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PERFORMANCE IMPROVEMENT TO EXISTING AIR-COOLED HEAT EXCHANGERS

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ABSTRACT

Many older air-cooled heat exchangers (ACHEs) currently in operation today are not performing to their original specified design points due to several factors such as age, poor design, and higher process cooling rates to name a few. Fortunately there are several options at your disposal to get more out of what you have without the need for brand new air-coolers. This paper will outline a step-by-step method by which an end user can systematically improve the heat transfer performance of his existing equipment, without, in most cases, spending a lot of money.

INTRODUCTION

Air-cooled heat exchangers (ACHEs) are used through out the world for process cooling and/or condensing. There are several thousands of these types of exchangers in use today cooling and/or condensing everything from engine jacket water to process steam to high viscous tar.

The operating principle for an ACHE is straightforward. As shown in Figure 1, hot process fluid enters the tubes on one end while ambient air flows over and between the externally finned surfaces. The process heat is transferred to the air, cooling the process fluid while expelling the heated air into the atmosphere. While this is a fundamentally simple concept, maintaining optimum ACHE performance takes diligence on the part of the end user.

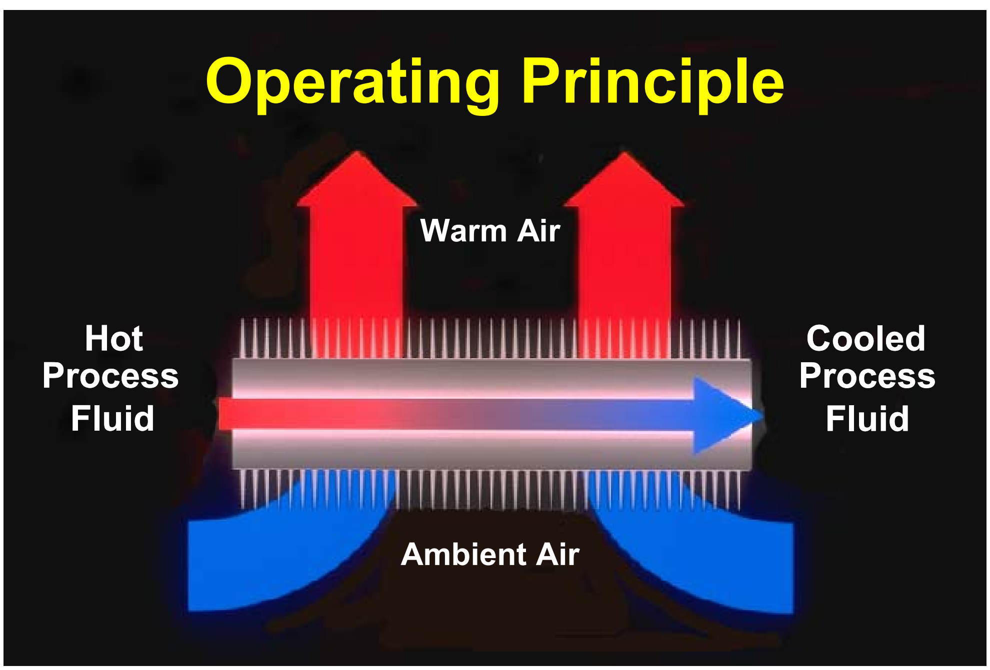

Figure 1. ACHE operating principle

Sizes of these units vary widely as well from the very small (car or truck radiator) to the very large (A-Frame Vacuum Steam Condenser). Therefore, optimization of existing ACHEs can take on several forms. For purposes of this paper, optimization will be limited to those ACHEs typically found in refinery, chemical or power plants built to American Petroleum Institute (API) Standard 661 (Reference 1).

AIR-COOLED HEAT EXCHANGER DESCRIPTION

A typical ACHE (Reference 2) consists of the following components as shown in Figures 2 & 3:

- One or more bundles of heat transfer surface consisting of finned or bare tubes connected by headers.
- An air-moving device, such as an axial flow fan, blower or stack.
- Unless it is natural draft, a driver (usually an electric motor) and power transmission device (usually belt or gear) to mechanically rotate the air-moving device.
- A plenum between the bundle or bundles and the air-moving device.
- A support structure high enough to allow air to enter beneath the ACHE at a reasonable flow rate.
- Optional header and fan maintenance walkways with ladders to grade.
- Optional louvers for process outlet temperature control.
- Optional recirculation ducts and chambers for protection against freezing or solidification of high pour point fluids in cold weather.
- Optional variable pitch fan hub or variable frequency drive for temperature control and power savings.

