- Recap: Lecture 8: 21st January 2014, 0830-0930 hrs.
  - First law for open systems
  - Conservation of mass
  - Flow work and the energy of a flowing fluid
  - Total energy of a flowing fluid
  - Energy analysis of steady flow systems
  - Steady flow energy equation
    - Nozzles/diffusers, compressors/turbines, throttling devices, mixing chambers

- Comparison of steady flow energy equation with Euler and Bernoulli equations

$$\dot{Q}_{in} + \dot{W}_{in} + \sum_{in} \underbrace{\dot{m}\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each inlet}} = \dot{Q}_{out} + \dot{W}_{out} + \sum_{out} \underbrace{\dot{m}\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each exit}}$$

The steady flow equation in differenti al form

$$\partial Q = dh + \overline{V}d\overline{V} + gdz + \partial W$$

Since $h = u + pv$ and $\partial Q = du + pdv$ (for a quasi - static process involving only pdv work),

$$du + pdv = du + pdv + vdp + \overline{V}d\overline{V} + gdz + \partial W$$

For an inviscid frictionle ss flow, say, through a pipe

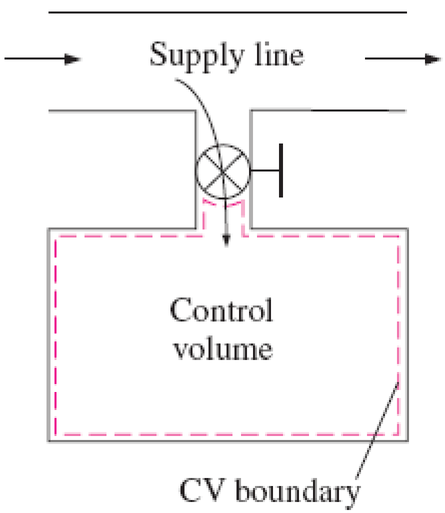
$$vdp + \overline{V}d\overline{V} + gdz = 0$$

This is the Euler equation.

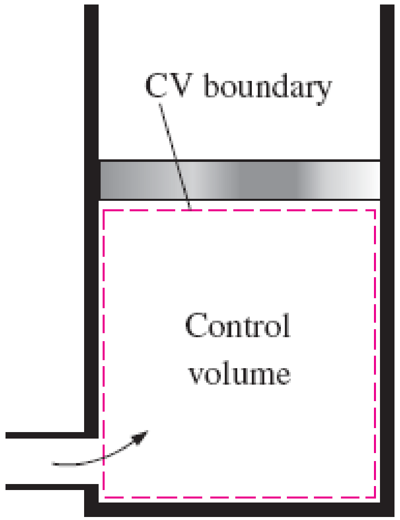
If we integrate between two sections,

$\dfrac{\text{p}}{\rho} + \dfrac{\overline{V}^2}{2} + gz = const$. This is the Bernoulli equation.

- **Unsteady flow processes**
  - important to keep track of the mass and energy contents of the control volume as well as the energy interactions across the boundary
  - Charging, discharging of tanks from pipelines, inflating tyres or balloons, cooking in a pressure cooker



Charging if a rigid tank from a supply line is an unsteady process, due to changes within the control volume.



