Ministry of Higher Education
Higher Institute for Engineering and Technology at Manzala
Electronics Engineering Dept.

Thermodynamics and Heat Transfer (MEC121)

Lecture 4: 1st Law of Thermodynamics

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1st Law for Open System

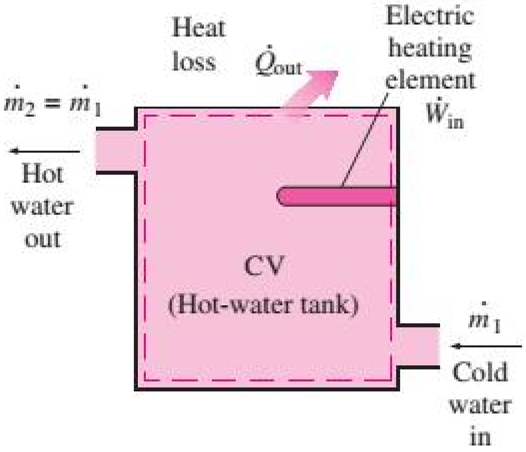
- **For Open System:**

$$\boxed{\sum_{out} \dot{m}\,(h + ke + pe) - \sum_{in} \dot{m}\,(h + ke + pe) = \sum \dot{Q} - \sum \dot{W}} \quad \ldots\ldots\ldots \quad (21)$$

Example:

$$\dot{m}_2\,(h_2 + ke_2 + pe_2) - \dot{m}_1(h_1 + ke_1 + pe_1) = \dot{Q} - \dot{W}$$

Since $\dot{m}_2 = \dot{m}_1 = \dot{m}$ Because it is a steady-flow system



$$\dot{m}\,[(h_2 - h_1) + (ke_2 - ke_1) + (pe_2 - pe_1)] = \dot{Q} - \dot{W}$$

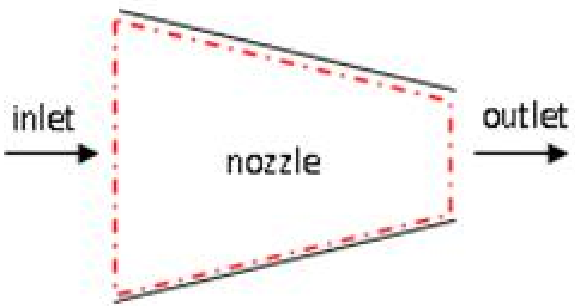
$$\dot{m}\,\left[(h_2 - h_1) + \left(\frac{V_2^2 - V_1^2}{2}\right) + g(z_2 - z_1)\right] = \dot{Q} - \dot{W}$$

Nozzle & Diffuser

- **Nozzles** and **diffusers** are commonly utilized in jet engines, rockets, and even garden hoses.
- The nozzle and diffuser perform opposite tasks.

Nozzle & Diffuser

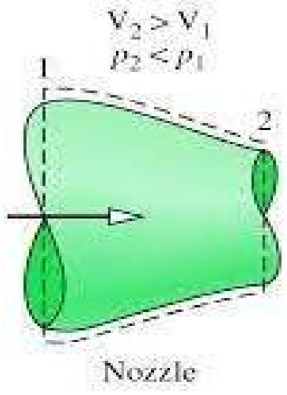
The cross-sectional area of a **<u>nozzle</u>** decreases in the flow direction. This device increases the velocity of a fluid at the expense of pressure. على حساب الضغط



<u>By applying 1st law of thermodynamics</u>:

$$\dot{m}\left[(h_2 - h_1) + \left(\frac{V_2^2 - V_1^2}{2}\right) + g(z_2 - z_1)\right] = \dot{Q} - \dot{W}$$

0 0 0

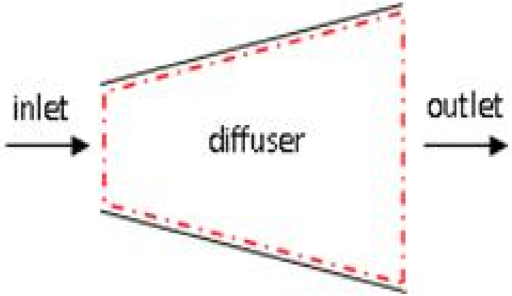


$$\left(\frac{V_2^2 - V_1^2}{2}\right) = -\,(h_2 - h_1)$$

$$\boxed{V_2 = \sqrt{V_1^2 - 2(h_2 - h_1)}} \quad \ldots\ldots\ldots (22)$$

Nozzle & Diffuser

The cross-sectional area of a **diffuser** increases in the flow direction. This device increases the pressure of a fluid by slowing it down (decreasing its velocity).

