Dynamic Energy Conversion in Space

Carnot Principles-*Sadi Carnot (1824)*

1.) ***Concept of Reversibility***

Heat transfer occurs from the heat source to the working fluid with zero temperature difference

2.) ***Concept of Maximum Efficiency***

No engine can produce more work for the same amount of heat added and the same heat source and sink temperature than one operating on a reversible cycle.

(see 2nd Law of Thermodynamics)

=======================================

Two Temperature Heat Engine (Figure)

$$\eta = \frac{\text{some useful work}}{\text{energy expended to achieve that effect}}$$

$$\eta = \frac{\left(\dot{Q}_{in} - \dot{Q}_{out}\right)}{\dot{Q}_{in}}$$

$$\eta = \frac{(T_H - T_L)}{T_H} = 1 - \left(\frac{T_L}{T_H}\right)$$

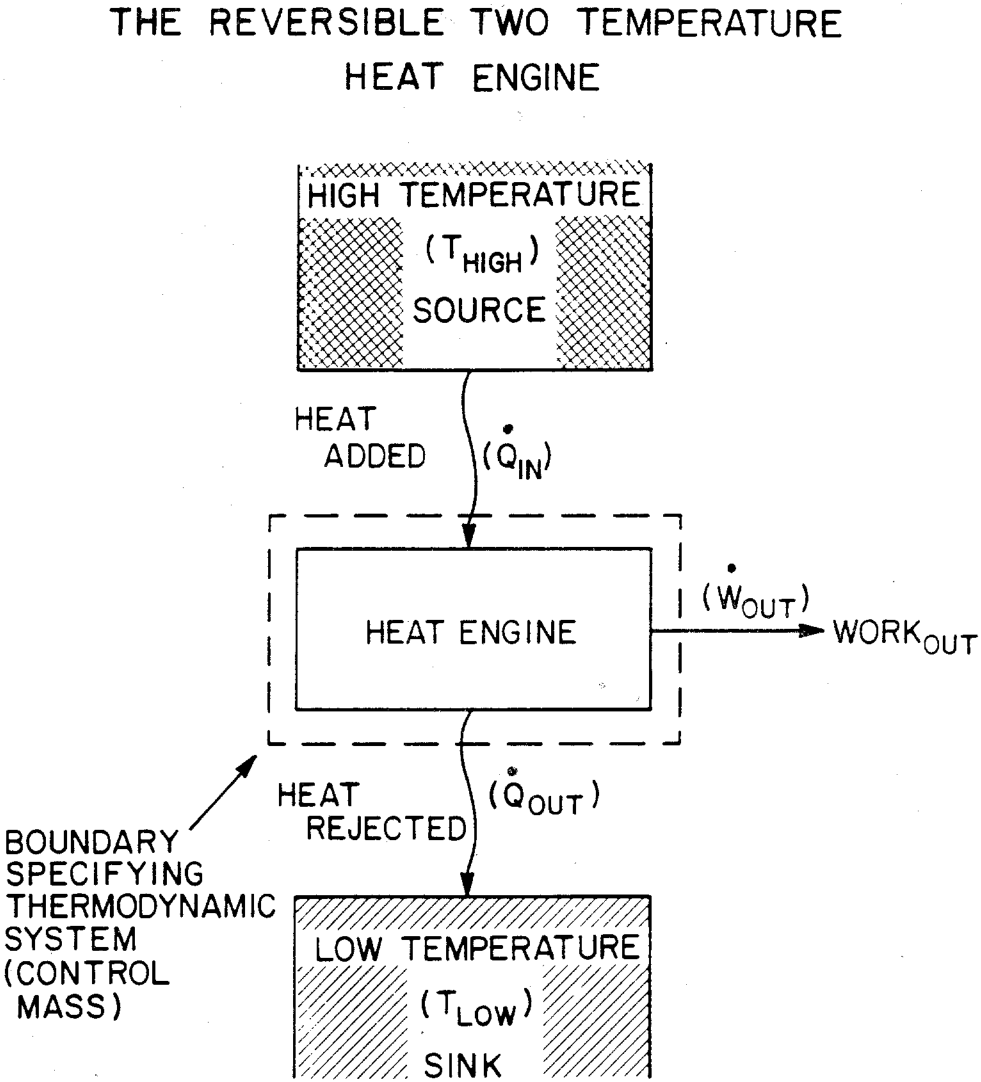


Fig. 5.2 The reversible two temperature heat engine.

Examples of Irreversible Processes

- **Heat transfer through a ΔT**
- **Chemical reaction**
- **Friction**
- **Electric load through a resistive load**
- **Magnetization**
- **Inelastic deformation**

Power System Conversion Efficiency

$$\eta_{PCS} = \eta_{th}\eta_{Device}$$

Carnot Cycle and Engine-2 figures

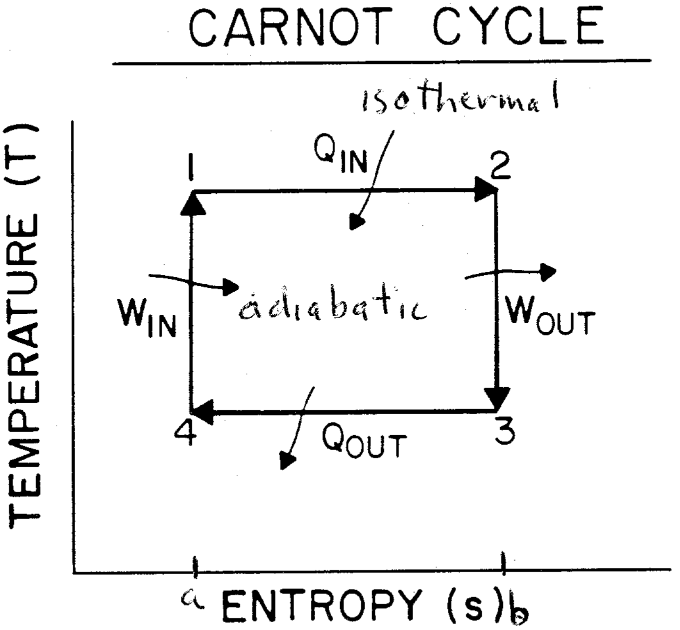
See Carnot Efficiency-Figure

Need to include the parameters of idealized turbines, compressors, and pumps.