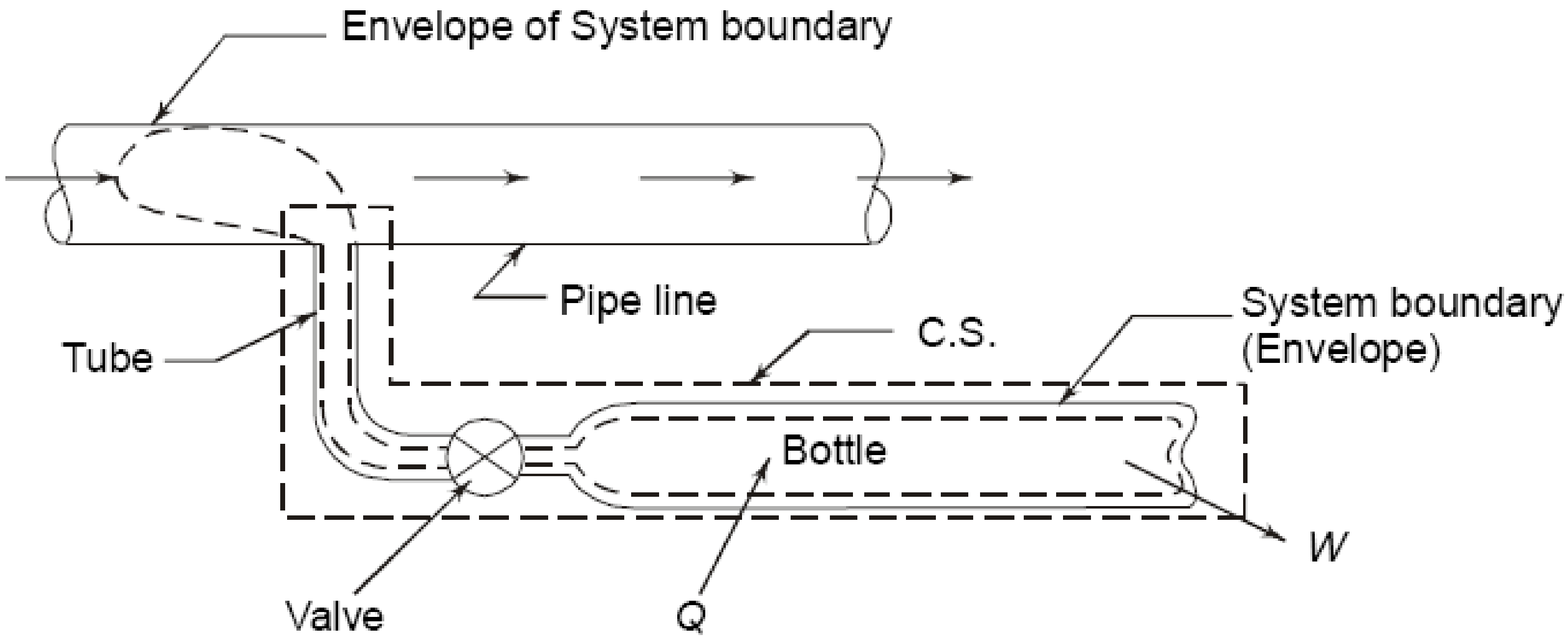
The shape and size of a control volume may change during an unsteady flow process.

The *mass balance* for any system undergoing any process can be expressed as

$$m_{\text{in}} - m_{\text{out}} = \Delta m_{\text{system}} \qquad \text{(kg)}$$

where $\Delta m_{\text{system}} = m_{\text{final}} - m_{\text{initial}}$ is the change in the mass of the system. For control volumes, it can also be expressed more explicitly as

$$m_i - m_e = (m_2 - m_1)_{\text{CV}}$$



- The bottle initially contains a mass m_1 at state $P_{1,}$ $T_{1,}$ $v_{1,}$ $h_{1,}$ and $u_{1.}$ As the valve is opened and gas flows into the bottle till mass m_2 at state $P_{2,}$ $T_{2,}$ $v_{2,}$ $h_{2,}$ and u_2 is attained.
- The state of the gas in the supply pipeline can be assumed to be constant $P_{p,}$ $T_{p,}$ $v_{p,}$ $h_{p,}$ u_p and $V_{p.}$

Energy of the gas before filling

$$E_1 = m_1 u_1 + (m_2 - m_1)\left(\frac{V_P^2}{2} + u_P\right)$$

Where, $(m_2 - m_1)$ is the mass of gas in the pipeline and the tube which would enter the bottle.

Energy of the gas after filling, $E_2 = m_2 u_2$

$$\Delta E = E_2 - E_1 = m_2 u_2 - \left[m_1 u_1 + (m_2 - m_1)\left(\frac{V_P^2}{2} + u_P\right)\right]$$

The KE and PE terms have been appropriately neglected.