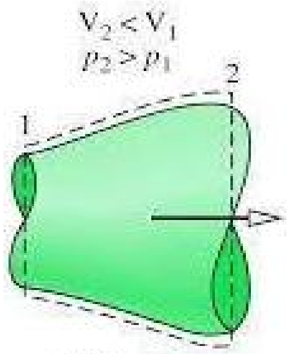


By applying 1st law of thermodynamics:

$$\dot{m}\left[(h_2-h_1)+\left(\frac{V_2^2-V_1^2}{2}\right)+\underbrace{g(z_2-z_1)}_{0}\right]=\underbrace{\dot{Q}}_{0}-\underbrace{\dot{W}}_{0}$$

$$\left(\frac{V_2^2-V_1^2}{2}\right)=-(h_2-h_1)$$

$$\boxed{h_2=h_1-\left(\frac{V_2^2-V_1^2}{2}\right)} \quad \ldots\ldots\ldots (23)$$



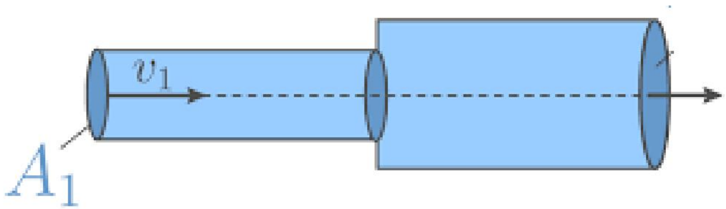
Diffuser

Nozzle & Diffuser

<u>To calculate the mass flow rate of a fluid flowing into any cross-sectional area:</u>

$$\boxed{\dot{m} = \rho A V \quad \left(\frac{kg}{s}\right)} \ldots\ldots 24$$

Where V is the velocity of the fluid and A is the cross-sectional area. V is always the velocity perpendicular to the cross-sectional area.



Example

Air at 10°C and 80 kPa (with a density of 0.98 kg/m^3) enters the diffuser of a jet engine steadily with a velocity of 200 m/s and an enthalpy of 10 kJ/kg. The inlet area of the diffuser is 0.4 m^2. The air leaves the diffuser with a velocity that is very small compared with the inlet velocity. Determine (a) the mass flow rate of the air and (b) the enthalpy of the air leaving the diffuser. **(Ans. 78.4 kg/s, 30 kJ/kg)**

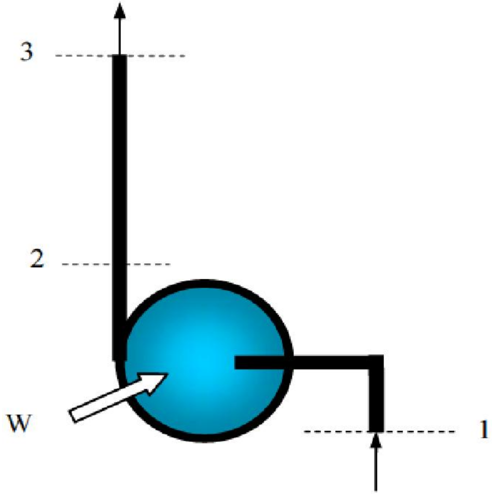
Water Pump

Pump is a device that moves liquids by mechanical action. Modern pump converts electrical energy into hydraulic energy (head).

By applying 1st law of thermodynamic:

$$\dot{m}\left[\cancel{(h_3 - h_1)} + \left(\cancel{\frac{V_3^2 - V_1^2}{2}}\right) + g(z_3 - z_1)\right] = \cancel{\dot{Q}} - \dot{W}$$

0 0 0



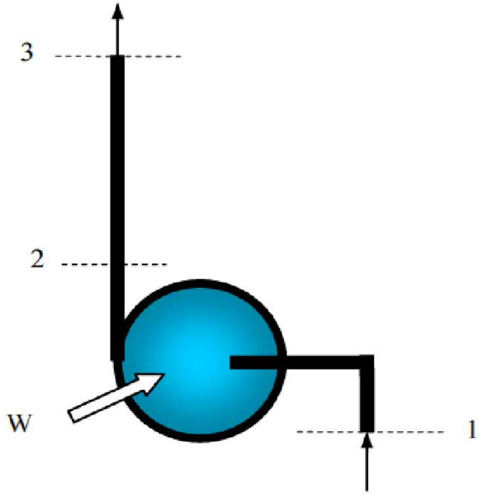
Where the pipes at pump inlet and exit has the same diameter, hence $v_1 = v_3$. Also, if there is no difference in water temperature and pressure between state 1 and 3, then $h_1 = h_3$.