There are two basic types of ACHEs found in petrochemical plants:

- Forced Draft: Fan is located below the process bundle and air is forced through the fin tubes.
- Induced Draft: Fan is located above the process bundle and air is induced or pulled through the fin tubes.

A subset of the forced draft unit is called a "Winterized" unit. Here, a forced draft unit is outfitted with one or more methods to control the process fluid temperature leaving the ACHE. This type of unit is typically found in colder climates but is also used in hotter climates such as the US Gulf Coast for process fluids with high viscosities and/or high pour points. A fully winterized unit is shown in Figure 4.

OPTIMIZING PERFORMANCE – A FIVE STEP PROCESS

Before the ACHE in question is even looked at, a fundamental question must be asked – what do you need your existing ACHE to do that it does not do now? For most end users the answer to that question is "more cooling" or "lower process outlet temperature". To others it may be "reduce power consumption". Still others may answer "better process control". Whatever the

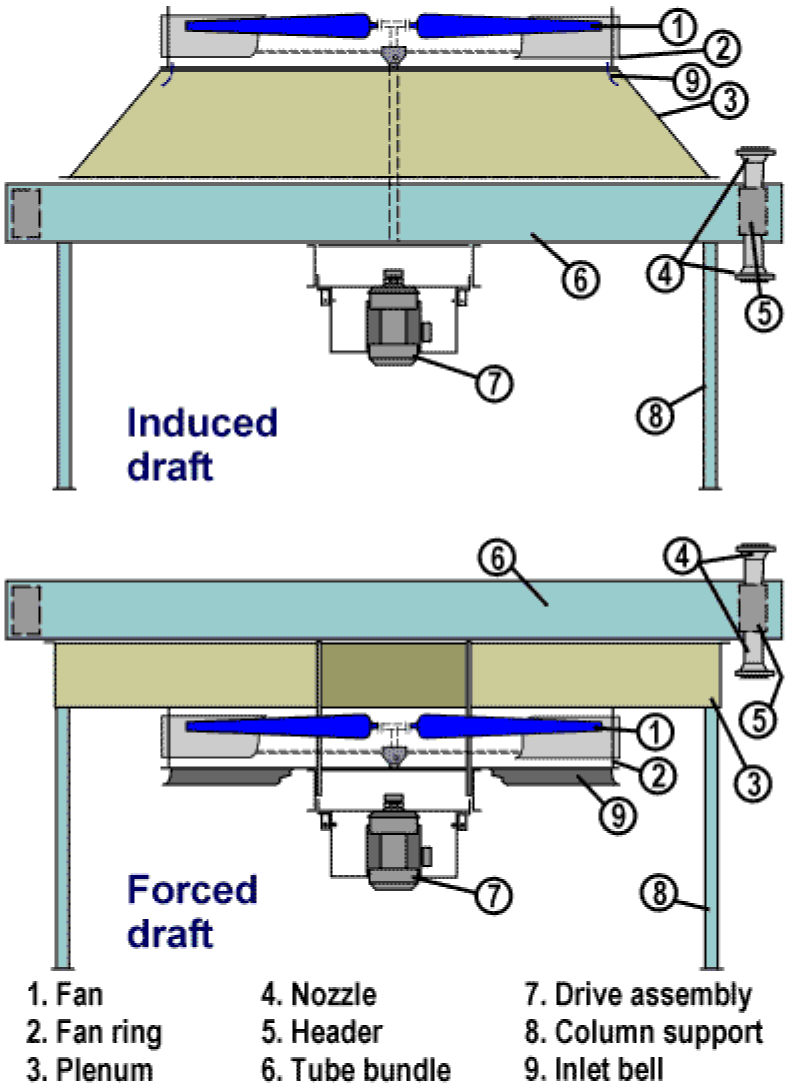

Figure 2. Typical components of an air-cooled heat exchanger

answer, the approach is usually the same. For purposes of this discussion we will assume the answer to be "more cooling".

