

# **CONDENSER APPLICATIONS<sup>©</sup>**

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# **GRYPHON INTERNATIONAL ENGINEERING SERVICES INC.**

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### **ABSTRACT**

This paper describes the many types of condensing systems which can be installed on the exhaust of condensing-type steam turbines, depending upon the type of condensing application, the location of the facility and/or the site environmental conditions.

Although condensing systems may have some technical variances, they all strive for the same basic result - lowering a steam turbine's exhaust pressure to below sub-atmospheric pressure, in order to maximize the reduction in exhaust steam enthalpy (internal energy), thus increasing system power output, and increasing cycle efficiency.

This paper presents and illustrates brief descriptions of several types of condensers and some of their applications.

Tube fouling, maintenance issues and condenser materials of construction are also briefly outlined.



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## 1.0 THE CASE FOR CONDENSING SYSTEMS

Many different types of **Condensers** and **Condensing Systems** exist in the power generation industry, depending upon the particular needs of the application and/or location. Although the systems may have some technical variances, they all strive for the same basic results - lowering the turbine exhaust pressure to reduce the exhaust steam enthalpy, thus increasing the system power output and increasing the cycle efficiency.

**Figure 1** is a Mollier diagram (a plot of steam enthalpy vs. entropy) representation which illustrates the basic benefit of employing a condensing system to increase the cycle efficiency and increase the power output of the steam turbine.

Beginning with typical steam turbine inlet conditions of 900 psig and 900 deg F, and a turbine isentropic efficiency of 80%, a simple expansion line is drawn for a steam turbine exhausting to atmosphere, i.e. an exhaust pressure of 14.7 psia.

The enthalpy difference between the inlet and exhaust conditions, combined with the steam mass flow, determines the output power of the unit. For this simple example, a turbine with an inlet mass flow of 200,000 lb/hr results in a net power output of **18.3 MW** when exhausting to atmosphere.

By adding a condensing system to the turbine exhaust, the turbine's exhaust pressure will be lowered, and the turbine output will be considerably increased, without increasing the inlet steam flow.

For illustration of this, on **Figure 1**, the same expansion line is extended to show a condensing steam turbine with an exhaust pressure of 1.5 inch HgA, or 0.7 psia. The net gain in turbine output power is substantial, since for the same steam flow, the power output of the steam turbine now increases to **26.4 MW**, i.e. an **8.1 MW** or **44%** power increase.

The additional auxiliary power required to operate the condensing system is small in comparison to the extra turbine output power obtained through the additional expansion. The overall system efficiency is increased, since more power is generated for the same amount of steam. As the turbine backpressure approaches a pure vacuum, the net gain in turbine power for an incremental drop in pressure is significantly increased.

In addition, in the absence of a condensing system, low pressure steam would be vented to atmosphere unless a suitable process was available to use the exhaust steam. Thus, an additional benefit of using a condenser is the recovery of condensate which is then reused as feedwater for the boiler.



## **2.0 TYPES OF CONDENSING SYSTEMS**

Section 1.0 establishes the need for condensers, the actual type of condensing system required varies, depending upon the environmental conditions.

The following sections briefly describe the different types of and applications of condensers, including:

- a) Water-cooled surface condensers and condensing systems
- b) Air-cooled condensers
- c) Alternative condensing systems

### **2.1 Water-Cooled Surface Condensers**

The most efficient, and subsequently the most popular condensing systems are the water-cooled surface condenser systems, which are popular in areas where a large amount of cooling water or makeup water is readily available, and where governing environmental agencies permit their use.

Water-cooled surface condensers can be further categorised by the means in which the heat rejection function is accomplished, including:

- a) Once-through surface condensers
- b) Surface condensers with evaporative cooling tower condensing systems
- c) Indirect dry cooling systems.

#### **a) Surface Condensers with Once-Through Cooling Water Systems**

Surface condensers with once-through cooling water systems are the simplest type, and typically offer the best performance for the least amount of auxiliary power consumption. They are typically applied when the powerplant is located close to an adequately sized river, lake or to the sea.



**Figure 2** illustrates a typical once-through cooling water system, and **Figure 3** shows a typical temperature profile through the cooling-water and steam-condensate cycle.

Cooling water is pumped directly from the cooling water source into the condenser inlet water box. The tubesheet connects the waterbox to the tubes, allowing cooling water to pass through the inside of the condenser without contacting the steam-



condensate circuit. The outside surface of the tubes makes up the condensing surface and it is this surface area and the cooling water temperature that dictates the condenser performance.

Exhaust steam from the turbine enters the condenser chamber and condenses upon contact with the outside surface of the cold tubes. The latent heat discharged by the condensed steam is transferred through the tube walls into the cooling water. Because the condenser chamber is a fixed volume and sealed from the ambient air, the state-change from saturated steam to saturated liquid (condensate) occurs at a constant pressure and a constant temperature. The large reduction in the fluid specific volume (cu.ft./lb) causes the pressure in the chamber to drop to a vacuum condition, to achieve a steady-state equilibrium.

Condensate is collected in the “hotwell” at the bottom of the surface condenser and is then pumped out for reuse in the boiler or HRSG feedwater cycle. The cooling water exits the tubes at an elevated temperature and discharges into the outlet waterbox and eventually returns to the cooling source.

To maintain a vacuum in the condenser, a vacuum pump or steam ejector system is used to remove non-condensibles such as air and other gases that infiltrate the system. The vacuum pump or a large “hogging” ejector is also used to evacuate the condenser at start-up.

Single-pass and multi-pass condensers are both available to suit site requirements. In some cases, multiple inlet/outlet configurations, with divided waterboxes are desired, to allow for flexibility in operation.

While a once-through cooling water cycle is simple and cost effective, it is not always environmentally acceptable to discharge the warm water directly back into the cooling water source. It is quite common for the environmental agencies to restrict the return water temperature discharging back into the original source to 18 deg F rise or less.

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As noted above, surface condensers with once-through cooling systems are typically utilised where adequate rivers or lakes, or the sea is available. **Figure 4** shows an interesting facet of an optimum once-through surface-condenser system’s cooling water circuit, i.e. the change in pressure of the cooling water as it progresses through the water circuit, and the ability of the system to **reduce pumping power** by utilising **syphonic pressure recovery**.

The amount of “syphonic pressure recovery” which is available to reduce pump sizing is dependent on:



- a) The elevation of the plant, i.e. the base barometric pressure.
- b) An allowance for barometric pressure variation (for storm conditions).
- c) The maximum cooling water discharge temperature.
- d) A margin for variations in water levels (i.e. for tides and seasonal discharges on river systems, etc.)

Typically the **maximum height** that the top of the condenser water box can be above the discharge water level is **26 feet**, as shown on **Figure 4**.

If executed properly, a syphonic recovery system can reduce pump head requirements to only friction losses for piping and tubes – a dramatic reduction in total pumping power compared to a non-syphonic system.

For this reason, you will find that surface condensers employing once-through cooling systems are located as low as possible on the plant site.

When this isn't possible for other reasons, and a once-through cooling system is still desired, sometimes the plant designers have employed “recovery turbine-generators” at the bottom of the return water piping. These units take advantage of the head and velocity developed in the return piping, to operate a typical hydraulic turbine-generator set, which can recover 50~75% of the power originally expended by the supply pumps which originally got the cooling water up the “hill” to the condenser.

### **b) Surface Condensers with Evaporative Cooling Towers**

Evaporative cooling towers eliminate the discharge of hot water back into the original cooling water source, by providing essentially a closed-circuit system for the condenser cooling water, as illustrated in **Figure 5**.

In general, air is forced or induced through the bottom of the cooling tower, and extracts heat by evaporation from the cooling water stream as it rises and eventually discharges through the top of the tower.

Some circulating water is constantly lost to evaporation, drift and blowdown from a cooling tower, thus an amount of makeup water is still required. In addition, chemical treatment of the circulating water, and the blowdown water is usually required. All cooling towers will generally exhibit a visible plume during operation, unless specific plume abatement measures are taken.

There are two basic types of evaporative cooling towers available:

- a) Natural-draft
- b) Mechanical-draft.





**Natural-draft** cooling towers have a distinctive **hyperbolic** shape, as shown in **Figure 5**. The air flow through these units is induced naturally by the hotter (less dense) air in the tower drawing the colder (more dense) air from outside at the bottom of the tower. Such natural-draft towers are typically very large, and more expensive than mechanical draft towers. They only become economically feasible for projects with long amortisation periods, where the additional initial capital cost is offset by the absence of fan power requirements and operation and maintenance of fans and motors, etc.



**Mechanical-draft** cooling towers create an airflow through the tower by using either:

- a) Induced-draft fans (**Figure 6**), or
- b) Forced-draft fans (**Figures 7**).

**Forced-draft fans** are located at the air inlets of the cooling tower and characteristically, these towers have high entrance and low exit velocities. This makes them less stable than the induced-draft type, because they are more susceptible to recirculation. Icing of the fans can become a concern for forced-draft towers because they are located in the cold ambient air stream.

**Induced-draft fan** towers have an air discharge velocity 3 to 4 times higher than the air entrance velocity, reducing the possibility of air recirculation due to fan operation. The fan is located in the warm air stream which serves to eliminate the problem of fan-blade icing in colder climates.

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There are two different air-flow to water-flow relationships which are available in cooling towers, and **Figure 6** illustrates an example of a **crossflow** unit, while **Figure 7** depicts a **counterflow** system.

In a **crossflow** unit (Figure 6), the warm condenser-discharge water flows into hot water fill basins at the top of the unit, where it is distributed



by gravity through metering orifices. As the hot water flows toward the lower basin, it is distributed by fill to maximise the crossflow area. Once the warm water is stratified, it is cooled by the forced or induced air which is travelling **perpendicular** to the water stream. Crossflow cooling towers normally have distribution fill and basins open to view and are considered a little easier to maintain during shutdown periods.



By comparison, **counterflow** cooling towers (Figure 7) move air vertically upward through the fill as the water falls down from the water intake plenum/basin. Increased spray water pressures, higher air pressure losses, and increased intake and discharge plenum sizes make counterflow cooling towers larger and less efficient than crossflow units at the smaller sizes. However, on a larger scale, however, these losses are not as significant and **counterflow** units become very competitive and actually become smaller and use less fan and pumping power than crossflow units because of the higher heat transfer efficiency.

**Figure 8** illustrates a typical temperature profile through an system with an evaporative cooling tower and a surface condenser.

### c) Indirect Dry Cooling Systems

In an indirect cooling system, a cooling water cycle is used to remove heat from the surface condenser. However, unlike the conventional systems, the cooling loop acts as an intermediate closed circuit, which is further cooled by air in a heat exchanger cooling tower arrangement (**Figure 9**).

This system requires no make-up water. The heat exchanger is cooled by forcing air over the heat exchanger coils making the tower's performance dependent on the dry bulb temperature of the air.

As this system does not require any make-up water, it can be used in arid areas of the world, where water is in short supply or expensive.

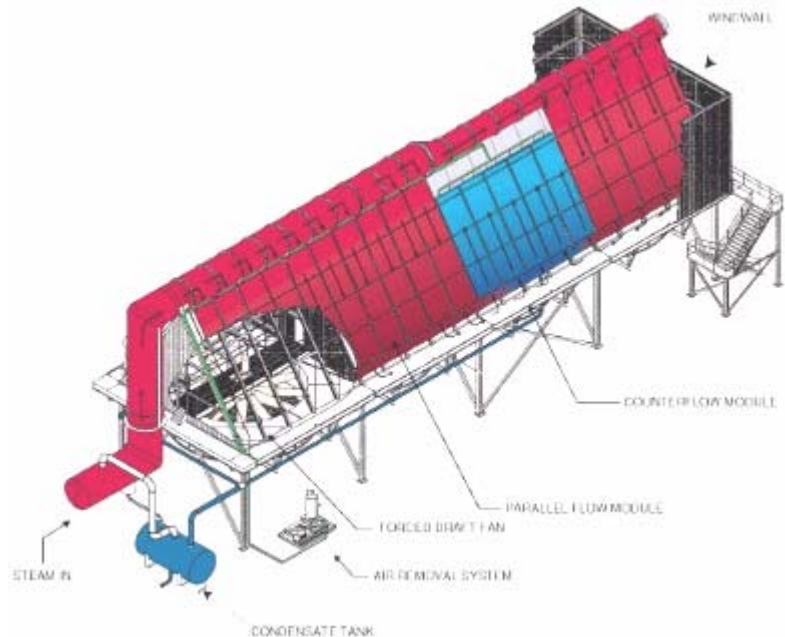
## 2.2 Direct Air-Cooled Condensers

In areas where water is extremely scarce, and powerplants cannot afford even small amounts of cooling water evaporation, sufficient cooling/condensing capacity must be provided without direct air contact with the cooling water circuit.



