Turbine, Generator & Auxiliaries - Course 334

THE CONDENSER

In the section on the steam turbine, we discussed how the turbine converted the heat energy of the steam passing through it to the mechanical energy of the rotating shaft. It is obviously to our advantage to extract as much work as possible from the saturated steam that is generated in the steam generator. In the simplest terms, the lower the temperature and pressure at the outlet of the low pressure turbine, the greater will be the amount of energy which can be extracted from the steam. In fact, if the exhaust of the turbine is near a perfect vacuum rather that at atmospheric pressure, roughly 35% more energy can be extracted from the steam passing through the turbine. It is the condenser which provides the means of maintaining this low absolute pressure at the exhaust of the low pressure turbine. The way in which the condenser provides this low pressure is through condensation of the steam into water.

At the outlet of the low pressure turbine, a kilogram of wet steam occupies 28 cubic meters. When this steam condenses to water, the one kilogram of water occupies .001 cubic meters (about one quart). Thus as one kilogram of steam condenses, almost 38 cubic meters of empty space (which was previously filled with steam) is left behind. It is this creation of empty space through the condensing of steam which provides the vacuum in the condenser.

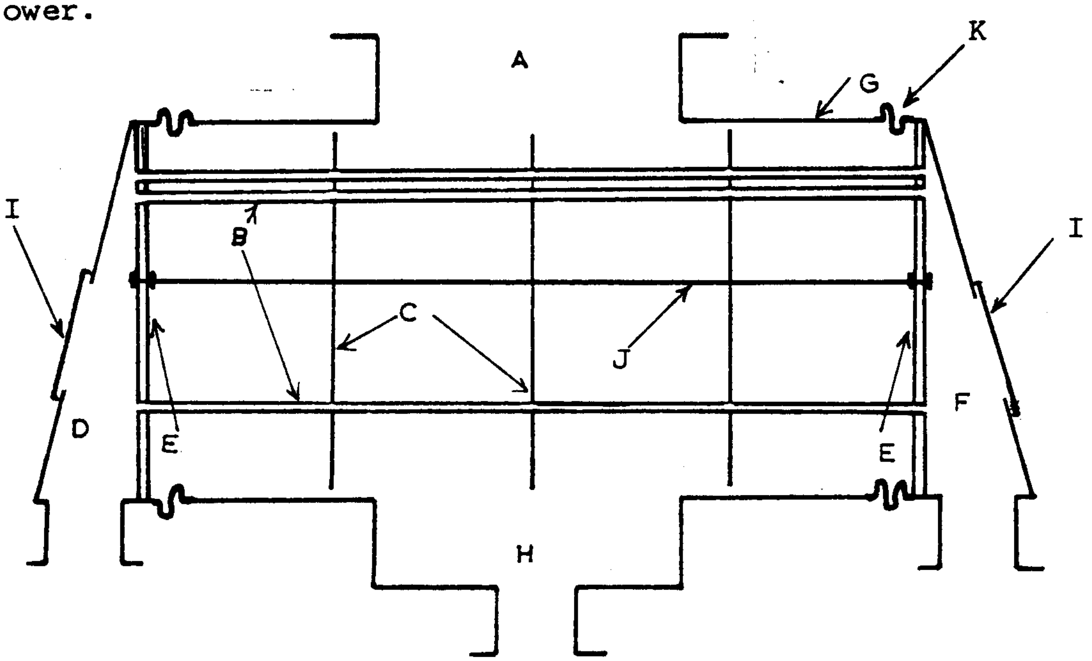
Figure 7.1 shows a sectional view of a condenser. The cooling water which removes the latent heat of vapourization and causes the steam to condense flows through the tubes. This condenser cooling water is taken from the lake or river, pumped through the condenser tubes, and then flows back to the lake or river. The condenser cooling water inlet to the condenser is known as the inlet water box and the condenser cooling water outlet as the outlet water box.

The type of condenser shown in Figure 7.1 is known as a single pass condenser since the cooling water passes through the condenser only once. Double pass condensers are also found in the Nuclear Generating Division but only on the smaller units. The tubes are supported at either end by tube sheets and along their length by sagging plates.

