Now Consider Evaporative Cooling

Evaporatively cooled heat exchangers can sometimes be better than air cooling or designs requiring a cooling tower. Look over these applications and advantages

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Evaporative coolers in many applications give greater heat transfer than air coolers. The evaporative equipment can do this by offering a lower temperature heat sink. Furthermore, the evaporative cooler can also have advantages over a design requiring a cooling tower.

WHAT IS EVAPORATIVE COOLING

To one not familiar with evaporative cooled exchangers perhaps the best description for this type of equipment would be to say that it is a combination shell and tube heat exchanger and cooling tower built into a single package. Some of the designs of evaporative cooled exchangers currently available today are shown in Figures 1 and 2. The tube surfaces are cooled by evaporation of water into the air.

A recirculating pump draws water from the basin under the unit and pumps it through a system of sprays (or water distributors) from which the water is directed onto the tube surfaces. Air is induced or forced over the wetted tube surfaces and through the rain of water droplets. By intimate contact of the air with the wetted tube surfaces and water droplets evaporation of part of the water occurs thus cooling both the tube surfaces and the water simultaneously. In this manner evaporation is used to increase the rate of heat transfer from the tubes to the air.

COMPARE WITH DRY AIR COOLING

Air cooled heat exchangers have received widespread interest lately because of the necessity for conserving water in some industrial locations. Many excellent articles[1-8] have discussed air cooled heat exchangers and practically every phase of this subject has been discussed with one large and important exception; that is, evaporative condensers and heat exchangers.

The lack of published information on evaporative cooling has deterred the use of this means of cooling. However, the facts about this subject are becoming better known and the result is a trend to greater popularity.

The increase in heat transfer rate over dry air cooling is considerable and the efficiency of evaporative cooling over dry air cooling is much higher. For example; a given weight of air increasing in

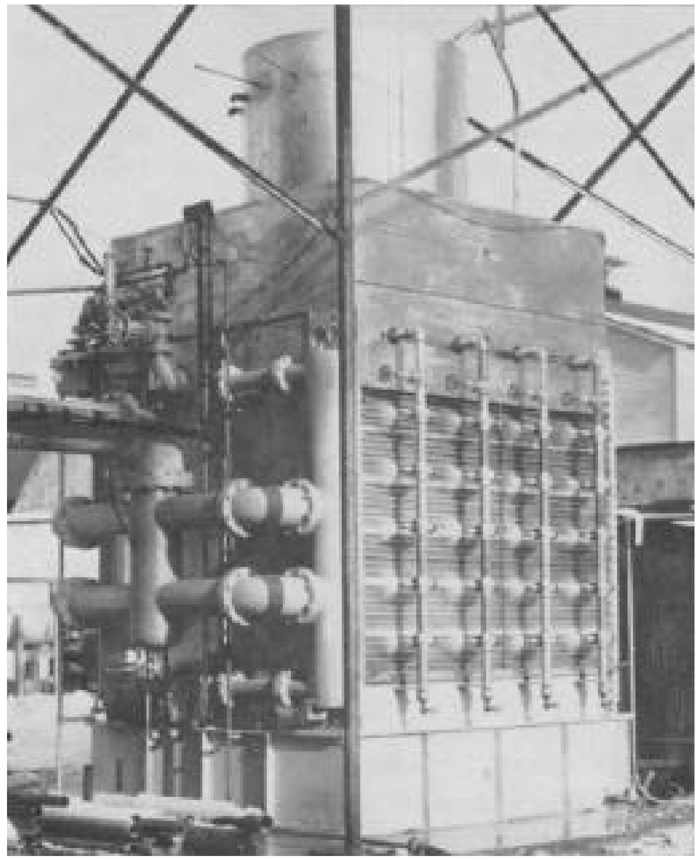

FIGURE 1-*Evaporative cooled heat exchanger is in service as vacuum steam condenser. It contains 1,500 square feet of surface and handles 3,490 pounds of steam per hour at 2.0 inches mercury absolute pressure. Ambient wet bulb temperature is 70° F.*

temperature from 60° F to 90° F will absorb nearly four times as much heat in an evaporative process as in a dry one. See Figure 3. This ratio of heat absorption increases with higher temperature rises and will vary with the temperature of the air. The water is, of course, recirculated within the unit while the moisture ladened heated air is expelled to the outdoors.

