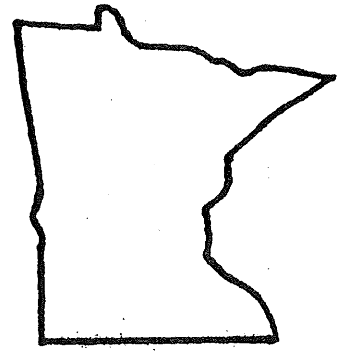


CONSIDERATIONS IN ELECTRIC POWER PLANT SITING

Cooling Water

POWER PLANT SITING PROGRAM

MINNESOTA ENVIRONMENTAL QUALITY BOARD

7 DECEMBER 1979

Conventional, coal-fired electrical power plants require large amounts of water and, in the past, an abundant and reliable source of water was a major requirement when deciding upon a site upon which a plant could be built. Today there are options available that lessen that water requirement. This brochure explains why power plants have required large quantities of water and then discusses some alternatives that reduce the requirement.

I. WHY WATER IS REQUIRED

Figure 1 is a simplified diagram of the steam and cooling water cycles of a typical coal-fired electrical power plant. The steam cycle, shown in red, begins in the boiler where water is heated to steam. The steam flows from the boiler through the turbine, causing the turbine to rotate and drive the electrical generator. After the turbine, the steam flows into the condenser where it is cooled and condensed back to water. The water, called condensate, is pumped back to the boiler and the entire process is repeated.

When the steam is condensed in the condenser, a low pressure, or vacuum, is produced. That vacuum is essential to the operation of steam power generation because it causes the steam to flow through the turbine. Unless a pressure difference exists between the boiler and the condenser, steam will not flow. To a large extent, the overall efficiency of steam power plants is controlled by conditions in the condenser. Cooler condensers create better vacuums and better condenser vacuums increase plant efficiency.

Normally condensers are cooled by pumping water from another source--such as a river, a lake, or a cooling tower--through the condenser. The cooling waters are then returned, somewhat heated to the river, lake, or cooling tower. The quantity of cooling water is large but will vary with many design particulars. An 800 megawatt plant with once-through cooling might require almost one-half million gallons per minute for condenser cooling. Although other plant systems also require water, the condenser cooling requirement is by far the largest and constitutes the reason for traditionally locating power plants on the shores of large, natural bodies of water.

II. ALTERNATIVES IN CONDENSER COOLING

Several alternative condenser cooling methods are currently available. Each method has its own set of advantages and disadvantages in terms of overall plant efficiency, economics, land and water requirements, and effect on the amount of pollution caused by the power plant. No particular