In addition to giving support to the condenser tubes, the sagging plates are spaced to ensure that the tubes are damped against vibration induced either by resonance with the turbine running frequencies or by steam passing over the tubes. The sagging plates are bolted or welded to the condenser shell and they contribute to the condenser shell strength. When the condenser is under full vacuum, the shell must withstand an external pressure of almost 100 kPa. The sagging plates help counteract this pressure force which is tending to collapse the condenser shell. Axial support is given to the tube sheets by staybars which run parallel to the tubes. These staybars tend to prevent any significant axial stresses from being carried by the tubes.

On the steam side of the condenser, the steam leaves the low pressure turbine through an exhaust trunk and enters the shell of the condenser where it passes around the tubes. The condensed water or condensate falls into the bottom of the condenser and is collected in a hotwell.

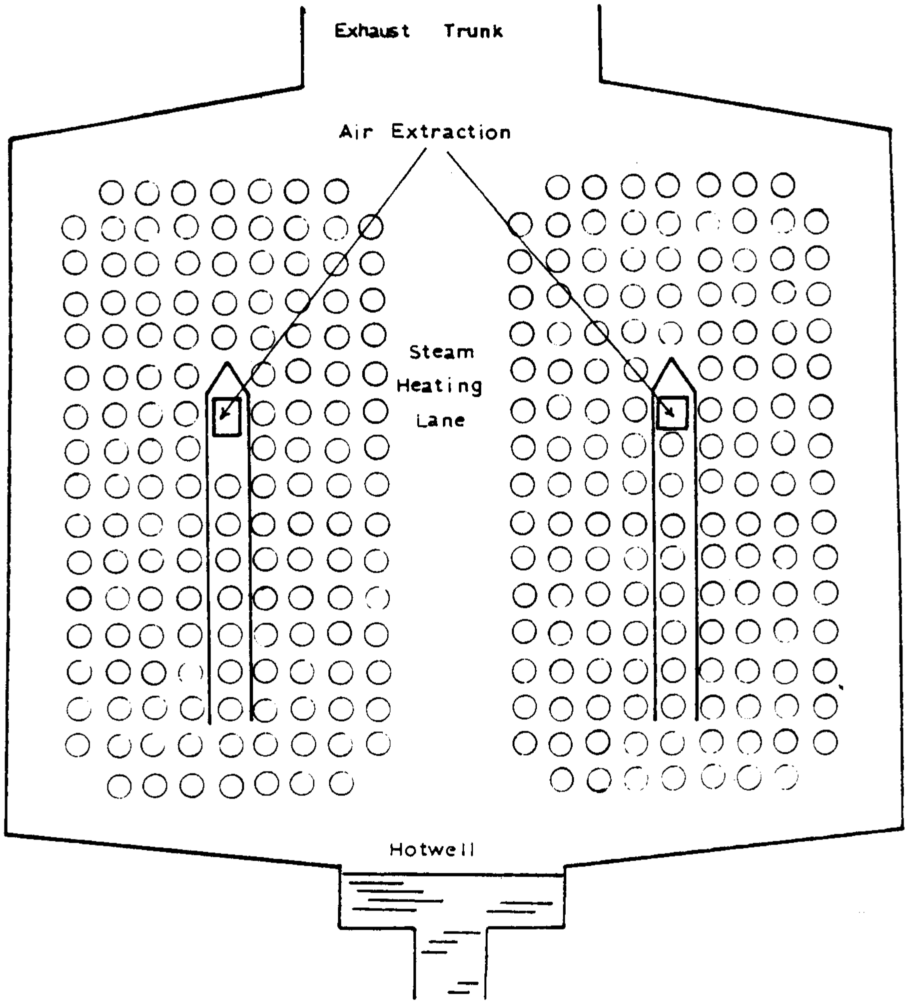
A large turbine unit generally has one condenser for each low pressure turbine. However, to prevent variations in the back pressures of each condenser, the shells of the condensers are joined by a large (say 2 metre diameter) balance pipe. This balance pipe also allows a condenser half to be shutdown for cleaning while the turbine unit remains at power.



A. Exhaust Trunk
B. Tubes
C. Sagging Plates
D. Inlet Water Box
E. Tube Sheet
F. Outlet Water Box
G. Shell
H. Hotwell
I. Inspection Doors
J. Staybars
K. Expansion Joints

Single Pass Condenser

Figure 7.1



Condenser Cross Section

Figure 7.2

Figure 7.2 shows a cross section of a typical single pass condenser. The exhaust trunk may be bolted or welded to the bottom of the LP turbine casing. Alternately it may be supported independently and connected to the LP turbine by a flexible bellows. The latter method is more typical of large turbine units since it allows the condenser to expand independent of the LP turbine.