Step 1 – Determine the Original Design Performance of the ACHE
The first thing one should do is obtain a copy of the original manufacturer's data or specification sheet for the unit or units. Normally, all ACHE OEM's provide this document, as it is an overall description of the unit design. It contains information such as:

- Basic design data
- Tube side performance data
- Air side performance data
- Design, materials and construction information
- Mechanical equipment information

- Control information
- Shipping information (e.g., size and weight)

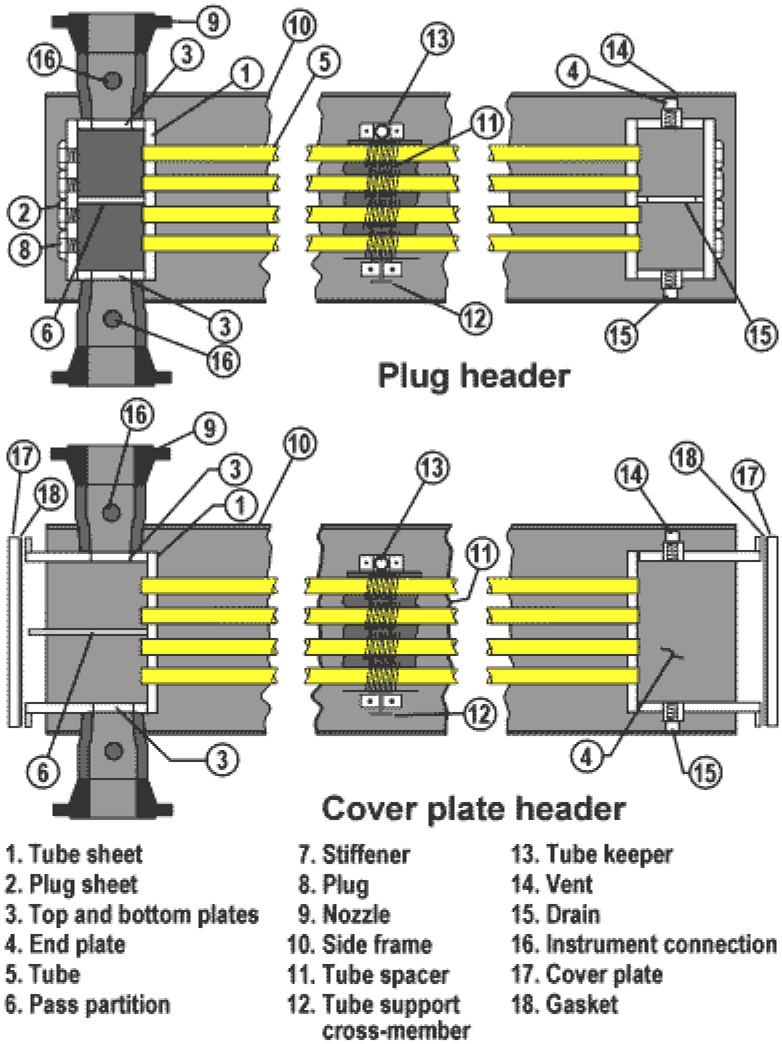

Figure 3. Typical construction of tube bundles with plug and cover plate headers

Once this document is located it should be checked against the current process operating conditions. It is not untypical to find that the current process conditions and associated unit duty requirements now exceed the "as-built" design by 5, 10, 20 or more percent. At this point you have your target value – the amount of additional cooling you want or need versus what was originally purchased.

Step 2 – Unit Inspection and Repair Back to Standard

Let's face it; most ACHEs are located at or near the top of a refinery on a pipe rack. As such, they usually only get looked at when there is a significant mechanical problem or during the summer months when ambient temperatures sometimes exceed the ACHE design air temperature and water spraying is employed. Other than that they are usually ignored. Therefore, the second step in this method is to walk the units. In other words, with the data sheet, paper and pen in hand head out and do a detailed visual inspection of the units. The following are the major items to inspect (they are not in any particular order but all should be done) and should be put into a form of a checklist for future reference.

Figure 4. Winterized forced draft units

Tube Bundle

- Frame – are they warped, distorted or sagging?
- Tube Supports & Tube Keepers – are they warped, distorted or sagging?
- Contoured Fin Supports or Wiggle Strips – are they skewed? Out of position?
- Air Seals – between units and under the headers - are they missing, damaged? Can you feel air leakage?
- Headers – are they warped or distorted? Are there leaks at the plugs or cover plate gaskets?
- Tubes – are the tube bundles dirty (e.g., from below can you see some daylight)? Are the tubes warped or distorted? Are the fins "loose"? Are the fins crushed (especially on the top rows)?

