1.10 BINARY CYCLES AND COGENERATION SYSTEMS

No single fluid can meet all the requirements as mentioned above. Although in the overall evaluation water is better than any other working fluid, at high temperatures, however, there are a few better fluids and notable among them are:

(a) Diphenyl ether $(C_6H_5)_2O$

(b) Aluminium bromide $AlBr_3$

(c) Liquid metals like mercury, sodium, potassium and so on. Among these only mercury has actually been used in practice.

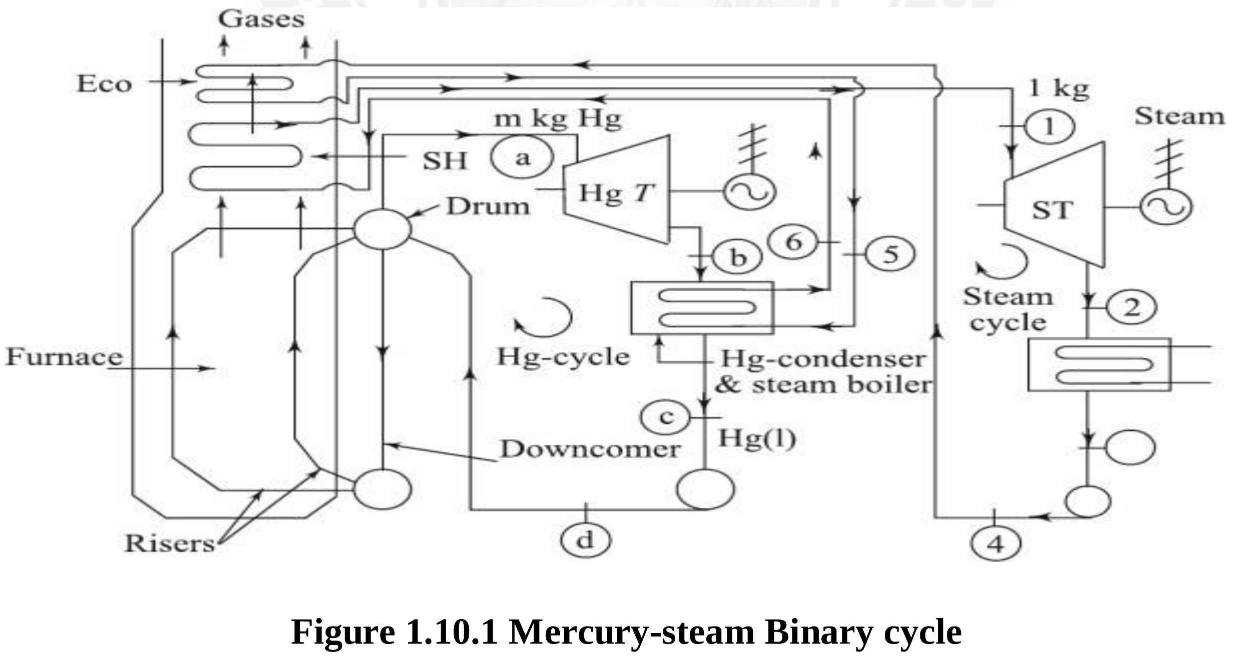


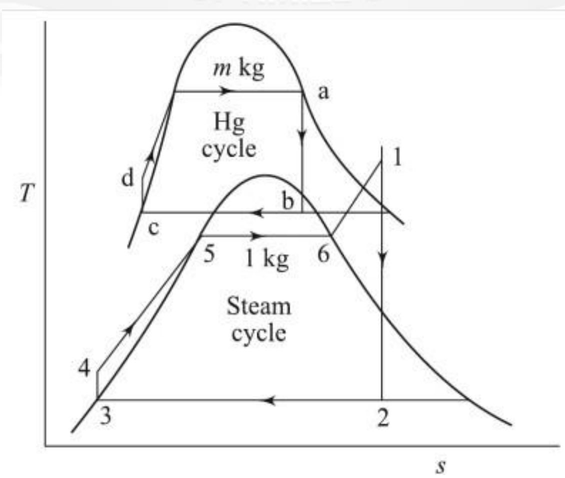
Figure 1.10.1 Mercury-steam Binary cycle
[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :11]

Diphenyl ether could be considered but it has not yet been used because like most organic substances, it decomposes gradually at high temperatures. Aluminium bromide is a possibility and yet to be considered.

As at pressure of 12 bar, the saturation temperatures for water, aluminium bromide and mercury are 187˚C,482.5˚C and 560˚C, its vaporization pressure is relatively low. Its critical pressure and temperature are 1080 bar and 1460˚C respectively.

But in the low temperature range, mercury is unsuitable because its saturation pressure becomes exceedingly low, and it would be impractical to maintain such a high vacuum in the condenser.

At 30˚C the sayturation pressure of mercury is only 2.7×10^{-4}cm Hg. Its specific volume at such a low pressure is very large, and it would be difficult to accommodate such a large volume flow.



T-S diagram of mercury-steam binary cycle

For this reason, to make advantage o f the beneficial features of mercury in the high temperature range and to get rid of its deleterious effects in the low temperature range, mercury vapour leaving the mercury turbine is condensed at a higher temperature and pressure, and the heat released during the condensation of mercury is utilized in evaporating water to form steam to operate on a conventional turbine.

Thus, in the binary (or two fluid) cycle, two cycles with different working fluids are coupled in series, the heat rejected by on being utilized in the other.

The flow diagram of mercury-steam binary cycle and the corresponding T-S diagram are given in Fig.32&33 respectively.

The mercury cycle a-b-c-d is a simple rankine cycle saturated vapour. The heat rejected by mercury during condensation (process b-c) is transferred to boil water and form saturated vapour (process 5-6).