There is a large steam heating lane or steam excess lane down the centre of the condenser shell which contains no cooling water tubes. The purpose of this lane is to ensure that a portion of the exhaust steam goes to the bottom of the condenser. By allowing a significant percentage of the steam to reach the bottom of the condenser, the following is achieved:

1. The water in the hotwell is kept at saturation temperature. If the water in the hotwell was allowed to become subcooled, it would be an unnecessary loss of heat from the condensate. This unnecessary loss of heat energy would make the steam/feedwater cycle less efficient as this lost heat would have to be put back into the condensate by either the feedheating system or the steam generator.
2. The lower condenser tubes are forced to transfer as much steam out of the condenser as the upper tubes. This ensures the entire tube surface is used to transfer heat.
3. The thermal expansion of the tubes is equalized. If the lower tubes were cooler than the upper tubes, it would produce a bending force on the condenser shell and tubesheets.

Condenser Air Extraction

The steam will continue to condense and maintain a good vacuum as long as four conditions are fulfilled:

1. No air enters the shell (steam) side of the condenser.
2. The tubes carry a normal flow of relatively cool lake water.
3. The tubes remain exposed to the steam.
4. The tube surfaces are not fouled by corrosion products or other materials.

Any change in the system which invalidates one of these statements will result in a decrease in the vacuum in the condenser. Apart from a decrease in turbine efficiency, a decreasing vacuum will result in overheating of the low pressure turbine blading as the blades must pass through higher density steam than they were designed to encounter.

If air enters the condenser, most of it will remain there because it cannot condense with the steam. The air will gradually fill up the empty space left by the condensing steam until the vacuum in the condenser is destroyed. In addition, some of the air which leaks into the condenser will dissolve in the condensing water. The oxygen in the air can cause considerable corrosion problems in the condensate and feedwater systems. Since the condenser operates below atmospheric pressure, there is a tendency for air to leak into the condenser and this air must be removed.

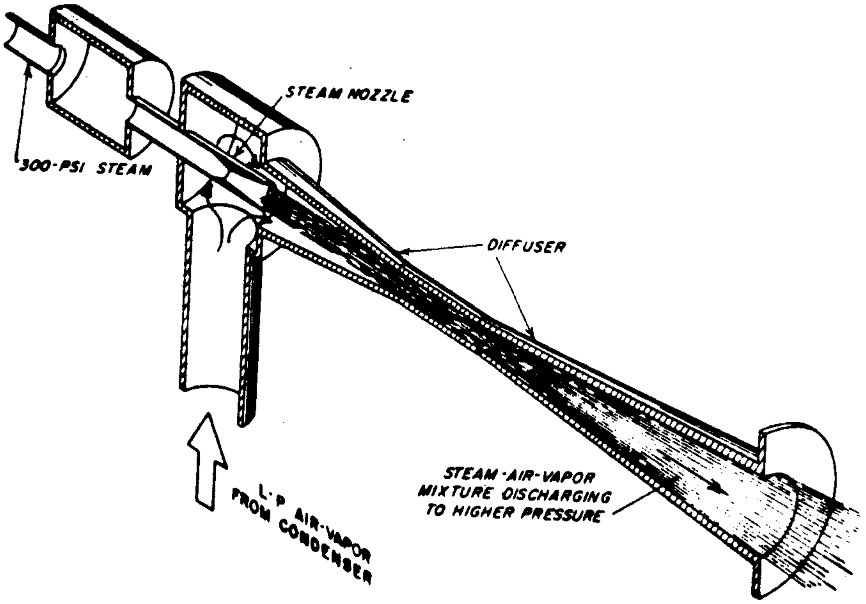
The normal method of starting up a turbine unit is to evacuate the condenser shell and turbine to a partial vacuum and then to evacuate the remaining air after rolling the turbine with steam. Once the condenser is at normal operating vacuum [about 5 kPa(a)], the air extraction system must remove only the small amount of air which leaks into the condenser.