Water Pump

Then, the equation can be written as:

$$\boxed{-\dot{W}_p = \dot{m}\, g(z_3 - z_1) \quad (W)} \quad \ldots\ldots \quad 25$$

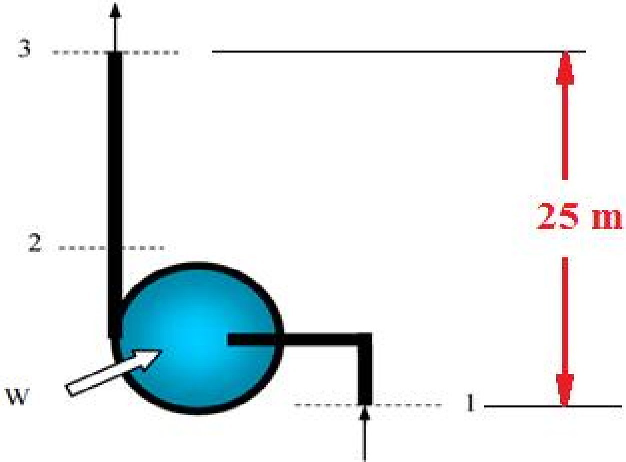
$$\boxed{-w_p = g(z_3 - z_1) \quad (J/kg)}$$



Example

A water pump, shown in the figure below, delivers 1 m^3/min at 50 kPa through a 2.5 cm diameter pipe. If the water is at 101 kPa and 27°C, has a negligible velocity at the inlet state. Neglect any friction and heat transfer that may occur. Also, neglect any change in water density, and **determine** the power required by the pump.

(Ans. = -4.08 kW)



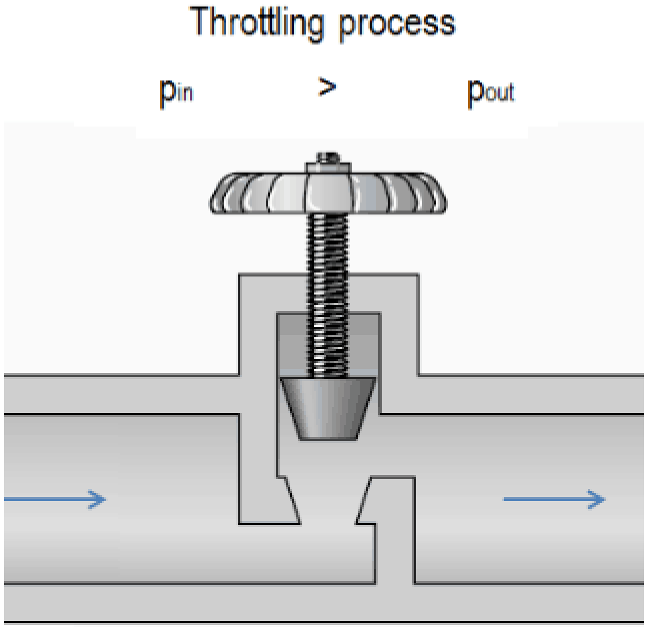
Throttling Process and Valves

A flow of fluid is said to be **throttled** when some restrictions معوقات, such as valve and capillary tube, is placed in the flow path وضعت فى مسار المائع.