This is accomplished by using a **dry or direct air-cooled condenser (Figure 10)**.

The turbine exhaust steam enters a central plenum/pipe located above a series of finned tubes, sloped down towards a condensate collection piping system, generally in an A-frame configuration. Cooling fans push ambient air across these finned tubes, causing the steam to condense as it progresses toward the hotwell.



For effective heat transfer, the tubes are designed with external fins and are usually arranged so that no more than 3 to 6 tubes are stacked in succession. This maintains a low enough cooling air temperature to ensure complete condensation at the condenser's exit, and minimises freeze problems during cold weather operation. Fin spacing and tube arrangement affect the rate of increase in cooling air temperature, which ultimately affects the performance and the cost of the unit.

Because direct water contact is non-existent in air-cooled condensers, the exhaust/condensing pressure is dependent on the dry bulb temperature of the ambient air. This means that in very hot weather, the exhaust pressure rises regardless of the relative humidity. In arid environments where the dry bulb temperature is very high but the relative humidity is low, the net difference in exhaust pressure between wet surface and air-cooled condensers is significant (**Figure 11**).

A major problem with direct air-cooled condensers is the removal of non-condensable gases. These are inert gases in the steam system, and are the result of feedwater treatment chemicals that have evaporated in the boiler drum but not condensed later in the system. They are also the result of air leakage in the system around shaft seals, flanges, gaskets and poor welds, etc. Most of the non-condensable gases that enter the system end up in the air-cooled condenser tubes where they must be continuously removed by vacuum pumps or steam jet ejectors.



For example, **Figure 12** illustrates a typical direct air-cooled condenser design showing the existence of gas pockets. While the gases are removed effectively from the centre of the header, gas pockets closer to the ends are much more difficult to remove. If these gas pockets extend into the tubes, the heat transfer rate is reduced and the condenser performance is affected (especially in the summer). These pockets can also be the cause of tube cracking/freezing in cold weather.

Cold weather operation is another major concern with direct air-cooled condensers. As the ambient temperature drops, the cooling capacity is increased which lowers the condenser pressure. The vacuum pumps or steam jet ejectors which remove non-condensable gases that have leaked into the system are designed to a certain minimum pressure which limits the vacuum created in the system. It is usually not desirable to allow the turbine backpressure to fall below a certain minimum pressure because, as illustrated in **Figure 13**, the exhaust velocities increase and could actually reduce the performance of the turbine and the overall system. The reduction in ambient temperature thus creates an excess cooling capacity which is used to subcool the condensate - a situation that generally occurs on very cold days or when the turbine is operating at part loads. To avoid freezing damage in cold weather, operators must reduce the cooling capacity by reducing the air flow or reducing the amount of heat transfer surface area.

The air flow is usually reduced by lowering the fan speed. If more than one fan exists, the operator can choose to reduce the speeds on all fans or shut off some fans entirely. Variable-speed drives on fan motors offer much more flexibility in terms of controlling the air flow at different stages of condensation. Reducing the amount of heat transfer surface available can be achieved by restricting flow to certain areas of the condenser.



Valving systems are designed to direct flow away from high heat transfer areas thus reducing the overall heat transfer rate of the condenser.

As environmental legislation and governing agencies become stricter on the maximum cooling water return temperature and the existence of large condenser thermal plumes, air-cooled condensers are becoming increasingly popular, even in areas where a modest water supply is available.

## 2.3 Alternative Condenser Systems

In addition to the direct-wet and direct-dry condensing systems above, there are several alternate condensing configurations which can be employed, including:

- a) Parallel condensing systems
- b) Wet-surface air-cooled condensers
- c) Cooling ponds
- d) Heller system
- e) Hybrid system.

### a) Parallel Condensing Systems

A properly-sized **Parallel Condensing System (Figure 14)**, will combine the best of wet and dry condensing systems, with the steam turbine's exhaust ducted directly to both a conventional surface condenser and a dry air-cooled condenser.

The exhaust steam which enters the surface condenser is condensed via a conventional circulating water & evaporative cooling-tower system (as per Figures 5, 6 or 7, and 8), while the exhaust steam entering the air-cooled condenser is directly cooled by ambient air (as per Figures 9 and 10). The condensate formed by each is usually routed to a common storage tank.

Each side of the system would be sized for about 40~75% of the maximum turbine exhaust heat load requirement. Both condensers would operate at essentially the same condensing pressure at all times, with the heat load shifting from one to the other, dependent upon the ambient conditions (temperature and relative humidity), the steam heat load, the availability of makeup water and/or maintenance considerations (number of fans on or off).

During low-ambients (fall, winter & spring), the dry side would tend to absorb a higher proportion of the steam. In the extreme, the wet system may even be shut off during the coldest conditions (to prevent cooling tower icing problems) with very little net impact on the condensing pressure. A secondary benefit at low temperatures is that with the air-cooled condenser not "oversized", the risk of "freezing damage" to it's tubes is minimised.

During high-ambients (summer), the wet side would automatically tend to absorb a higher proportion of the steam, although the dry side would continue to operate, absorbing heat and saving (cooling tower) makeup water.

Such parallel systems can be implemented at the plant initial design phase, or be retro-fitted to dry air-cooled only plants, or to wet-only plants, if steam turbine exhaust conditions change.

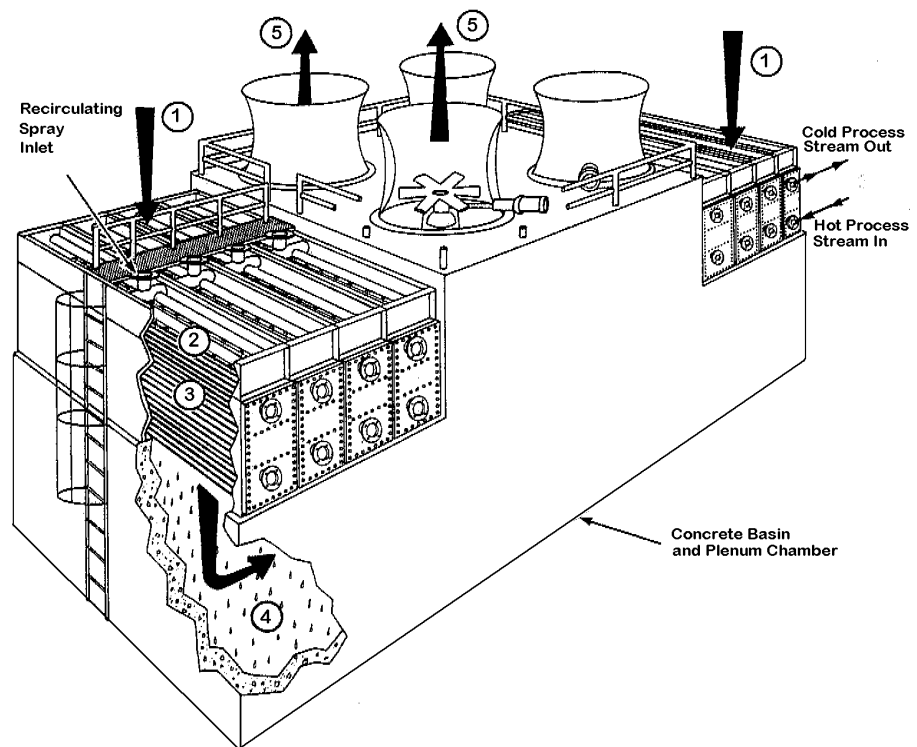


## b) Wet Surface Air-Cooled Condensers

A limitation of direct air-cooled condensers is the limit on temperature difference between the condensate outlet and the inlet air temperature. The overall plant performance can be increased significantly, if this temperature difference is reduced.

Because direct air-cooled condensers are generally situated in areas which lack an abundant source of cooling water, the solution must also restrict the amount of water that is required. In addition, traditional condenser & cooling tower arrangements are very susceptible to freezing in cold weather climates. The use of a **Wet Surface Air-Cooled Condenser** can eliminate some of these problems.

Wet surface air-cooled condensers are equipped with spray nozzles that provide a thin layer of water on the outside surface of the condenser tubes (**Figure 15**). Instead of cooling air passing over dry tubes, it contacts a more efficient wet surface which ultimately reduces the condensate temperature and the turbine backpressure.



The warm cooling water flowing over the outside of the condenser tubes also helps eliminate freezing of the tubes (compared to direct air-cooled systems).

Heat is transferred from the condensing steam (inside the tube) through the tube wall and into the cooling water flowing over the exterior of the surface. The water is then cooled by a combination of sensible heat transfer to the air, and the latent heat of evaporation. The temperature differential is, therefore, based on the wet bulb rather than the dry bulb air temperature.

Some concerns with these units include freezing of tubes, capacity modulation, and



plumes. Freezing can be a concern with this type of unit if the spray water does not blanket the entire tube surface or if a section of tube (especially the first tube rows seeing the coldest air temperature) becomes air blanketed. Plumes from the unit can also be a concern but can be reduced by re-heating the air leaving the condenser - this, however with a subsequent performance penalty.

Both capacity modulation and freeze protection are addressed by using dampers to redirect some of the hot cooling air into the fresh air stream. A simple control system can provide a constant cooling air temperature even when the ambient temperature is fluctuating significantly. The warm air also serves to keep the surface water at the desired temperature to avoid freezing and precipitation of solids on the outside of the tubes. In extreme conditions, the cooling fans are turned off to maintain an acceptable cooling air temperature.

Scaling can also occur on the air-side of the tubes, reducing the unit's performance. To avoid this, the surface water quality must be carefully treated and monitored.

### c) Cooling Ponds

When land is available at a reasonable price, **Cooling Ponds** are popular, since they are often the simplest, cheapest, and least water-intensive method of cooling for large power plants.



In general, an earthen dike is constructed on a large tract of land, to retain the cooling water and the system makeup water. Cooling water is pumped directly from the pond into the condenser and is discharged into the opposite end of the pond. Cooling Ponds have very low heat transfer rates, thus require large tracts of land for sufficient cooling surface area.

Typically, **one to two acres** of Pond is required for each **megawatt** of installed capacity. Another problem is the fog that can be created on cold days which, depending on the size of the plant, can cause significant problems to surrounding inhabitants. Because ponds are open to atmosphere, they are also more susceptible to infiltration of potentially corrosive contaminants.

### d) Heller System

An interesting type of air-cooled condenser system is the **Heller System** illustrated in **Figure 16**. Turbine steam is exhausted into the condenser where spray headers



are located and equipped with several nozzles to spray cooling water directly onto the entering steam. Condensation occurs upon contact, and the cooling mixture of water and condensate falls by gravity, and is collected in the condenser hotwell. This mixture of condensate and cooling water is extracted from the condenser and used to supply both the boiler feedwater system and the condenser cooling water system. After the boiler feedwater take off, the cooling water system passes through a heat-exchanger cooling tower arrangement, shown in **Figure 16**. A direct air contact system is not practical since the cooling circuit is pressurised at this point.

Because the cooling water contacts the turbine exhaust steam, the water pressure must be reduced to the desired condenser backpressure. This is accomplished while improving the system efficiency, by passing the cooling water through a pressure reduction hydraulic turbine. The turbine is directly coupled to the condenser extraction pump to offset some of the motor power required, while the cooling water pressure is reduced sufficiently to be sprayed into the condenser.

#### e) **Hybrid Systems**

In very arid environments, the use of conventional cooling tower arrangements is often not feasible. These areas of scarce or unreliable water supplies have inspired the development of alternative condensing techniques, to minimise the water loss due to evaporation, drift, and blowdown. One such alternative is the **Hybrid** cooling system.