Fans

- Blade Pitch – are they all pitched the same? Does the pitch match the data sheet?
- Blade Tracking – are the blades all tracking in the same plane?
- Tip Clearance – is there excessive clearance between the blade tips and the inside fan ring wall?
- Seal Disc – if included, is the fan seal disc intact? Is it missing?
- Inlet Bell - if included, is the fan inlet bell intact? Is it missing?
- Fan RPM – are the fans rotating per the data sheet RPM speed?
- Vibration/Pulsing – are the fans vibrating (may be out of balance or operating near a resonate frequency)? Are they pulsing (may be in stall due to low speed or excessive pitch)?

Mechanicals

- Belts - are they frayed? Broken? Tensioned properly?
- Sheaves – are they cracked or worn?
- Alignment – are the belts and sheaves properly aligned? If cog type, are belts and sheaves meshing correctly?
- Motors - Do the motor amps correspond to the design horsepower? If not it may be an indication of improper pitch and/or dirty fin tube bundle.

Controls

- Louvers - Do they fully open, close?
- Actuators - Are the louver actuators working properly? Do the louvers open and close when they should?
- Steam Coil - Is the steam coil leaking, cracked?
- Auto-Variable Hub – does the blade pitch vary with changes in supply air pressure? Do the blades feather out to neutral or zero pitch when in operation? Is the supply air connected? Operational? Set to the correct pressure?

Once this mechanical inspection is complete, steps should be taken as necessary to bring the ACHE back to the "as built" condition. It should be noted here that if the ACHE frames and supports are found to be warped or sagging this is a strong indication of a potentially severe structural or thermal expansion problem. This should be addressed immediately before consideration of any bundle cleaning or fan/mechanical upgrades. In some instances simple bundle cleaning and fan adjustments/repairs/modifications can bring the unit back to near design performance. If so, that is good but it does not mean you are getting all you can from your ACHE. To get to the next level takes some additional effort and time.

Step 3 – Determine Current ACHE Performance Baseline

Getting to the next level requires that you determine the current performance of your ACHE. All the previous time and effort was spent reconditioning the ACHE back to standard. In most instances, even though you may see a drop in process outlet temperature (an increase in duty) you probably have not reached your goal. At this point, since all the obvious (and cheap) improvements have been done, testing is needed to determine what you need to do to reach your goal.

Airside testing is simply the measurement of the airflow and associated temperature rise across the bundle or bundles of your ACHE for the purpose of calculating the amount of heat rejected to the air. There are various methods for accomplishing this such as ASME (Reference 3) and AIChE (Reference 4) testing methods with most air-cooler manufacturers or testing services employing a variation of one or both. This data is then converted into an airside thermal duty number, (typically in Btu/hr or kW/hr) that tells you how much heat is being rejected from the process to the air as follows:

$$\mathbf{Q_{air} = (r\ V\ A)\ (c_p)\ (T_{out} - T_{in})}$$

Where: Q = heat duty; W (Btu/hr)

r = average air density at the measurement point; kg/cum (lbm/cuft)
V = average measured velocity; m/hr (ft/hr)
A = measurement area; sqm (sqft)
c_p = average air specific heat; J/kg-C (Btu/lb-F)
T_{out} = average air temperature leaving bundle; C (F)
T_{in} = average air temperature entering bundle; C (F)

The calculated airside heat transfer duty should then be compared to the design duty to determine how much more cooling is needed or desired. This testing is critical in order to establish a baseline on the ACHE. Without such a baseline, performance enhancement, and the amount actually gained for payback calculations, is an educated guess at best.

Step 4 – Install Upgrades
Now that you have completed Steps 1, 2 and 3 it is now time to roll up your sleeves and open up the checkbook. Fortunately, you still have several options at your disposal to improve and optimize your ACHE. The following are the typical steps that can be taken in order of increasing cost. Note that this is not an exhaustive list but covers those items common to all ACHEs.

<u>Fans & Mechanicals</u>
In most applications, one of the quickest ways to obtain more duty out of your ACHE is to increase airflow from the fans. Increased airflow has the most effect on condensers, as the airside thermal resistance is the dominant factor and the least effect on viscous coolers as the tube side thermal resistance is dominant. Table 1 gives a general "rule of thumb" for the expected increase in ACHE duty for a 10% increase in airflow.

ACHE Service	Thermal Duty Increase	
	Minimum	Maximum
Condensing	5%	7%
Liquid Cooling	3%	6%
Vapor Cooling	2%	5%
Viscous Cooling	½%	1%

Table 1. Typical ACHE duty increase for 10% more airflow

Therefore, depending on your service, increasing airflow may be a quick and nominally expensive way to reach your goal.

