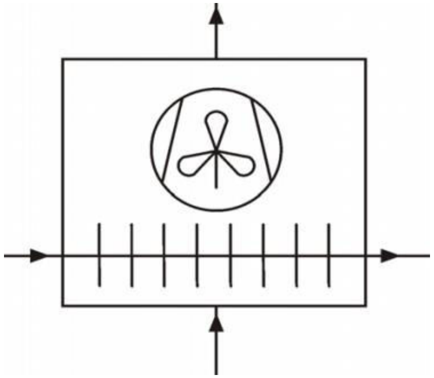


Fig. 14. Finned tube evaporator with axial fan symbol

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