The steam cycle is a practical one, it is the basis of virtually all steam power plants and hence electricity generation. The main difficulties of the Carnot cycle are overcome by complete condensation in the condenser and by superheating (optional). We shall first consider the Rankine cycle in its generalised form without looking at the details of processes within components. Considering individual components:

**Turbine**

**SFEE:**
Thermal losses are normally very small compared to the work output. Potential terms and inlet velocities are usually ignored. The outlet velocity term may be significant when the turbine is considered in isolation.

Condenser

**SFEE:**

\[
(W_T \text{ is positive})
\]

\[\dot{Q} - W_T = \dot{m}_s \left( (h_4 + \frac{V_4^2}{2}) - h_3 \right)\]

All work and heat symbols are rates

The condenser is normally a constant pressure component with the heat transfer effected by cooling water. The inlet velocity term may be significant when the condenser is considered in isolation. (Sub cooling is not considered here)

Feed Pump

**SFEE:**

\[
(\dot{Q}_c \text{ is negative})
\]

\[\dot{Q}_c = \dot{m}_s \left( h_1 - (h_4 + \frac{V_4^2}{2}) \right)\]

The condenser is normally a constant pressure component with the heat transfer effected by cooling water. The inlet velocity term may be significant when the condenser is considered in isolation. (Sub cooling is not considered here)
$W_{FP}$ is relatively small since a nearly incompressible liquid is pumped.

**Boiler**

SFEES:

$\dot{Q}_B$ is positive

$$\dot{Q}_B = m_3 (h_3 - h_2)$$

The boiler is normally a constant pressure component with the heat transfer effected by high temperature gases from a furnace. The superheater is simply a part of the boiler where heat transfer takes place in the absence of saturated liquid, at exit from the boiler.

**Idealised Rankine Cycle: P-V Diagram**
This expression may be simplified at low boiler pressures by considering the feed pump term.

\[ \dot{W}_{T} - \dot{W}_{FP} = m_s (h_3 - h_4) - m_s (h_2 - h_1) \]

\[ \frac{\dot{W}_{T} - \dot{W}_{FP}}{\dot{Q}_B} = \frac{m_s (h_3 - h_4) - m_s (h_2 - h_1)}{m_s (h_3 - h_2)} \]

This expression may be simplified at low boiler pressures by considering the feed pump term.

\[ -\dot{W}_{FP} = m_s (h_2 - h_1) \]

- an isentropic process.

Applying Tds = dh - vdp
We have: dh = vdp
But:

\[-W_{FP} = m_2 \int \frac{1}{1} dh\]

Hence:

\[-W_{FP} = m_2 \int \frac{1}{1} \nu dp\]

Which is the shaded area on the P-V diagram and since water is nearly incompressible over normal pressure ranges we may write:

\[-W_{FP} = m_2 \nu_1 (P_2 - P_1)\]

Under boiler pressures of about 25 bar it is normal to neglect feed pump work in the efficiency expression since it is small compared to the other terms. It is emphasised that this is a matter of judgement. Hence, if the feed pump term is neglected:

\[\eta_{rankine} = \frac{(h_3 - h_4)}{(h_3 - h_2)}\]

**Turbine and Feed pump irreversibilities**

Consider an expansion over a fixed pressure range on the T-S plane, such as in the Rankine cycle.

Each diagram shows a portion of the saturated vapour line on the T-S plane. An isentropic expansion is shown from state 1 to 2' and the corresponding real (irreversible) expansion in steady flow in some real turbines is shown as a dotted line. Note the increase in the specific entropy. Then:

Real work output

\[= m_2 (h_1 - h_2)\]
Isentropic work output

\[ = m_s (h_1 - h_2) \]

The real work output is less than the isentropic work output because \( h_2 > h_2' \).

The effect of irreversibilities is taken account of by defining:

Isentropic efficiency is the ratio of the real work output obtained to the work output that would be obtained from an isentropic expansion over the same pressure range, i.e.

\[ \eta_{isen} = \frac{(h_1 - h_2)}{(h_1' - h_2')} \]

for a turbine

A similar approach may be adopted for the feed pump process.

By analogy with previous expression, showing a portion of the saturated liquid line:

\[ \eta_{isen} = \frac{(h_2' - h_1)}{(h_2' - h_1')} \]

for a feed pump

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