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EVAPORATIVE PRE-COOLERS FOR AIR COOLED HEAT EXCHANGERS

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ABSTRACT

Evaporative precooling of air cooled heat exchangers provides the thermodynamic advantages of water cooling towers with the reduced maintenance requirements of air cooled heat exchangers. In areas where water conservation, cooling tower plume abatement, or water discharge permits are a problem, evaporative precooling of the air going to the heat exchanger can be the solution. This paper discusses the advantages of precoolers and presents some basic design considerations.

INTRODUCTION

Evaporative cooling of air is an ancient and well known technique for reducing the dry bulb temperature of air. Evaporative cooling is widely used throughout the continental United States and many arid regions of the world. In the USA, evaporative cooling systems are commonly used in the following applications:

Cooling of greenhouses, poultry houses and other agricultural applications
Comfort cooling in arid climates
Humidification of heated air during winter in cold climates
Inlet air cooling for stationary gas turbines
Air washers for humidity control in various industrial processes

An application of evaporative cooling that has not received very much attention is the precooling of the ambient air entering an ACHE (air cooled heat exchanger). It should be noted that the commercial application of precooling the air entering an air cooled heat exchanger is not new. Hudson Products sold a product called the “Combinaire” for many years. There is however, new technology which improves the process and reduces the capital cost and maintenance requirements.

The two most common devices used to reject heat to the atmosphere are ACHEs and water cooling towers. Water cooling towers have two main advantages. First, they cool water close to the wet bulb temperature which is always colder than the dry bulb temperature. The difference between the wet bulb temperature and the dry bulb temperature varies based on climate. In the eastern US a typical summer daytime difference is about 15°F/8°C. In the arid southwest US, the difference can be more than 40°F/22°C. The second advantage is the higher heat transfer coefficients for water to metal surfaces vs. air to metal surfaces. Air cooled systems require much more metal surface to transfer a given amount of heat.

There are however, three main disadvantages to water cooling towers. One is the need for large quantities of make up water. Two is the need to dispose of the bleed-off or blow-down water which is contaminated with water treatment chemicals. Third is the need to manage the corrosive effects of water on all of the equipment that it contacts.

Evaporatively precooling the inlet air for an ACHE gives us the thermodynamic advantages of water cooling towers while minimizing the disadvantages of wet systems. Evaporative cooling uses very little energy so the additional cost of operation is low. Once the equipment is installed, the cost of the water and the energy to run the recirculating pump are the primary additional operating costs. Here are the important points of comparison.

1. Depending on the design, precoolers have evaporative efficiencies of 80-90%. With an ambient WBT (wet bulb temperature) of 70°F/21°C and a DBT (dry bulb temperature) of 110° F/43.3°C, the DBT of the air entering the ACHE would be 74°F – 78°F (23.3°C – 25.5°C). This is comparable to the cold water temperature for a water cooling tower operating under the same conditions.

2. The precooler is only needed when temperatures are high. During the cooler months of the year the water can be turned off. On an annual basis, a typical precooler/ACHE system will use about half the water of a water cooling tower.

3. With a precooler/ACHE system, water does not contact the heat exchange surfaces. The water is contained in the precooler casing and does not affect the tube bundles. Since the casing and the evaporative media are constructed from corrosion resistant materials, this greatly simplifies the water treatment requirements. Generally, no corrosion inhibitor chemicals are need in the water system. In some cases, the required water quality can be maintained by manipulating the amount of bleed off and no water treatment chemicals are needed at all.