The air extraction system has to be capable of dealing both with vacuum raising and normal maintenance of vacuum. When raising vacuum, the air extraction system has to remove not only the air which fills the condenser shell during shutdown, but also the air in the HP and LP turbines and pipework back to the emergency stop valves. The volume of air which must be removed is typically about 6500 cubic meters. To prevent excessive startup time being expended in drawing a vacuum, this air must be removed in something on the order of an hour. On the other hand, the maximum amount of air leakage into an operating unit is something like one cubic meter per minute. This requires nowhere near the air removal capacity that initial evacuation requires. Whatever the method of air extraction, there will typically be a large air removal capacity for initial evacuation and a smaller capacity for maintaining vacuum.

The air extraction system removes air and other non-condensable gases from the condenser by either a steam air ejector or vacuum pumps. Whatever the method of air removal, the system creates area of lower pressure than condenser vacuum. Air flows from the condenser to this low pressure area where it can be removed. In Figure 6.2, you can see the air extraction points in the condenser. They are located within the tube bundles to ensure that gases moving toward these points must pass over many tubes prior to removal from the condenser. The air extraction system will remove any gas and would just as soon suck out steam as air.However, in passing over the tubes, the steam is condensed and the air extraction system only removes non-condensable gases.

Steam Air Ejectors

Figure 7.3 shows a sectional view of a typical steam air ejector. Steam at about 2000 kPa(g) enters the nozzle where steam heat energy is converted to velocity. The high velocity steam jet is directed into a diffuser. The diffuser inlet has a much larger cross sectional area than that of the high speed jet entering it. This creates an extremely low pressure at the inlet to the diffuser. This low pressure area is connected to the condenser. The low pressure air-vapour mixture from the condenser comes into physical contact with the



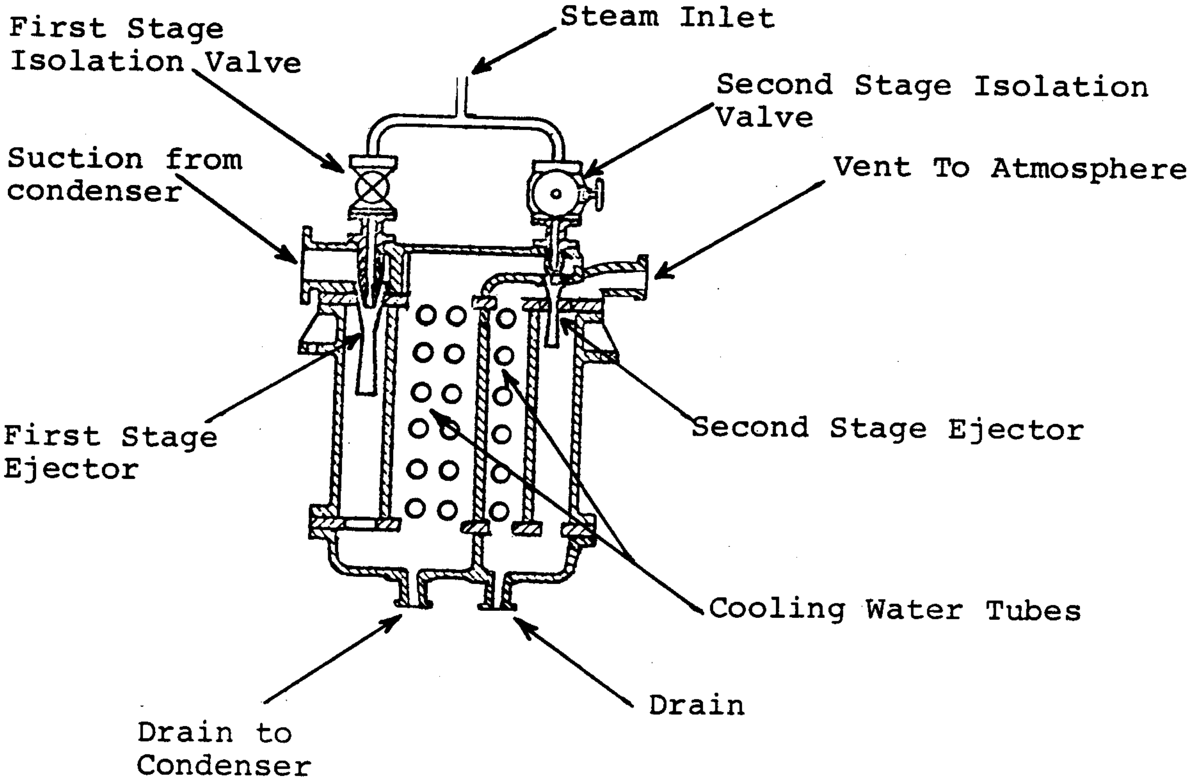
Steam Air Ejector

Figure 7.3

high speed jet and is "batted" along by the steam entering the diffuser. The air travels through the diffuser with the steam and is discharged to a higher pressure region. This constant removal of low pressure airvapour mixture at the diffuser inlet encourages more air to flow into the diffuser. This establishes a continuous flow from condenser into ejector.

