UPPSC-AE 2020

Uttar Pradesh
Public Service Commission

Combined State Engineering Services Examination

Assistant Engineer

Mechanical Engineering

Energy Conversion

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

MADE EASY Publications

Energy Conversion

Contents

CHAPTER 7

Rankine Cycle

7.1 Introduction

A steam power plant continuously converts the energy stored in fossile fuels or fissile fuels into shaft work and ultimately into electricity. The working substance is water which is some times in the liquid phase and sometimes in the vapour phase. The fluid is undergoing a cyclic process, there will be no net change in its internal energy over the cycle $(\oint dE = 0)$ and consequently the net energy transferred to the unit mass of the fluid as heat during the cycle must equal the net energy transfer as work from the fluid.

$$\Sigma Q_{net} = \Sigma W_{net} \qquad \text{(First law of thermodynamics for a cycle)}$$

$$Q_1 - Q_2 = W_T - W_P$$

where,

Q_1 =heat transferred to the working fluid kJ/kg

Q_2 =heat rejected from the working fluid kJ/kg

W_T =work transferred from the working fluid kJ/kg

W_P =work transferred into the working fluid kJ/kg

$$\eta_{cycle} = \frac{W_{net}}{Q_1} = \frac{W_T - W_P}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

NOTE : Working substance in steam power plant – water.

Working substance in steam turbines – steam.

7.2 Rankine Cycle

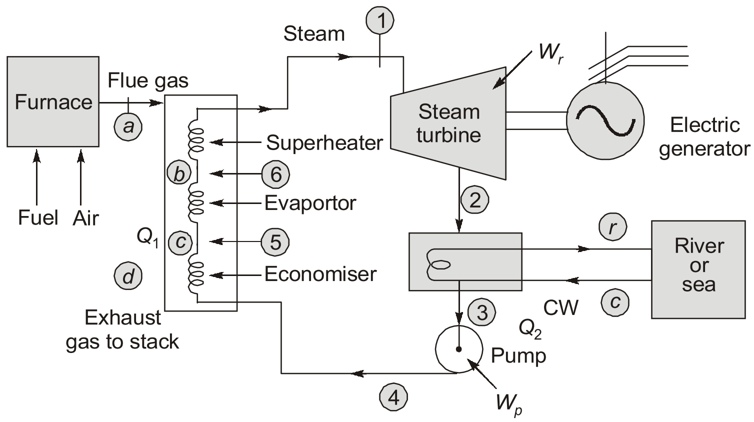
The Rankine cycle is a model used to predict the performance of steam turbine systems. It was also used to study the performance of reciprocating steam engines. The Rankine cycle is an idealized thermodynamic cycle of a heat engine that converts heat into mechanical work while undergoing phase change.

The Rankine cycle slosely describes the process by which steam-operated heat engines commonly found in thermal power generation plants generate power.

It is the practical cycle used in steam power plants.

- This cycle consists of four processes:
  - **For steam boiler:** reversible constant pressure heating process of water
  - **For turbine:** reversible adiabatic expansion of steam.
  - **For condenser:** reversible constant pressure heat rejection
  - **For pump:** reversible adiabatic compression.

- When all these four processes are ideal, the cycle is an ideal cycle, called a **Rankine cycle**.



- Now,

  For 1 kg of fluid, the steady flow energy equation to each processes:

  For boiler, $Q_1 = h_1 - h_4$

  For turbine, $W_T = h_1 - h_2$

  For condenser, $Q_2 = h_2 - h_3$

  For pump, $W_P = h_4 - h_3$

  Efficiency of Rankine cycle

$$\eta = \frac{W_{net}}{Q_1} = \frac{W_T - W_P}{Q_1} = \frac{(h_1 - h_2) - (h_4 - h_3)}{h_1 - h_4}$$

$$W_P = h_4 - h_3 = -\int_3^4 \nu d_p \ ; \qquad \nu \rightarrow \text{specific volume of liquid at 3}$$

  Volume of liquid at 3.

  Since, $\nu_{\text{steam or gas}} >> \nu_{\text{liquid}}$

  $\therefore$ $W_p >>> W_T$

  So, W_p is often neglected.

- **Steam rate:** The capacity of a steam plant is often expressed in terms of steam rate or specific steam consumption. It is defined as the rate of steam flow (kg/s) required to produce unit shaft output (1 kW).

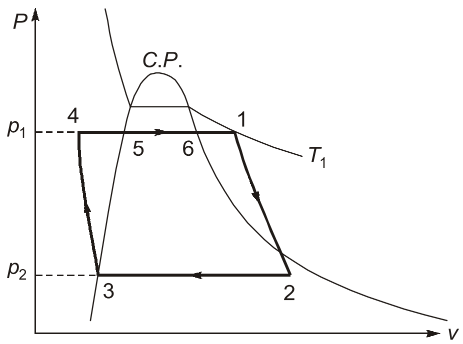
$$\text{Steam rate} = \frac{1}{W_{net}} \text{kg/kWs} = \frac{3600}{W_{net}} \text{kg/kWh}$$