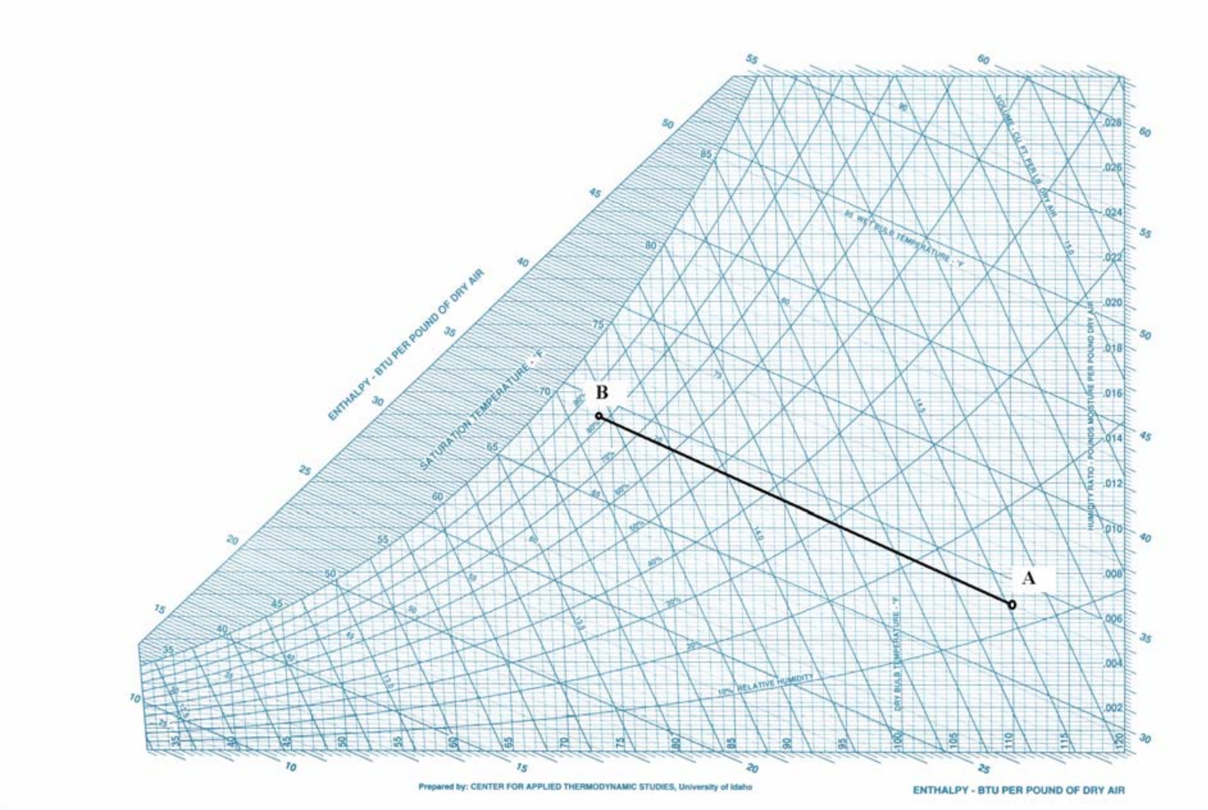
4. When the precooler is operating in the wet mode, it acts as a scrubber to protect the finned tubes from air borne dust and dirt. This helps to prevent reductions in capacity and reduces the maintenance requirements for the ACHE.

EVAPORATIVE COOLING FUNDAMENTALS

In order to understand the modern techniques of evaporative cooling it is worthwhile to briefly review the psychrometric fundamentals that apply to evaporative cooling. Evaporative cooling is a process whereby the sensible heat of air is used to supply the latent heat of evaporation for water. Air is cooled without changing its energy content or enthalpy. For this reason evaporative cooling is sometimes called adiabatic cooling. Three things happen in an evaporative system at steady state:

1. Water is vaporized into the air, increasing the absolute humidity of the air.
2. The dry bulb temperature of the air decreases
3. The relative humidity of the air increases

One way to illustrate the process is to use the psychrometric chart. Fig 1 shows what happens to entering air starting at point A and ending at point B in a 90% efficient evaporative cooler. The conditions of the air at each point are given below.



Property	Point A	Point B
Dry bulb temp. °F/°C	110/43.3	74/23.3
Wet bulb temp. °F/°C	70/21.1	70/21.1
Absolute humidity lb H2O/lb air	0.0066	0.0149
Relative humidity	12%	82%

Fig. 1

While the evaporative cooling process is called adiabatic for the system as a whole, there is energy exchanged at the interface between air and water. The energy necessary to vaporize the water comes from the air. Since the water is cooler than the air, heat flows from air to the water. All of the heat that flows from the air is used to vaporize water so the temperature of the water does not change.

EVAPORATIVE COOLING EQUIPMENT

There are many different ways to evaporatively cool air. In order to build an effective and economical precooling system the correct equipment must be used. The evaporative system must be capable of being mated with the air cooled heat exchanger. The evaporative system must not promote corrosion of the heat exchanger, reduce its effectiveness or require unreasonable maintenance.