When to Use Evaporative Cooling. Perhaps the greatest advantage the evaporative cooler can offer over dry air cooling is a lower temperature heat sink. In dry air cooling the heat transferred per pound of air is dependent upon the allowable temperature rise of the air. The use of water cooled exchangers in series with an air cooled exchanger becomes necessary when the process heat must be removed at temperatures below 150° F.

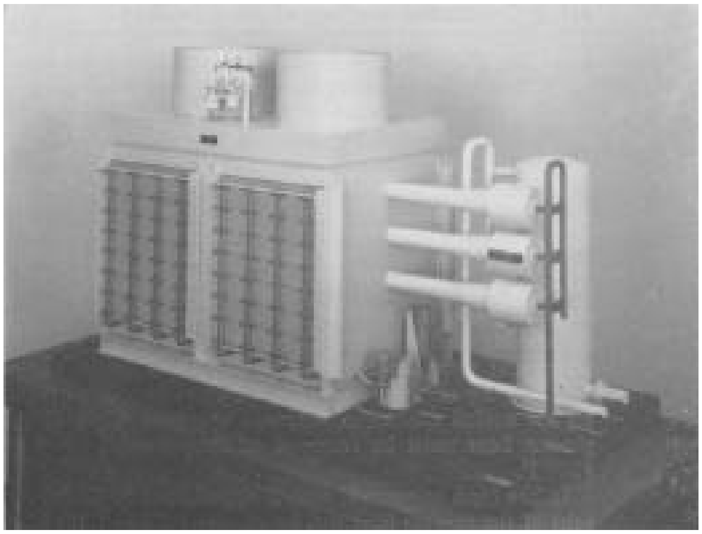

FIGURE 2-*This twin cell evaporative cooled steam condenser services a steam vacuum refrigeration system for producing 45°F chilled water. The flash tank and three booster ejectors are shown on the right.*

It has been suggested that if approximately 75 percent of the process heat can be removed above 150° F, dry air cooling should be considered. It is significant to note that with the exception of a small overlap in operating temperatures the evaporative cooler can take over where dry air cooling must drop out of the picture. The evaporative cooler has limited use for process temperatures above 170° F due to high tube wall temperature causing a more rapid build up of scale on the wetted surface of the tubes.

The evaporation rate at 115° F is sufficiently high to form a soft scale on the tubes, unless the recirculating water has an unusually low amount of impurities. If the recirculating water temperature does not exceed 115° F the deposit on the tubes will usually be soft enough so that most of it washes off the tubes as fast as it forms. As the recirculating water temperature increases above 115° F the rate of scale deposit will increase and the hardness of the scale will increase.

At recirculating water temperatures above 150° F the rate of scale deposit and hardness of the scale can be too high to be tolerated for some applications unless extra precautions are made to treat the make-up water or increase the blow rate to reduce the hardness of the recirculating water. Table 1 will serve as a rough guide to various make up and recirculating water conditions.

When viscous fluids or gases are cooled, the heat transfer film rate may be sufficiently low so that the recirculating water and tube wall temperatures will be below 150° F and 170° F, respectively, even though the fluid inlet temperature is well above these temperatures. It is also possible to reduce the recirculating water and tube wall temperatures by increasing the air flow. The fan bhp will be increased accordingly, however.

In most cases, therefore, the evaporative cooled heat exchanger has its field well defined at process temperatures between 170° F maximum down to about 10° F above the design wet bulb temperature of the ambient air. The 170° F temperature limit can be extended to higher temperatures by using treated or pure makeup water. In the case of steam condensers, which are evaporatively cooled, the condensate is frequently available as a source of pure make-up water.

If we consider that for most cases the process temperature limit for evaporative cooling is 170° F then there is only a small range between 150° to 170° F where either evaporative cooling or dry air cooling can be considered. In these borderline cases other factors peculiar to the installation will often determine which of these two possibilities should be given preference. Evaporative cooled units will, of course, require less surface and less air than dry air cooled units, as shown in Table 2.