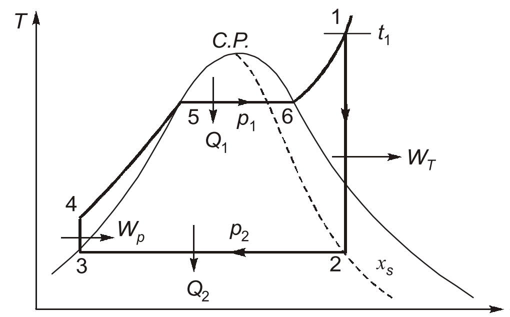
  It varies from 3 to 5 kg/kWh

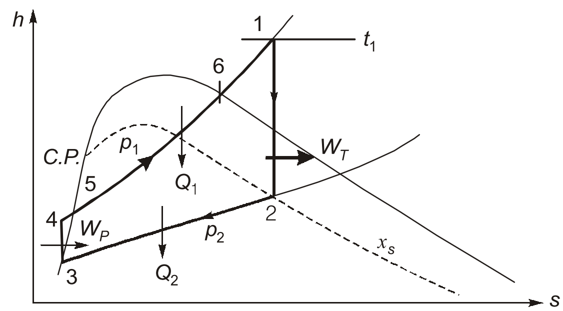
- **Heat rate:** The cycle efficiency is sometimes expressed alternatively as heat rate which is the rate of heat input (kJ/s) required to produce unit shaft output (1 kW)

$$\text{Heat rate (H.R.)} = \frac{Q_1}{W_T - W_P} = \frac{1}{\eta}\frac{\text{kJ}}{\text{kWs.}}$$

7.3 Economiser, Evaporator and Superheater







- Water is first heated sensibly in the economiser in the liquid phase at a certain pressure till it becomes saturated liquid.
- Economiser heats the feedwater (sensibly) by using the heat of exhaust flue gases. This reduces the fuel consumption in the boiler.

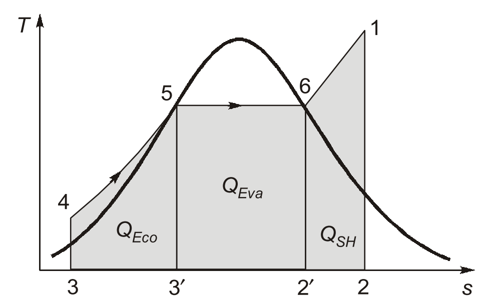
$$Q_{Eco} = h_5 - h_4$$

- In the evaporator there is phase change or boiling by absorbing the latent heat of vapourization at that pressure

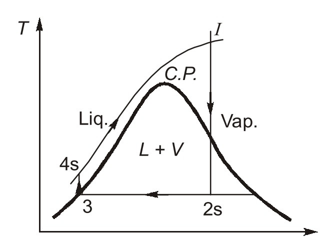
$$Q_{Evo} = h_6 - h_5 = h_{fg}$$

- The saturated vapour is further heated at constant pressure in the superheater to superheated state

$$Q_{SH} = h_1 - h_6$$



- As pressure increases, the latent heat decreases and so the heat absorbed in evaporator decreases and the fraction of the total heat absorbed in the superheater increases.
- For steam generators operating above the critical pressure there is no evaporator or boiling section. because enthalpy of vaporization becomes zero at critical point. However, there is a transition zone where all the liquid on being heated suddenly flashes into vapour.



Rankine Cycle with Supercritical Pressure

Example - 7.1 The function of economizer in a boiler is to

(a) Superheat the steam (b) Reduce fuel consumption

(c) Increase steam pressure (d) Maintain saturation temperature

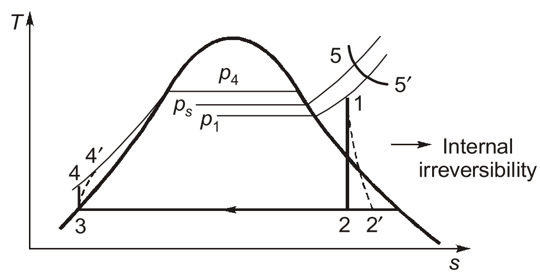
Solution: (b)

Economiser extracts heat flow the flow gases to heat feed water and reduces fuel consumption.

7.4 Internal Irreversibility

- Internal irreversibility of Rankine cycle is caused by fluid friction, throttling and mixing.
- Due to rapid processes in pumps and the turbines and large flow rates involved, heat loss per unit mass is negligible.

  Though the assumption of adiabatic flow in them is still valid, due to fluid friction the expansion and compression processes are not reversible and entropy of the fluid in both increases.
- The isentropic Efficiency (η_T) of the turbine is $\eta_T = \dfrac{h_1 - h_2}{h_1 - h_{2s}}$



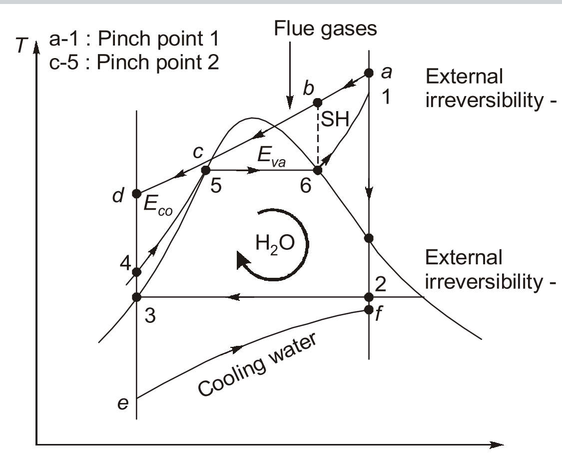
- The liquid leaving the pump must be at higher pressure then turbine inlet as there is pressure drop in boiler pipes, valves etc. and reaches at P_1 from P_4 as shown above.
- The isentropic Efficiency of the Pump, $\eta_p = \dfrac{h_{4s} - h_3}{h_4 - h_3}$.
- The actual pump work would be, $W_p = \dfrac{h_{4s} - h_3}{\eta_P} = \dfrac{\nu_3(p_4 - p_3)}{\eta_P}$.

Thus turbine produces less work and the pump absorbs more work.

NOTE: Processes in turbines and pumps in steam power plants are ADIABATIC and IRREVERSIBLE.