Work done because of the collapse of the envelope of gas volume, $W = P_P(V_2 - V_1) = P_P\left[0 - (m_2 - m_1)v_P\right]$

$$= -(m_2 - m_1)P_P v_P$$

Using the first for the process, $Q = \Delta E + W$

$$Q = m_2 u_2 - m_1 u_1 - (m_2 - m_1)\left(\frac{V_P^2}{2} + u_P\right) - (m_2 - m_1) P_P v_P$$

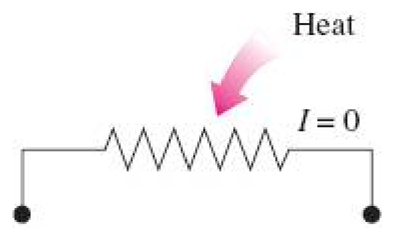
$$= m_2 u_2 - m_1 u_1 - (m_2 - m_1)\left(\frac{V_P^2}{2} + h_P\right)$$

This gives the energy balance for this process.

This equation can also be derived using the control volume (Eulerian) approach.

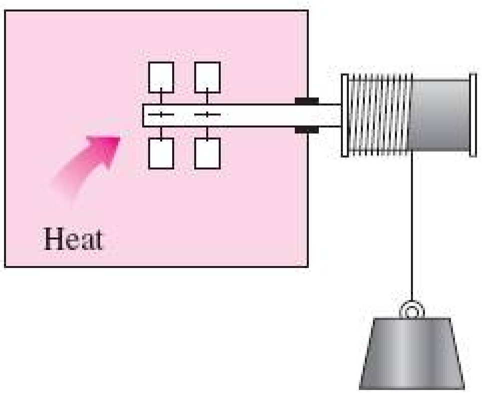
Second law of thermodynamics

- Need for the second law of thermodynamics
  - Limitations of the first law of thermodynamics
  - Directionality of a process
  - Quality of energy
- Examples
  - A hot object does not get hotter in a cooler room.
  - Transferring heat to a resistor will not generate electricity.



Electricity cannot be generated by transferring heat to a wire

A cup of hot coffee will not get hotter in a cooler room



A paddle wheel cannot be rotated by transferring heat to it.

Second law of thermodynamics

- Processes proceed in a certain direction and not in the reverse direction.
- The first law places no restriction on the direction of a process.
- This inadequacy of the first law to identify whether a process can take place or not is remedied by the second law of thermodynamics.
- A process cannot occur unless it satisfies both the first and the second laws of thermodynamics.

Second law of thermodynamics

- The first law of thermodynamics was concerned only with the quantity of energy and its transformations.
- Second law reveals that energy has quantity as well as quality.
- Second law of thermodynamics determines theoretical limits for feasibility of a process.