In many cases the combination of a dry air cooled and an evaporative cooled exchanger will be the best solution to the situation. In this case the dry air cooled surface can be very neatly incorporated into the same unit with the evaporative cooler. The dry surface can reduce the process temperature to say 150° F at which point the evaporative or wetted surface can accomplish the remaining part of the duty. The same fan serves both sections of the heat exchanger.

Advantages Over Conventional Cooling Towers. Comparing the evaporative cooled exchanger to a cooling tower-shell and tube exchanger combination there are several basic advantages to the evaporative cooled exchanger. First of all, lower process temperatures are obtainable by combining two steps of heat transfer into one, thereby utilizing the maximum possible temperature difference between the process temperature and the prevailing wet bulb temperature.

For example, in a cooling tower-shell and tube steam condenser combination, the cooling tower cools the water down to within about 7 to 15° F of the prevailing wet bulb temperature. If the wet bulb temperature is, say, 75° F the water may be cooled to about 85° F. Similarly in the condenser a temperature difference must also be maintained as a driving force for the heat transfer. With a 15-degree rise on the cooling water through the shell and tube condenser the minimum condensing temperature would be limited to about 5° above the outlet water temperature or in this case 105° F (2.24" Hg Abs). With a condenser that is evaporatively cooled, however, the condensing temperature could be easily within 15° F of the prevailing wet bulb temperature, or in this case 95° F (1.66" Hg Abs), 10 degrees lower than with the cooling tower and water cooled heat exchanger.

The advantages offered by the evaporative cooled condenser is, of course, dependent upon the ability of the cooler to raise the temperature and humidity of the cooling air to the highest possible point consistent with cost. It would be false economy to achieve the last few degrees of temperature rise at the expense of a disproportionate rise in the cost of the equipment and its operating cost. The example cited here is merely typical of the lower process temperatures that can be achieved with evaporative cooled condensers as compared to a cooling tower and water cooled condensers. One must consider the size of the installation as well as other factors for each case to accurately assess the merits of each system.

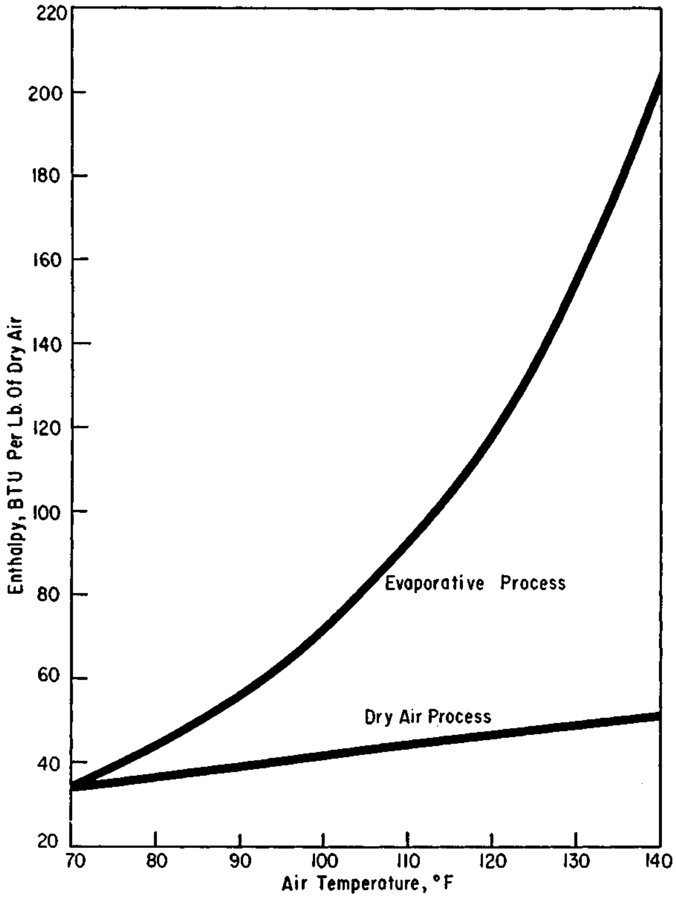

FIGURE 3-*For an initial wet bulb temperature of 70°F, here is how evaporative cooling compares with dry air cooling.*