Increase the fan blade pitch: This will increase airflow so long as the fan does not enter stall and you have enough motor horsepower. If you are horsepower limited, a motor upgrade will be required to achieve the required airflow. Remember, for every 10% increase in airflow there is a 21% increase in static pressure and a 33% increase in required horsepower.

Increase the fan speed: This will also increase airflow and help keep you out of stall problems as long as you have enough motor horsepower. However, the downside is that as the fan speed is increased, noise will increase as well. If you are currently still using V-Belt drives, upgrading to cog belt drives will increase power transmission efficiencies as well as maintain design fan speeds. The downside is that cog belts emit slightly more noise near (3 to 10 ft) the drives. If you have a gearbox a new one with a different ratio will be necessary to increase speed. Figure 5 shows a typical ACHE mechanical drive layout.

(Note: In both of the above options, it is strongly recommended that the fan performance be checked against the fan manufacturers rating software to ensure the existing fan will operate properly at the new set points).

Reset tip clearances: If not done as part of your mechanical assessment, correcting excessive tip clearance (Reference 5) can, depending on the gap, significantly improve fan performance (e.g., move more air at the same horsepower). Depending on the starting tip clearance, airflow gains of 2 to 5% and noise reductions of 0.5 dBA can be achieved. Some ACHE manufacturers allow for some adjustment in