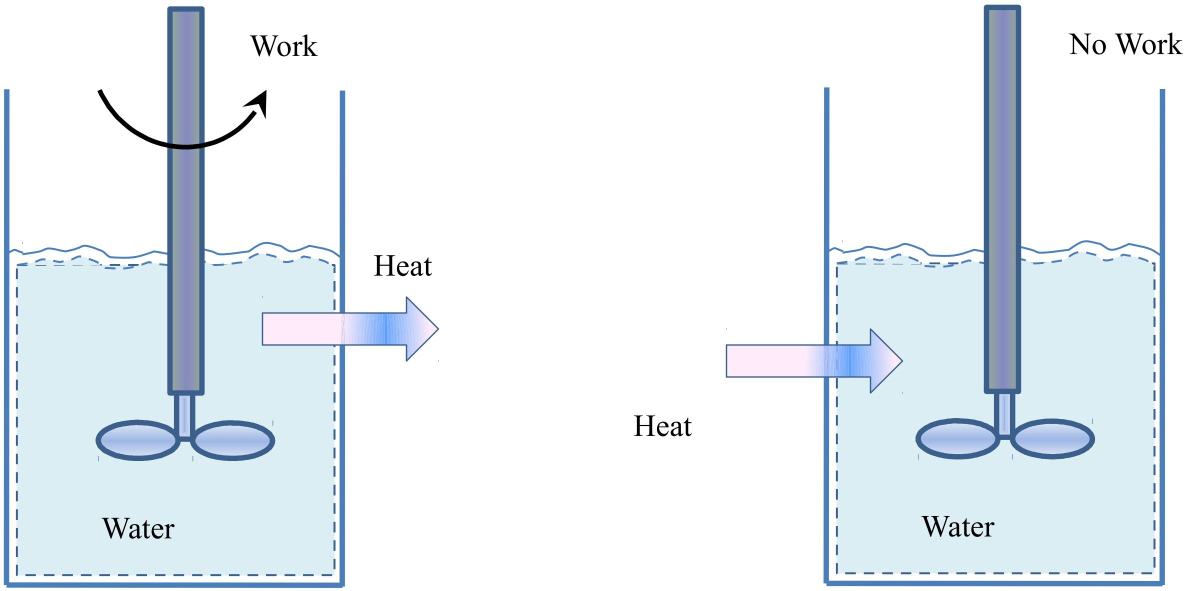
Thermal energy reservoir

- A hypothetical body with a relatively large thermal energy (mass x specific heat).
- Supply or absorb infinite amounts of heat without any change in its temperature
- Eg. Oceans, lakes, atmosphere
- A reservoir that supplies energy in the form of heat: Source
- A reservoir that absorbs energy in the form of heat: Sink

Heat engines

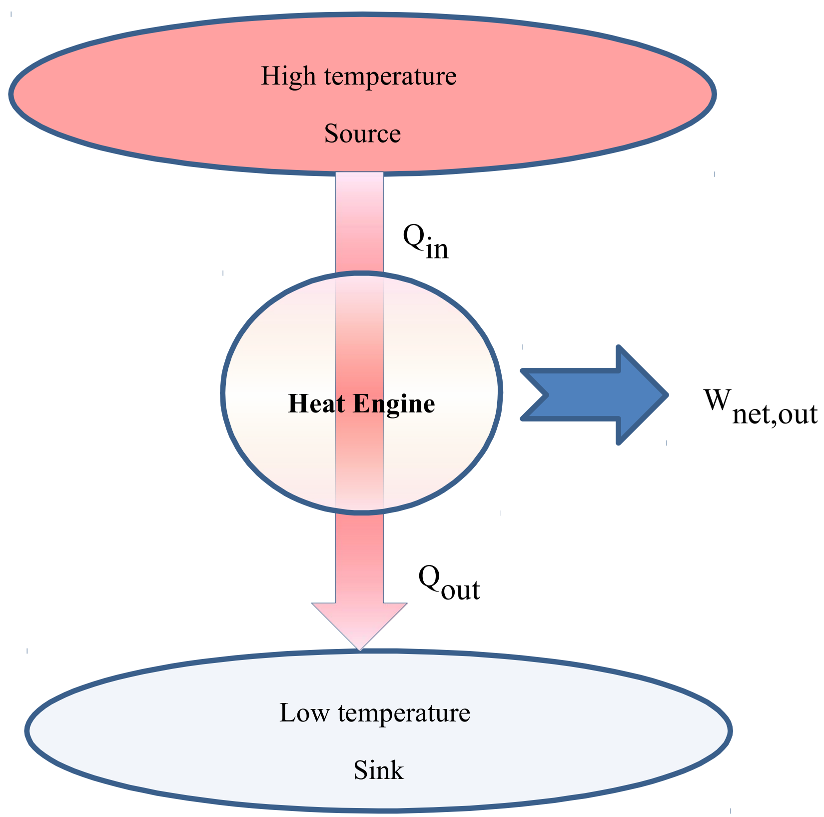
- Work can be rather easily converted to heat.
- The reverse process is not easy and requires special devices: heat engines
- Receive heat from a high-temperature source (solar energy, oil furnace etc.).
- Convert part of this heat to work
- Reject the remaining waste heat to a low-temperature sink
- Operate on a cycle