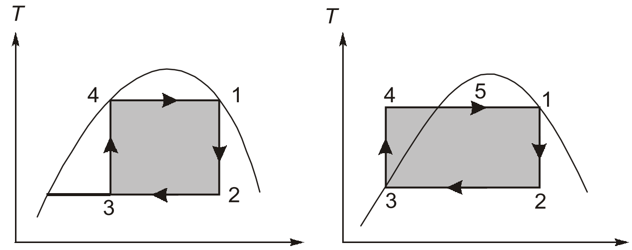
7.5 External Irreversibility

- External irreversibility of the rankine cycle is caused due to the temperature differences between the combustion gases and the working fluid on the source side and the temperature- difference between the condensing working fluid and the condenser cooling water on the sink side.
- The point where minimum temperature difference occur are called pinch point.



Carnot Cycle : Why it is not practical

- To compress the wet steam from state 3 will require a large work consuming compressor.
- It this case, pump work ($h_4 - h_3$) will be large. Also it is impossible to supply heat at constant temperature from 4 to 5.
- The dryness fraction at the lower stages of turbine expansion will be less and there will be problem of blade erosion.



(a) (b)

- It is not possible to control condensation process in such a manner that the desired quality of steam is obtained.
- It is not possible to design a pump which can handle liquid vapour mixture phase.
- It is not possible to add heat at constant temperature but with decreasing pressure.

NOTE ▶

Carnot cycle (in any of the above two cases) will have very less work ratio because of large pump work

$$\text{Work Ratio} = \frac{W_T - W_P}{W_T}$$

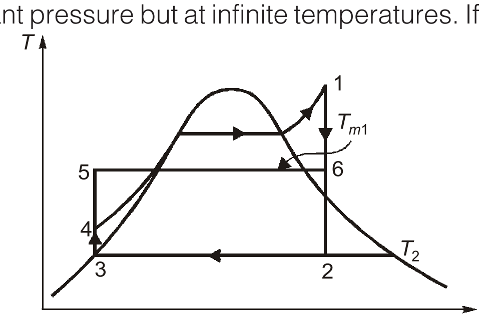
7.6 Mean Temperature of Heat Addition

- In the Rankine cycle, heat is added reversibly at a constant pressure but at infinite temperatures. If T_{m1} is the mean temperature of heat addition then

  Heat added is

$$Q_1 = h_1 - h_4 = T_{m_1}(s_1 - s_4)$$

$$\therefore \quad T_{m_1} = \frac{h_1 - h_4}{s_1 - s_4}$$



  Heat rejected

$$Q_2 = h_2 - h_3 = T_2(s_1 - s_4)$$

$$\eta_{Rankine} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_{m_1}}$$

- Lower is the condenser temperature, the higher will be the Efficiency of the Rankine cycle. Since it is fixed due to ambient conditions so $\eta_{Rankine} = f(T_{m_1})$ only.
- The higher the mean temperature of heat addition, the higher will be the cycle efficiency.

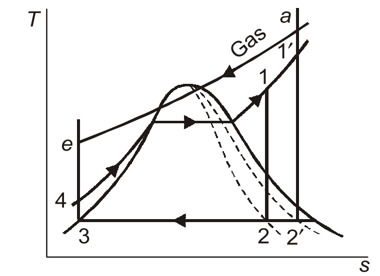
NOTE: In winters or colder regions, $T_2 \downarrow \Rightarrow \eta_{Rankine} \uparrow$

7.7 Effect of Superheat

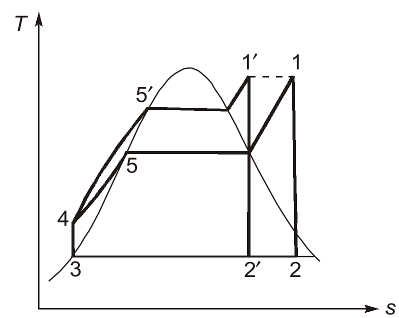
(a) Mean temperature of heat addition is increased, hence efficiency is increased.

(b) The quality of steam at turbine exhaust is increased as the expansion line shifts to right. Hence performance of turbine is improved.

- The maximum temperature of steam that can be used is fixed from metallurgical considerations.
- As the operating steam pressure at which heat is added in the boiler increases, the mean temperature of heat addition increases. But when the turbine inlet pressure increases the ideal expansion line of steam shifts to the left and the moisture content of steam in the later stages of the turbine is high and strike the blade with high velocity and erode their edges, as a result of which the life of the blades decreases.



Superheating at same inlet pressure



Superheating at increased inlet pressure and same inlet temperature

$$T_1' = T_1$$

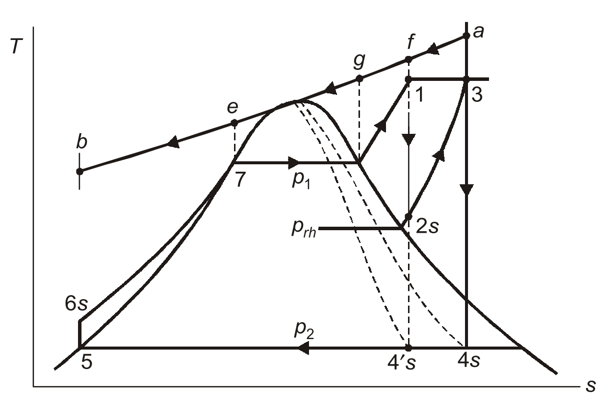
$$P_1' > P_1$$

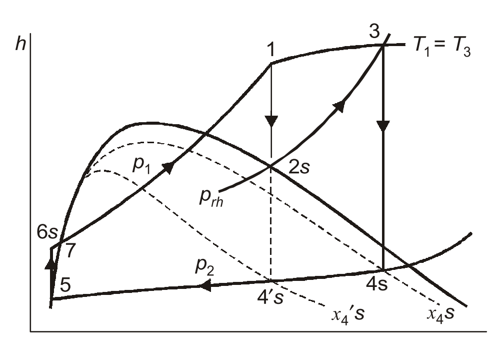
$$x_2' < x_2$$

- At turbine exhaust quality of steam should not fall below 90% to avoid blade erosion.