The two most common systems to evaporatively cool air today are spray systems and pad or media systems. In a spray system, high pressure nozzles are used to create droplets which evaporate in the air stream. Sometimes the droplets are completely evaporated, but most often a drift or mist eliminator is required to remove excess droplets from the air stream. In a pad system, water is distributed over a pad or media which increases the surface area of water exposed to the air. The air flows through the pad at a velocity between 200 and 700 FPM (1 – 3.5 m/s). Some pads systems only pass the water over the pad once but most systems collect the water at the bottom of the pad and recirculate it back to the top of the media. All pad systems are designed as cross flow systems where the air flows horizontally though the media and the water flow down through the media.

In general, pad systems are superior to spray systems for most applications. Pad systems have the following advantages over spray systems.

1. Pad systems are more energy efficient. The water pumps for spray systems must operate at much higher pressures than pad systems. This translates into higher operating costs.

2. Spray systems are very sensitive to water quality. Pad systems can operate with sea water on a once through basis if necessary. Some spray systems require reverse osmosis or similar quality water to operate in a trouble free manner.

3. Maintenance costs are typically higher for spray systems.

4. Spray systems have the potential to damage the fin tube bundles if the water droplets do not completely evaporate.

There have been many different types of pads or media used in evaporative cooling systems. In the past, such things as lava rock, hogs hair, rubberized hogs hair, wood shavings, cement coated wood shavings, thin plastic fibers, expanded aluminum sheets, expanded paper sheets and various other materials have been used. All modern systems use cross corrugated, film fill type media made from paper, fiberglass or PVC (polyvinyl chloride). The paper media and the fiberglass media have been used for precooler applications but these types of media are more appropriate for light duty uses such as comfort cooling or low cost systems for agricultural applications. Industrial grade systems require the use of PVC media for rugged, low maintenance systems. The PVC media used is the same media used in water cooling towers.

A common arrangement for an evaporative cooling system using a cross corrugated PVC media with a recirculating water system is illustrated in Fig 1. The main components of a typical system are as follows:

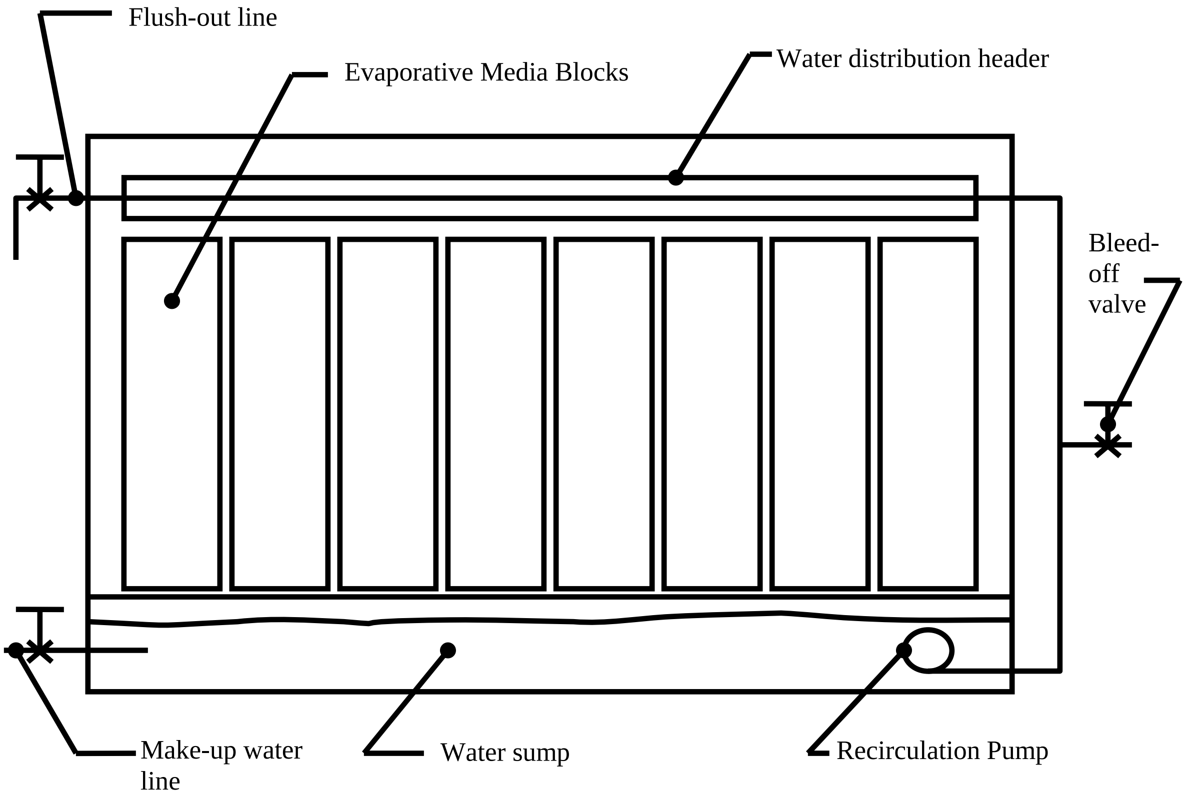


Fig. 2 – Front View

1. Casing - The casing should enclose the pad and prevent air bypass. Common materials are galvanized steel, stainless steel and fiberglass. The casing should provide support for the bottom of the media. A good rule of thumb is that 25% of the bottom of the media should be supported. There should also be a lip in the front and back of the media to prevent the media from being bumped or knocked out of the casing. Lips should be provided at the top and bottom of the pad.

2. Sump - The sump collects the water leaving the bottom of the pad. The sump can be integral to the casing or it can be outside the casing.

3. A drain.

4. Pump - For small systems it is common to use a submersible pump located in the sump of the unit but any low head pump will do the job. The head required for a typical system is very small since the pressure drop across the distribution pipe should not be more than 24 in.wg. (610 mm wg.)

5. Bleed off - A provision for a bleed off or purge valve is necessary to maintain proper water quality during operation. The best place to locate the valve is on the pressure side of the pump between the pump and the water distribution system.

6. Water distribution pipe - One of the easiest and best ways to distribute the water over the evaporative pad is to use a PVC header pipe with a cover plate. The header should have holes

that point upwards into the cover plate. A very convenient cover pipe can be made from a larger PVC pipe cut in half lengthwise. When installed and operated correctly, the water jets out of the pipe and impinges on the cover plate. The water fans out and forms two sheets that fall off each edge of the pipe. The most important consideration when designing the water distribution system is to get equal amounts of water between each sheet of the media.