Note Figure of 1D steady Flow

The Carnot Engine

The Carnot cycle is a fundamental theoretical concept



Area represents net work of cycle

$$\eta = \frac{W_{cycle}}{Q_{12}} = \frac{\text{area } 1\text{-}2\text{-}3\text{-}4\text{-}1}{\text{area } 1\text{-}2\text{-}b\text{-}a\text{-}1}$$

$$= \frac{(T_H - T_C)(S_1 - S_2)}{T_H\,(S_1 - S_2)}$$

$$= \frac{T_H - T_C}{T_H}$$

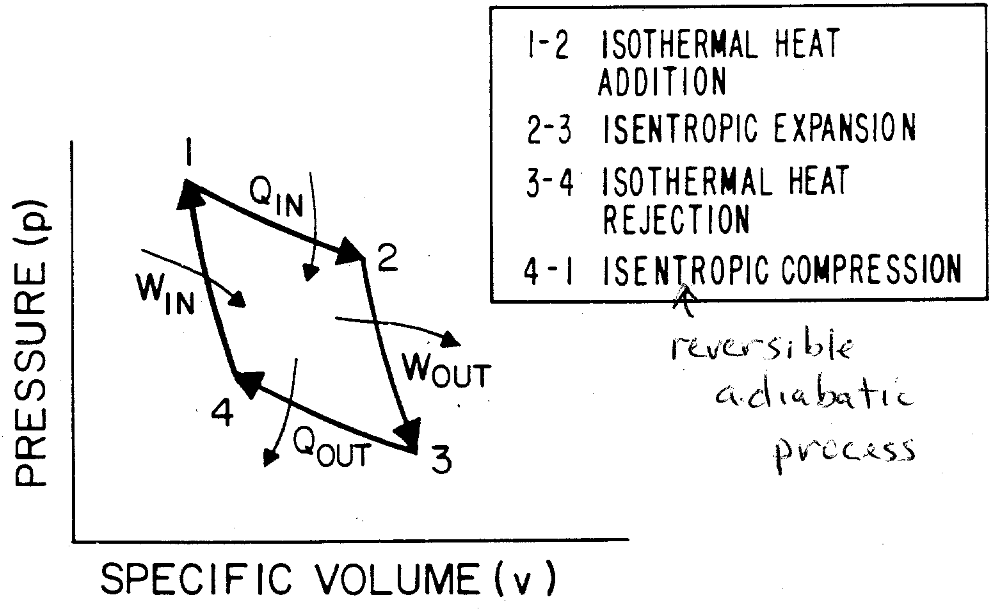


Fig. 5.3 Carnot cycle.