7.8 Reheating of Steam

- Reheating is done to utilize higher boiler pressure while maintaining better quality of steam at turbine exhaust.
- In reheating, the expansion of steam from initial state 1 to condenser pressure is carried out in two or more steps.
- Initially the steam is expanded from state 1 to 2s in high pressure (HP) turbine, then reheated from 2s to 3 in a reheater and then expanded from 3 to 4s in low pressure (LP) turbine.





$$Q_1 = h_1 - h_{6s} + h_3 - h_{2s}$$

$$Q_2 = h_{4s} - h_5$$

$$W_T = h_1 - h_{2s} + h_3 - h'_{4s}$$
$$W_p = h_{6s} - h_5$$
$$\eta = \frac{(h_1 - h_{2s} + h_3 + h_{4s}) - (h_{6s} - h_5)}{h_1 - h_{6s} + h_3 - h_{2s}}$$

- The net work output of the plant increases with reheat, and hence the steam rate decreases. Reheating also improves the quality at turbine exhaust.
- With reheating, cycle efficiency decreases or increases depending upon whether mean temperature of heating addition in process $2s - 3$ is higher than that in $6s - 1$.
- By increasing the number of reheats, still higher steam pressure could be used, but the mechanical stresses increases in much higher proportion than the pressure because of prevailing high temperature. In that way the maximum steam pressure gets fixed and more than two reheats results in cycle complication and increases capital cost that are not justified by improvement in the cycle efficiency.
- The optimum reheat pressure for most of the modern power plant is 0.2 to 0.25 of the initial steam pressure.
- For too low a reheat pressure the exhaust steam may even be in the-supersaturated state, which is not good for the condenser.

NOTE

With reheating
1. Quality at turbine exhaust ↑ ⇒ Erosion of blades ↓
2. Condenser load ↑
3. Work output ↑
4. Efficiency may or may not increase

"To increase the dryness fraction at exhaust is the main aim" of reheating.

Example - 7.2 If a re-heater is added to a Rankine Cycle, then usually:

(a) the net work and efficiency decreases
(b) the net work increases and efficiency remains same
(c) the net work and efficiency increases
(d) the net work remains same and efficiency increases

Solution: (c)

Efficiency may increase or decrease but net work always increases.

7.9 Regeneration

- With the help of regeneration, the mean temperature of heat addition is increased by decreasing the amount of heat added at low temperatures (liquid phase) in the economiser section.
- In regeneration, the energy is exchanged internally between the expanding fluid in turbine and compressed fluid (after pump work) before heat addition.
- A well known gas cycle that uses regeneration is the stirling cycle comprising two reversible isotherms and two reversible isochores. Ideal stirling cycle has the same efficiency as the carnot cycle.

- In the Ideal regenerative cycle the condensate after leaving the pump circulates around the turbine casing so that heat is transferred from the vapour expanding in the turbine to the condensate circulating around it. It is assumed that this heat transfer process is reversible.

$$\Delta T(\text{water}) = -\Delta T(\text{steam})$$

$$Q_1 = h_1 - h_5 = T_1(s_1 - s_5)$$

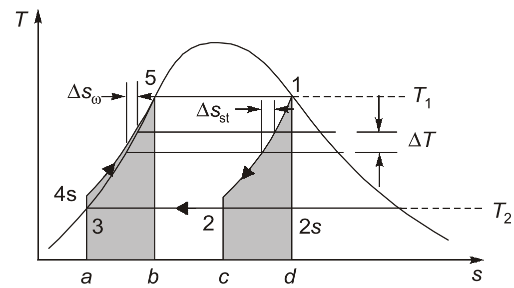
$$Q_2 = h_2 - h_3 = T_2(s_2 - s_3)$$

for reversible heat transfer:

$$\Delta s_{univ} = \Delta s_{water} + \Delta s_{steam} = 0$$

$$\Delta s_{water} = -\Delta s_{steam}$$

$$\eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$



Ideal Regenerative Cycle

Pump work remains same as in Rankine cycle i.e.

$$W_p = h_{4s} - h_3$$

- The efficiency of ideal regenerative cycle is equal to Carnot cycle.
- The net work output of the ideal regenerative cycle is thus less and hence, its steam rate will be more; although it is more efficient compared to the Rankine cycle. However the cycle is not practicable– because
  - reversible heat transfer cannot be realized in finite time.
  - heat exchanger in the turbine is mechanically impracticable
  - the moisture content of the steam in the turbine is high, which leads to excessive erosion of turbine blades.

Example - 7.3 In ideal regenerative cycle the temperature of steam entering the turbine is same as that of

(a) water entering the turbine
(b) water leaving the turbine
(c) steam leaving the turbine
(d) water at any section of the turbine

Solution: (b)

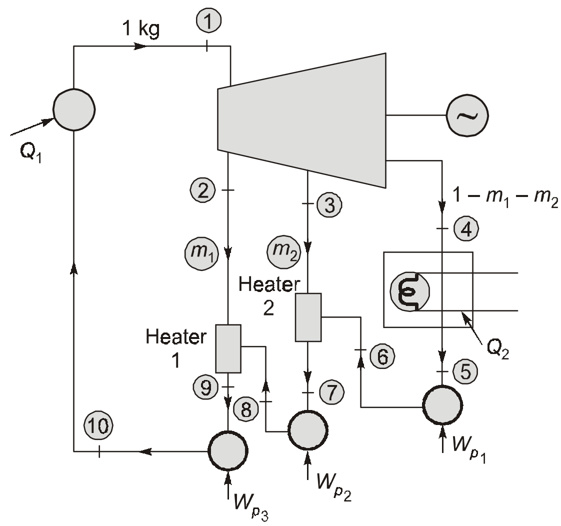
In an ideal regenerate cycle

$$\Delta T_{water} = -\Delta T_{steam}$$

Heat transfer between steam and water takes place reversibly so that decrease in temperature of steam is equal to the increase in temperature of water leaving the turbine.