The goal of reducing water loss in this Hybrid system is accomplished by adding dry sections to a wet surface cooling tower. Water approaching the wet cell first flows through a dry-surface, finned-tube heat exchanger, where the temperature is lowered by sensible heat transfer to a minimum level of the air dry bulb temperature. If this satisfies the final cooling water temperature requirement, then the water bypasses the wet section and continues into the cooling cycle. If the dry bulb temperature does not offer sufficient cooling, then the water enters the wet cooling section where the remaining heat is removed via conventional cooling tower evaporation methods.

This Hybrid system significantly reduces the water lost to evaporation, blowdown, and drift, but increases the system capital cost. These units can only be justified economically when cooling water supplies are scarce and a maximum turbine backpressure must be maintained.





### **3.0 HEAT ABSORPTION BY AIR**

The main purpose of a condensing system is to ultimately transfer heat from the steam turbine's exhaust, to the ambient air.

**Figure 16** illustrates the significant difference in the ability of the air to absorb heat by dry and by evaporative systems. The amount of heat absorbed by evaporation of moisture in the air increases considerably as the air temperature increases.

### **4.0 TUBE FOULING**

Condenser tube fouling refers to the adherence of deposits on the cooling water or condensate side of the tubes. These deposits vary in type and are detrimental to both the flow and the heat transfer performance of the system. Fouling can be organic or inorganic and can occur at various temperatures.

**Precipitation Fouling** involves the crystallisation of dissolved material in the cooling system whenever the fluid becomes supersaturated with the dissolved material. Inorganic salts can show normal or inverse solubility. Normal solubility means that solubility increases with increasing water temperature. For inverse solubility, the solubility decreases with an increasing water temperature. Precipitation fouling results in the crystallisation of a pure, inorganic salt material which is hard and adheres well to the hot tube surfaces. This "scaling" is very detrimental to system performance.

**Freeze Fouling** is the deposit of ice on the inner or outer surface of the tubes. This deposit reduces the condenser performance because it has a high resistance to heat transfer. It must be removed before severe tube damage occurs.

**Particulate and Corrosion Fouling** are the results of an accumulation of particles from a fluid containing suspended solids. Corrosion of equipment such as boilers and condensers results in iron oxide particles being admitted into the process water circuit. Cooling towers are also susceptible to particulate infiltration from the air passing over the cooling water.

**Bio-fouling** consists of an organic film being created on the tube surfaces. The film is made from micro-organisms and their products, or macro-organisms such as barnacles or zebra mussels. Chemical treatment can usually control the organism growth in closed systems but once-through sea-water or river-water circuits are much more difficult to control. Lower amounts of chlorine and lower temperature cooling water is the result of stricter environmental legislation on effluent which is resulting in an increased concern with biological fouling. Macro-organisms pass



easily through water strainers in their early life form and then grow inside a condensing system. Micro-organisms produce a slime which enters the system, attaches to the surface of the hot tubes, and collects particulate as it passes through the system.

A plethora of literature is available discussing causes and treatments of different types of fouling. The treatments are often case specific and require research on each particular situation.

## **5.0 SURFACE CONDENSERS - MATERIALS OF CONSTRUCTION**

The selection of material types is dictated by the condenser design and environmental conditions of the plant location. Ultimately the goal is to select the materials that will offer the lowest overall cost, including the initial capital cost, as well as life expectancy and operation and maintenance costs.

For **non-corrosive service**, Carbon Steel is the most popular material choice for condenser shells because of its availability and relatively low cost. Most condenser systems utilize carbon steel in some form, depending primarily on the location and the water quality.

For **corrosive service**, the materials employed for condenser tubes are much more specialised, in order to combat the large number of different corrosive agents. A thorough knowledge of the cooling fluid composition is important, so that the proper material can be selected for each particular service.

Corrosive-resistant materials used for condensing systems can range from Ferritic Stainless Steels (which are used to resist sulphur laden and mildly acidic fluids), to Copper-based alloys (which are popular for sea or brackish water).

In some instances, Copper-based alloys are not permitted, because there may be a high ammonia content in the steam.

For **very corrosive service**, Titanium-based or Nickel-based alloys such as Monel are frequently used as substitutes.

Cooling Towers often use concrete and wood for the construction of their structures, and wood and PVC for the fill, which may affect the material selection.

The overall heat transfer coefficient varies for different tube materials, and for the thickness of tube employed. The variation in heat transfer coefficient, for various tube materials and tube thicknesses is given in the following normalised<sup>(1)</sup> **Table 1**.



<b>TABLE 1 - CONDENSER APPLICATIONS© HEAT TRANSFER COMPARISON for VARIOUS TUBE MATERIALS <sup>(1)</sup></b>							
<b>Tube Materials</b>	<b>Tube Wall Gauge - BWG</b>						
	<b>24</b>	<b>22</b>	<b>20</b>	<b>18</b>	<b>16</b>	<b>14</b>	<b>12</b>
<b>Thickness (inch)</b>	<b>0.022</b>	<b>0.028</b>	<b>0.035</b>	<b>0.049</b>	<b>0.065</b>	<b>0.083</b>	<b>0.109</b>
Admiralty Metal	1.06	1.04	1.02	1.00 <sup>(1)</sup>	0.96	0.92	0.87
Arsenical Copper	1.06	1.04	1.02	1.00	0.96	0.92	0.87
Aluminum	1.06	1.04	1.02	1.00	0.96	0.92	0.87
Aluminum Brass	1.03	1.02	1.00	0.97	0.94	0.90	0.84
Aluminum Bronze	1.03	1.02	1.00	0.97	0.94	0.90	0.84
Muntz Metal	1.03	1.02	1.00	0.97	0.94	0.90	0.84
90-10 Cu-Ni	0.99	0.97	0.94	0.90	0.85	0.80	0.74
70-30 Cu-Ni	0.93	0.90	0.87	0.82	0.77	0.71	0.64
Cold-Rolled Low Carbon Steel	1.00	0.98	0.95	0.91	0.86	0.80	0.74
Stainless Steels							
Type 410/430	0.88	0.85	0.82	0.76	0.70	0.65	0.59
Type 304/316	0.83	0.79	0.75	0.69	0.63	0.56	0.49
Type 329	0.78	0.76	0.74	0.69	0.65	0.60	0.54
Titanium	0.85	0.81	0.77	0.71	---	---	---

1. The above table is for comparison only, and assumes a value of unity (1.00) for the heat transfer coefficient for the base 18 BWG Admiralty Metal tube. The actual heat transfer coefficient for this tube can be obtained from condenser suppliers and industry literature.

To calculate the amount of surface area [A] required for an alternate tube material and/or tube thickness, the appropriate factor  $U_2$  from the table can be applied into the formula  $A = [Q] / [U \times LMTD]$ , simplified to  $A_2 = k / U_2$  for a first-cut approximation.

For example, a condenser utilising 24 BWG Titanium tubes would require a surface area some  $1.00 / 0.85 = 118\%$  larger (i.e. longer and/or greater number of tubes) than one incorporating the base 18 BWG Admiralty Metal tubes.



## 6.0 CONCLUSIONS

Condensers and Condensing Systems increase the overall efficiency and power output of modern industrial power plants using steam turbines, while returning condensate for re-use in the feedwater and steam process circuit.

There is a consensus on the need for condensing systems, but the type to be used varies depending on the particular application or location.

**Figure 18 - Typical Condenser Performance Comparison** summarises the types of condensing systems, based on their performance (i.e. condenser pressure) at different dry bulb ambient temperature conditions.

The best performance is offered by **once-through surface condensers**, followed by **cooling towers**, then **wet surface air-cooled systems**, and finally **direct or indirect dry-cooling** systems, with **parallel wet-dry systems** somewhere in between.

The selection of a Condensing System cannot be based solely on performance, but must also consider cooling water availability and local environmental legislative requirements.



Figure 1 – Mollier Diagram Representation for a Backpressure Steam Turbine and a Condensing Steam Turbine