Heat engines



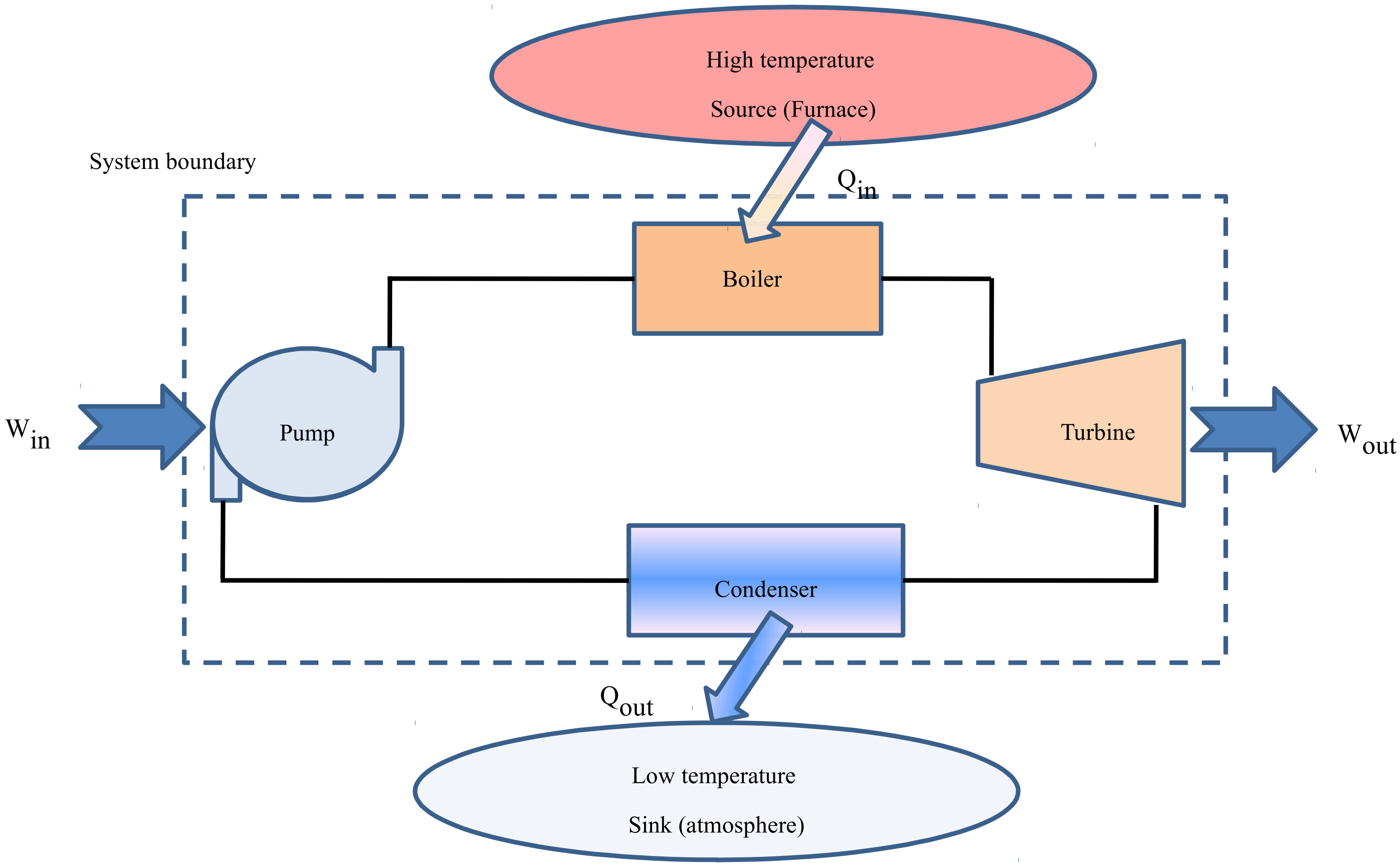
Work can be easily converted to heat, but the reverse does not occur naturally.

Heat engines



Heat engines convert part of Q_{in} to $W_{net,out}$ and reject the balance heat to the sink.