By applying 1st law of thermodynamic:

$$\dot{m}\left[(h_2-h_1)+\cancelto{0}{\left(\frac{V_2^2-V_1^2}{2}\right)}+\cancelto{0}{g(z_2-z_1)}\right]=\cancelto{0}{\dot{Q}}-\cancelto{0}{\dot{W}}$$

$$\boxed{h_2=h_1}\quad\dots\dots\dots(26)$$

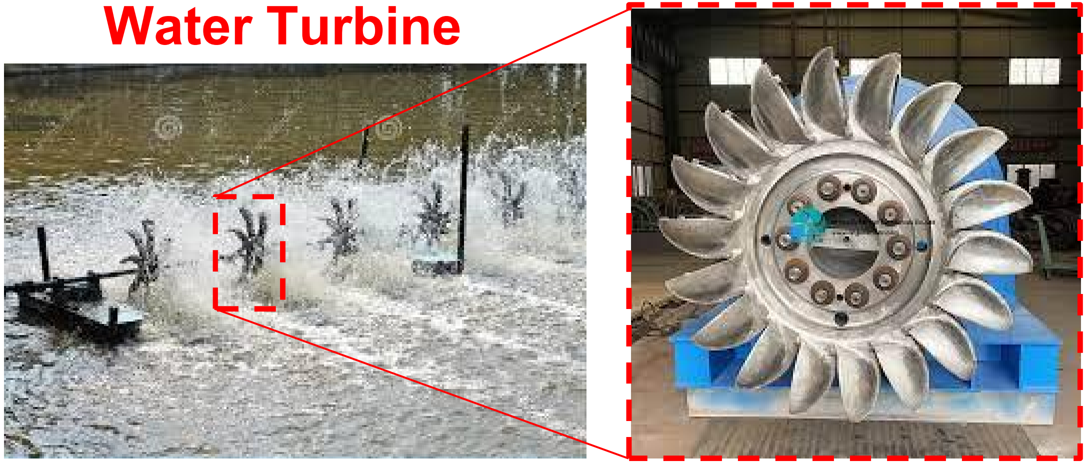


Turbines

Turbine is a device that convert the fluid energy into mechanical energy (rotation). It is always connected with a generator to produce electrical energy.

Wind Turbine

Water Turbine



Steam or Gas Turbine

Turbines

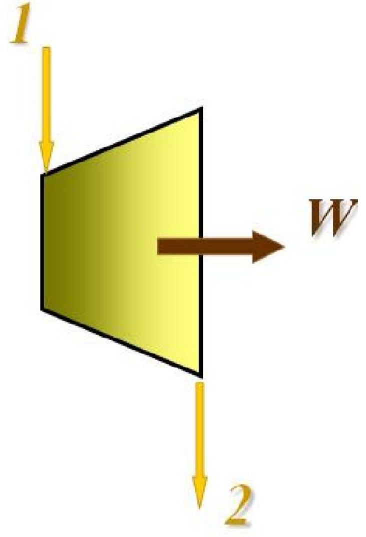
By applying 1st law of thermodynamic:

$$\dot{m}\left[(h_2 - h_1) + \cancel{\left(\frac{V_2^2 - V_1^2}{2}\right)} + \cancel{g(z_2 - z_1)}\right] = \cancel{\dot{Q}} - \dot{W}$$

$$\quad 0 \qquad\qquad 0 \qquad\qquad 0$$

$$\boxed{-\dot{W}_t = \dot{m}\,(h_2 - h_1) \quad (W)} \quad \ldots\ldots 27$$

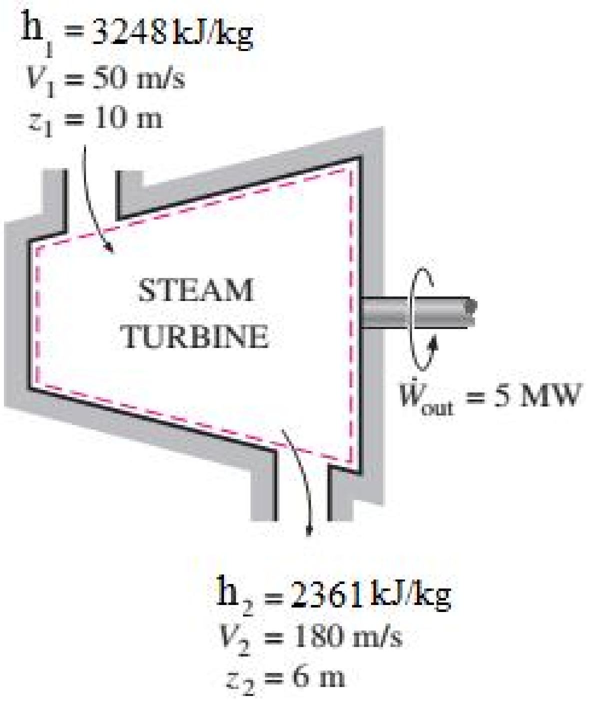
$$\boxed{-w_t = h_2 - h_1 \quad (J/kg)}$$



Example

The power output of an adiabatic turbine is 5 MW, and the inlet and the exit conditions of the steam are as indicated in the opposite figure. Calculate the mass flow rate of the steam flowing through this turbine.