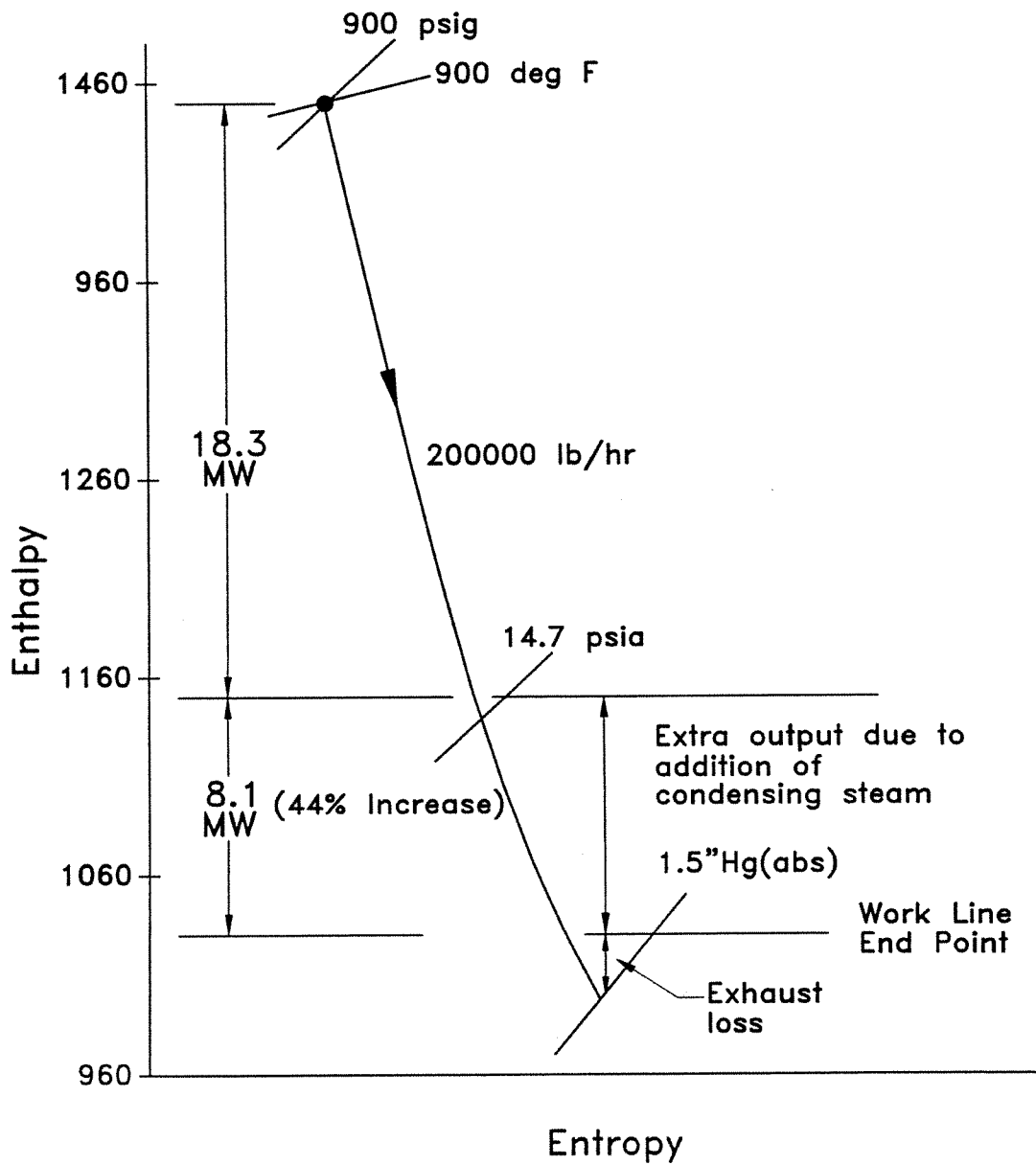


Figure 2: Surface Condenser With Once – Through Cooling Water System

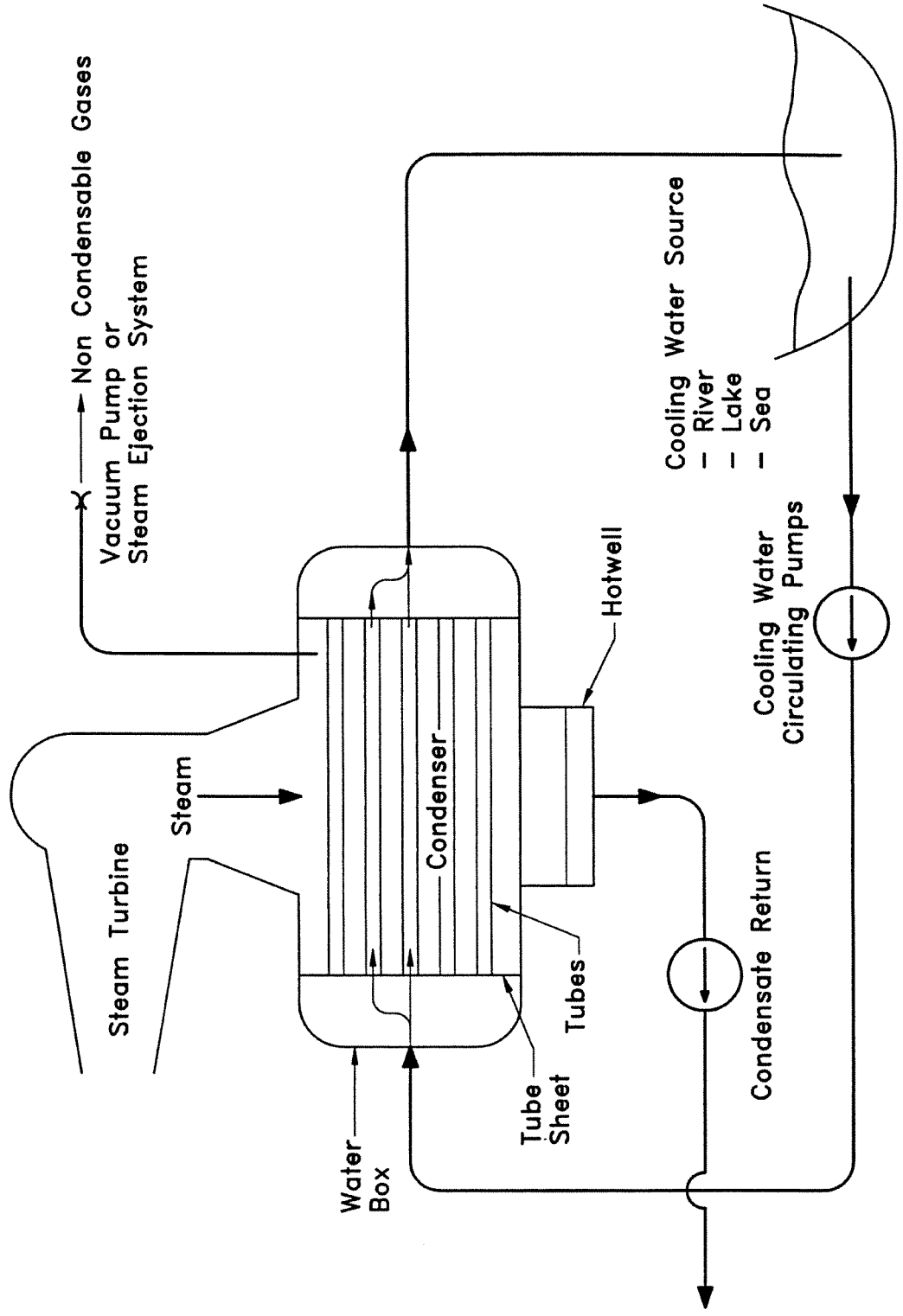


Figure 3: Once-Through Surface Condenser

$$\text{Heat Rejection} = A \times U \times \text{LMTD}$$

$$A = \text{Surface area of Tubes (ft}^2\text{)}$$

$$U = \text{Heat transfer Coefficient } \left( \frac{\text{Btu}}{\text{ft}^2 \times \text{hr} \times \text{°F}} \right)$$