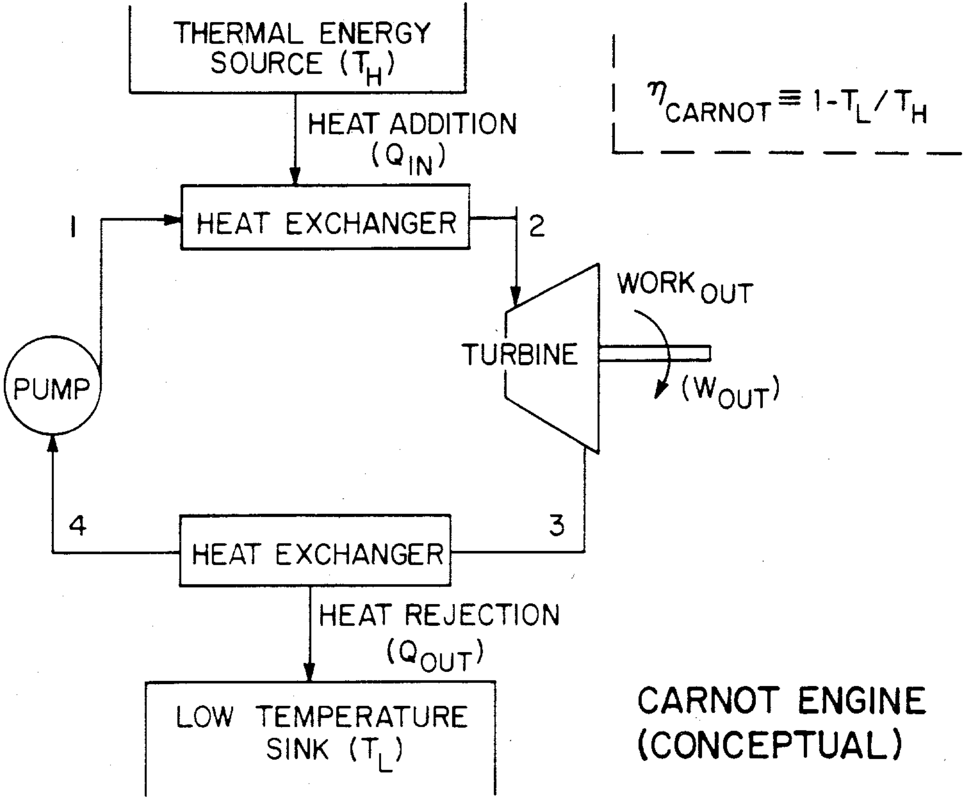
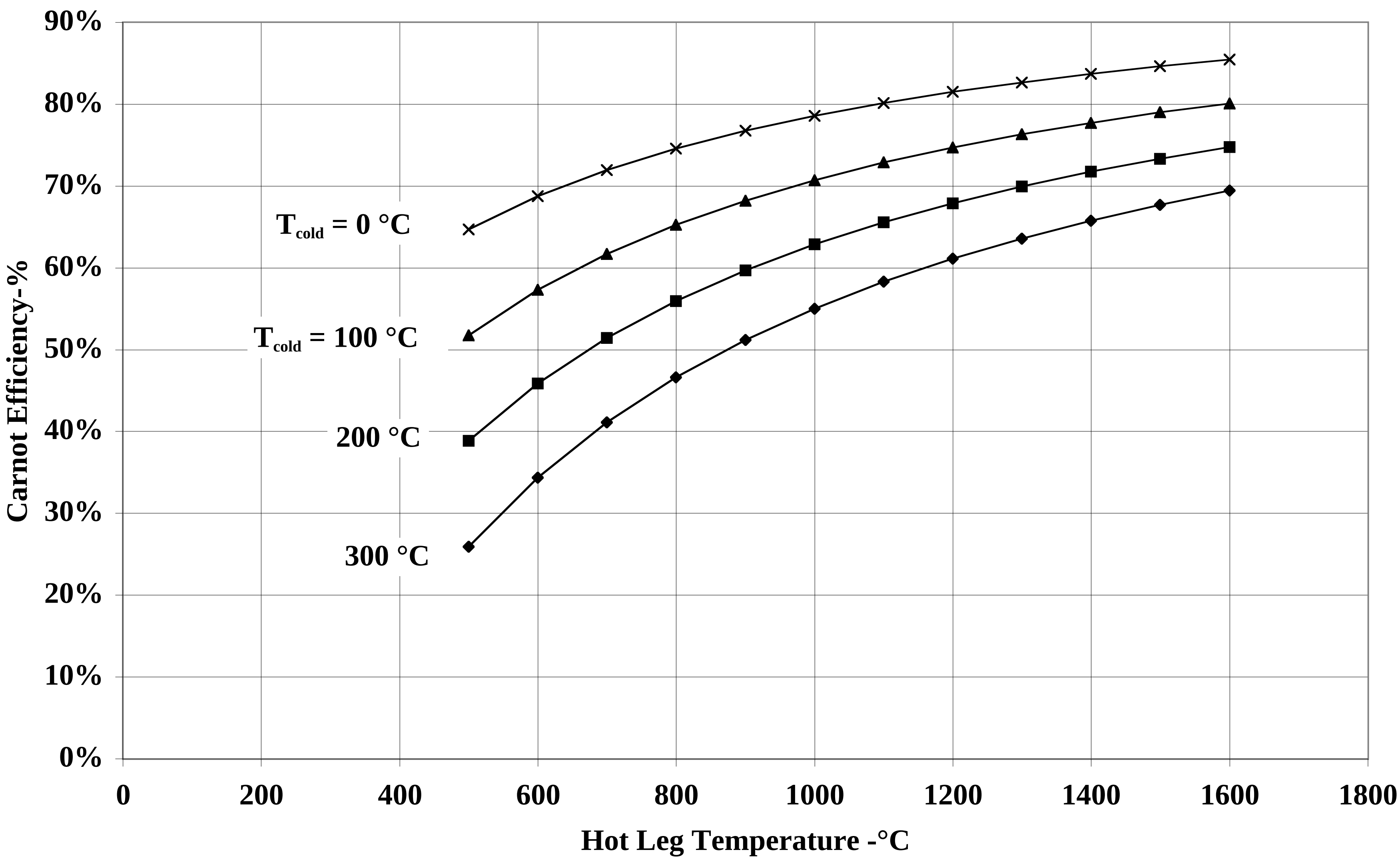


Fig. 5.4 Carnot engine (conceptual).



Variation of Carnot Efficiency With Heat Rejection Temperature

$$\dot{\mathbf{W}} + \dot{\mathbf{Q}} + \dot{\mathbf{m}}\left[\left(\mathbf{e}_2 + \mathbf{p}_2\mathbf{v}_2\right) - \left(\mathbf{e}_1 + \mathbf{p}_1\mathbf{v}_1\right)\right] = \mathbf{0}$$

Where $\dot{W}$ is the shaft work
m =mass flow rate
e = specific energy content of fluid
(includes internal, kinetic, and potential energy)
p = working fluid pressure
v =specific volume of working fluid
pv = is the flow work

note provision for potential energy

Turbine (figure)

$$\dot{W}_{shaft} = \dot{m} \bullet (h_1 - h_2)$$

Compressor (figure)

$$\dot{W}_{in} = \dot{m} \bullet (h_2 - h_1)$$

Pumps (Figure)

(v constant)