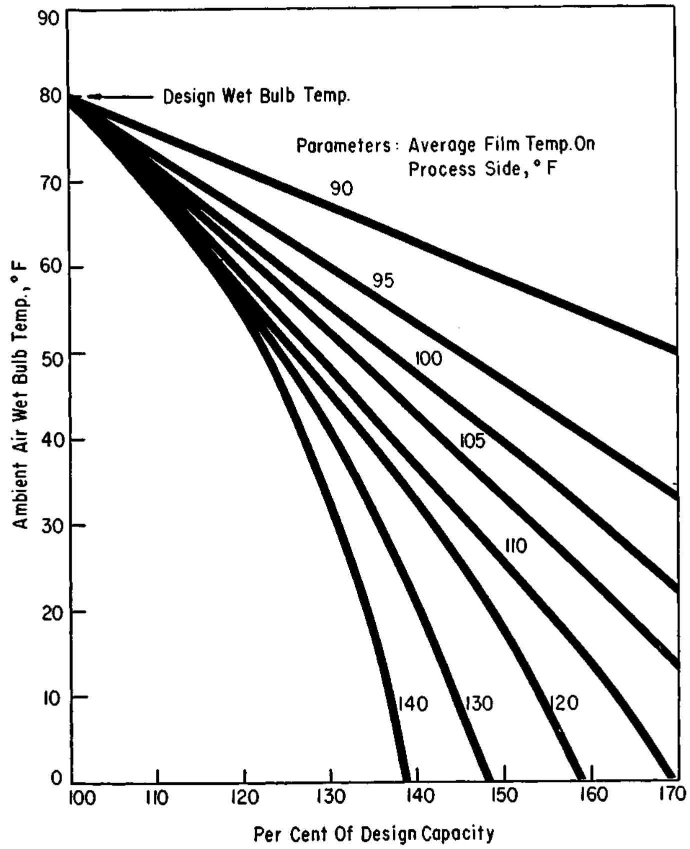

FIGURE 4-*Typical performance for an evaporatively cooled heat exchanger with constant~speed fixed-pitch induced flow fan.*

Some of the other considerations are:

- Pumping costs of each system
- Packaged construction advantages
- Space requirements
- Piping costs of each system (process and water piping)
- Installation costs.

KEEP THESE DESIGN CONDITIONS IN MIND

Since the performance of an evaporative cooled heat exchanger depends entirely upon the ambient wet bulb temperature and air density, only the maximum wet bulb temperature and approximate altitude of the installation site are required to determine the surface and fan size for a particular heat exchanger duty. Accepted design wet bulb temperatures for many applications are usually set at a figure which will be exceeded only 5 percent of the total hours during June to September inclusive. There are, however, a few applications where the process temperature is critical enough to warrant designing the unit for a wet bulb temperature that will not be exceeded more than 1 percent of the hours during June to September. With the advent of controllable pitch fans and carefully engineered equipment the extra cost for these high wet bulb temperature designs has had some of the sting taken out of them.

By merely increasing the air flow through an evaporative heat exchanger it is possible to increase its capacity.

Fan Horsepo wer. In designing a large industrial unit the design engineer must keep an eye on both the initial equipment cost and the operating costs in order to come up with a practical design. In doing so, therefore, he uses all the fan horsepower he can at the design wet bulb temperature to reduce both the amount of cooling surface required and the initial equipment cost, but at the same time, he does not exceed a fan horsepower that will make the operating cost of his design unduly high. There is, therefore, always a little more air flow available at an increased operating cost, if the unit is furnished with a controllable pitch fan and a sufficiently large motor to handle the extra air horsepower. A multispeed fan motor or a steam turbine driven fan will also provide control on the air flow. For those few hours of the year when the wet bulb temperature exceeds the normal design wet bulb temperature, the controllable pitch fan, multispeed motor or turbine drive can boost the air flow to meet these extreme conditions without sacrificing all the economy of purchasing equipment that is designed for a normal maximum wet bulb temperature. The extra cost for a controllable pitch fan with a slightly higher horsepower motor will be approximately $1,700 for most applications. Compare this to increasing the design wet bulb temperature from, say 72° F to 80° F, to include the highest wet bulb temperature on record for the particular locality in question. The increase in design wet bulb temperature would increase the surface anywhere from 6 to 15 percent which could result in several thousand dollars additional cost on a large unit.