(Ans. = 5.73 kg/s)

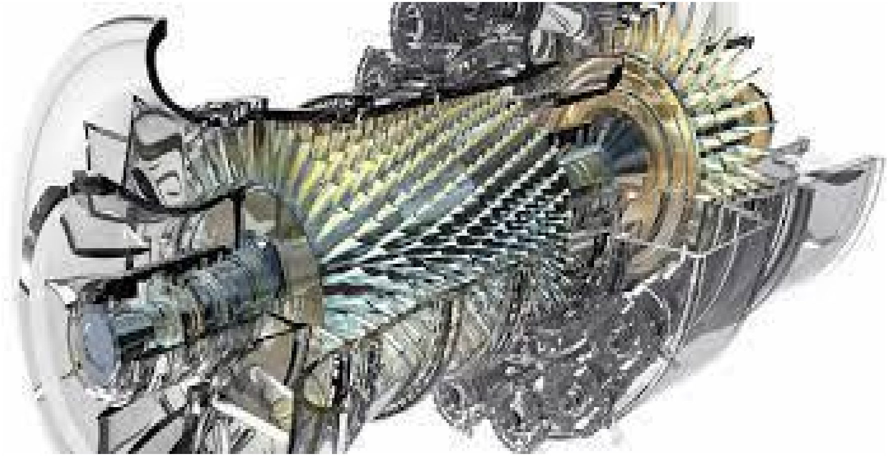


Compressors

Compressor is a device that increases the pressure of a gas by mechanically decreasing its volume.

Reciprocating Compressor

Rotary Compressor



Compressors

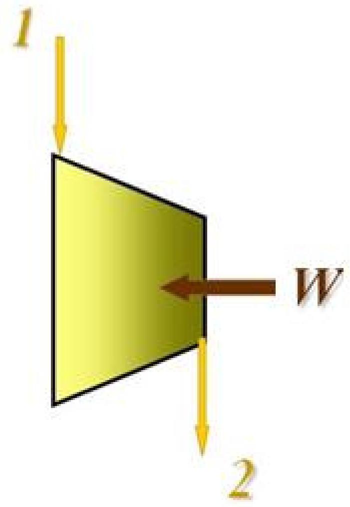
By applying 1st law of thermodynamics:

$$\dot{m}\left[(h_2 - h_1) + \cancel{\left(\frac{V_2^2 - V_1^2}{2}\right)} + \cancel{g(z_2 - z_1)}\right] = \cancel{\dot{Q}} - \dot{W}$$

$$\quad 0 \qquad\qquad 0 \qquad\qquad 0$$

$$\boxed{-\dot{W}_c = \dot{m}\,(h_2 - h_1) \quad (W)} \quad \ldots\ldots 27$$

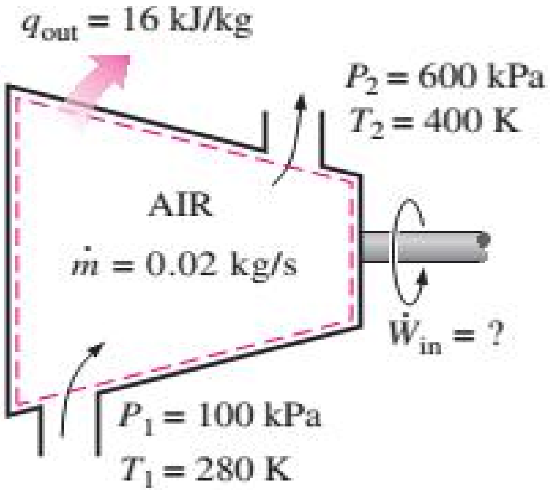
$$\boxed{-w_c = h_2 - h_1 \quad (J/kg)}$$