$$\dot{W}_{in} = \dot{m}v \bullet (P_2 - P_1)$$

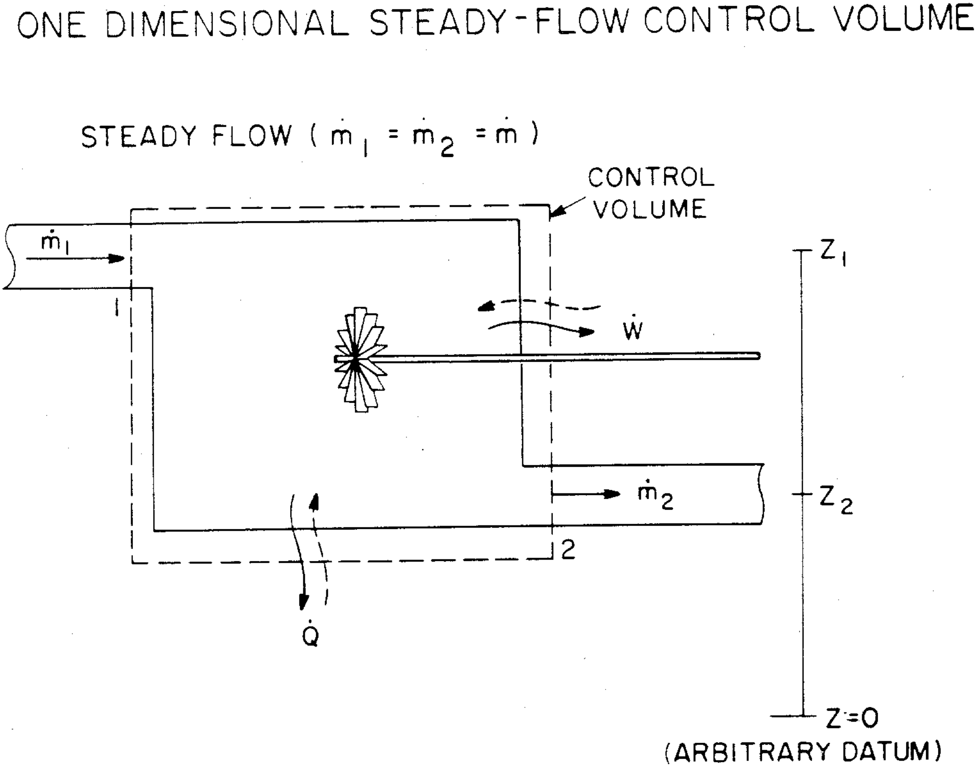


Fig. 5.5 One dimensional steady-flow control volume.

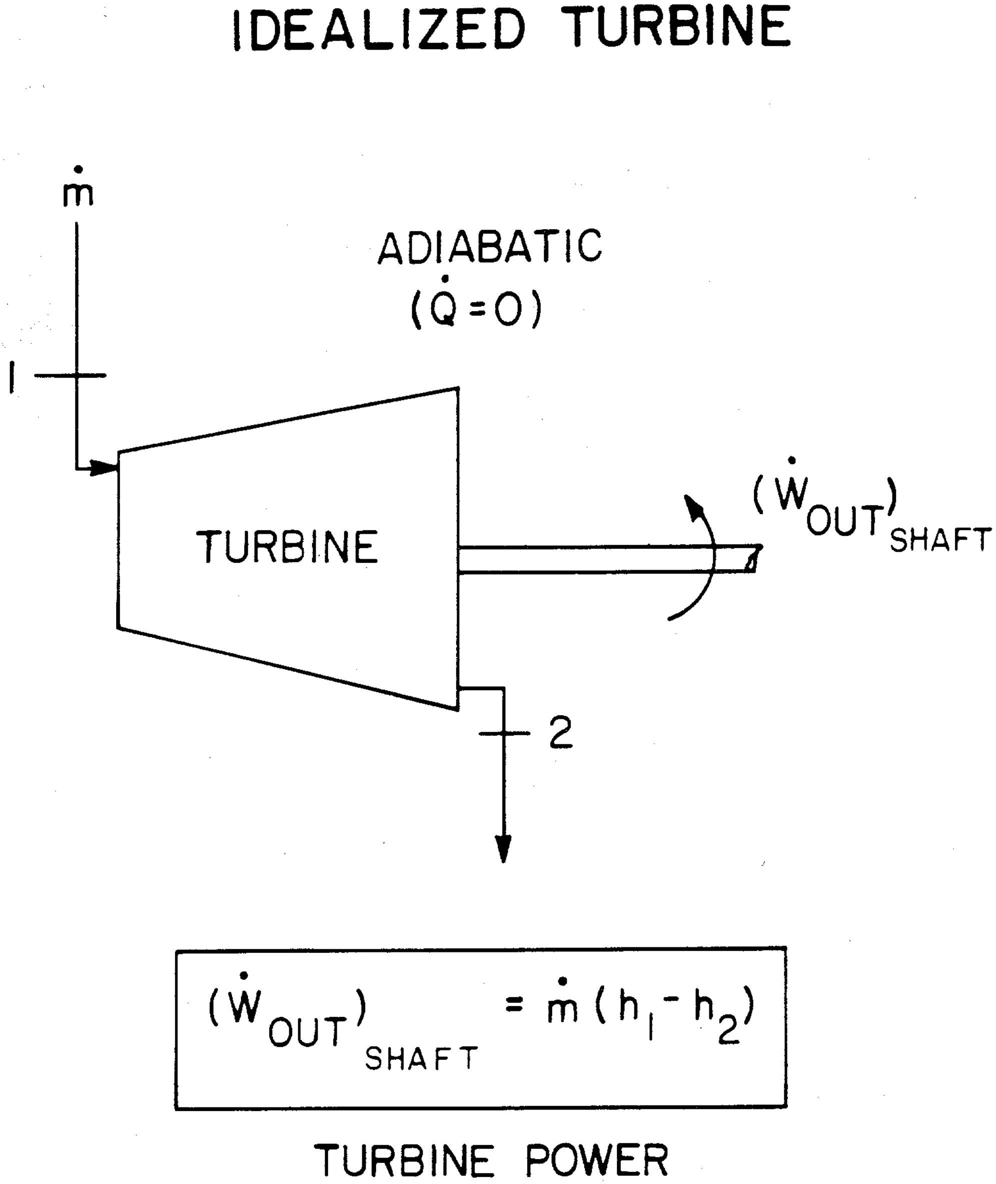


Fig. 5.6 Idealized turbine.