An excellent example of an application with high design wet bulb temperature is a condenser for a steam vacuum refrigeration unit furnishing chilled water for air conditioning. In this case the equipment must handle its maximum heat load during the hottest and most humid time of the year. If the condenser fails to produce the correct pressure, due to an unusually high wet bulb temperature, the boosters will fail to operate properly and the air conditioning system will not cool. With a controllable pitch fan, multispeed motor or turbine fan drive, however, the condenser could handle the higher wet bulb condition with a temporary sacrifice in operating economy. This condition may occur only one day out of the year for three or four hours so it would be difficult to justify purchasing a larger condenser at several thousand dollars extra cost, but $1,700 for the controllable pitch fan is not unreasonable.

The controllable air flow also has a much more frequent advantage than just described. The power savings on a large installation will be quite substantial if the fan throughput and horsepower can be reduced by varying the pitch of the blades or reducing the fan speed during those times of the year when the wet bulb temperature or heat load is below the design condition.

As the ambient wet bulb temperature drops, the capacity of the evaporative cooler increases. The variation in heat capacity for various wet bulb temperatures at various process temperatures is shown in Figure 4 for a typical unit operating with an induced draft fan having a constant volume rating. With a controllable pitch or variable-speed fan it is important to compare the average power consumption of the fan to the constant power requirement for a fixed pitch fan, since the maximum power for the controllable fan may occur for only 1 percent of the total annual operating time.

Another advantage of the controllable fan is that it provides an excellent means of preventing freezing during winter months. While the air flow can also be regulated by means of shutters or dampers to prevent freezing and provide control over the process temperatures, this method of control will not reduce the power consumption of the fan to any appreciable extent. In some designs, however, it may be necessary to use shutters where several heat exchangers are combined in one large unit and it is necessary to control the air flow through various sections of the unit. If complete shut down is necessary during cold weather the evaporative cooler can be designed to provide complete and rapid drainage. The few drainage points required can be opened either electrically or pneumatically from a remote location so as to facilitate shutdowns if the process is intermittent. If the shut downs occur for only a few hours a small electric or steam heater strategically located in the recirculating water basin will provide economical and convenient freeze protection for short periods.

TABLE 1—How To Judge Water Hardness

Hardness, PPM	General Classification
Less than 10 PPM	Very Soft
10 to 50 PPM	Moderately Soft
50 to 150 PPM	Moderately Hard
150 to 250 PPM	Hard
250 to 500 PPM	Very Hard
Over 500 PPM	Extremely Hard

Water Requirements. Aside from the initial charge of water to fill the basin only a small quantity of make-up water is required to maintain the evaporative cooling cycle. This make-up water is determined by the amount of water that is lost from the system due to:

- Evaporation — Approximately ¾ lb. per 1000 Btu of cooling duty.
- Blowdown — Depends on several factors — allow for ¾ lb. per 1000 Btu.
- Drift Losses — very small in properly designed unit.

The evaporation rate is dependent upon the temperature of the recirculating water and the temperature of the air at the inlet and exit of the cooler. The recirculating water temperature will vary between 90° F and 150° F depending upon the process temperatures to be maintained. The latent heat of the water will, therefore, vary between 1042.9 and 1002.3 Btu/hr. The latent heat of evaporation accounts for most of the heat that is dissipated. The sensible heating of the air will account for some additional heat dissipation. By referring to a psychrometric chart the enthalpy change of the air will permit one to determine the change in absolute humidity per pound of dry air. By multiplying the dry air flow by the change in absolute humidity per pound of dry air, the exact rate of evaporation in lbs/hr. can be determined.

The blowdown rate is dependent upon several factors, namely the purity of the make-up water, the impurities added to the water from the air, and the purity to be maintained in the recirculating water.