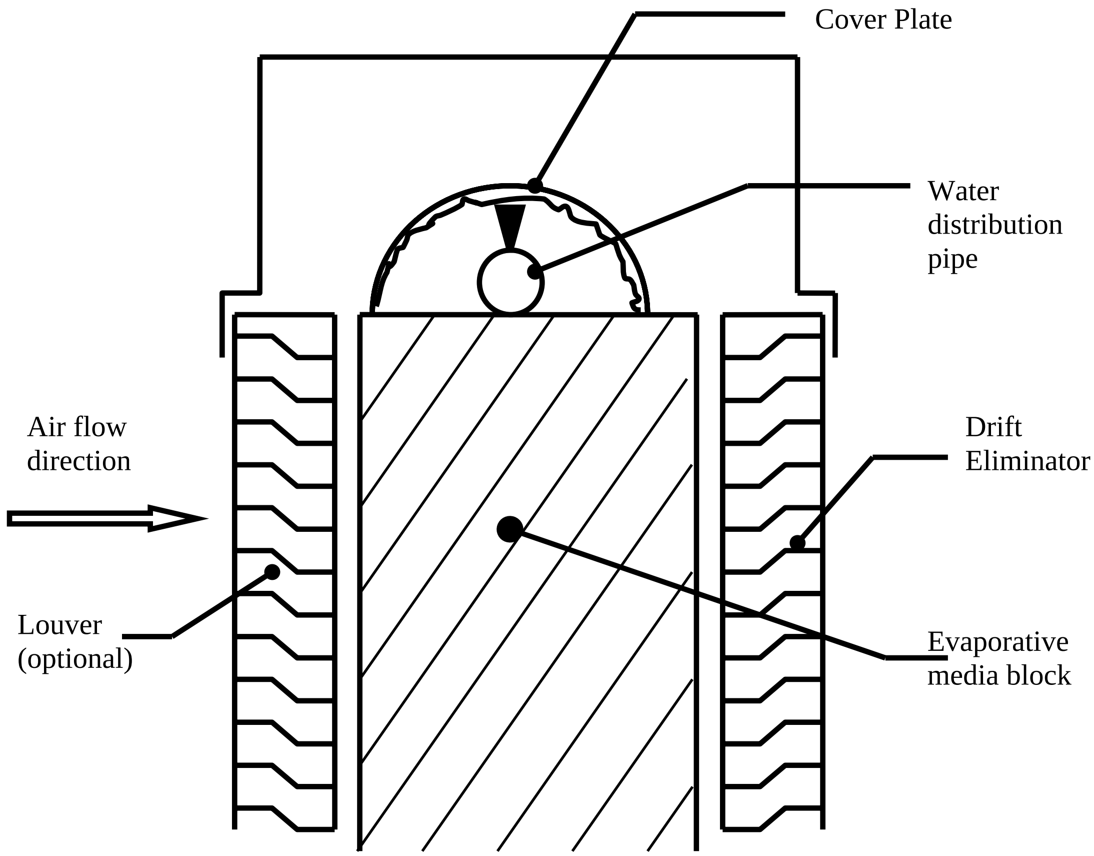


Fig. 3 – Side View

Another feature that is useful and recommended on the water distribution pipe is a flush-out valve at the end of the pipe. Particles of dirt and scale will tend to accumulate at the end of the pipe where the water velocities are low. If these accumulations are not periodically flushed out, they will eventually clog the water distribution holes at the end of the pipe.

7. Drift eliminator – A simple, low pressure drop eliminator is recommended to prevent droplets from leaving the pad and impinging on the tube bundles.

8. Media - The cross corrugated media comes in blocks that are 12 in. (305mm) wide, 12 or 24 in. (305 or 670 mm) deep and up to 10 ft. (3.05m) high for a single block. It can be stacked horizontally and/or vertically to create evaporative coolers of virtually any size.

The addition of an evaporative precooler to an ACHE is very simple in concept. Usually the entire air inlet area is enclosed to keep the air velocity as low as possible.

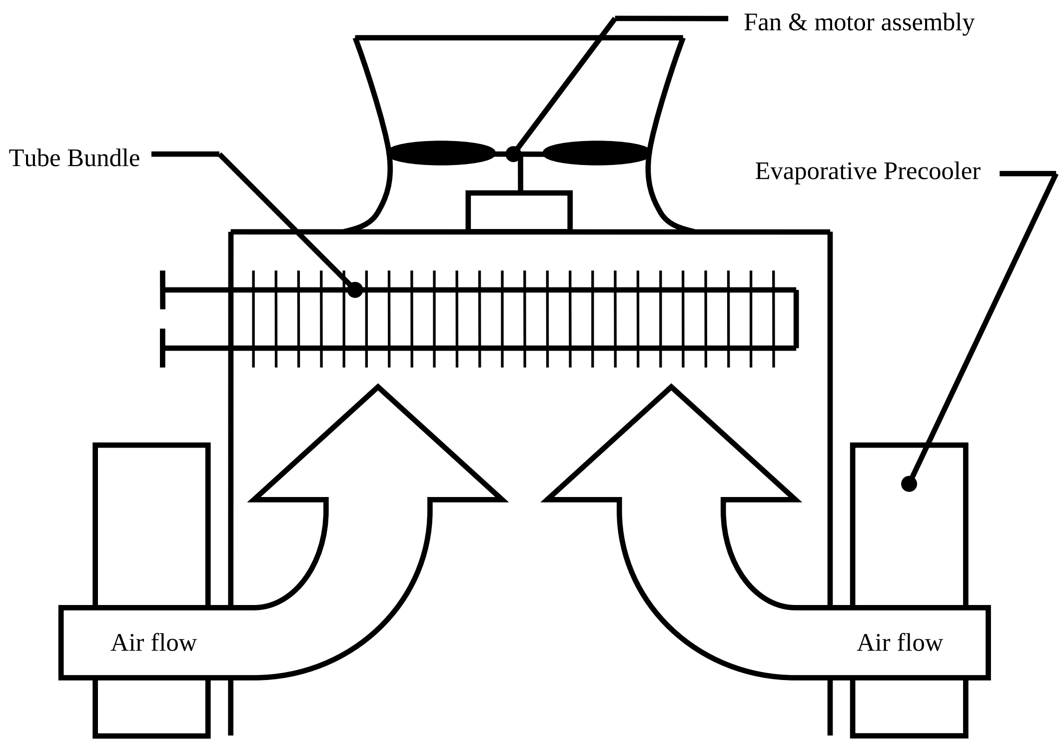


Fig. 4 – Side View

SIZING AND DESIGN OF EVAPORATIVE PRECOOLERS

In order to size an evaporative precooler one must know the basic requirements of the system.

1. Amount of air to be cooled.
2. Amount of cooling required or desired.
3. Amount of resistance to air flow that can be tolerated.