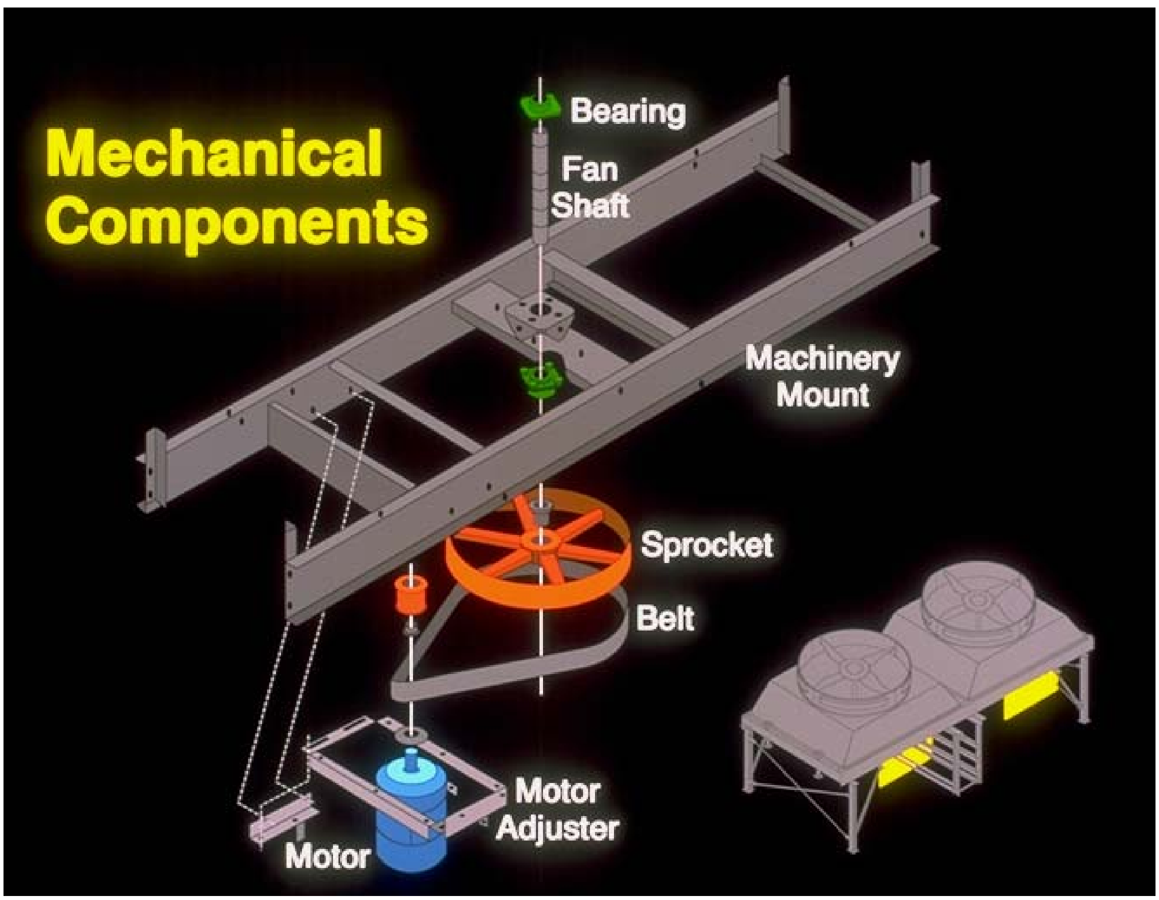

Figure 5. ACHE mechanical drive system

the fan rings or shrouds. For those that do not, various ACHE manufacturers provide tip seal kits that will fill the gaps to a preset distance (Figure 6). For reference, API-661 (1) recommends the following tip clearances as good design practice as listed in Table 2.

Figure 6. Typical tip seal retrofit

Fan Diameter Meters (feet)	Radial Clearances Minimum	 Maximum
1 m (3 ft) to 3 m (9 ft)	6 mm (1/4 inch)	13 mm (1/2 inch)
3 m (9 ft) to 3.5 m (11 ft)	6 mm (1/4 inch)	16 mm (5/8 inch)
> 3.5 m (11 ft)	6 mm (1/4 inch)	19 mm (3/4 inch)

Table 2. Recommended radial clearances for fan blade tips

Install inlet bells: Many ACHEs have sharp edged entrances at the fan inlet. The addition of an inlet bell (usually made out of fiberglass or galvanized sheet steel) can typically increase total airflow by 2 to 3% and can reduce noise by as much as 1 dBA. Figure 7 shows a photo of a typical fan inlet bell.

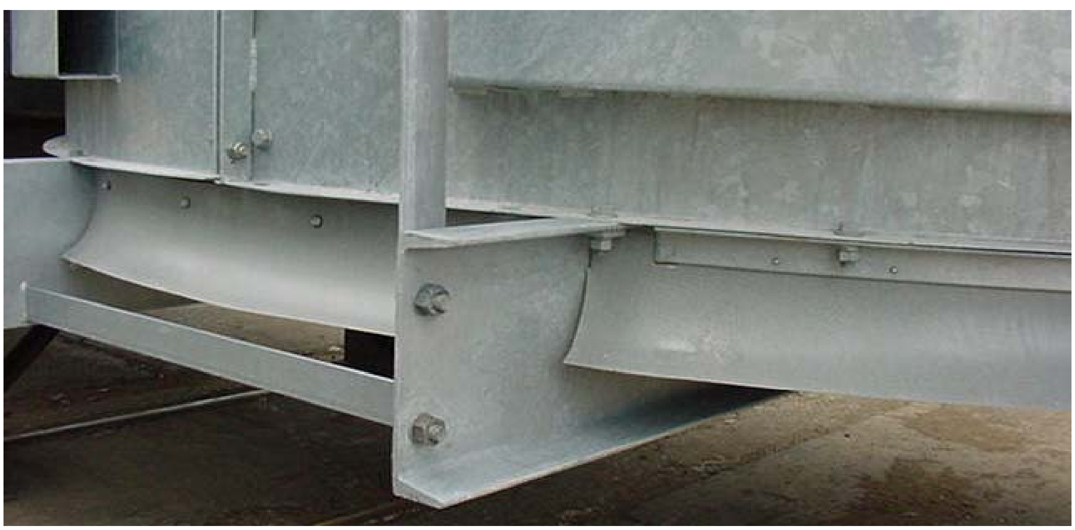

Figure 7. Typical ACHE inlet bell

Install fan seal disc: Depending on the fan manufacturer, a hub seal disc is sometimes supplied to prevent reverse flow at the inboard section of the fan. This simple device is typically made out of fiberglass or aluminum and normally covers 25 to 35% of the inner fan diameter

(Reference 5). If missing or airflow measurements show a negative or downward flow (Figure 8) near the hub a seal disc should be considered. The amount of airflow improvement will vary but a 2 to 3% increase in airflow is not unusual.

Install high efficiency fans: Older ACHEs or lower quality ACHE manufactures will usually have low efficiency straight chord aluminum fan blades. Typically straight chord blades have total efficiencies between 35 and 55%. Today's more modern fans (Fiberglass and Aluminum) are more aerodynamic with a tapered chord and increasing pitch or twist as one moves from the blade tip to the hub. This tapered-twisted shape allows for a more uniform airflow off the fan blades leading to significantly greater efficiency – normally 75 to 85% total efficiency (Figure 8). It is not uncommon to obtain 25 to 40% more airflow with high efficiency fans at the same or slightly more motor horsepower.