As the impurities in the recirculating water become concentrated due to the evaporation process, some of the recirculated water must be drained off, either

TABLE 2—Comparison Of Dry Air Cooled Condenser And Evaporative Condenser For Turbine Steam Condensing Service

	Dry Air Cooling	Evaporative Cooling
B.H.P. Required		
Fan	38.8	7.5
Recirc. Pump	0.	4.5
Total	38.8	12.0
Space Required	28′ x 21′	14′ x 10′
Tube Surface		
Sq. Ft. Bare	3,980	2,110
Sq. Ft. Total	66,404	2,110
Press. Drop Tube side, In. Hg.	1.38	.50
Tube Size	1″ x 18 BWG x 30′	¾″ x 18 BWG x 12′
Type of Tubes	2¼″ O.D. Fins	Bare Tubes
Air Flow Req'd. #/Hr.	1,520,000	160,500
*Approximate Price	$29,800	$25,600

DESIGN CONDITIONS:
Steam Condensed: 14,300 #/hr.
Pressure @ Steam Inlet: 7.57″ Hg. Abs. (22.43″ Hg. Vac.)
Steam Saturation Temp. @ Inlet to Condenser: 150 °F.
Design Dry Bulb Temperature: 90 °F.
Design Wet Bulb Temperature: 70 °F.

* Prices are net F.O.B. Manufacturer's Plants. Price of Dry Air Cooled Condenser does not include Steam Jet Air Ejector, Condensate Hotwell nor Condensate Pump while evaporative condenser price includes all of the accessories.

TABLE 3—Materials of Construction

Part	Standard	Special
Process Side		
Tubes	Admiralty	To Suit
Tube Sheets	Steel	To Suit
Bonnets	Steel	To Suit
Fluid Inlet	Steel	To Suit
Fluid Outlet	Steel	To Suit
Air Side		
Tube Supports	Steel	Aluminum
Water Basin	Steel (Coated Inside)	Aluminum
Eliminator	Galvanized Steel	Aluminum
Water Piping	Galvanized Steel	Aluminum
Panels	Galvanized Steel	Aluminum
Fan Stack (S)	Galvanized Steel	Aluminum
Fan Blades	Aluminum	Aluminum
Structural Parts	Steel	Aluminum
Bolting	Steel	Cadmium Plated
Spray Nozzles	Brass	Nickel Plated


SERVICE OF UNIT | ITEM NO.
SIZE | TYPE
SURFACE PER UNIT | SQ. FT.
NO. OF UNITS | ARRANGEMENT | ENGRS.

PERFORMANCE OF ONE UNIT

TUBE SIDE		AIR SIDE
FLUID CIRCULATED		ALTITUDE, FT.
TOTAL FLUID ENTERING	°/HR.	DESIGN W. B. TEMP. °F.
VAPOR	°/HR.	DRY AIR FLOW, °/HR.
LIQUID	°/HR.	DES. EXIT W. B. TEMP. °F.
STEAM	°/HR.	MECHANICAL EQUIPMENT
NON-CONDENSABLES	°/HR.	NO. FANS REQ'D
FLUID VAPORIZED OR CONDENSED	°/HR.	SIZE OF FANS
STEAM CONDENSED	°/HR.	NO. BLADES/FAN
GRAVITY LIQUID		MAT'L OF BLADES
VISCOSITY LIQUID		FAN SPEED RPM
MOLECULAR WEIGHT VAPORS		BHP/FAN
SPECIFIC HEAT	BTU/°/°F.	TYPE OF DRIVE
CONDUCTIVITY		
TEMPERATURE IN	°F.	NO. RECIRC. PUMPS
TEMPERATURE OUT	°F.	PUMP BHP
OPERATING PRESSURE	P.S.I.G.	
NUMBER OF PASSES		ELECTRICAL MOTORS
VELOCITY	FT./SEC.	VOLTS CPS PHASE
PRESSURE DROP	P.S.I.	TYPE OF MOTORS
FOULING RESISTANCE		MOTOR STARTERS
HEAT EXCHANGED B.T.U./HR.		