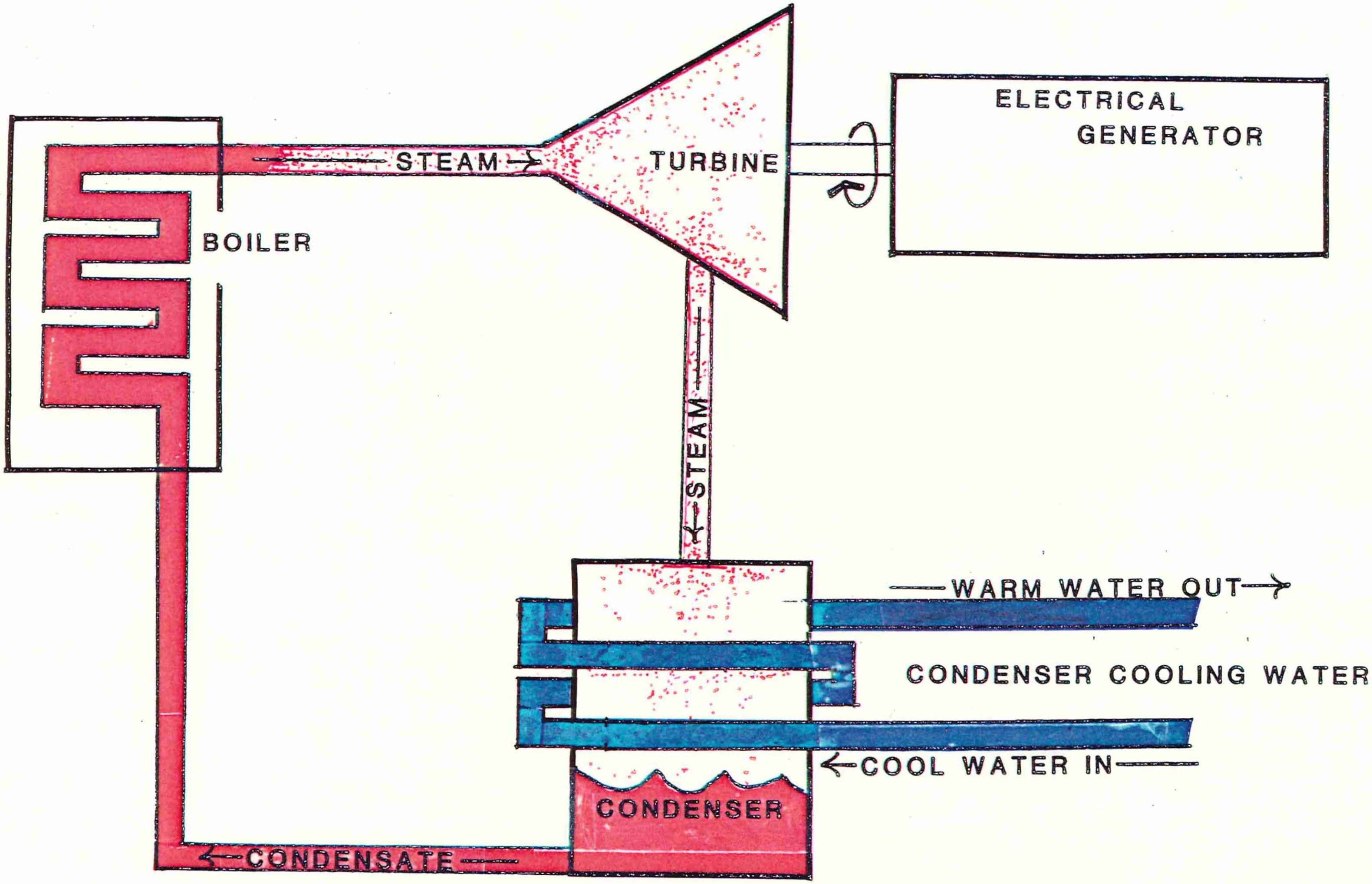

ELECTRICAL GENERATOR
STEAM
TURBINE
BOILER
STEAM
WARM WATER OUT
CONDENSER COOLING WATER
COOL WATER IN
CONDENSER
CONDENSATE

figure 1

method is inherently better than another. Rather, the particular method used must be chosen after an evaluation of all the relative advantages and disadvantages.

ONCE-THROUGH-COOLING

With a "once-through" system cooling water is taken from a natural body of water, pumped through the condenser, and then returned to the river or lake. Although large quantities of water are required--perhaps one-half million gallons per minute for a 800 megawatt plant--this water is not actually consumed. Rather, it is diverted from the natural body, pumped through the condenser, and then returned to the natural body of water.

Once-through cooling has two primary advantages: it is the cheapest cooling alternative; and it is the most effective condenser cooling method. The economic advantage is achieved in two ways. First, capital costs of the once-through system are lower than other alternatives and secondly, because most effective condenser cooling is achieved, plant efficiency means lowered fuel costs (as well as lowered emissions of pollutants from the burning of coal).

But there are also serious disadvantages to once-through cooling. Discharging the heated waters back to lakes or rivers causes thermal pollution of those lakes and rivers. Generally cooling systems are designed so the discharge water is approximately 15 degrees Fahrenheit warmer than intake water. Some appreciation of the amount of heat being discharged can be appreciated by referring again to the quantity of water required. Aquatic plant and animal life are generally affected and frequently extensive growths of algae can be expected in the summer. And, unless long pipelines are built, plants using once-through systems must be located on the shores of large lakes or rivers with large flows. Many such sites already have power plants and the remaining places, where flows are sufficiently large, have become extremely scarce. Such sites are also generally esthetically or recreationally attractive.

With once-through cooling, the heat of the condenser is transferred to the natural body of water. Very little water is thought to be actually consumed, however, it is unknown how much additional evaporation occurs when a lake or river becomes heated.

Evaporative Cooling Systems

Largely to avoid the problems associated with the severe thermal pollution from once-through cooling systems, utilities began using evaporative cooling systems. Although some slight variations occur, evaporative systems are generally of two types: closed-loop cooling ponds and wet cooling towers.

The evaporative rates of these systems are different during different seasons, but over a full year the amounts of water evaporated are approximately equal. Of course, the amount of water lost by evaporation must be replaced. A disadvantage common to all evaporative systems is fog, snow, or ice can be produced Particularly in winter, fog clouds can extend for up to two miles, often causing icing of roads or other structures.