7.10 Regenerative Feedwater Heating

- In practical regenerative cycle, steam is bled from the turbine and feed water is heated with it.
- In multistage regenerative cycle, more number of feedwater pumps are used and heat added at low temperature (in economizer) is minimized.



Energy balance for heater 1

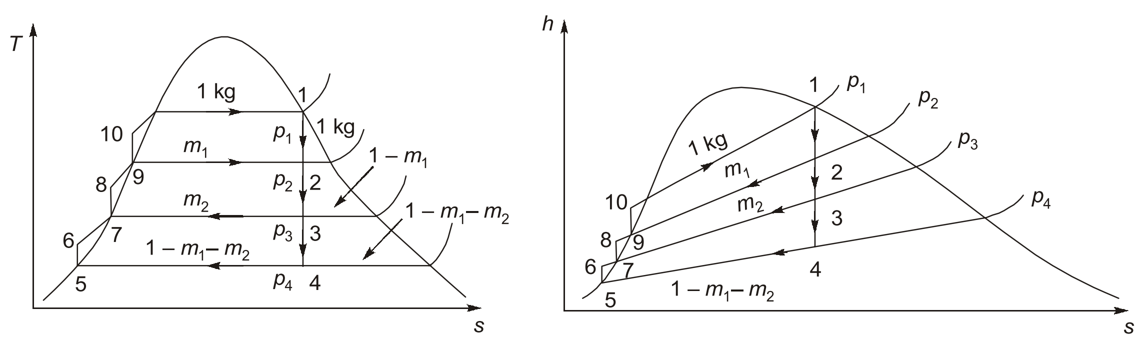
$$m_1h_2 + (1 - m_1)h_8 = 1\ ha$$

$$\therefore \qquad m_1 = \frac{h_9 - h_8}{h_2 - h_8}$$

Energy balance for heater 2

$$m_2h_3 + (1 - m_1 - m_2)h_6 = (1 - m_1)h_7$$

$$\therefore \qquad m_2 = (1 - m_1)\frac{h_7 - h_6}{h_3 - h_6}$$



$$W_T = 1(h_1 - h_2) + (1 - m_1)(h_2 - h_3) + (1 - m_1 - m_2)(h_3 - h_4)$$

$$W_P = (1 - m_1 - m_2)(h_6 - h_5) + (1 - m_1)(h_8 - h_7) + (h_{10} - h_9)$$

$$Q_1 = 1(h_1 - h_{10})$$

$$Q_2 = 1(1 - m_1 - m_2)(h_4 - h_5)$$

$$\eta = \frac{Q_1 - Q_2}{Q_1} = \frac{W_T - W_P}{Q_1}$$

- The effects of regenerative feedwater heating for the same turbine output may be summerized as below:
  1. It significantly increases the cycle efficiency by increasing the mean temperature of heat addition and reduces the heat rate.
  2. It increases the steam flow rate, (requiring bigger boiler).
  3. It reduces the steam flow to the condenser (needing smaller condenser)
  4. If there is no change of boiler output, the turbine output drops.

NOTE

Regeneration

Steam rate ↑ ($\because W_{net}$ ↓) ⇓ Boiler size ↑ (and so capital cost ↑)

Heat rate ↓ ($\because \eta$ ↑) ⇓ Operating costs ↓

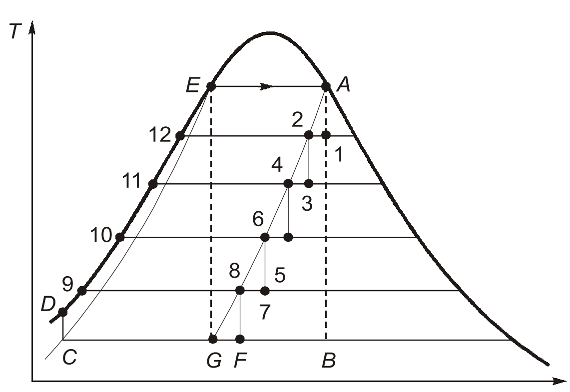
7.11 Feed Water Heaters

- These are of two types viz., open heaters and closed heaters. In an open or contact type heater, the extracted steam is allowed to mix with feed water and both leave the heater at a common temperature.
- In a closed heater, the fluids are kept separate and are not allowed to mix together.
- The condensate (saturated water at the steam extraction pressure), sometimes called the heater drip, then passes through a trap into the next lower pressure heater.
- The drip from the lowest pressure heater could similarly be trapped to the condenser, but this would be throwing away energy to the condenser cooling water.
- To avoid this waste a drip pump, pumps the drip directly into feed water stream.
- The advantages of the open heater are simplicity lower cost, and high heat transfer capacity. The disadvantage is the necessity of a pump at each heater to handle the larger feedwater stream.
- In most steam power plants, closed heater are favoured but at least one open heater is used, Primarily for the purpose of feedwater deaeration. The open heater in such a system is called the dearator. Closed heaters are mostly horizontal.