Example

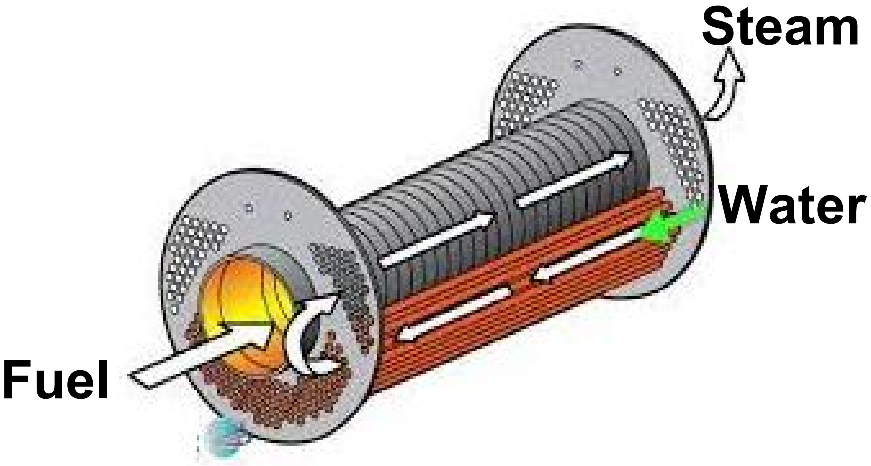
Air at 100 kPa and 280 K (h_1 = 280.13 kJ/kg) is compressed steadily to 600 kPa and 400 K (h_2 = 400.98 kJ/kg) . The mass flow rate of the air is 0.02 kg/s, and a heat loss of 16 kJ/kg occurs during the process. Assuming the changes in kinetic and potential energies are negligible, determine the necessary power input to the compressor.

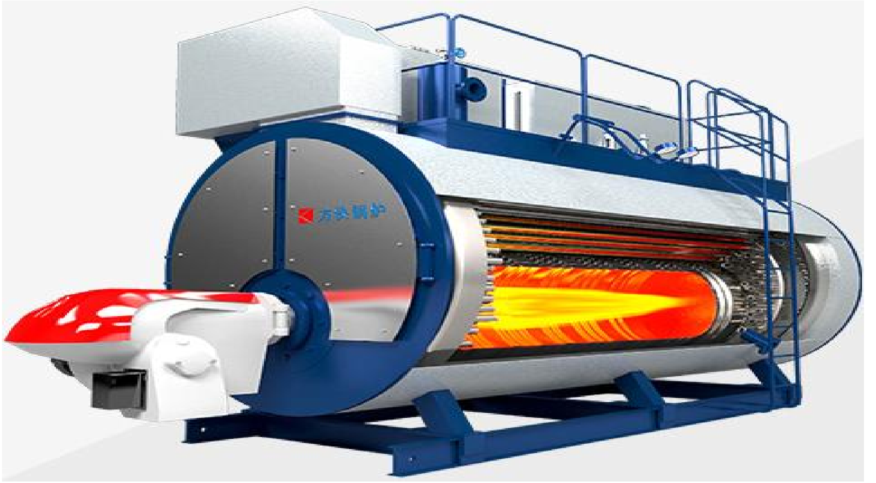
(Ans. = 2.74 kW)



Boilers

Boiler is a closed vessel in which water is heated and evaporated forming steam. This occurs using an energy resource such as fossil fuels, solar energy, etc.





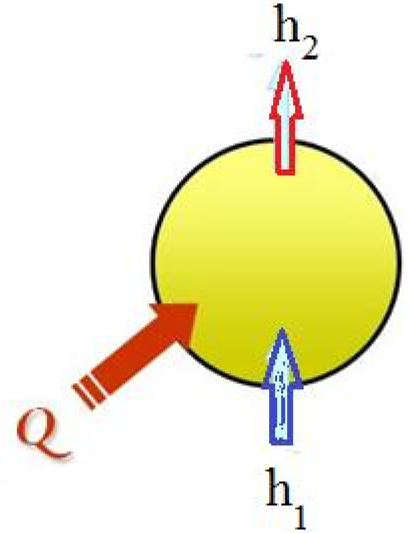
Boilers

By applying 1st law of thermodynamics:

$$\dot{m}\left[(h_2 - h_1) + \cancelto{0}{\left(\frac{V_2^2 - V_1^2}{2}\right)} + \cancelto{0}{g(z_2 - z_1)}\right] = \dot{Q} - \cancelto{0}{\dot{W}}$$

$$\boxed{\dot{Q}_B = \dot{m}\,(h_2 - h_1) \quad (\text{W})} \quad \ldots\ldots \quad (27)$$