For startup purposes, when large volumes of air must be removed, a high capacity steam ejector called a hogging ejector is used. This high capacity ejector can evacuate the condenser and turbine unit to normal vacuum in something like 45 minutes. The hogging ejector uses large quantities of steam. After passing through the ejector, the steam is released to atmosphere. While this improves the capacity of the hogging ejector, it makes the ejector wasteful of steam. Thus while the hogging ejector is desirable for rapid vacuum raising, it is far too inefficient for normal operation.

During normal operation, a much smaller steam ejector is used. This holding ejector as it may be called, is normally a two stage steam ejector as shown in Figure 7.4. When the air ejector is working properly, the air from the main condenser is drawn into the first stage. The steam and air mixture from the first stage pass into an intercondenser where most of the steam is condensed. The air is then drawn



Typical Two-Stage Condensing Air Ejector

Figure 7.4

into a second stage. The steam and air mixture from the second stage pass into an aftercondenser where the steam is condensed and the air released to atmosphere. The cooling water for both the intercondenser and aftercondenser is main condensate taken from the condensate extraction pump prior to the low pressure feedheaters. The advantage of having two stages in the air ejector is that the air is raised from condenser vacuum to atmospheric pressure in two steps rather than one. The first stage raises pressures from 5 kPa(a) to about 35 kPa(a), while the second stage raises pressure from 35 kPa(a) to normal atmospheric pressure - 101.3 kPa(a).

Vacuum Pumps

An alternative method of air extraction is use of vacuum pumps. These pumps are of a variety of designs although they are normally rotating positive displacement pumps. The usual configuration is to have more than one pump. The number of pumps running depends on the vacuum conditions. Pickering NGS-A, for example, has three screw type positive displacement vacuum pumps for each condenser. All three pumps are used for initial vacuum raising. During normal operation, only one pump is required. However, if backpressure rises to 8 kPa(a), a second pump will start; if the backpressure rises to 12 kPa(a), the third pump will start.

Another possible combination is to use vacuum pumps for normal vacuum maintenance and a hogging ejector for initial vacuum raising.

There is really no clearcut advantage of one air extraction method over the other. Vacuum pumps allow easier on-off control and tend to increase plant efficiency since they don't use steam. However, in practice, they require more maintenance and are generally less reliable.

Condenser Cooling Water

The condenser cooling water system, or CCW system as it is most often called, is used to remove the latent heat of vapourization from the exhaust steam entering the condenser. The rise in CCW temperature across the condenser is limited to about 10°C for three reasons:

1. The higher the temperature rise of CCW across the condenser, the higher condenser pressure and therefore, the lower cycle efficiency.
2. The higher the temperature rise, the greater the tendency for air to come out of solution and collect in the high points of the CCW system.
3. If the water leaves the condenser much warmer than it enters, there is a rapid growth in marine life in the warm outflow. The prevention of this biologic polution has resulted in legal limits on condenser temperature rise.

The heat energy which must be removed from each kilogram of exhaust steam is about 2450 KJ. In increasing its temperature by 10°C, a kilogram of CCW water can remove about 42 KJ. Thus it requires about 58 kilograms of CCW water (2450 KJ/42 KJ) to condense one kilogram of exhaust steam. It requires about 60 cubic meters of CCW flow per second for a single large turbine unit. This extremely large flow rate presents two problems:

1. an extremely large amount of pumping power must be consumed, and
2. there can be little placed in the CCW system for water treatment and purification which impedes flow.