CONSTRUCTION OF ONE UNIT

DESIGN PRESSURE TUBE SIDE				P.S.I.G.	
TEST PRESSURE TUBE SIDE				P.S.I.G.	
DESIGN TEMPERATURE TUBE SIDE				°F.	
TUBES	NO.	O.D.	BWG.	LENGTH	PITCH
BASIN				THICKNESS	
PANELS				FAN STACKS	
BONNET					
TUBE SHEETS—STATIONARY					
WATER PIPING				SPRAY NOZZLES	
ELIMINATOR				TUBE SUPPORTS	
TYPE JOINTS—TUBES					
GASKETS					
CONNECTIONS IN		OUT		SERIES	
CORROSION ALLOWANCE					
CODE REQUIREMENTS					
WEIGHTS EMPTY		OPERATING		FULL OF WATER	
REMARKS—					

FIGURE 5-*This specification sheet will help you get what you need when you specify evaporatively cooled heat exchangers and condensers.*

intermittently or continuously, in order to maintain a reasonably low level of impurities in the system. Additional impurities will be added to the system due to pollens, dust, smoke and vapors from the ambient air that are drawn or blown through the system. The air borne impurities are difficult to predict, but normally do not represent a large portion of the impurities that are brought into the system. The air borne impurities are, therefore, usually brought under control by adjusting the blow down rate after the unit is in operation.

The drift losses are small in a properly designed unit. A generous plenum chamber and a mist eliminator similar to that in a cooling tower can reduce the entrainment of liquid particles to an imperceptible rate.

The three factors mentioned above, though general are fairly typical for most applications and for estimating purposes one can figure on about 1.5 pounds of make-up water for every 1,000 Btu's of heat to be dissipated where the impurities in the make-up water and air are not usually high. If we assume a 15° F rise for cooling water in a shell and tube heat exchanger then an evaporative cooler would require less than 3 percent of the water required for the shell and tube unit on a "once-through" basis. In addition to the drastic reduction in water requirements, pumping costs, water piping costs and conservation of sewer capacity are also important considerations for heat exchanger installations.

MATERIALS OF CONSTRUCTION AND DESIGN FEATURES

Evaporative cooled heat exchangers are available in any of the materials normally used for heat exchangers. Normally, only the materials on the process side of the exchanger need be altered to suit a particular application since the air side will almost always be subjected to the usual corrosion encountered with air and water. The process side can be therefore, steel, stainless steel, copper, nickel, nickel-chrome alloy, aluminum, aluminum alloy, cupro-nickel, admiralty, lead, carbon or a number of other materials commonly used for heat exchangers.

On the air side it is possible to prolong the life of the unit by using aluminum which is more resistant to normal atmospheric corrosion than steel. The list of materials in Table 3 refers to the construction of evaporative heat exchangers as shown in Figures 1 and 2. This list indicates where aluminum can be used to good advantage in the construction of the unit, the aluminum construction being only slightly more in cost.

Special precautions are taken with aluminum to prevent contact with steel brass or any other metals that would produce galvanic corrosion. It is important, therefore, to keep the air side materials either standard or all aluminum.

Standard designs utilize either ¾" or 1" OD 18 BWG tubes in any even numbered tube lengths from 8 feet to 20 feet. Tube lengths over 20 feet may be practical provided the cost of the longer water basin does not offset the savings resulting from the longer tube length. In combined dry and wetted surface construction the dry air cooled section will utilize either low or high finned tubes to produce additional surface per foot of tube length. With dry air cooling, finned tubes will yield substantial savings over bare tubes. In the wetted sections, bare or low finned tubes are used. Preliminary testing of low finned tubes for evaporative coolers indicate that scale deposits on low fins present no serious problems. Considerable extra surface can be obtained with the low fins. For cooling viscous fluids low finned tubing is recommended while for some non-viscous fluids and particularly vacuum steam condensing bare tubes appear to be more practical because of the higher pressure drop in the smaller flow area of the low finned tubes.

For evaporatively cooled heat exchangers, all of the details needed for specifying a service are shown in Figure 5.