Closed-Loop Cooling Ponds Closed-loop cooling ponds function exactly like once-through systems except that a shallow, constructed pond is used rather than a natural body of water, and the discharged water is recirculated and reused. Because the water is recirculated, cooling ponds have a tendency to become heated and do not cool quite as effectively as once-through systems. Never-the-less, they are second only to once-through systems as efficient coolers. With only a slight decrease in cooling effectiveness, cooling ponds solve the thermal pollution problems of natural waters associated with once-through cooling. And, if pipelines are built, the use of cooling ponds can eliminate the need to locate power plants on the shore of natural bodies of water (when ponds are used, pipelines are more practical then when once-through cooling is used because, after the pond has been filled, only evaporative water loss need be replaced).

However, cooling ponds have their own disadvantages. In Minnesota slightly more than one acre of pond surface is required per megawatt of generating capacity. For an 800 megawatt plant a cooling-pond of almost 900 acres is required. The costs of creating such a large reservoir make cooling ponds extremely expensive, and the elimination of that area from other land uses, particularly agricultural, must be considered.

Wet Cooling Towers Wet cooling tower systems transfer heat from the condenser to the atmosphere, mostly by evaporation of water. Heated cooling water is pumped from the condenser to the top of the tower from which it splashes down over a series of slats or steps. As the hot droplets fall they are cooled by an air stream that passes over them. Cooling water then collects at the base of the cooling tower and is eventually pumped back to the condenser for another cycle of cooling. Figure 2 diagrams a plant with a wet cooling tower. If that air stream is created by large fans, the tower is called a "mechanical draft wet cooling tower." If the tower is built sufficiently tall to create its own air stream, it is called a "natural draft (or hyperbolic) wet cooling tower."

In both cases the water lost to evaporation must be replaced. On a hot Minnesota summer day, for an 800 megawatt plant, that means about 9½ million gallons per day must be replaced. During the winter, considerably less water is evaporated. Although evaporated water must be replaced, the remaining water is recycled repeatedly, thus reducing the overall plant water requirement from that of once-through systems. This reduction allows plants to be sited on smaller rivers or lakes than when once-through cooling is used.

Natural draft towers are generally not used in regions where severe winters are common. Icing problems make them difficult to operate. Mechanical draft towers, however, can be used and icing problems can be somewhat controlled by individually operating the fans.