$$\text{LMTD} = \frac{t_1 - t_2}{\ln \frac{t_1}{t_2}}$$

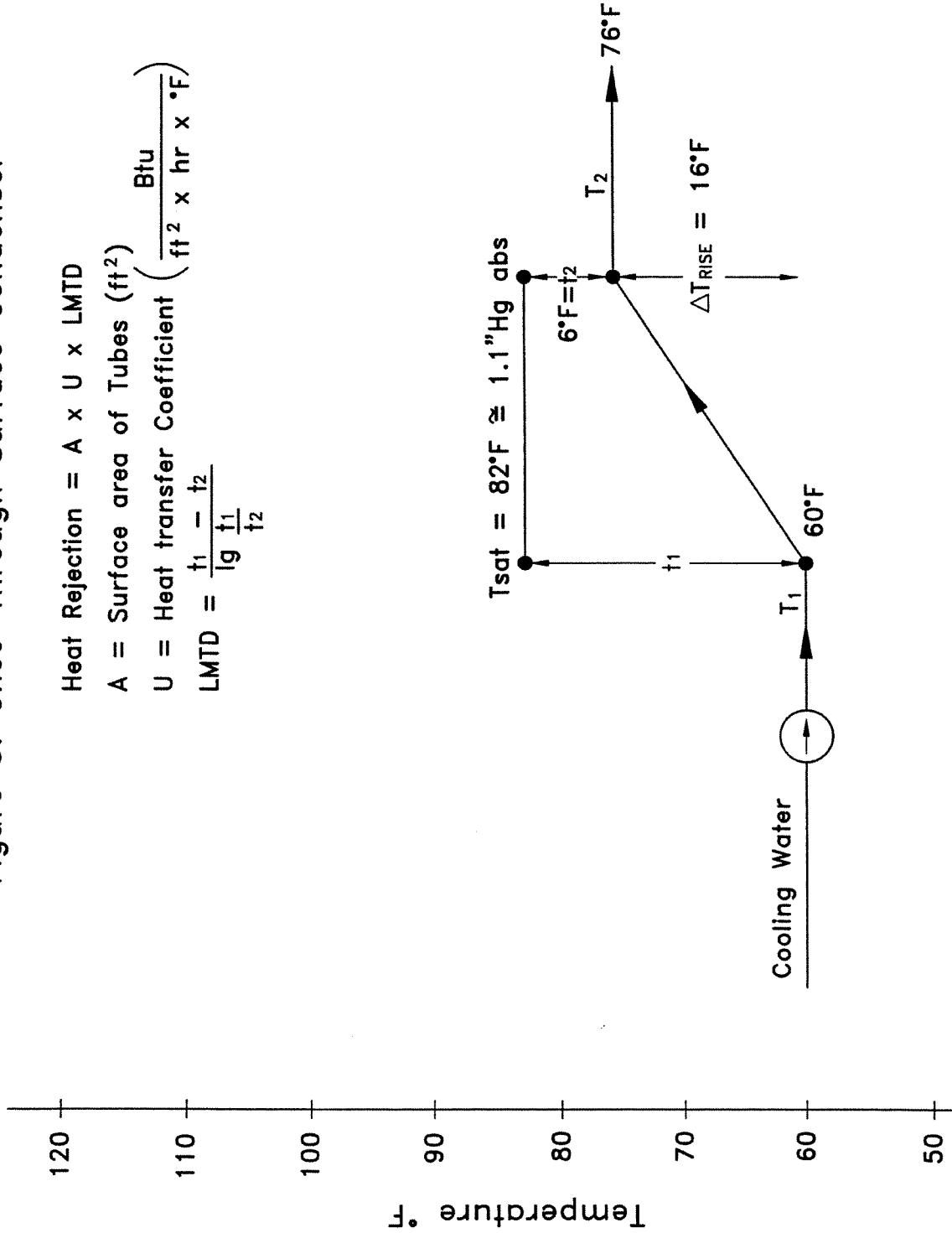


Figure 4: CW System Hydraulic Gradient Once-Through System

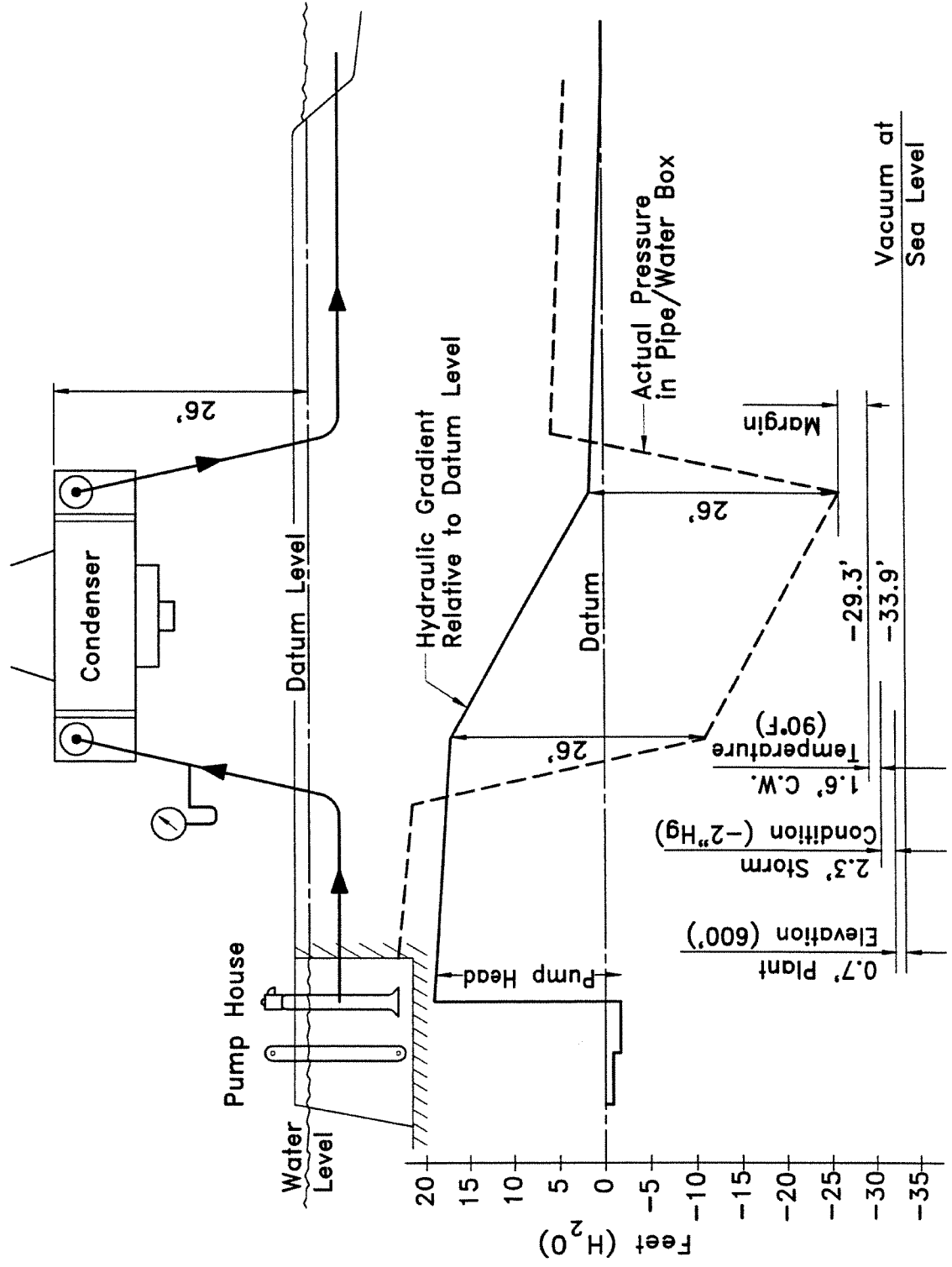




Figure 5: Surface Condenser With a Natural Draft Evaporative Cooling Tower

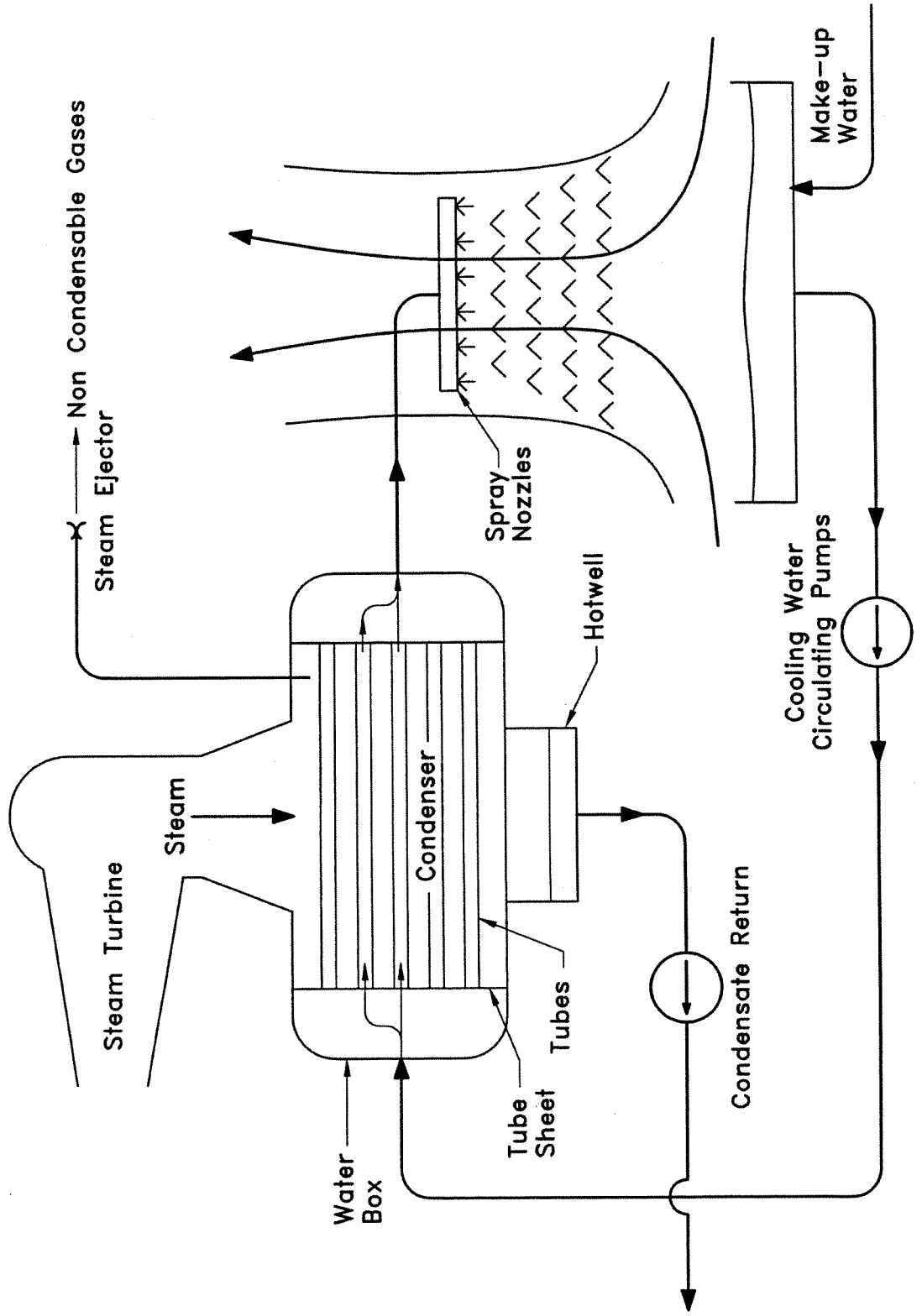


Figure 6: Surface Condenser With a Induced Draft Crossflow Evaporative Cooling Tower

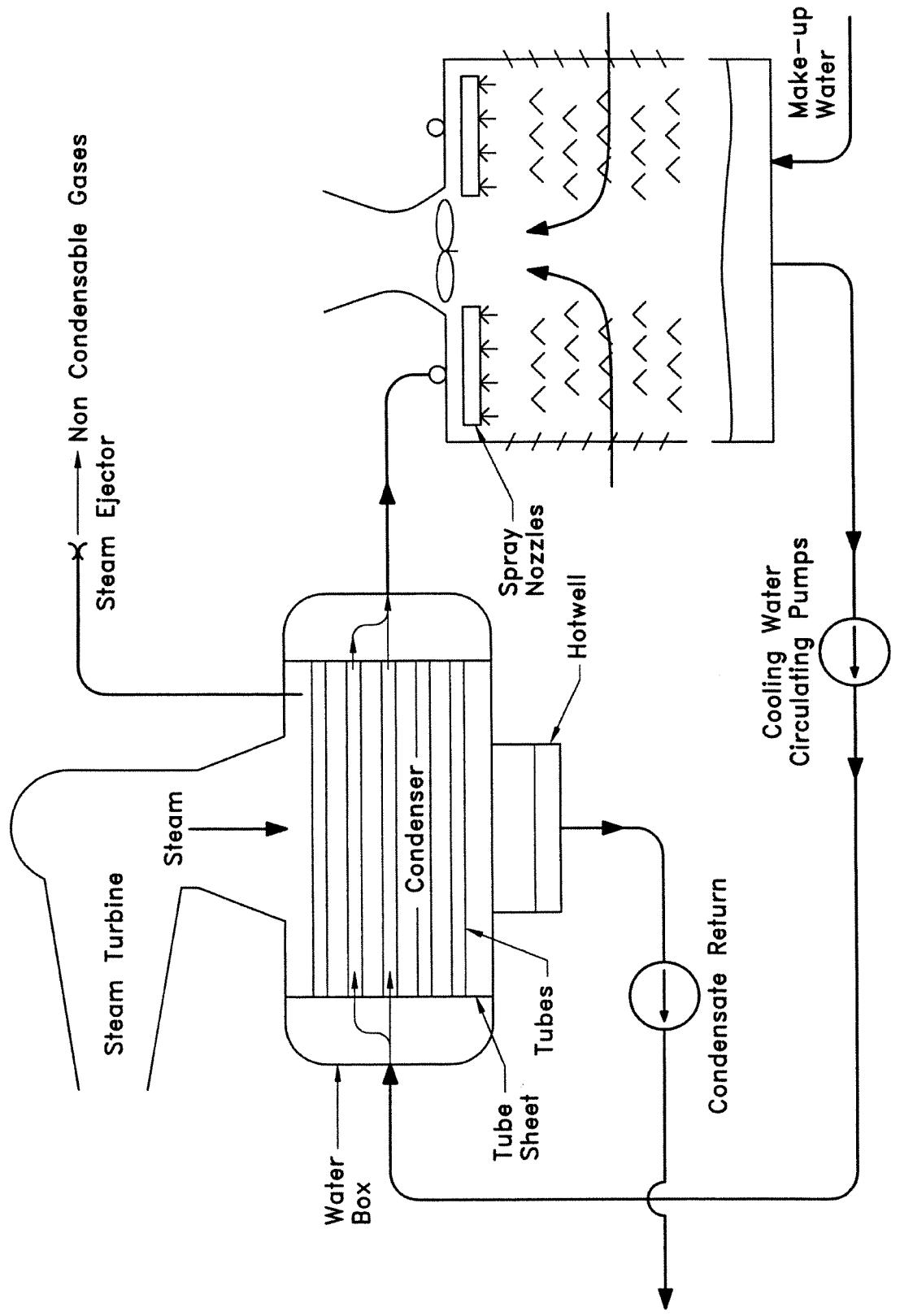


Figure 7: Surface Condenser With a Forced Draft Counterflow Evaporative Cooling Tower