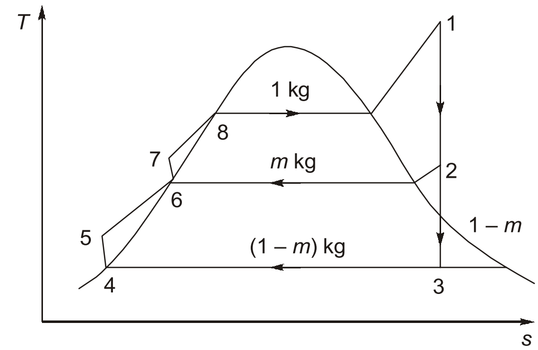
NOTE : Open feed water heater → Low cost, high temperature rise
Closed feed water heater → Costly, low temperature rise

7.12 Carnotization of Rankine Cycle

- With infinite number of extraction stages, the irreversible process DE-the heating from condenser to boiler saturation temperature could thus be made reversible.
- The area of parallelogram CEAG which represent cycle output will be equal to the area of rectangle ABGE, which represent the output of Carnot cycle.



- Regenerative feed water heating by turbine extraction is, therefore, also termed as the carnotization of the Rankine cycle. A regenerative feed heating cycle with an in finite number of feedwater heaters has thus an efficiency equal to that of carnot cycle.
- Complete carnotization of Rankine cycle is not possible with a finite number of heaters. If there is one feedwater heater used, M kg of steam is extracted from the turbine for each kg of steam entering it to heat the feed water.



thermal efficiency of the cycle is, $\eta = 1 - \dfrac{(h_2 - h_6)(h_3 - h_4)}{(h_2 - h_4)(h_1 - h_6)}$

- Maximum efficiency is obtained in regeneration, when the total enthalpy rise of feed water from condenser temperature to boiler temperature is equally distributed in feedwater heaters and economizers.

NOTE : Efficiency gain in feedwater heating follows "law of diminishing return" i.e., increment in efficiency successively diminishes with number of heaters. Five to seven points of extraction are used in practice.

Example - 7.4 Mean temperature of heat addition gets increased resulting in an increase in cycle thermal efficiency. What is this cycle called?

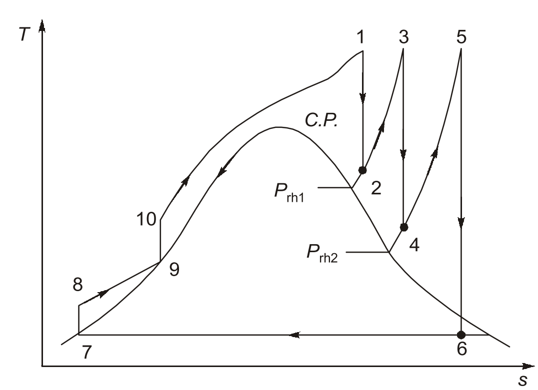
(a) Regenerative cycle (b) Reheat cycle
(c) Carnot cycle (d) Brayton cycle

Solution: (a)

The main aim of regenerative cycle is to increase the mean temperature of heat addition in order to increase the cycle efficiency.

7.13 Super Critical Pressure Cycle

Steam is generated in a "once through" boiler at a pressure above the critical point of 221.2 bar. If the plant incorporates reheat and several stages of feedheating, there is about a 2% gain in thermal efficiency compared with the corresponding subcritical cycle. However, such an increment is gained only at the expense of increased cost and complexing of the plant.

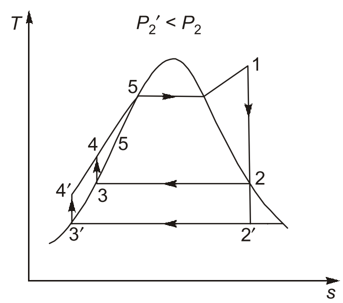
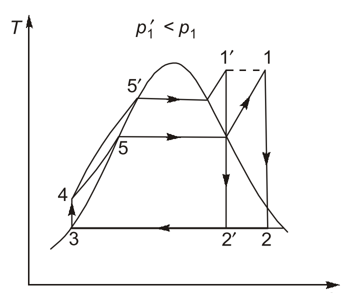


7.14 Deaerator

- One of the feedwater heaters is a contact type open heater, known as deaerator, others being closed heaters. It is used for the purpose of deaerating the feedwater. The presence of dissolved gases like oxygen and carbon dioxide in water makes the water corrosive. These gases are removed by heating the feed water to its saturation temperature by steam extracted from turbine.

- To neutralize the effect of residual dissolved oxygen and CO_2 gases in water sodium sulphite (Na_2SO_3) or hydrazine (N_2H_4) is injected in suitable, calculated doses into the feed water at the suction of the boiler feed pump (BFP).

7.15 Effect of Operating Conditions on Rankine cycle

Variable	T-s Plot	Effect
Condenser pressure ↓		1. $W_T \uparrow\uparrow$, $W_P \uparrow$ } $W_{net} \uparrow$ 2. $T_{MA} \downarrow$, $T_{MR} \downarrow\downarrow$ } $\eta \uparrow$ 3. $x_2' < x_2$ (i.e., moisture ↑)
Maximum pressure ↑ at same temperature		1. $W_{net} \rightarrow$ No change 2. $T_{MA} \downarrow \Rightarrow \eta \uparrow$ 3. $x_2' < x_2$ (i.e., moisture ↑)

NOTE : Above mentioned variables are not used to increase efficiency because
$x \downarrow \Rightarrow$ Moisture ↑ $\Rightarrow$ Blade erosion

7.16 Efficiencies in a Steam Power Plant

- The overall efficiency of a power plant is defined as

$$\eta_{overall} = \frac{\text{Power available at the generator terminals}}{\text{Rate of energy release by the combustion of fuel}}$$

$$= \frac{MW_e \times 10^3}{W_f \times C.V.}, \qquad W_f = \text{Fuel burning rate.}$$

- The boiler efficiency is $\eta_{boiler} = \dfrac{\text{Rate of energy absorption by water to form steam}}{\text{Rate of energy release by the combustion of fuel}}$

$$= \frac{W_s(h_1 - h_4)}{W_f \times C.V.}$$

W_s = is the steam generation rate.