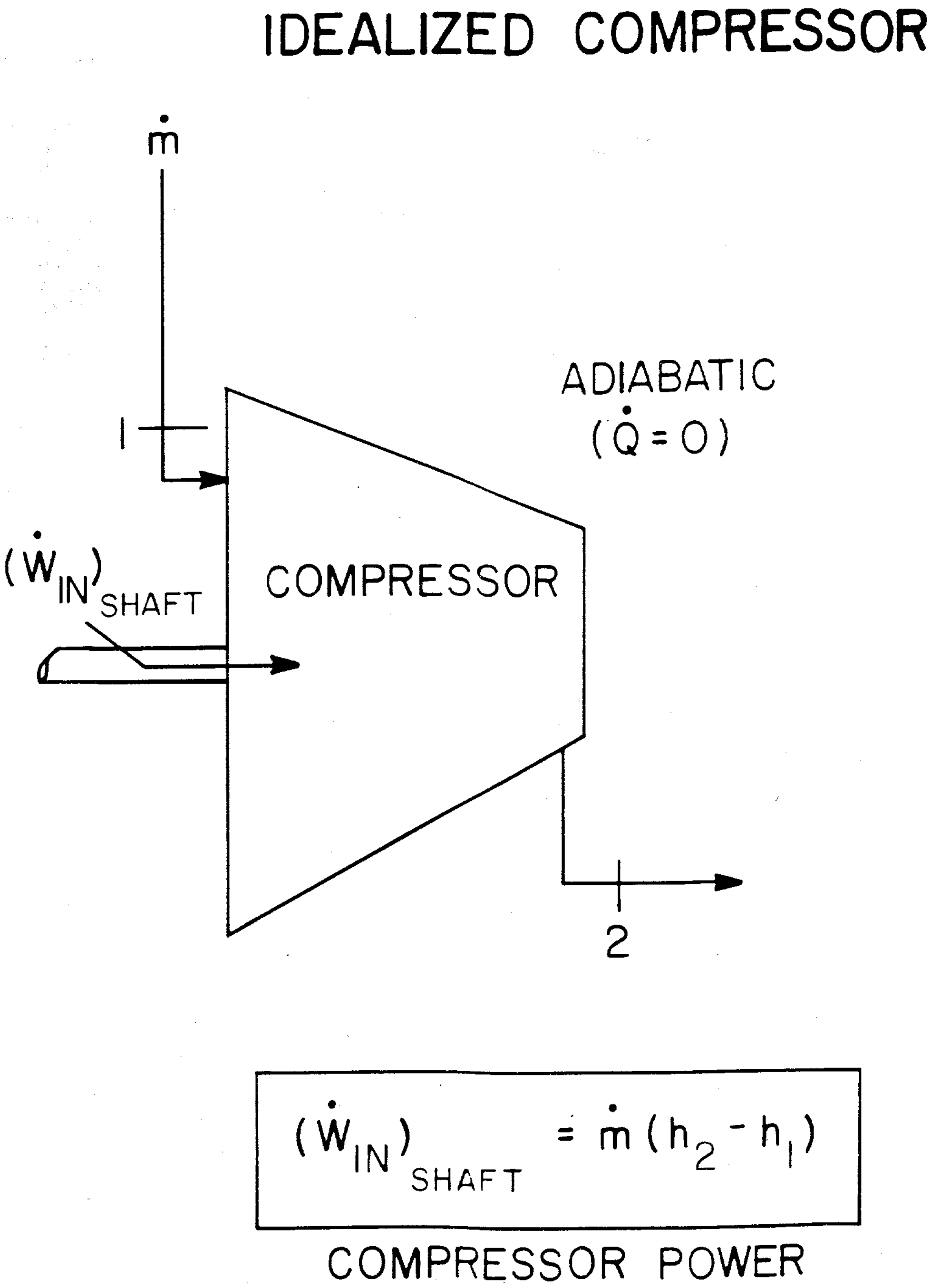
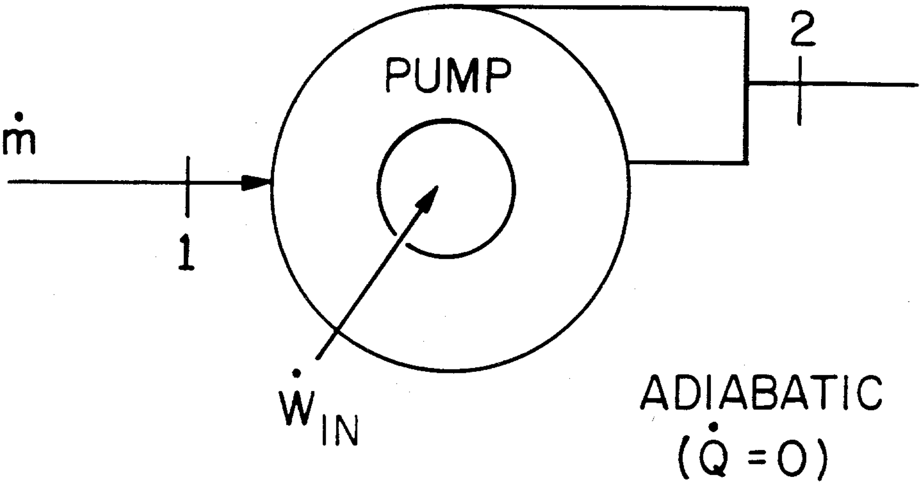


Fig. 5.7 Idealized compressor.

IDEALIZED PUMP (INCOMPRESSIBLE FLOW)



$$\boxed{\dot{W}_{IN} = \dot{m}\,\nu\,(p_2 - p_1)}$$

PUMP POWER

Fig. 5.8 Idealized pump (incompressible flow).

Rankine Cycle

William Rankine (1820-1872)

$$\eta_{\text{th}} = \frac{\left(\textbf{work out}\right)_{\textbf{turbine}} - \left(\textbf{work in}\right)_{\textbf{pump}}}{\left(\textbf{heat added}\right)}$$