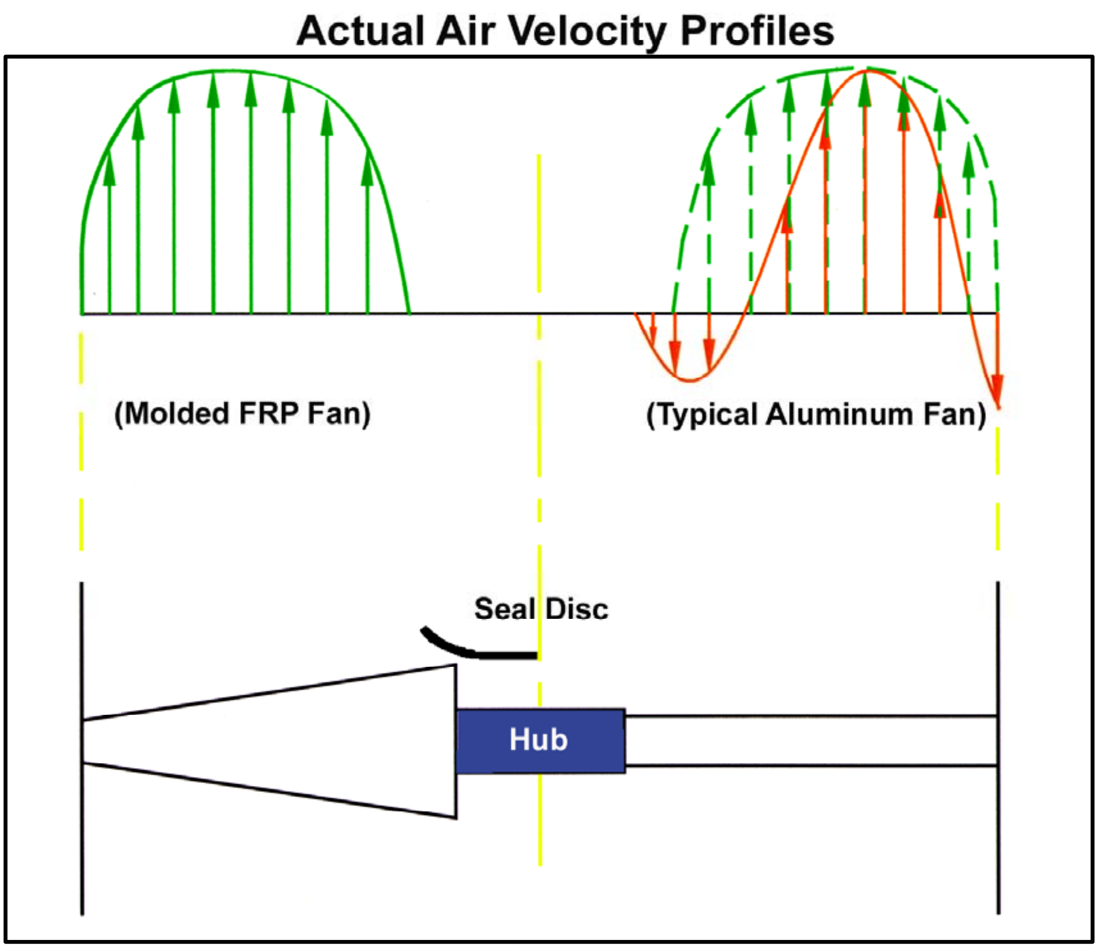

Figure 8. Comparison of air velocity profiles

Tube Bundle

The heart of the ACHE is the tube bundle. A tube bundle is an assembly of tubes, headers, side frames and tube supports as shown in Figure 2. Typically the airside tube surface has extended surface (Figure 9) in the form of helical fins to compensate for the low heat transfer rate of air at atmospheric conditions and low velocities. Due to tube side process pressures normally in excess of 1 Atm (15 psi), the prime tube is usually round and can be of any metal suitable for the process fluid in terms of corrosion, pressure and temperature. Fins can be formed from aluminum, copper, or steel to name a few. The most prevalent fin material is aluminum for reasons of good thermal properties, weight and economy of fabrication. Steel