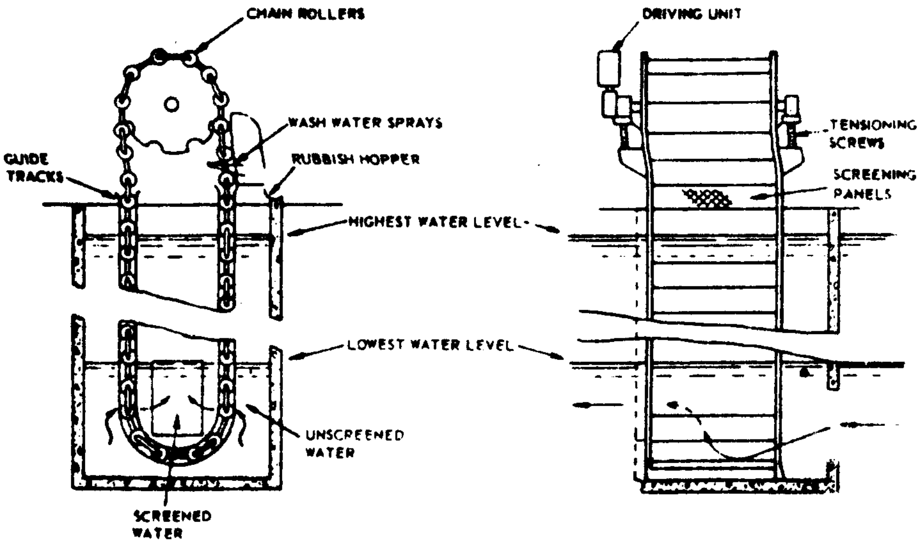
For a large CANDU generating station, the required CCW pumping power is on the order of 4 MW per unit. To keep this pumping power within economic limits, the pumps are generally of high capacity and low discharge head. Since the condenser is normally located above the level of the lake or river, appreciable pumping power may be expended to raise the water up to the condenser. Much of this power requirement can be eliminated by operating the CCW system as a siphon. This means the pump is only required to overcome the friction flow losses.

When a CCW system is operated as a siphon, the CCW side of the condenser operates below atmospheric pressure. As water passes through the condenser, air which has dissolved in the CCW water comes out of solution. These gases tend to collect in the condenser tubes and water boxes blocking flow and destroying the siphon. The CCW system is protected against the air binding of the tube side of the condensers by an air removal system. This vacuum priming system as it is called, removes air from the condenser water boxes. It is worth mentioning that this system is completely separate from the air removal system for the shell side of the condenser.

Because of the extremely large flow rate of CCW water, there is little water treatment except intermittent chlorination and trash removal. Water first passes through a coarse screen. The spacing between bars must be small enough to prevent logs, boats, people or ice from being swept into the CCW system. On the other hand, the spacing must be wide enough to prevent a large quantity of small fish or seaweed from rapidly plugging the screen. The coarse screen spacing is generally 2 to 15 cm, with exact spacing largely determined by the water conditions near the station: the "dirtier" the water, the finer the mesh of the coarse screen.

The CCW flow next passes through a band screen or travelling screen as it is alternatively called. This screen has a fine mesh (typically 1 cm or less) and is driven by a motor. When the screen accumulates sufficient trash to raise the differential pressure, the motor is turned on and the screen slowly rotates to a new position. The screen is washed with high pressure water jets near the top of its travel. The purpose of the screen is to block any trash large enough to block the tubes.