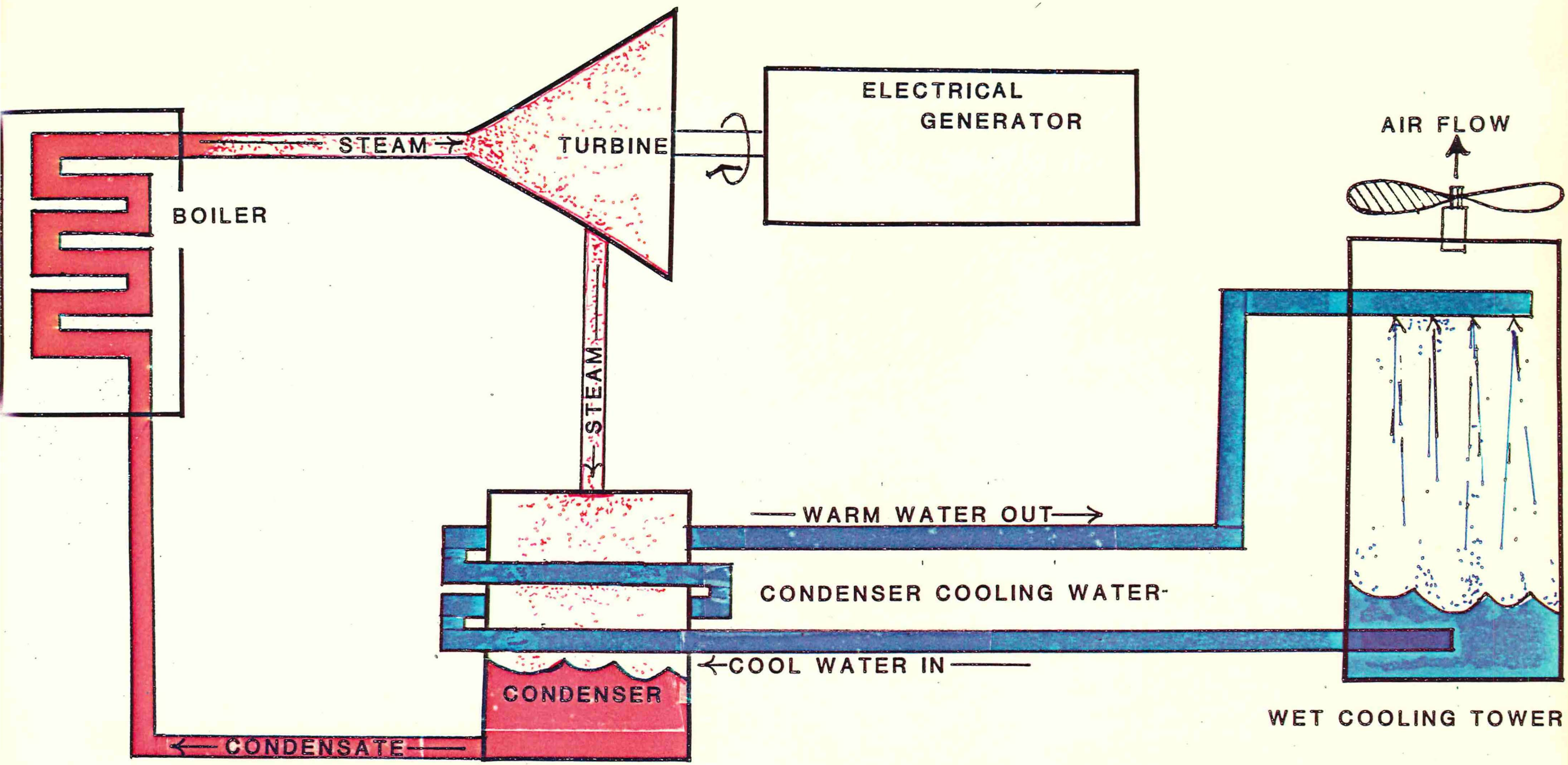
Both types of wet tower systems are effective in cooling the condenser. Condenser vacuums are almost as good as with once-through or closed-loop cooling ponds, however, the adverse impacts of those two systems are reduced.

But even cooling towers have their disadvantages. Water consumption is high, as with all the evaporative systems. As a portion of the water evaporates, the dissolved and suspended solids in the remaining portion become increasingly concentrated. To avoid unacceptably high concentrations some water, called "blowdown", must be continually withdrawn and replaced. The "blowdown", if discharged into a river or lake, may increase the dissolved and suspended solids concentration of that water. Cooling towers also create a plume of water vapor that may cause fogging or icing problems.

Dry Cooling

A fairly recent concept, at least in U.S. power plant technology, is the idea of dry cooling. With dry cooling, water is not evaporated and the overall plant water requirement is drastically reduced. That reduction greatly expands the number of locations upon which a power plant could be built.

There are several variations of the dry cooling scheme. The simplest employs what is called a "direct air-cooled" condenser. The condenser is located outdoors and its outer surface consists of many finned heat exchanger tubes. Fans force air over the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CONDENSER
CONDENSATE
WET COOLING TOWER

figure 2

condenser's outer surface, transferring heat from the surface to the atmosphere. Again, condensate collects in the bottom of the condenser and is returned to the boiler for another cycle.

A variation is the "indirect air-cooled system", shown in Figure 3. With this system, a conventional, water-cooled condenser is used, however, the condenser cooling water is not evaporated in a wet cooling tower. Rather it is cooled in a closed, finned, heat exchanger, analagous to a car radiator. Again, fans pass air over the finned heat exchanger surface for cooling. Whether an indirect or direct dry system is used depends largely upon the volume of steam being exhausted from the turbine. From a siting, or environmental point-of-view, the systems are equivalent.