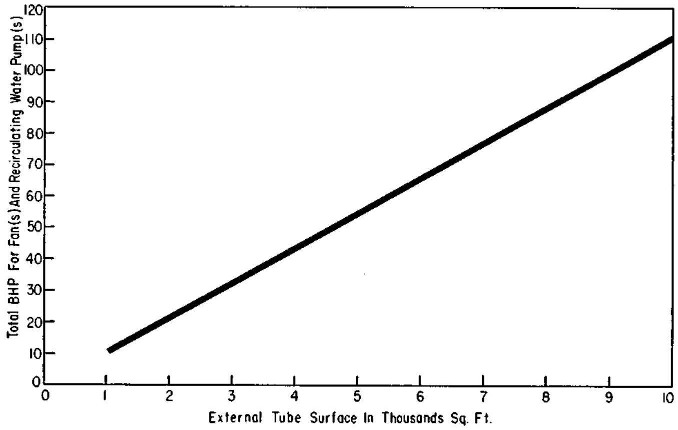

FIGURE 6-*Typical maximum horsepower requirements for evaporatively cooled exchangers. By increasing the cooling surface in a particular application the fan power requirements can be reduced to some suitable level.*

OPERATING COSTS AND MAINTENANCE

The operating costs for evaporative condensers are normally less than a cooling tower designed to dissipate the same heat load. This is generally true because the air flow for evaporative condensers will be about equal for equivalent service and the recirculating water pumping cost will usually be less.

The fan static pressure for the evaporative cooler will usually be between 0.2 inch and 0.8 inch of water which is also true for the cooling tower. Comparison of brake horsepower requirements for equivalent service indicate that the evaporative cooler will generally be equal to or lower than the cooling tower.

The rate of recirculating water in an evaporative cooler is less than half of the recirculating rate required for a cooling tower-exchanger combination designed for equivalent service. The total pressure drop through the spray system in the evaporative cooler will be about 30 feet which is generally less than that required for the water circuit of a cooling tower-exchanger combination, particularly if the cooling tower must be located any distance from the heat exchanger.

Typical fan and recirculating pump bhp requirements for evaporative condensers used for condensing steam or cooling non-viscous liquids are shown in Figure 6. For cooling of viscous liquids and fluids with inherently low heat transfer film coefficients the fan horsepower requirements will be considerably less than indicated by Figure 6, since there will be less air flow required per square feet of tube surface in these applications.

Maintenance requirements for evaporative coolers are comparable with shell and tube heat exchangers. If proper fouling resistances are used to determine the cooling surface, the frequency of cleaning can be reduced to practically any level desired. A few designs permit visual inspection of the external tube surface without shutting down the unit. Even cleaning of the outside tube surface can be accomplished either chemically or mechanically without shutting down the unit. Tube side inspection can be accomplished through inspection ports in the bonnets which permit viewing a section of the tubes throughout their entire length by removing the blind flanges on the inspection ports of opposing bonnets. In the case of vapor condensing or gas cooling it is sometimes possible to replace the blind flanges with glass or plastic which will permit viewing the tube side without shutting the unit down. Cleaning of the basin and pump suction strainer are recommended at those times when the unit is shut down. The fan and recirculating water pump require only the normal maintenance procedures for these types of equipment. In general, the maintenance requirements for evaporatively cooled heat exchangers are about equal to a cooling tower-shell and tube heat exchanger combination for equivalent service.

TYPICAL APPLICATIONS

Some typical applications for evaporative cooled exchangers are:

PROCESS VAPOR CONDENSERS.

- Distillation towers
- Deodorizers
- Refrigerant condensers
- Vapor recovery
- Glycerine condensers

STEAM CONDENSERS.

- Steam turbines
- Steam vacuum refrigeration systems
- Steam jet ejectors
- Evaporator condensers
- Waste or contaminated steam condensers

HEAT EXCHANGER.

- Water cooling for air compressors
- Water cooling for internal combustion engines
- Oil coolers for internal combustion engines
- Transformer oil coolers
- Compressor discharge gas cooling

Because of the relatively small sizes of evaporative cooled exchangers as compared to dry air cooled units, indoor or semi-indoor installations are often practical in addition to the usual outdoor installations. If the indoor installation can be made adjacent to a wall, the air intake and discharge can be easily made through the wall. For architectural purposes, as in the case of an office building, it may be desirable to conceal the unit by installing it under the roof of the building allowing for louvered air intakes and exhaust openings.

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