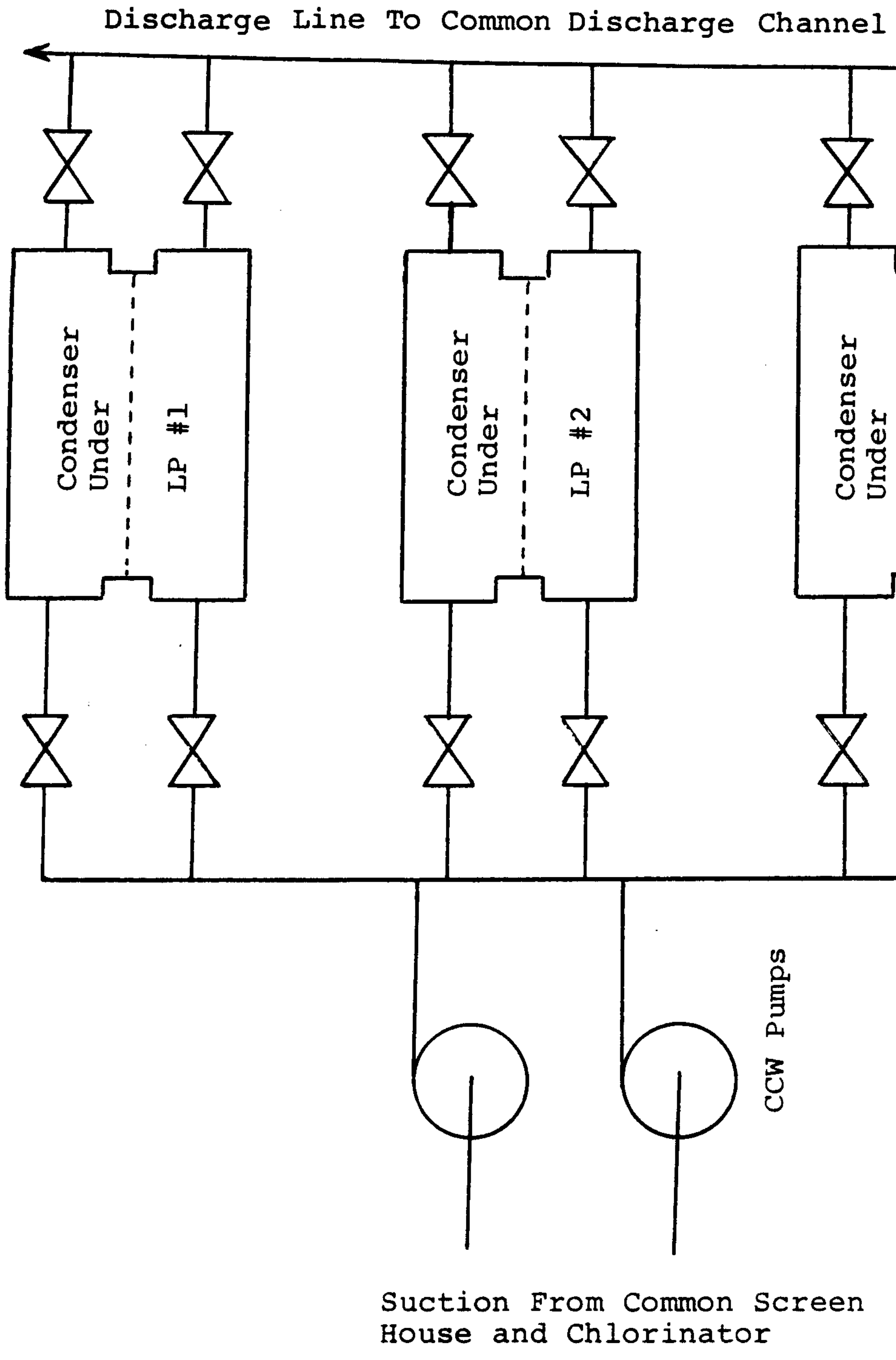
Some marine life may pass both the coarse and travelling screens and accumulate on the condenser tube sheets and tube surfaces. The warm conditions and constant renewing of water result in rapid growth of this marine life. This growth can rapidly result in tube plugging. To restrict the growth rate chlorine is intermittently injected into the CCW intake. The chlorine injection rate must be low enough to prevent poisoning of the marine life in the CCW outflow.



Travelling Screen

Figure 7.5

Regardless of what methods are used to restrict tube and tube sheet fouling, eventually the tube sheets (particularly the inlet tube sheet) must be cleaned. To facilitate cleaning of condenser CCW sides while operating, the circulating water system of large stations supply individual condenser halves which can be isolated from each other. The arrangement shown in Figure 7.6 allows half of one condenser to be isolated and opened for cleaning. The balance piping between condensers ensures the remaining five condenser halves are sufficient to keep the unit at power.



CCW System For Single Turbine Unit with Three LP Turbines

Figure 7.6

ASSIGNMENT

1. Why does the LP turbine exhaust to a vacuum rather than to atmosphere?

   How is this vacuum maintained?

2. Draw a cross section of a typical condenser showing:

   (a) exhaust trunk
   (b) tubes
   (c) tube sheets
   (d) inlet and outlet water boxes
   (e) sagging plates
   (f) staybars
   (g) shell
   (h) hotwell
   (i) expansion joints
   (j) waterbox inspection doors

3. Why are turbine units with more than one condenser fitted with balance pipes between condensers?

4. Why are the air extraction points for the condenser shell surrounded by tubes?

5. What is the purpose of a steam heating lane.

6. Why must air be extracted from a condenser shell? From condenser waterboxes?

7. What is a hogging ejector?

8. How does a steam air ejector work?

9. What provisions are made to prevent blockage of condenser tubes?

R.O. Schuelke