Heat engines



Heat engines

- The net work output of the heat engine

$$W_{net,out} = W_{out} - W_{in} \quad \text{(kJ)}$$

- The heat engine system may be considered as a closed system and hence $\Delta U=0$.

$$W_{net,out} = Q_{in} - Q_{out} \quad \text{(kJ)}$$

Thermal efficiency

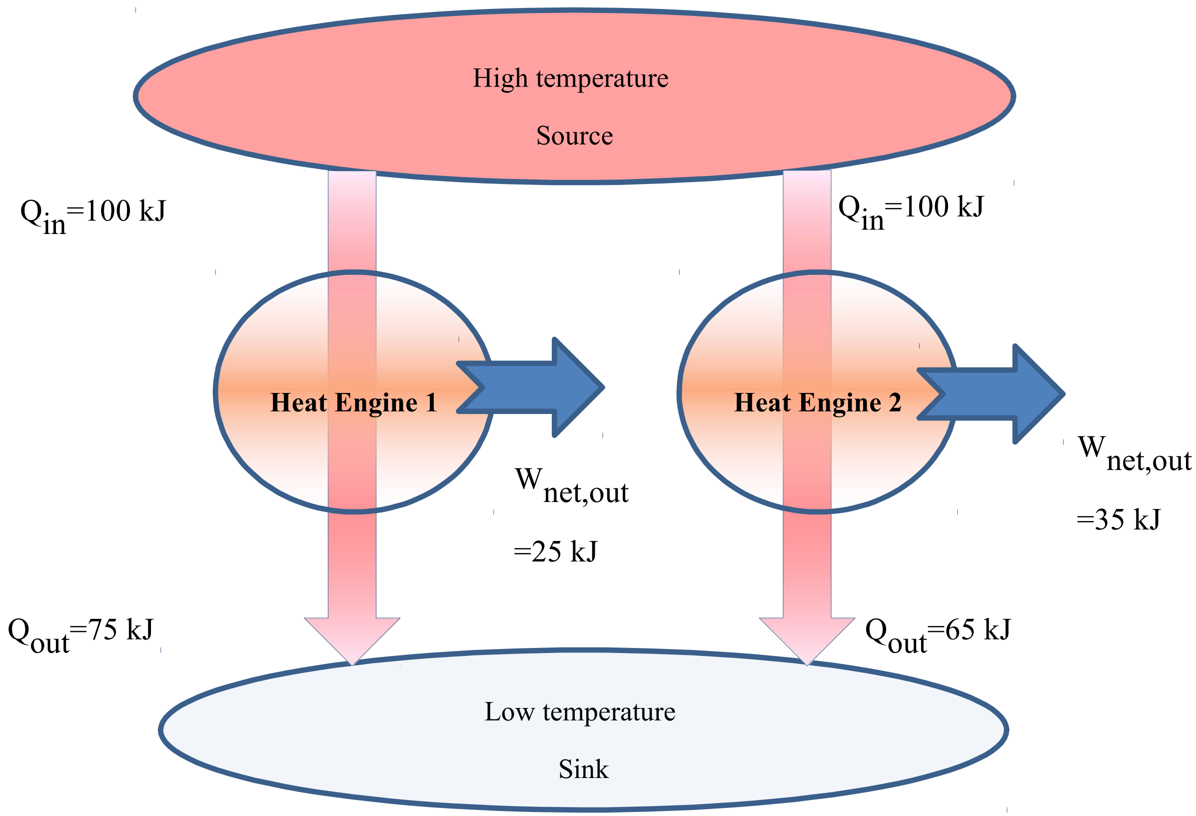
- Q_{out}: energy "wasted" during the process
- Only part of the heat input can be converted to useful work output.
- For heat engines, thermal efficiency is defined as

$$\text{Thermal efficiency} = \frac{\text{Net work output}}{\text{Total heat input}}$$

$$\eta_{th} = \frac{W_{net,out}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$$

$$(\text{since } \mathrm{W}_{\text{net,out}} = Q_{in} - Q_{out})$$

Thermal efficiency



$$\eta_{th1} = \frac{25}{100} = 0.25$$

$$\eta_{th2} = \frac{35}{100} = 0.35$$

All heat engines do not perform the same way.

Thermal efficiency

- Even the most efficient heat engines reject a huge fraction of the input energy.
- Thermal efficiency of common heat engines
  - Automobile engines: 20-25%
  - Aero engines: 25-30%
  - Gas turbine power plants: 40%
  - Combined cycle power plants: 60%