Sizing the system is relatively simple in that one must determine the face area required and the depth of pad required. The amount of air to be cooled will give one a rough estimate of the face area required. In general, a good starting point for a design is to size the units for 500 FPM (2.5 m/s) face velocity. One can go up or down depending on the physical constraints of the equipment but 500 FPM (2.5 m/s) represents a good starting place.

The amount of cooling that a given system will do can be calculated if one knows the wet bulb depression, the depth of pad to be used and the air velocity through the pad. Chart 1 gives the saturation efficiency of a typical cross corrugated media as a function of air velocity and pad depth. The following relation holds for ambient conditions:

$$e = \frac{EDBT - LDBT}{EDBT - WBT} \times 100$$

Solving for LDBT

$$LDBT = EDBT - \frac{e\,(EDBT - WBT)}{100}$$

Where:

e	evaporative efficiency %
WBT	wet bulb temperature °F
EDBT	entering dry bulb temperature °F
LDBT	leaving dry bulb temperature °F

Using these relationships and Chart 1 allows us to find the thickness of pad that will give the required cooling for a given job. The only other important step in the process of sizing the cooler is to find what the resistance to air flow will be. Chart 2 gives the pressure drop through the pads as a function of pad depth and air velocity. If this is a new system, it is only necessary to add the pressure drop to the other resistances of the system and correctly size the fan and motor. If this is a retrofit application, it will be necessary to determine if the fan will be capable of working against the additional pressure drop. Some times it may be necessary to add horsepower and modify the blade pitch or fan speed to insure full performance.