The cycle efficiency is given by

$$\eta_{cycle} = \frac{h_1 - h_2}{h_1 - h_4}$$

- The mechanical efficiency of the turbine will be

$$\eta_{turbine(mech)} = \frac{\text{Brake output of the turbine}}{\text{Internal output of the turbine}} = \frac{\text{brake output}}{w_s(h_1 - h_2)}$$

- The generator Efficiency of the electric alternator is

$$\eta_{generator} = \frac{\text{Electrical output at generator terminals}}{\text{Brake output of the turbine}}$$

NOTE: $\eta_{overall} = \eta_{boiler} \times \eta_{cycle} \times \eta_{turbine} \times \eta_{generator}$.

Example - 7.5 The overall efficiency of thermal power plant is

(a) Boiler efficiency, turbine efficiency and generator efficiency
(b) Boiler efficiency, turbine efficiency, generator efficiency and gas cycle efficiency
(c) Carnot cycle efficiency
(d) Regenerative cycle efficiency

Solution: (b)

Here, in (b) gas cycle efficiency refers to the rankine cycle efficiency.

Example - 7.6 Economiser used in power plants is used to heat

(a) Flue gases
(b) Intake air
(c) Steam
(d) Feed watger

Solution: (d)

Economiser heats feed water with the heat of flue gases.

Example - 7.7 The ideal cycle for a steam power plant is Rankine cycle instead of the Carnot cycle because

(a) the Rankine cycle has higher efficiency
(b) Rankine cycle efficiency equals the Carnot cycle efficiency
(c) Rankine cycle has higher work ratio and is easier to implement.
(d) the Carnot cycle gives lower turbine work

Solution: (c)

Due to lesser pump work, rankine cycle has higher work ratio.

Student's Assignment

Q.1 The function of an economizer in a steam power plant is to
(a) increase the temperature of air supplied to a boiler
(b) increase the enthalpy of feed water
(c) condense the exhaust steam from the turbine
(d) heat the fuel before combustion

Q.2 Consider the following statements: The purpose of reheating the steam in a steam turbine power plant is to
1. increase specific output
2. increase turbine efficiency
3. reduce the turbine speed
4. reduce specific steam consumption

Which of these statements are correct?
(a) 2 and 4 (b) 1 and 3
(c) 1, 2 and 4 (d) 1, 3 and 4

Q.3 In a regenerative cycle, steam with enthalpy of 3514 kJ/kg is expanded in h.p. turbine to a state corresponding to saturated enthalpy of water equal to 613 kJ/kg. If the pump work requirements in high pressure and low pressure zones are respectively 3 and 1 kJ/kg, amount of heat transferred in boiler is
(a) 2897 kJ/kg (b) 2898 kJ/kg
(c) 2904 kJ/kg (d) 2905 kJ/kg

Q.4 Consider an actual regenerative Rankine cycle with one open feed water heater. For each kg steam entering the turbine, m kg steam with a specific enthalpy of h_1 is bled from the turbine. Specific enthalpy of water entering the heater is h_2. The specific enthalpy of saturated liquid leaving the heater is equal to
(a) $mh_1 - (h_2 - h_1)$ (b) $h_1 - m(h_2 - h_1)$
(c) $h_2 - m(h_2 - h_1)$ (d) $mh_2 - (h_2 - h_1)$

Q.5 What is the efficiency of an ideal regenerative Rankine cycle power plant using saturated steam at 327°C and pressure 135 bar at the inlet to the turbine, and condensing temperature of 27°C (corresponding saturation pressure of 3.6 kPa)?
(a) 92% (b) 33%
(c) 50% (d) 42%

Q.6 Which combination of the following statements is correct?
The incorporation of re-heater in a steam power plant
A. Always increases the thermal efficiency of the plant
B. Always increases the dryness fraction of steam at condenser inlet
C. Always increases the main temperature of heat addition
D. Always increases the specific work output

(a) A and D only (b) B and D only
(c) A, C and D only (d) A, B, C and D

Q.7 In a regenerative feed heating cycle, the economic number of the stages of regeneration
(a) increases as the initial pressure and temperature increase
(b) decreases as the initial pressure and temperature increase
(c) is independent of the initial pressure and temperature
(d) depends only on the condenser pressure

Q.8 In thermal power plants, the deareator is used mainly to
(a) remove air from condenser
(b) increase fire water temperature
(c) reduce steam pressure
(d) remove dissolved gases from feed water

Q.9 Which one of the following cycles working within the same temperature limits has the highest work ratio?
(a) Carnot cycle (b) Joule cycle
(c) Otto cycle (d) Rankine cycle

Q.10 What is the difference between the temperature of feed water outlet and saturation temperature of steam entering the heater called ?