Figure-Ideal

$$\eta_{th} = \frac{(h_1 - h_2) - (h_4 - h_3)}{(h_1 - h_4)}$$

Figure - Superheat

Figure- Reheat

Figure- Regeneration

Figure K Rankine Cycle

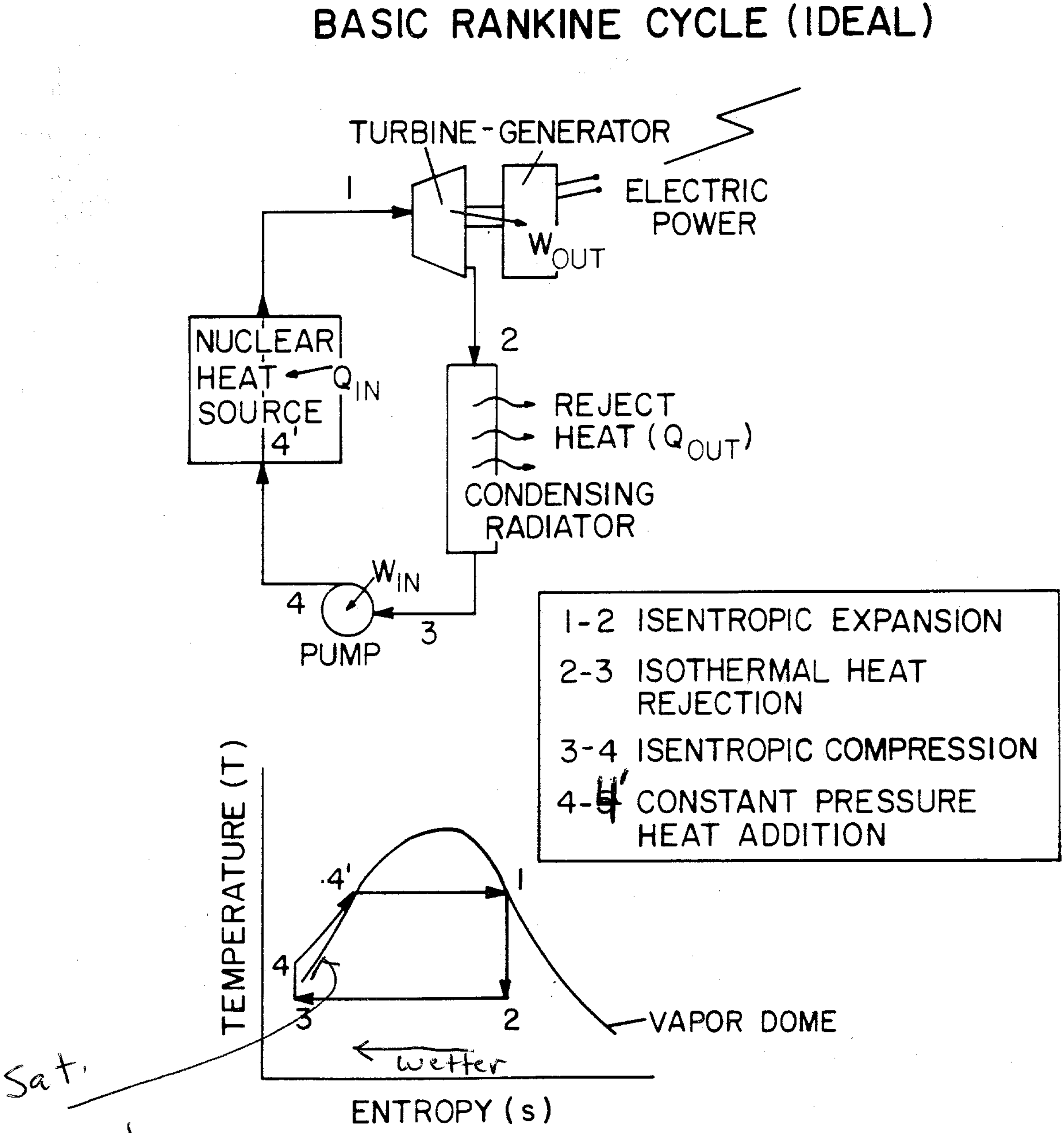


Fig. 5.9 Basic Rankine cycle (ideal).