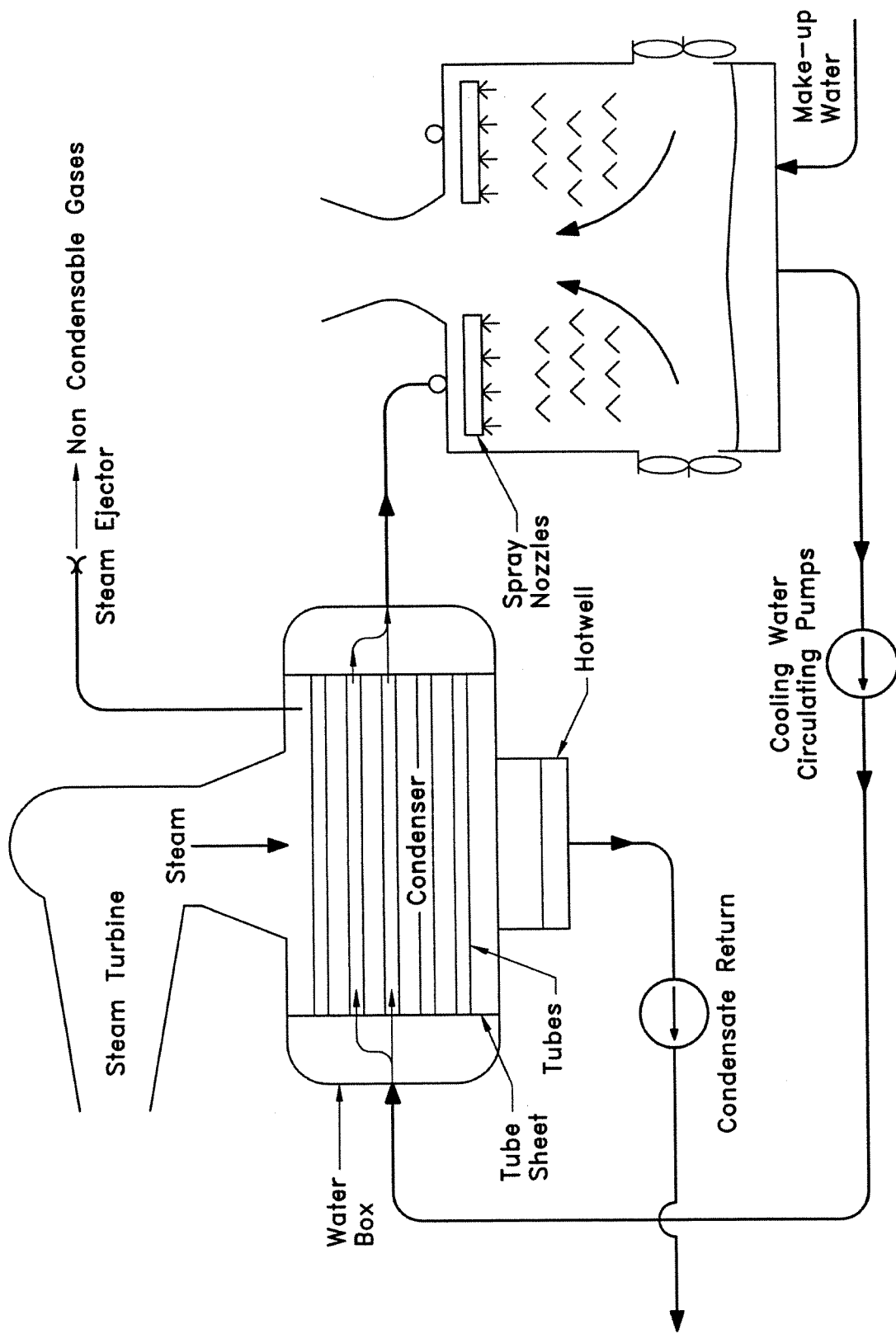


Figure 8: Evaporative Cooling Tower with Surface Condenser

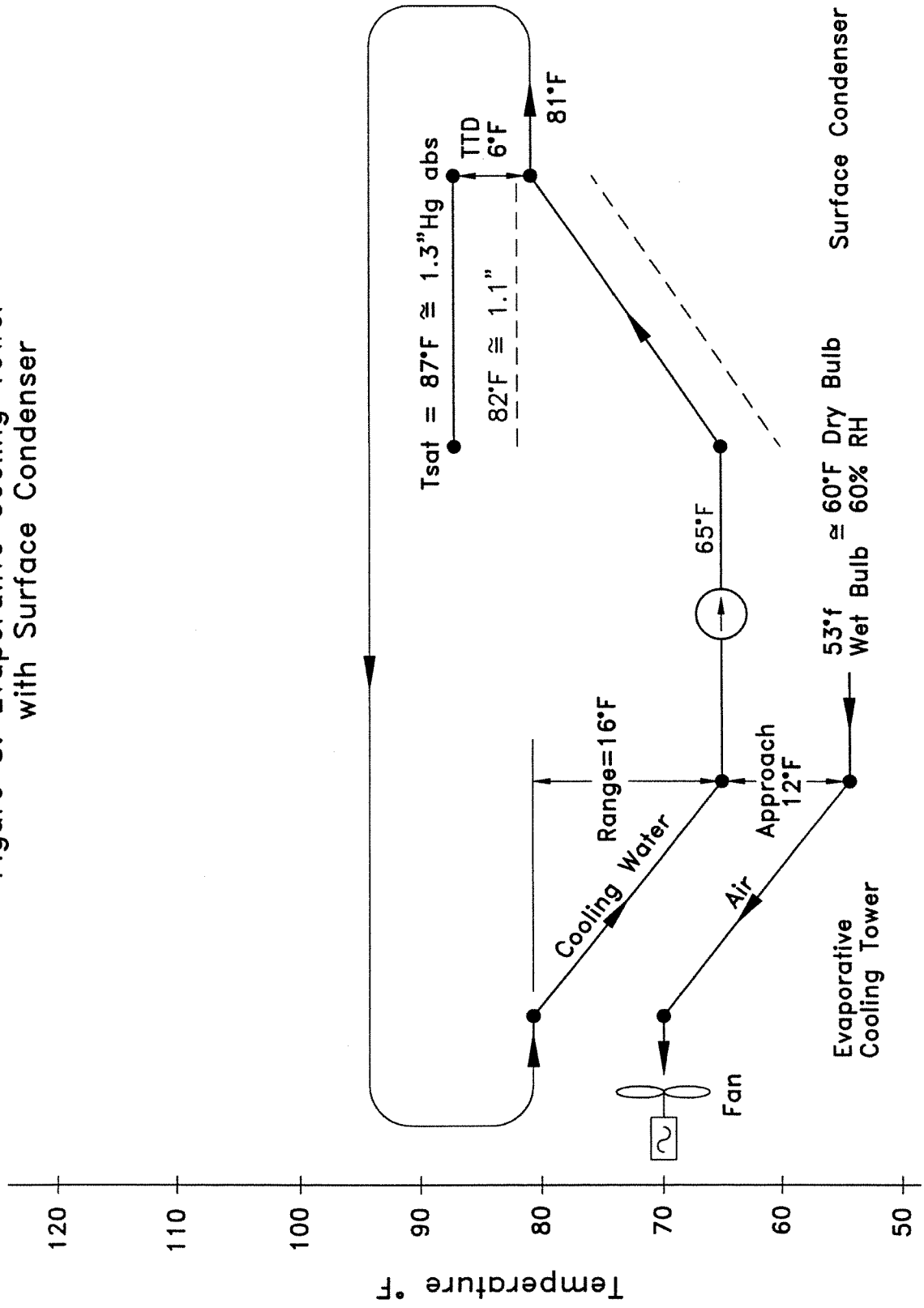




Figure 10: Direct Air Cooled Condenser

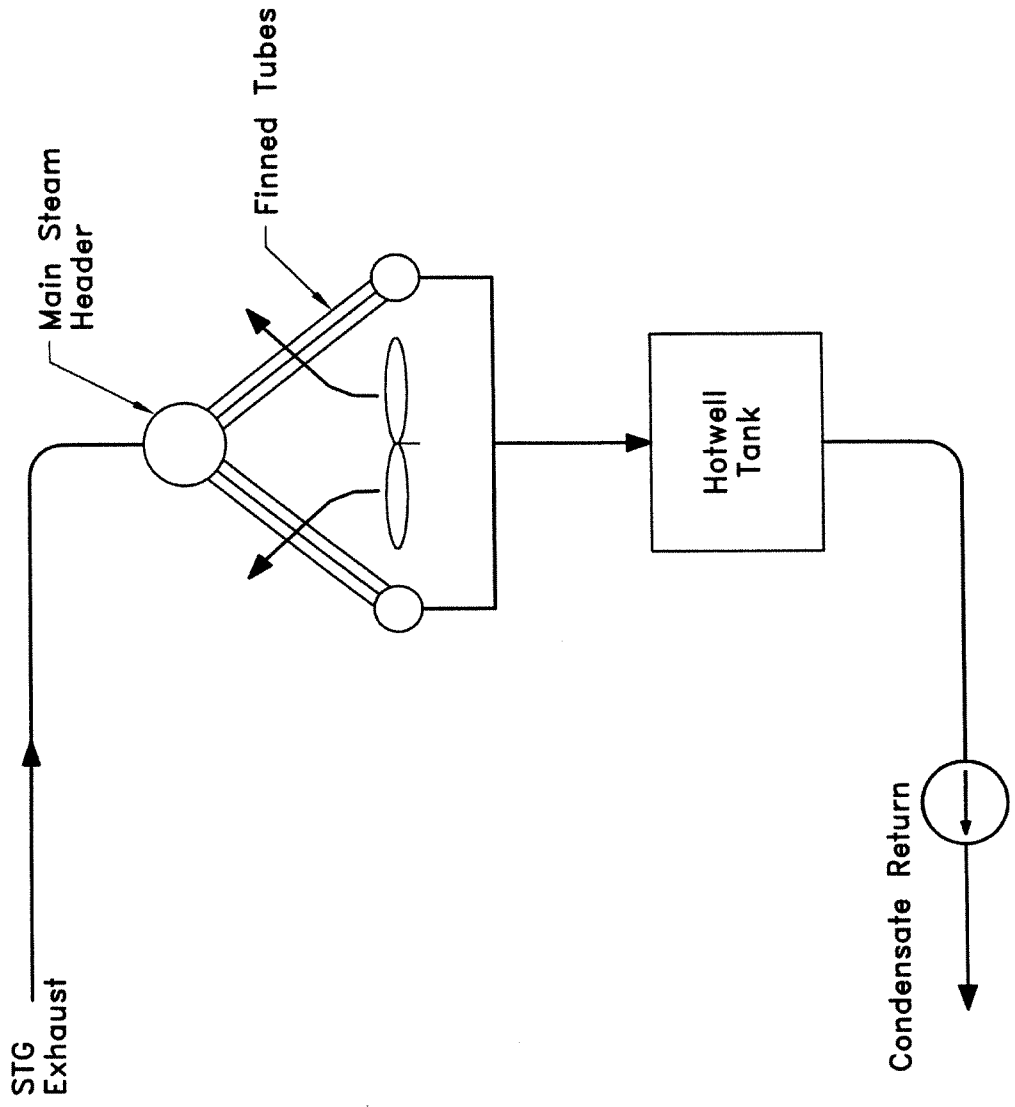


Figure 11: Direct Air Cooled Condenser

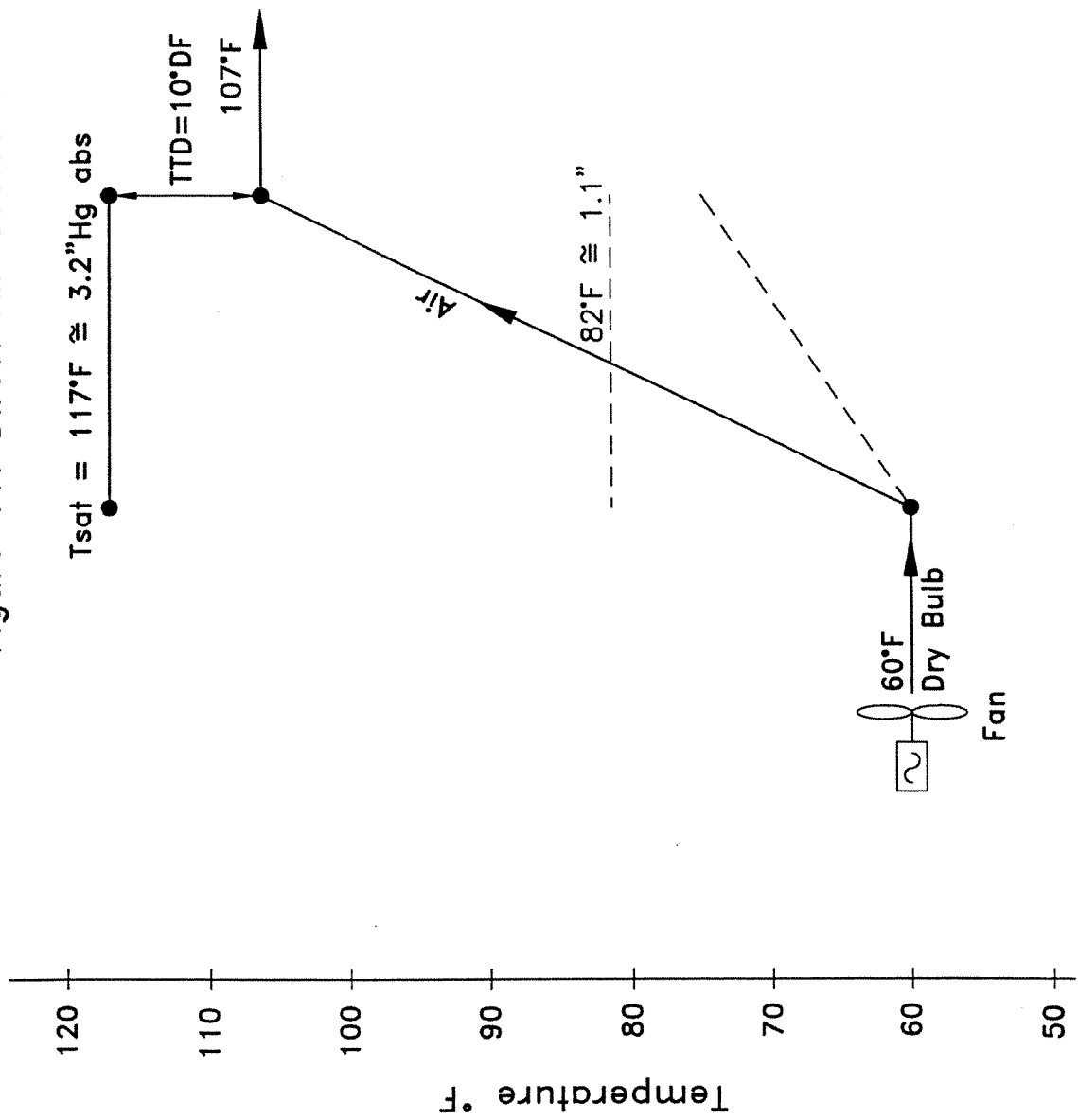