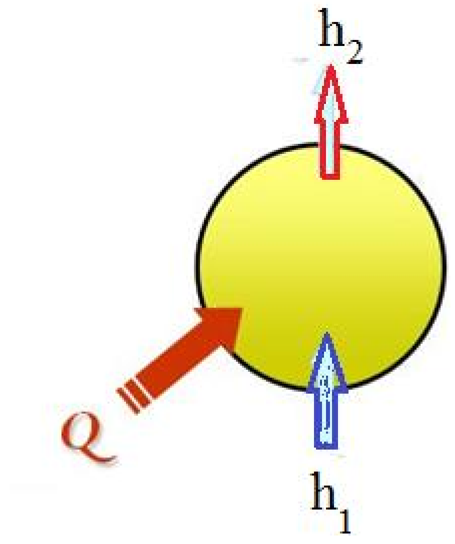
$$\boxed{q_B = h_2 - h_1 \quad (\text{J/kg})}$$



Example

Water enters a boiler at 10 bar and 40˚C (h_1 = 167 kJ/kg) and exits as steam at the same pressure and 250˚C (h_2 = 2,943.2 kJ/kg). This boiler uses natural gas as a fuel. Take the mass flow rate and the heating value of the natural gas as 1kg/s and 45,000 kJ/kg. Neglecting any type of loss, **calculate** the mass flow rate of the steam produced from this boiler.

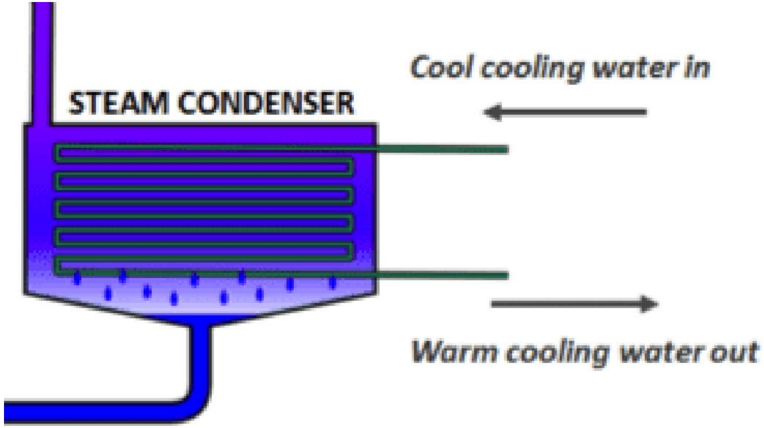
(Ans. =16.21 kg/s)



Condensers

Condenser is a device that acts as a heat-rejection unit in which the steam (vapor) condenses and changes into liquid form .

Steam Condenser



Refrigerator Condenser

Boilers

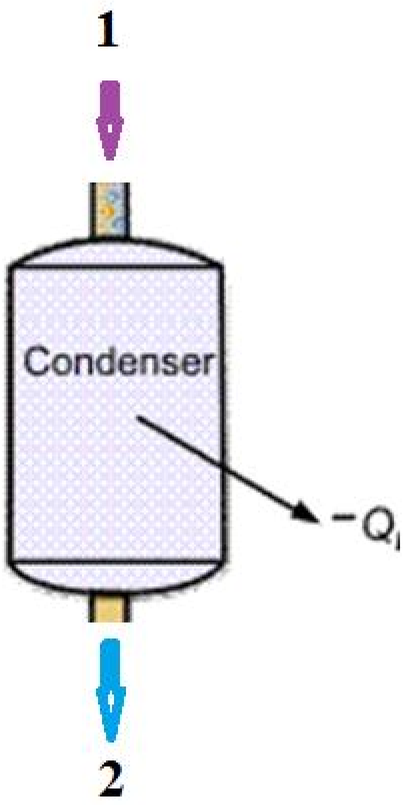
By applying 1st law of thermodynamics:

$$\dot{m}\left[(h_2 - h_1) + \cancel{\left(\frac{V_2^2 - V_1^2}{2}\right)} + \cancel{g(z_2 - z_1)}\right] = \dot{Q} - \cancel{\dot{W}}$$

0 0 0

$$\boxed{\dot{Q}_c = \dot{m}\,(h_2 - h_1) \quad (W)} \;\ldots\ldots \quad 27$$

$$\boxed{q_c = h_2 - h_1 \quad (J/kg)}$$



Discussion About

- Any questions?