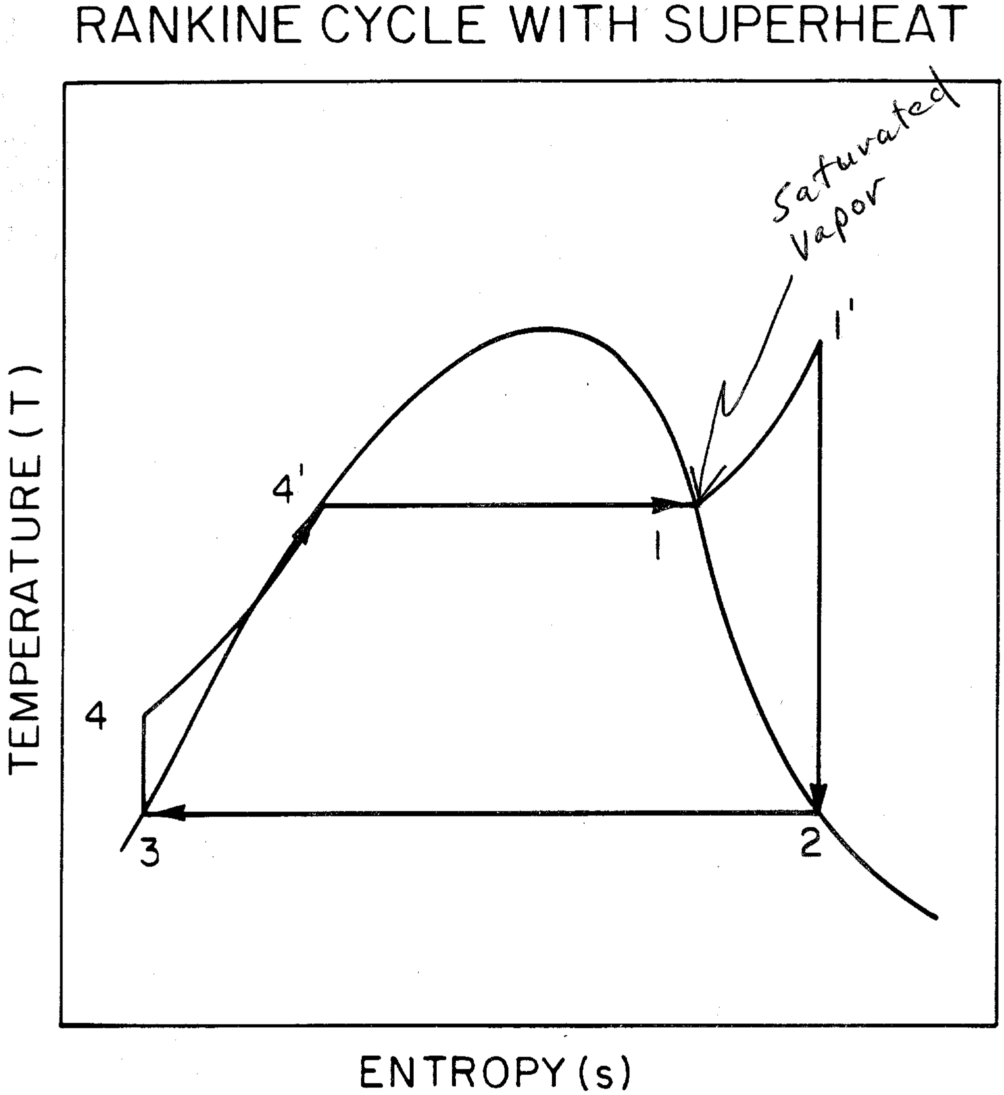
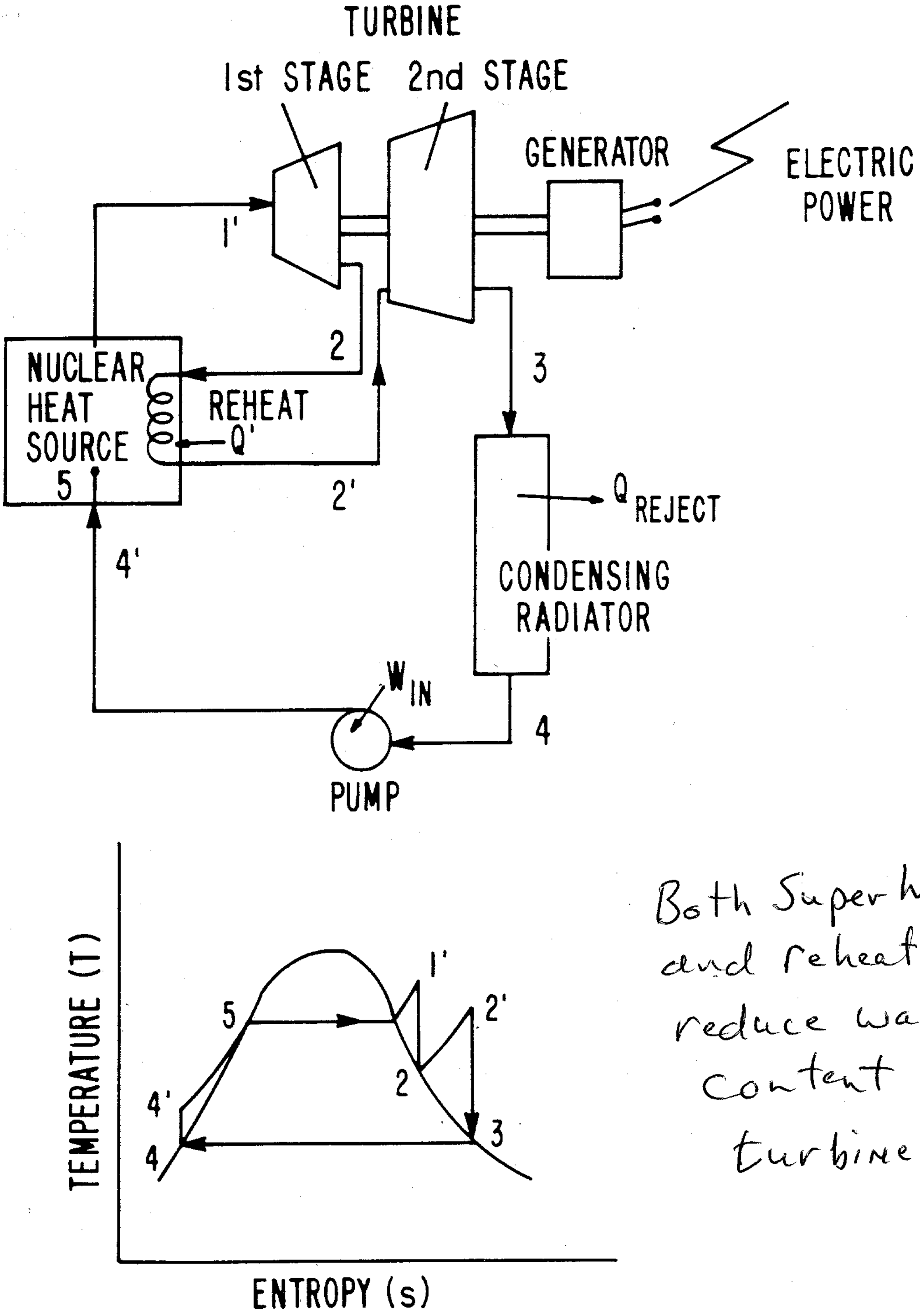


Fig. 5.10 Rankine cycle with superheat.