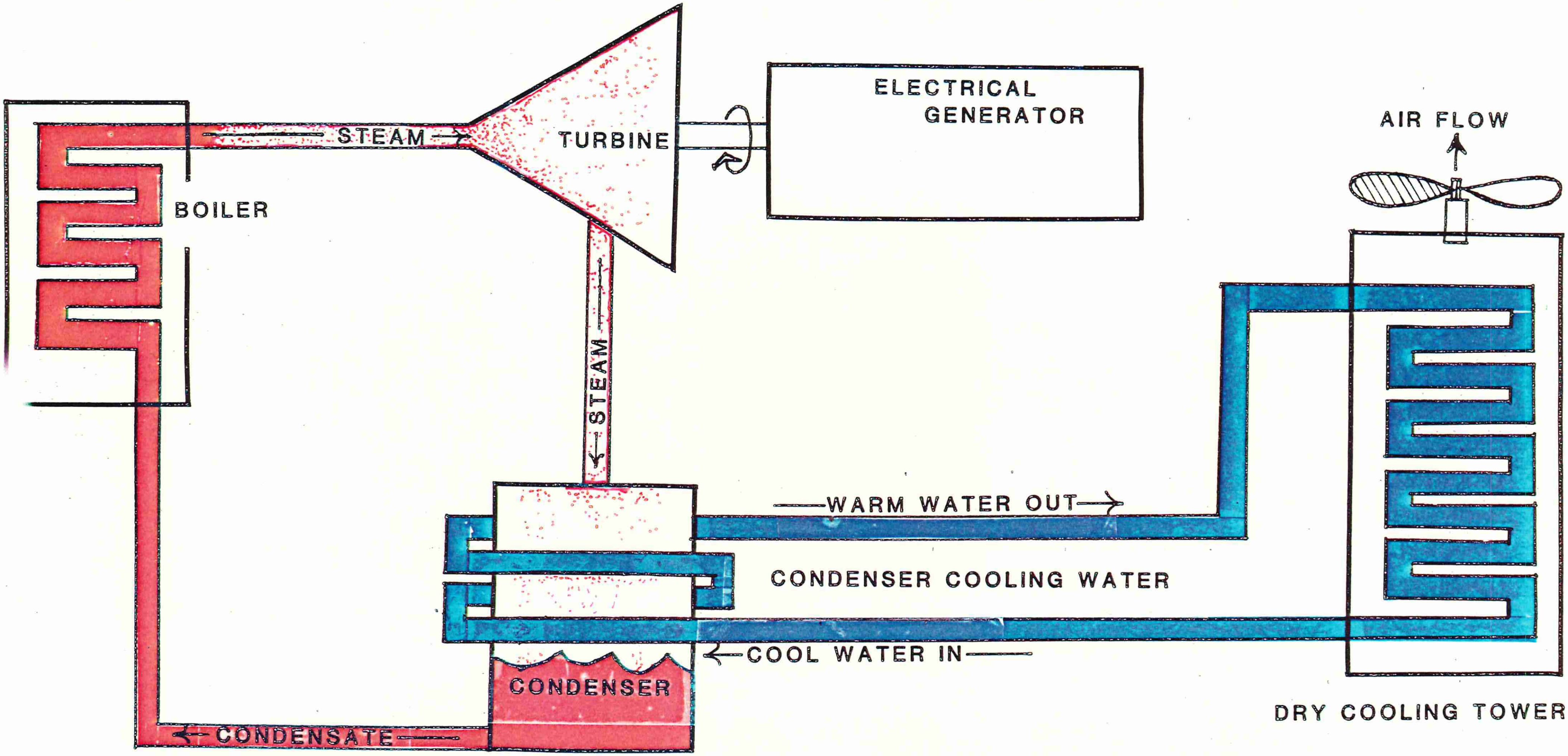
The use of dry systems solve many of the problems associated with wet cooling towers and make siting a plant at almost any location technically feasible, however, they also have serious disadvantages. Dry cooling systems are the least effective method of cooling condensers. Because the condenser operates at a higher temperature, high backpressures may be present on the turbine, greatly reducing overall plant efficiency. This problem is compounded in most regions where the peak electrical load occurs during the warmest time of the year. Also, reduced plant efficiency means increased fuel consumption, and that means more air pollution.

Wet/Dry Systems

Cooling systems that combine the features of wet and dry systems are now available and appear attractive, minimizing the disadvantages and maximizing the advantages of each. The relative amount of cooling that occurs in the wet and dry sections of the combined tower can be controlled according to the weather. During the summer, when 100% dry systems are least effective, the wet portion of the combined system can achieve sufficient condenser cooling so turbine backpressure is not a major problem. And during the winter the combined dry portion of the system can be used to eliminate fog and ice problems associated with 100% wet systems. Combined, wet/dry systems are now being used on some power plants currently under construction.

SUMMARY

The considerations involved in selecting a plant site are complex and involve many considerations other than plant cooling systems. Generally each choice has its own set of advantages and disadvantages and compromises must be made. For a more thorough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DRY COOLING TOWER

figure 3

discussion of this subject, a report entitled "Definition of Model Coal-Fired Electric Generating Plants in the 50 MW to 2400 MW Range" is available from:

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