Figure 12: Typical Direct Air Cooled Condenser Header Design

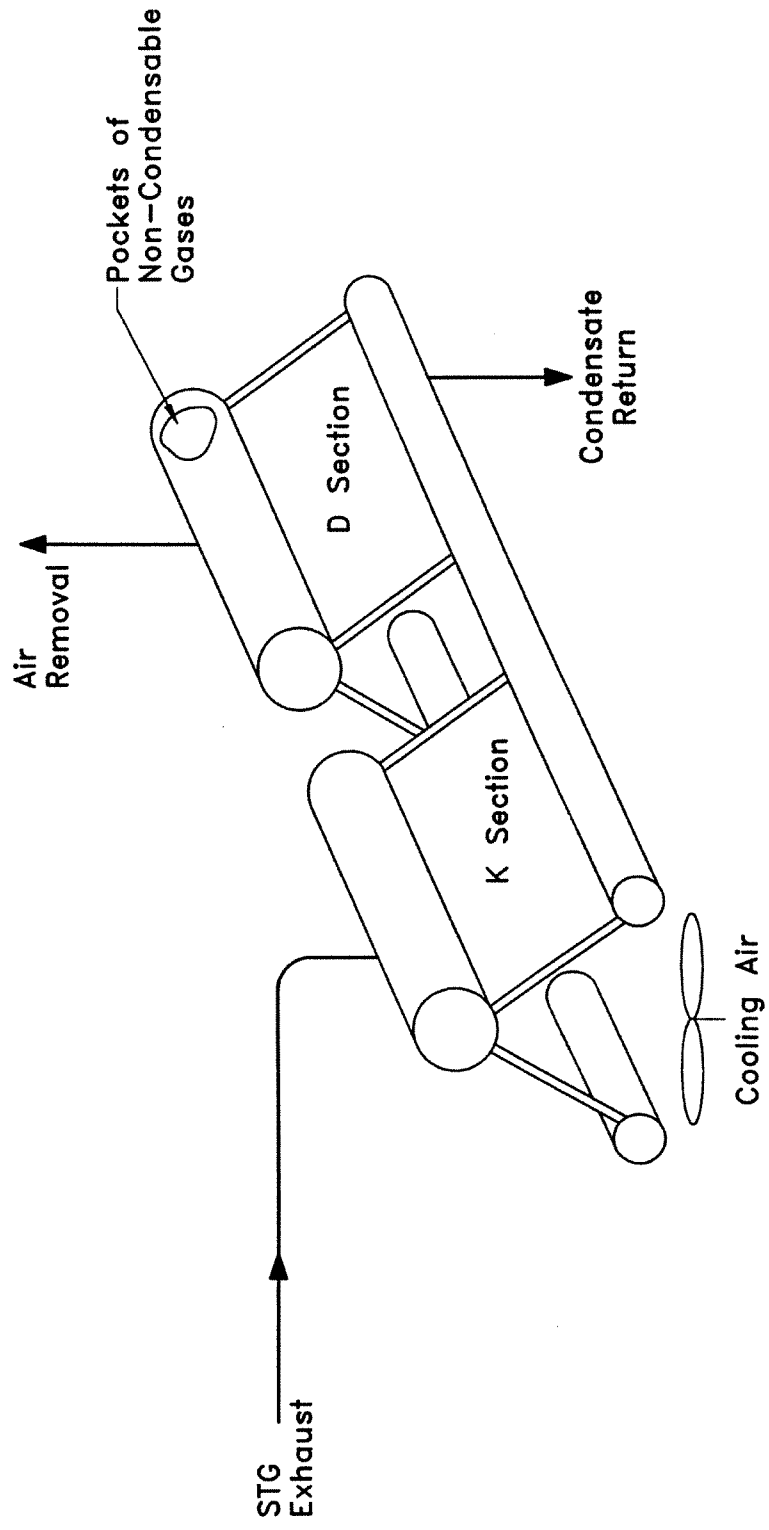




Figure 13: Exhaust Loss Curve for a Steam Turbine

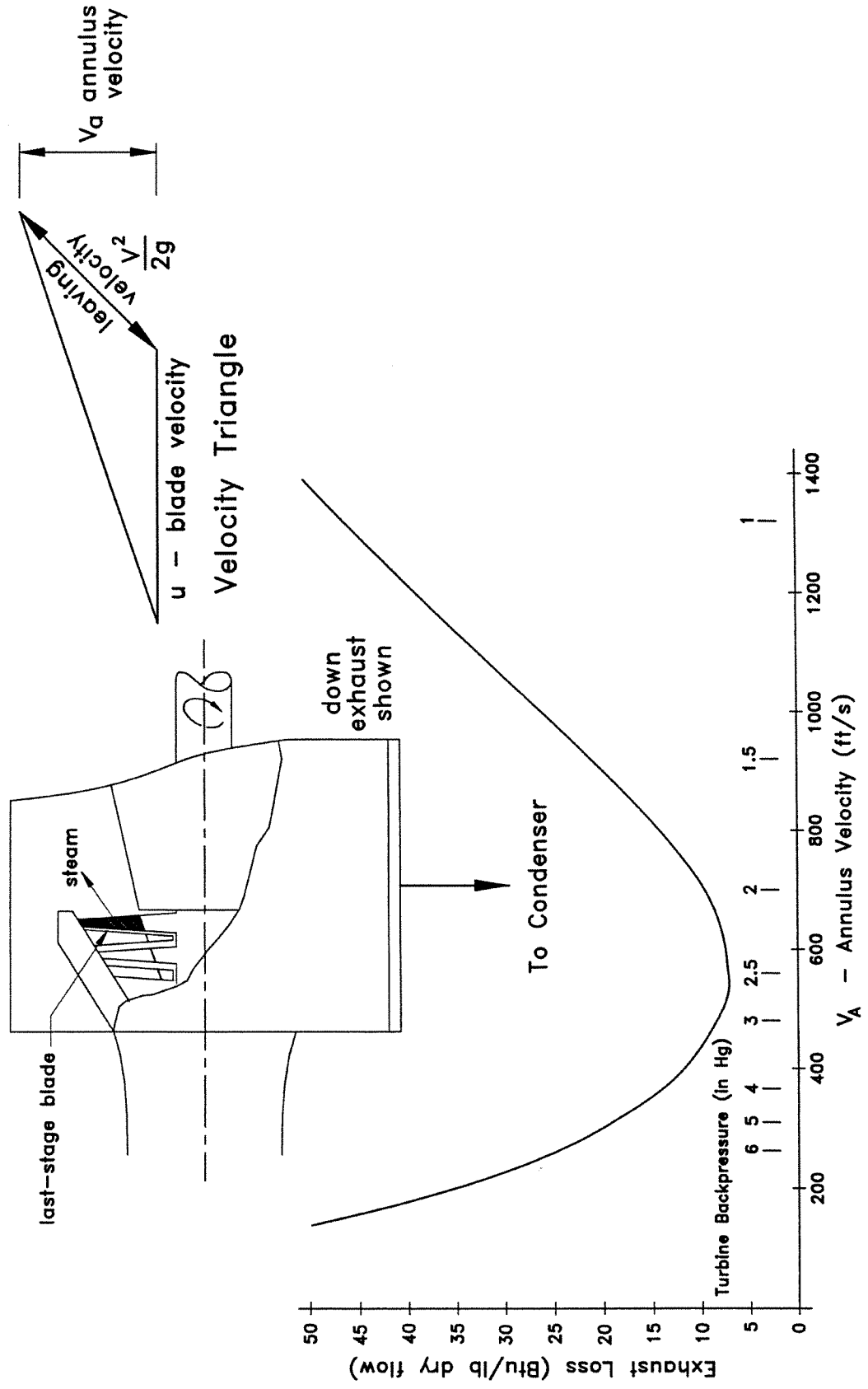


Figure 14: Parallel Condensing System

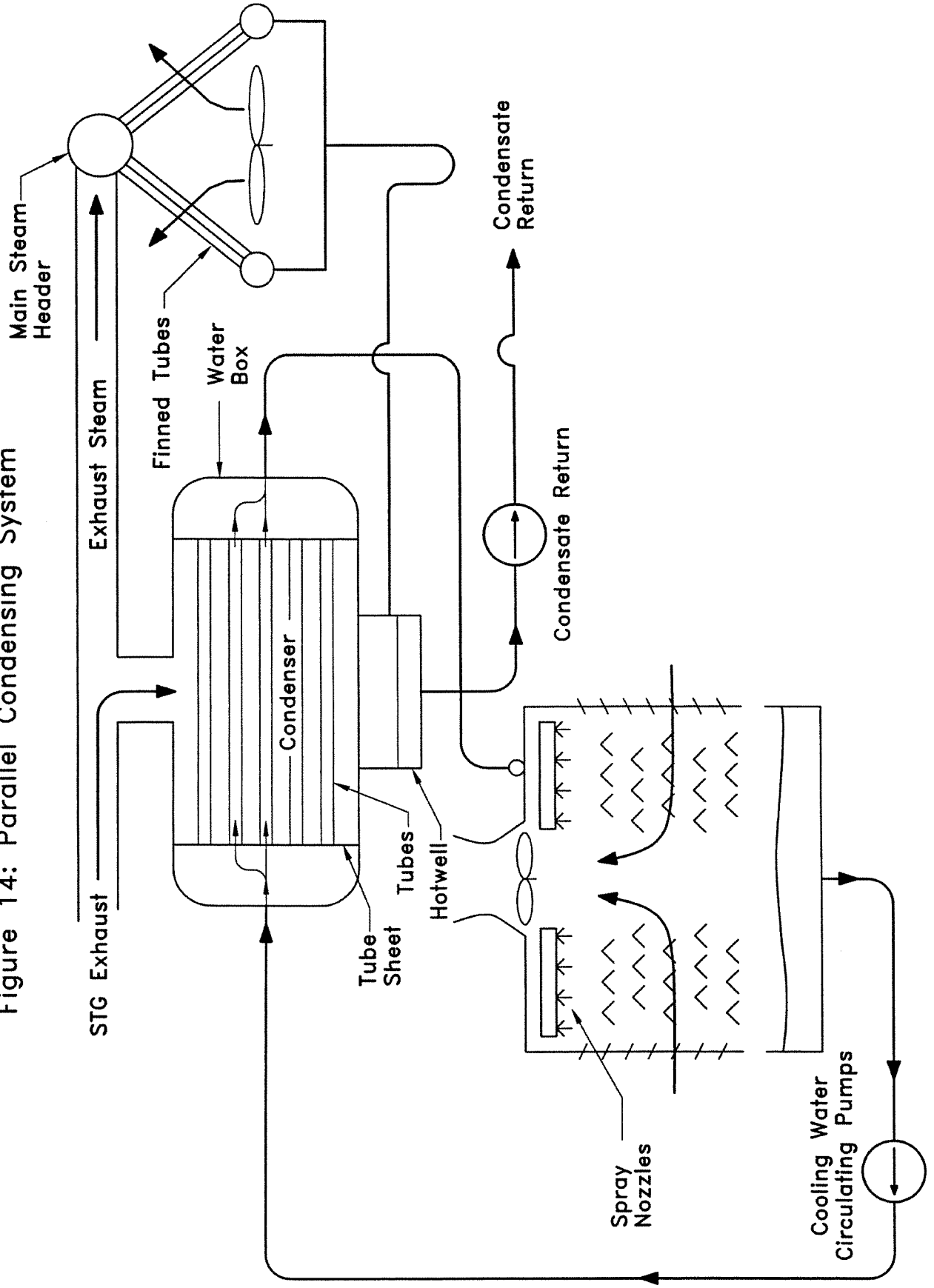


Figure 15: Wet Surface Air Cooled Condenser