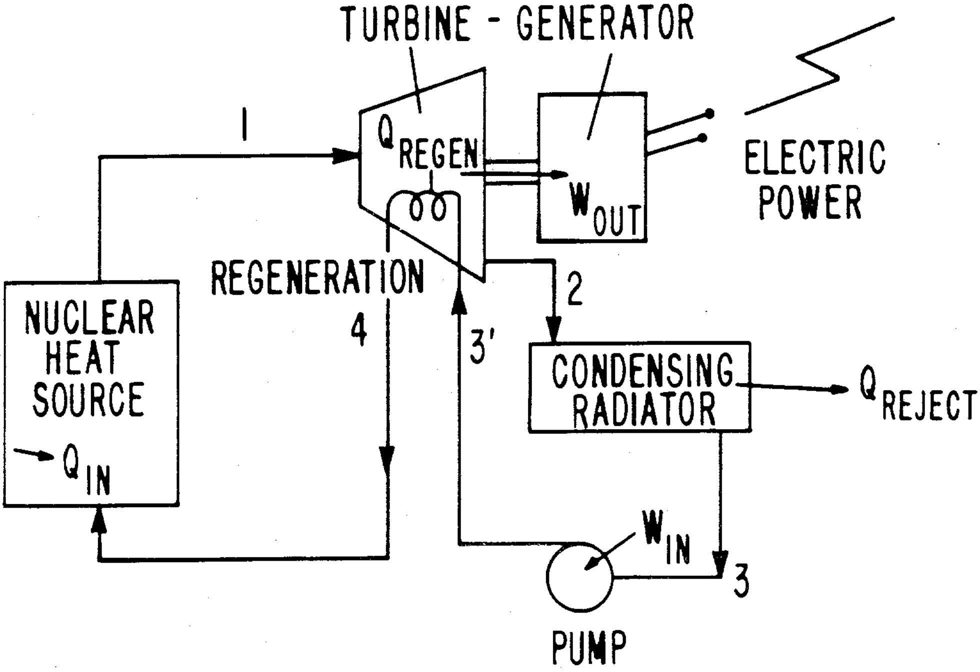
RANKINE CYCLE WITH REHEAT

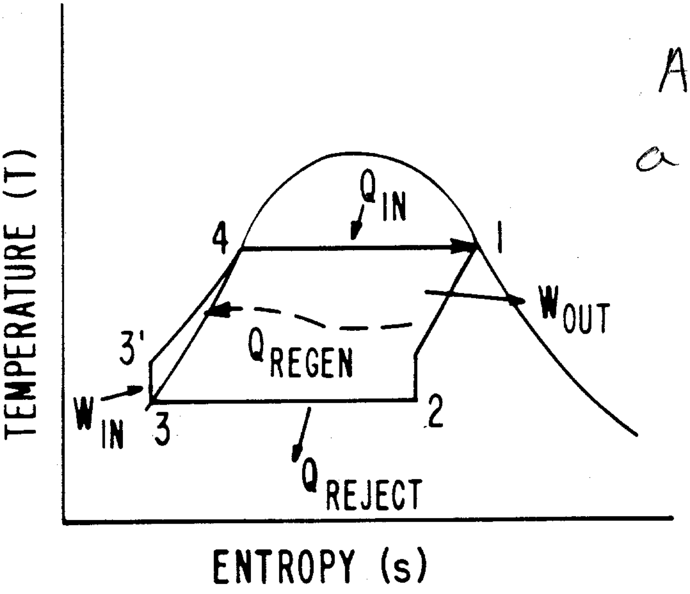


Both Superheat and reheat reduce water content to turbine

Fig. 5.11 Rankine cycle with reheat.

IDEAL RANKINE CYCLE WITH REGENERATION





Allows a 'nearer' approach to Carnot because the ΔT at point of heat transfer is reduced making it more 'reversible'

Fig. 5.12 Ideal Rankine cycle with regeneration.

This System might achieve 19% overall efficiency (

POTASSIUM RANKINE CYCLE

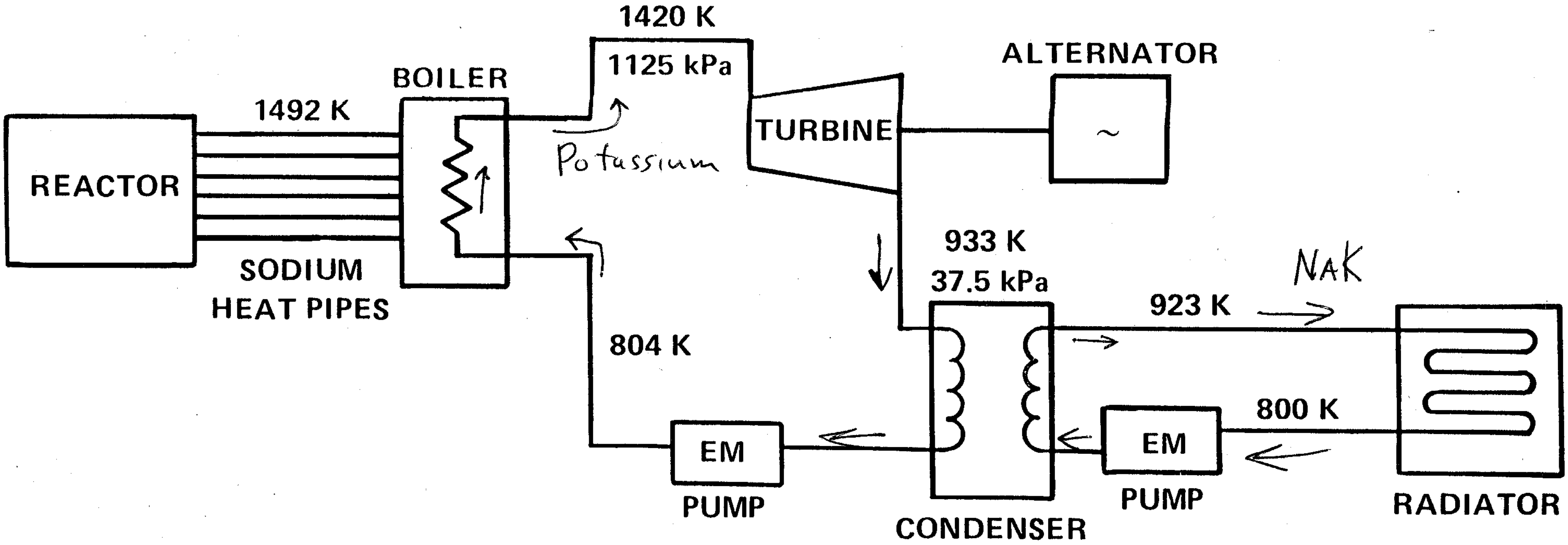


Fig. 5.13 Proposed potassium Rankine cycle [*1*].

Problem was that this system had too much liquid K in Turbine
(Quality ~ 80%)