(a) Pinch point
(b) Terminal temperature difference
(c) LMTD
(d) Terminal point

Q.11 The most efficient ideal regenerative steam power cycle is
(a) Rankine cycle (b) Carnot cycle
(c) Brayton cycle (d) Joule cycle

Q.12 Which one of the following is the correct statement?
Reheating of steam under ideal conditions takes place at constant
(a) entropy (b) enthalpy
(c) pressure (d) temperature

Q.13 The enthalpy of steam entering a turbine in a Rankine cycle is 3200 kJ/kg. The enthalpy after isentropic expansion is 2400 kJ/kg and the enthalpy at the end of actual expansion is 2560 kJ/kg. What is the turbine efficiency ?
(a) 75% (b) 80%
(c) 85% (d) 90%

Q.14 In a Rankine cycle, with the maximum steam temperature being fixed from metallurgical consideration, as the boiler pressure increases
(a) the condenser load will increase
(b) the quality of turbine exhaust will decrease
(c) the quality of turbine exhaust will increase
(d) the quality of turbine exhaust will remain unchanged

Q.15 Employing superheated steam in turbines leads to
(a) Increase in erosion of blading
(b) Decrease in erosion of blading
(c) No erosion in blading
(d) No change in erosion of blading

Q.16 Consider the following statements pertaining to the features of a regenerative steam cycle plant as compared to a non-regenerative plant:
1. It increases the cycle efficiency.
2. It requires a bigger boiler.
3. It requires a smaller condenser.
Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2
(c) 2 and 3 (d) 1 and 3

Q.17 In ideal regenerative cycle the temperature of steam entering the turbine is same as that of
(a) water entering the turbine
(b) water leaving the turbine
(c) steam leaving the turbine
(d) water at any section of the turbine

Q.18 The work done in a steady flow process is equal to $-\int vdp$. In the Rankine cycle, the turbine work is much greater than the pump work because
(a) The specific volume of water is much higher than that of steam
(b) The specific volume of steam is much higher than that of water
(c) The pressure drop in the turbine is much higher than that in the pump
(d) There is less irreversibility in the turbine than in the pump

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ANSWER KEY // STUDENT'S ASSIGNMENT

1. (b)	**2.** (d)	**3.** (a)	**4.** (c)	**5.** (c)
6. (b)	**7.** (a)	**8.** (d)	**9.** (d)	**10.** (b)
11. (b)	**12.** (c)	**13.** (b)	**14.** (b)	**15.** (b)
16. (a)	**17.** (b)	**18.** (b)		

HINTS & SOLUTIONS // STUDENT'S ASSIGNMENT

1. (b)

A common application of economizer in steam power plant is to capture the waste heat from boiler stack gases (flue gases) and transfer it to the boiler feed water. This raises the temperature of the boiler feedwater, lowering the needed energy input and thus increases the enthalpy of feed water.

2. (d)

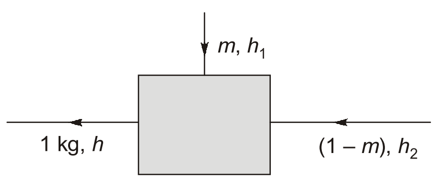
The purpose of the reheating of steam in steam power plant is to:
1. increase the quality at turbine exhaust thus the blade erosion decreases.
2. increase the condenser load.

3. increase the work output.
4. Turbine speed decreases.
5. The turbine efficiency may or may not increases.

3. (a)

$W_T = 3514 - 614 = 2901$ kJ/kg
$W_P = 3 + 1 = 4$ kJ/kg
$\Sigma Q_{net} = \Sigma W_{net} = 2901 - 4 = 2897$ kJ/kg

4. (c)



$$1 \times h = mh_1 + (1 - m)h_2$$
$$h = h_2 - m(h_2 - h_1)^2$$

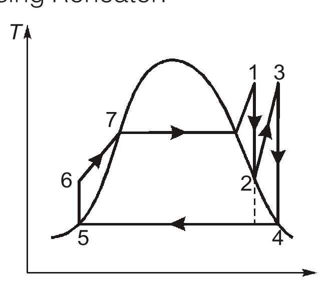
5. (c)

The efficiency of ideal regenerative cycle is equal to that of Carnot cycle working between same temperature limits.

$$\therefore \eta = 1 - \frac{T_2}{T_1} = 1 - \frac{(27+273)}{(327+273)} = 50\%$$

6. (b)

Effect of using Reheater:



$W_{turbine} \uparrow$
W_{pump} = Constant
$W_{net}\ (W_T - W_P) \uparrow$
Heat supplied ↑
Heat rejected ↑
Mean temperature of heat addition - may increase or decrease
Mean temperature of heat rejection - constant
Efficiency - may increase or decrease
Dryness fraction of steam at condenser inlet - increases.

7. (a)

Since efficiency is proportional to gain in feed water temperature. As initial temperature and pressure increases, the gain in feed water temperature decreases because gain follows the law of diminishing return with increase in the number of heater.

8. (d)

The purpose of deareator is to reduce dissolved gases, particularly oxygen to a low level and improve a plant's thermal efficiency by raising the water temperature.
In addition, deareator provides feedwater storage and proper suction conditions for boilder feedwater pumps.

10. (b)

Performance of feed water heaters is quantified using a parameter called "terminal temperature difference". Terminal temperature difference (TTD) refers to the difference of temperature between temperature of feed water outlet and saturation temperature of steam entering the heater.

11. (b)

Regenerative feedwater heating by turbine steam extraction is termed as the carnotization of the Rankine cycle. A regenerative feed heating cycle with an infinite number of feed water heaters has an efficiency equal to that of carnot cycle.

13. (b)

$$\eta_{turbine} = \frac{3200 - 2560}{3200 - 2400} = \frac{640}{800} = 0.8 \text{ or } 80\%$$

14. (b)

As the boiler pressure increases, quality of the steam at the exit of the turbine decreases.

15. (b)

Superheated steam in turbines leads to decreases in erosion of blading, i.e. increase in the life of turbine blade.

16. (a)

Effect of regenerative cycle over simple Rankine cycle

1. Thermal efficiency is improved because the mean temperature of heat addition to the cycle is increased.
2. Due to many extractions there is an improvement in the turbine drainage and it reduces erosion due to moisture.
3. A small size condenser is required.
4. For given power a large capacity boiler is required.

18. (b)

Workdone = $-\int vdP$ (for steady flow process)

Workdone in turbine is much greater than that of pump because in turbine, working fluid is steam and in pump, working fluid is water.

And specific volume of steam is much higher than that of water.

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