The saturated vapour is heated from the external source (furnace) in the super heater(process 6-1). Super heated steam expands in the turbine and is then condensed. The condensate is then pumped to the economizer where it is heated till it becomes saturated liquid by the outgoing flue gases (process4-5).

The saturated liquid then goes to the mercury condenser-steam boiler , where the latent heat is absorbed. In an actual plant, the steam cycle is always a regenerative cycle with feed water heating, but for the sake of simplicity, this complication has been omitted.

Let m represent the flow rate of mercury in the mercury cycle per kg of steam circulating in the steam cycle. Then , for 1 kg of steam,

$$\begin{aligned} Q_1 &= m(h_a-h_d)+(h_1-h_6)+(h_5-h_4) \\ Q_2 &= h_2-h_3 \\ W_T &= m(h_a-h_b)+(h_1-h_2) \\ W_P &= m(h_d-h_c)+(h_4-h_3) \end{aligned} \qquad \text{-------------(1)}$$

$$\eta_{cycle} = \frac{Q_1 - Q_2}{Q_1} = \frac{W_T - W_P}{Q_1} \; and$$

$$steam\, rate\, (SSC) = \frac{3600}{W_T - W_P} \; Kg/kWh$$

COGENERATION SYSTEMS

There are several industries such as paper mills, textile mills, chemical factories, jute mills, sugar factories, rice mills and so on where saturated steam at the desired temperature is required for heating, drying etc.

For constant temperature heating (or drying), steam is a very good medium since isothermal condition can be maintained by allowing saturated steam to condensate at that temperature and utilizing the latent heat released for heating purposes.

Apart from the process heat, the factory also needs power to drive various machines, for lighting and other purpose.

Earlier, steam of power purposes was generated at a moderate pressure and saturated steam of process work was generated separately at a pressure which gave the desired heating temperature.

Having two separate units for process heat and power is wasteful, for the total heat supplied to the steam generator for power purposes, a greater part will normally be carried away by the cooling water in the condenser.

Back pressure Turbine

By modifying the initial steam pressure and exhaust pressure, it is possible to generate the required power and make available the required quantity of exhaust steam at the desired temperature for process work.

In Fig.34, the exhaust steam from the turbine is utilized for process heating, the process heater replacing the condenser of the ordinary rankine cycle.

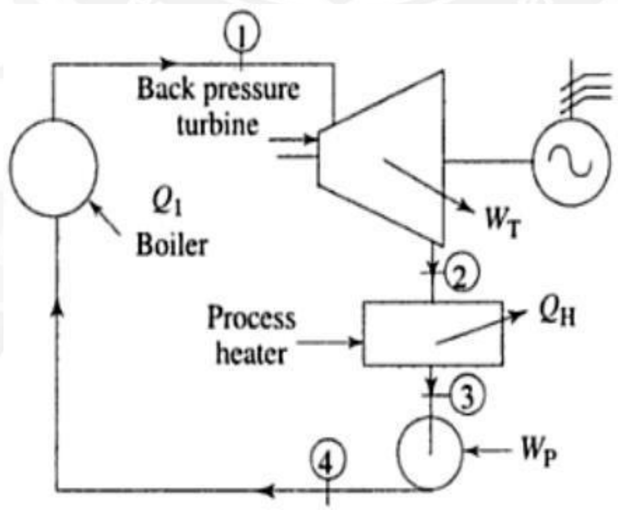


Figure 1.10.2 Cogeneration plant

[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :11]

The pressure at exhaust form the turbine is the saturation pressure corresponding to the temperature desired in the process heater such a turbine is called a back pressure turbine.

A plant producing both electrical power and process heat simultaneously is called a **cogeneration plant**.

When the process steam is the basic need, and the power is produced incidentally as a by- produce the cycle is often called a byproduct power cycle.

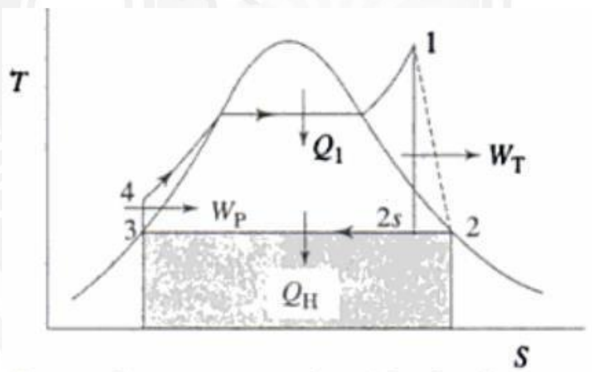


Figure 1.8.1 power cycle with a back pressure turbine

[Source: "power plant Engineering" by Anup Goel ,Laxmikant D.jathar,Siddu :12]

Figure shows the T-S plot for such a cycle. If W_T is the turbine output in kW, Q_H is the process heat required in kJ/h, and w_s are the steam flow rate in kg/h.

$$W_T \times 3600 = (h_1 - h_2) and$$

$$Q_H = (h_2 - h_3)$$

$$W_T \times 3600 = \frac{Q_H}{h_2 - h_3}(h_1 - h_2)$$

$$Q_H = \frac{W_T \times 3600 \times (h_2 - h_3)}{(h_1 - h_2)} \quad \frac{kJ}{h} - - - - (1)$$

Total energy input Q_1 (as heat) to the co-generation plant, W_T part of it only is converted into shaft work or electricity.

The remaining energy (Q_1-W_T), which would otherwise have been a waste, as in the rankine cycle, by second law, it is utilized as process heat.

The co-generation plant efficiency η_{co} is given by

$$\eta_{co} = \frac{W_T + Q_H}{Q_1} - - - - - (2)$$