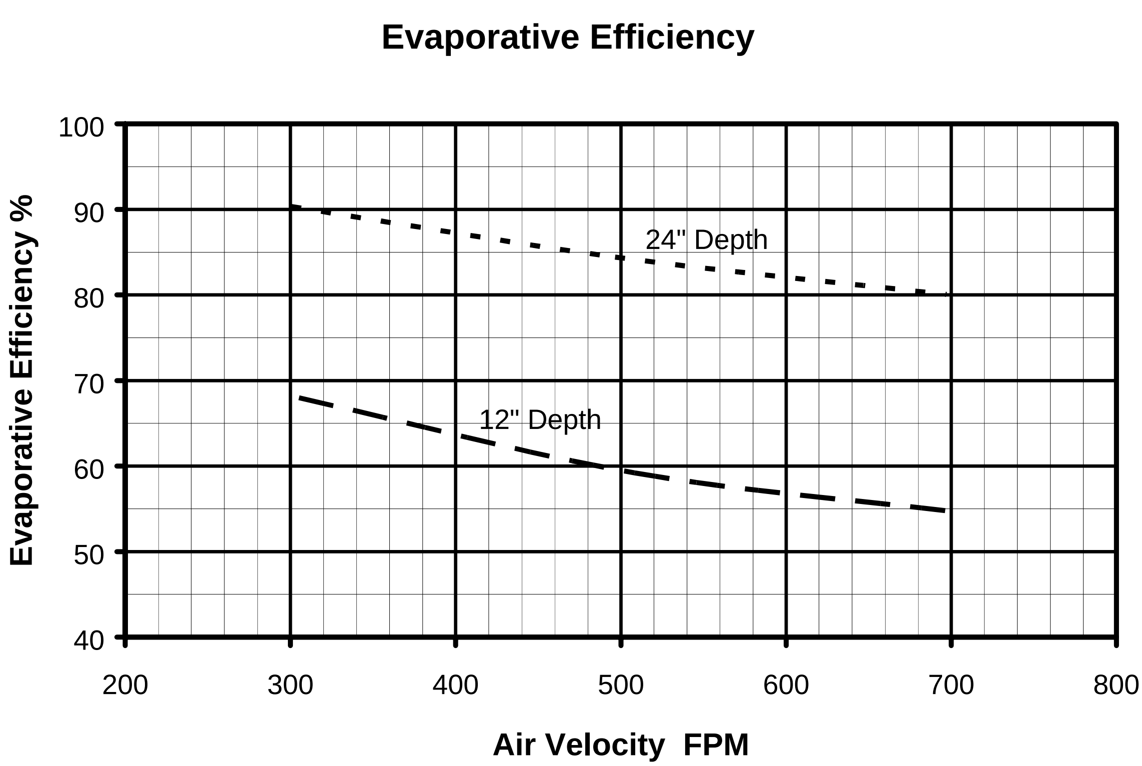


Chart 1

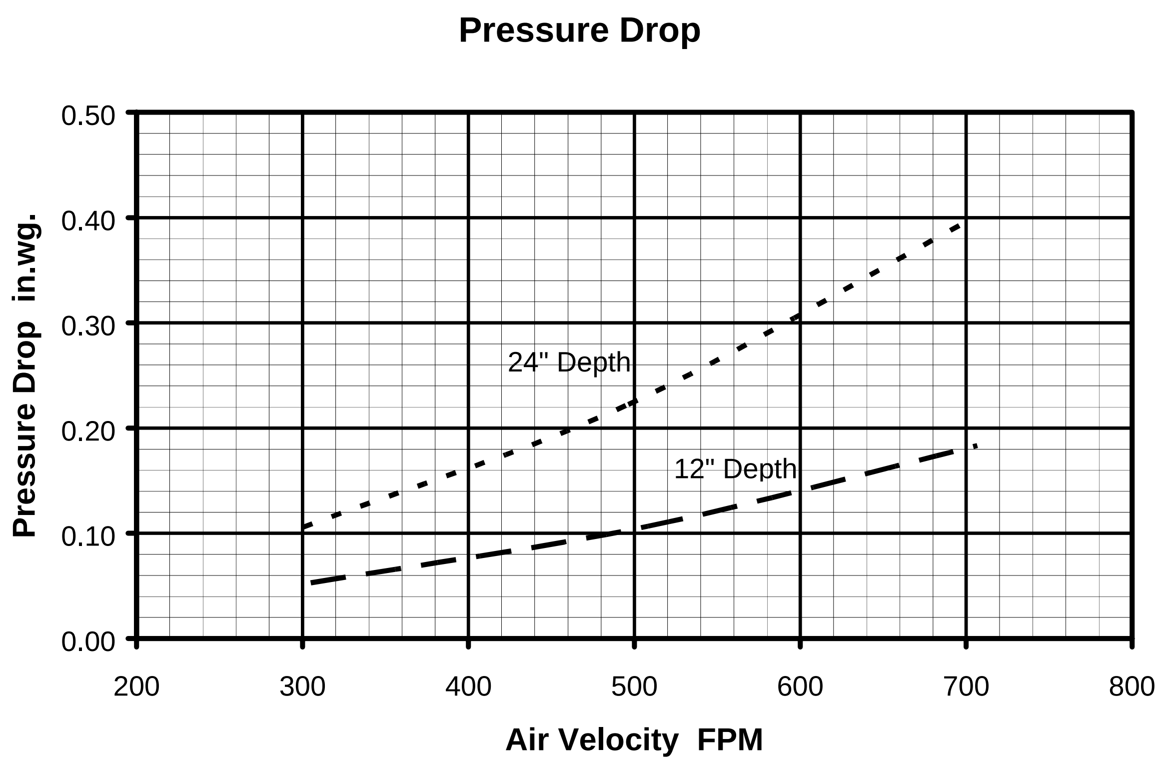


Chart 2

The data in Charts 1 & 2 is based on lab test results. The media is a cross-corrugated, PVC media with 0.5in/12.5mm sheet spacing. The packs have a vertical orientation with unequal angles of corrugation. The surface area has been enhanced with microstructure.

ECONOMICS

Before purchasing or building a precooler to add on to an air cooled heat exchanger one must justify the additional expense. A comprehensive economic analysis is beyond the scope of this paper. There are however, several approaches one can take when evaluating the advantages of a precooler system. In many cases it depends on the process that the precooler is serving.

For retrofit systems, an economic evaluation will typically focus on one of the following areas.

1. Increased production due to greater throughput during summertime operation. In processing plants where production rates must be curtailed in the summertime due to high temperatures, it is very easy to justify the addition of a precooler to an air cooled exchanger. Payback times can sometimes be measured in months rather than years.

2. Additional capacity through the same equipment. If additional throughput is need or planned it may be more cost effective to add a precooler to an existing heat exchanger rather than build another exchanger.

3. Decreased energy usage. For HVAC systems this is the most common way to make an economic evaluation. By increasing the heat rejection capacity of the condenser, the head pressure on the compressor will be reduced. Reduced head pressure will reduce the power required by the compressor. In addition, running at lower head pressures will extend the life of the compressor.

4. For new systems the savings could be calculated based on reduced capital costs and power costs.

These advantages must be weighed against the cost of water, water treatment and the capital cost of the equipment. Water treatment is probably the greatest unknown when contemplating a system. In general, water treatment need not be complicated or expensive unless high cycles of concentration are required. If high cycles of concentration are required the best course of action is to employ the services of a good independent water consultant. If a sufficient quantity of poor quality water is readily available, a once through system can often avoid problems associated with high dissolved solids concentration in recirculating systems.