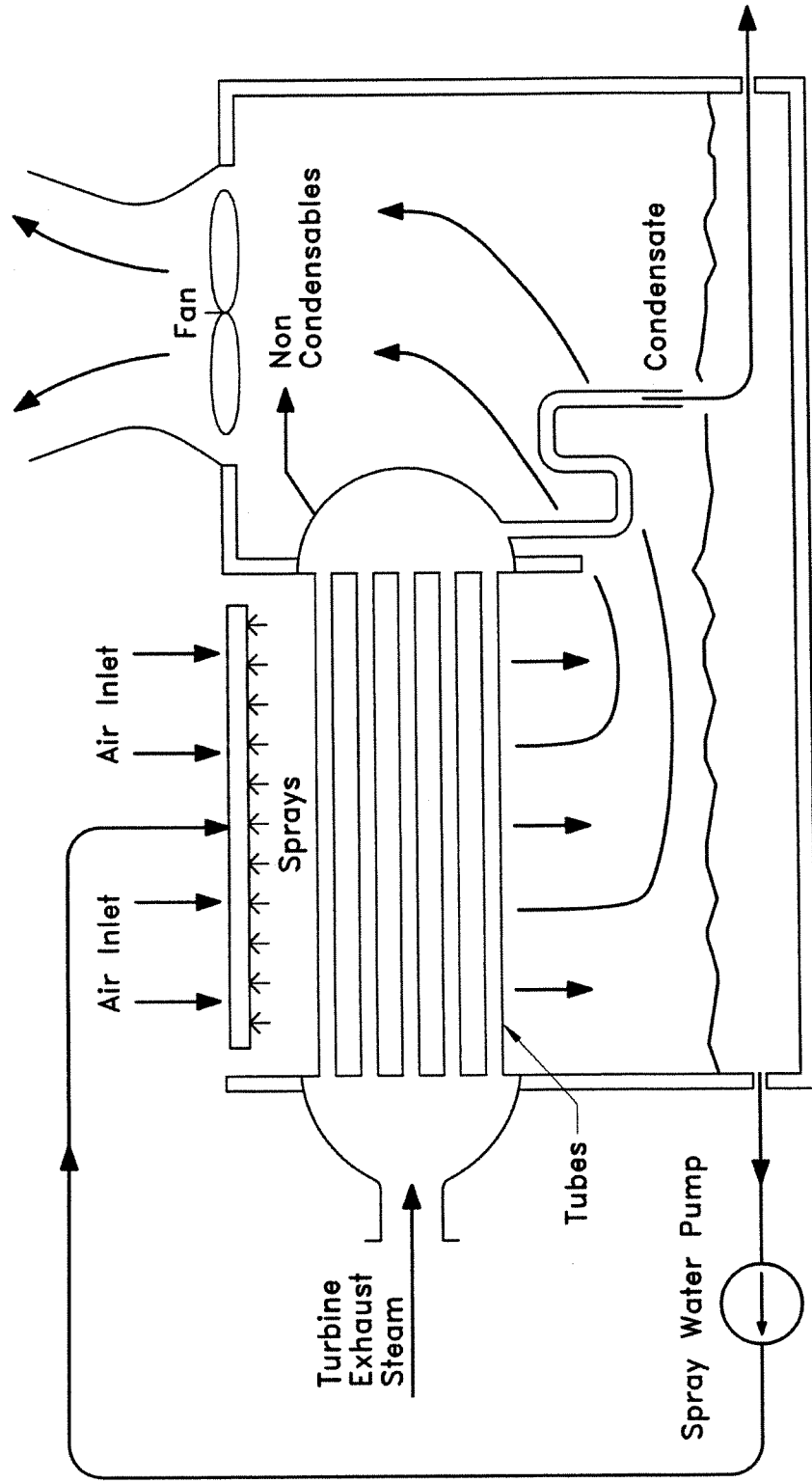


Figure 16: Heller System

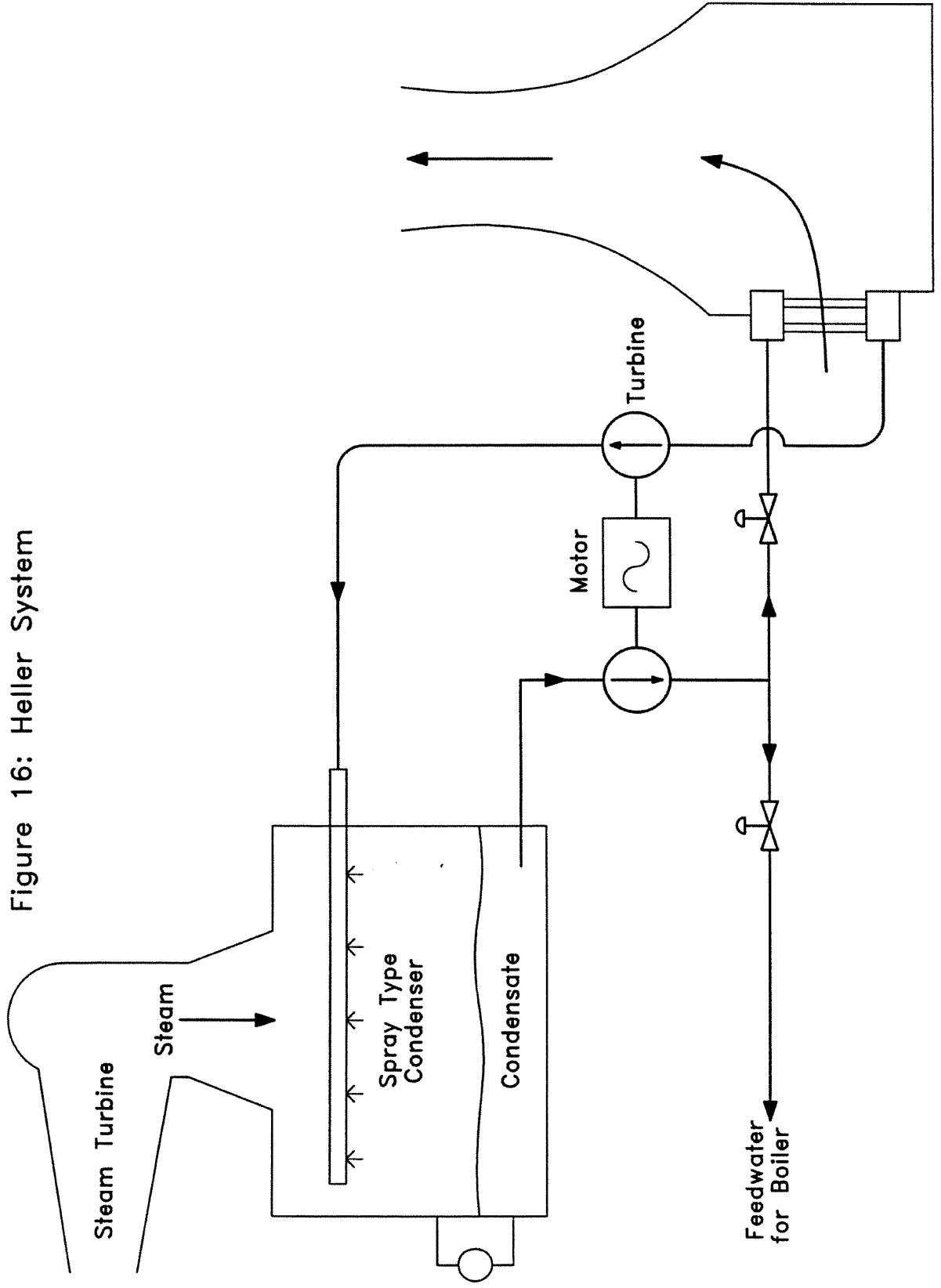


Figure 17: Heat Absorption By Air

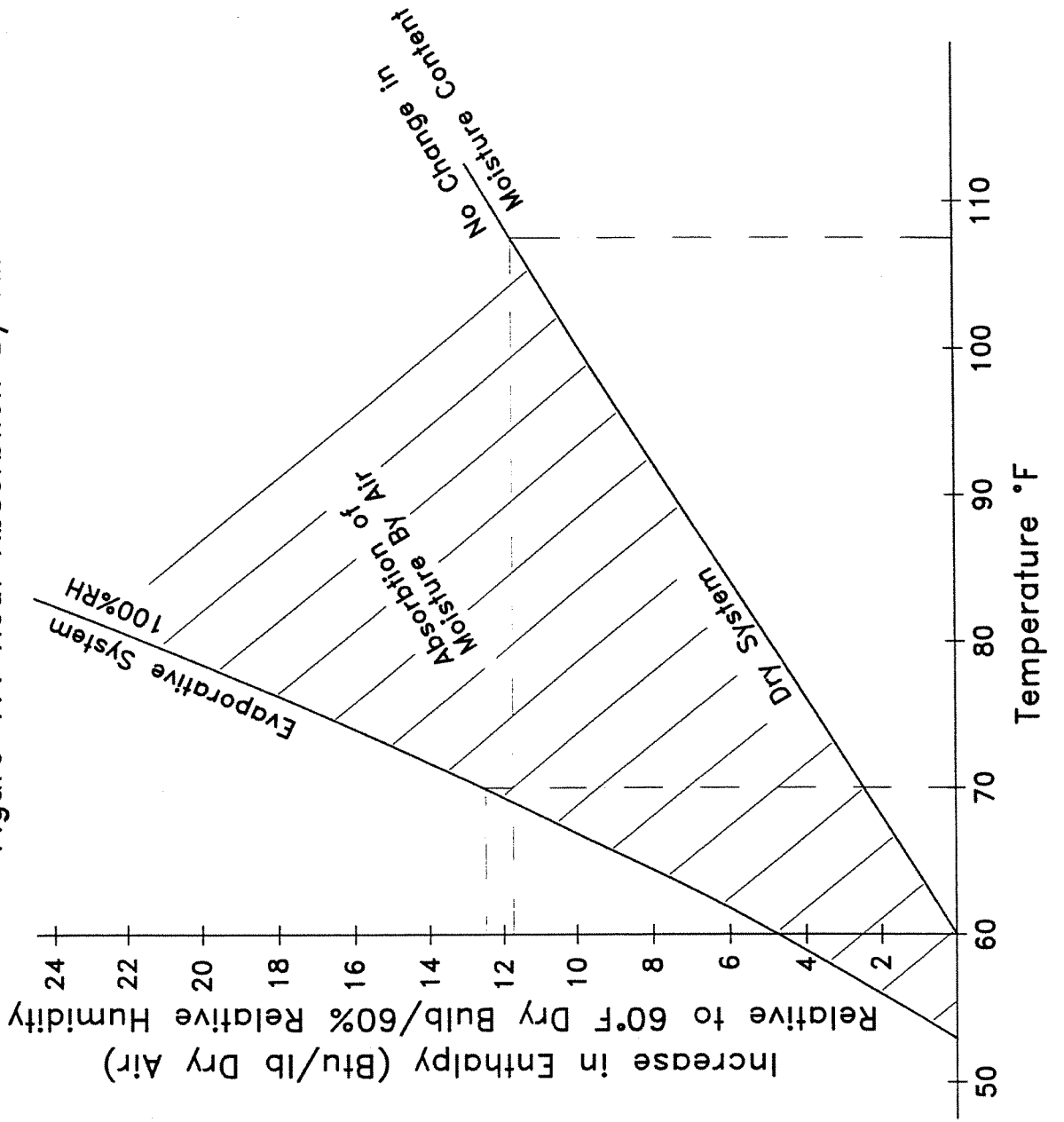
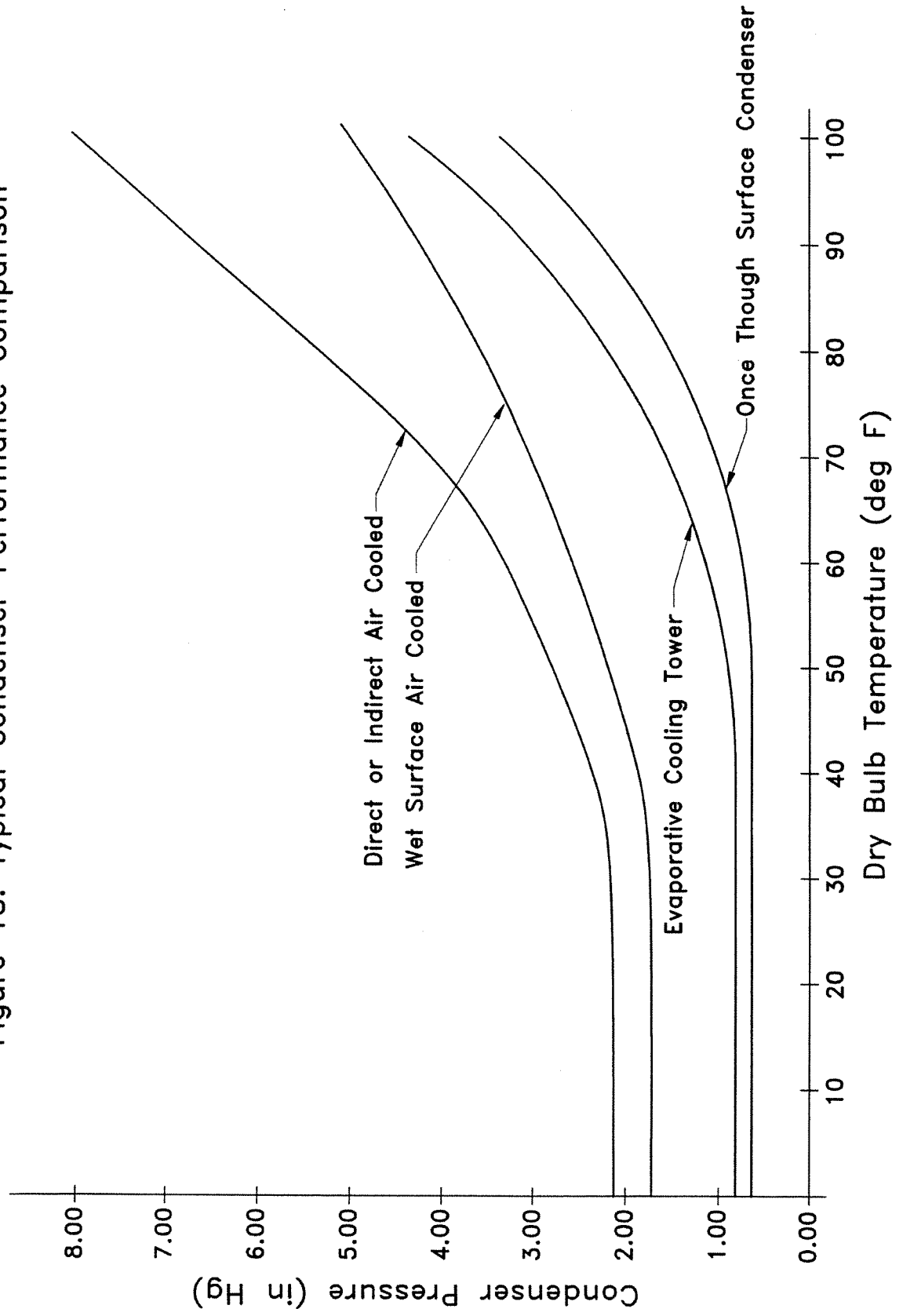


Figure 18: Typical Condenser Performance Comparison



25c Condensing Locomotive  
South African Railways