EXAMPLES

The following table gives a comparison for a typical ACHE with and without evaporative precooling. Case 1 and 2 show the possible reduction in size and power required for new units that include precooling. Case 1 utilizes 1 ft. (305mm) of media and case 2 has 2 ft. (610mm) of media. Case 3 and case 4 show the increase in capacity for a retrofitted system with either 1 or 2 ft. (305 or 610mm) of media.

	Base Case	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Service	Gas Cooling	Gas Cooling	Gas Cooling	Gas Cooling	Gas Cooling
Duty (MMBtu/hr/MW)	40.0 / 11.7	40.0 / 11.7	40.0 / 11.7	62.0 / 18.2	72.0 / 20.8
% Increase Duty				55%	80%
ACHE Type	Forced	Forced	Forced	Forced	Forced
Process Inlet Temp (F/C)	140 / 60	140 / 60	140 / 60	140 / 60	140 / 60
Process Outlet Temp (F/C)	112 / 44.4	112 / 44.4	112 / 44.4	112 / 44.4	112 / 44.4
Air Inlet Temp (F/C)	92.0 / 33.3	72.8 / 22.7	65.1 / 18.4	72.8 / 22.7	65.1 / 18.4
Air Outlet Temp (F/C)	118 / 47.7	113 / 44.9	111 / 43.8	113 / 44.9	111 / 43.8
Finned Tube Surface Area (sqft /sqm)	597,000 / 55,400	389,000 / 36,100	343,000 / 31,900	597,000 / 55,400	597,000 / 55,400
% Decrease Area		35%	42%		
Length (ft/m)	40 / 12.2	40 / 12.2	40 / 12.2	40 / 12.2	40 / 12.2
Fan Diameter (ft/mm)	14 / 4267	12 / 3658	13 / 3962	14 / 4267	14 / 4267

Static Pressure (inH20/mmH2O)	0.51 / 12.95	0.60 / 15.24	0.71 / 18.03	0.60 / 15.24	0.71 / 18.03
Number of Fans	10	8	6	10	10
Width (ft/m)	80 / 24.4	52 / 15.9	46 / 14.0	80 / 24.4	80 / 24.4
ACHE Price ($)	$594,000	$389,000	$344,000	$597,000	$597,000
Total Fan Shaft Power (HP/KW)	247 / 184.3	181 / 135.0	184 / 137.3	279 / 208.1	310 / 231.3
Motor Req'd (HP /KW)	30 / 25	30 / 25	40 /30	40 / 30	40 / 30
Fan PWL*** (dBA)	98.7	98.3	99.3	98.9	96.5
Item Perimeter (ft /m)	240 / 73.2	184 / 56.1	172 / 52.4	240 / 73.2	240 / 73.2
Item Height +++ (ft/m)	9 / 2.74	9 / 2.74	9 / 2.74	11 / 3.35	11 / 3.35
Perimeter Face Vel. (FPM/m/min)	665 / 202.7	550 / 167.6	550 / 167.6	550 / 167.6	550 / 167.6
Media Thickness (in./mm)	0 / 0	12 / 305	24 /610	12/305	24 / 610
Media Volume (cuft/cum)	0 / 0	2,160 / 61.2	3,312 / 93.8	2,640 / 74.8	5,280 / 149.5
Media Cost ($)	$0	$20,000	$30,000	$24,000	$48,000

*** Does not include sound reduction from evaporative media pack.
+++ Does not include cost to raise units 2 ft (600 mm) to obtain 550 FPM (2.8 m/s) face velocity to the media.

SUMMARY

Precooling of industrial air cooled heat exchangers is now viable primarily due to advances in evaporative cooling systems. A precooled heat exchanger offers the thermodynamic advantages of a conventional water cooling tower but has additional advantages.

1. Water can be conserved by using the heat exchanger in a dry mode if water supplies are not available.

2. Water does not contact metal heat exchange surfaces so corrosion is minimized.

3. Less water treatment chemicals are required because corrosion is not a factor.

4. Freezing in wintertime not a problem since the system can run totally dry in cold weather.

5. The evaporative media acts as an air scrubber to protect the metal heat exchange surfaces by filtering out insects, dust and other substances that have the potential to foul the heat exchange surfaces.

6. Greater thermal capacity is available due to lower air temperatures and higher thermal driving forces.

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