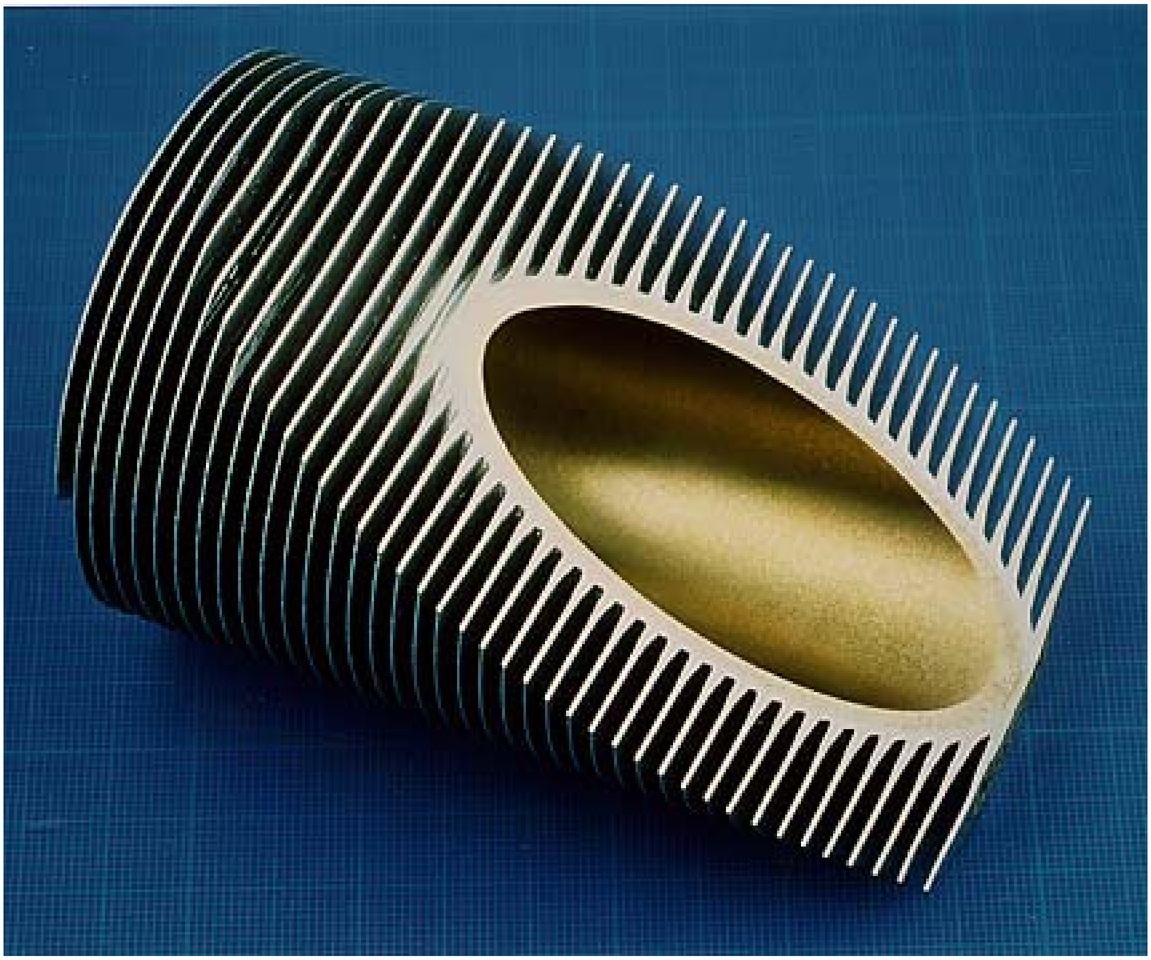

Figure 9. Typical ACHE fin tube

is typically used for high-temperature applications and copper for special severe corrosion applications. There are three basic types of aluminum fins depending on the attachment method (Figure 10):

- Extruded where the fins are extruded from the wall of an aluminum tube that is integrally bonded to the base tube.
- Embedded (G-Fin) where a strip of aluminum is helically wrapped where the root is embedded in to a precut groove and then mechanically locked in tight to secure it.
- Wrap-On (L-Base or L-Foot) where a strip of aluminum that is footed at the root is helically wrapped on the tube.

Serrations or cuts are sometimes cut into the fin tips or fin body to increase the airside heat transfer rate. However this is improvement is accompanied by higher airside pressure drop and, depending on the physical location of the ACHE, have a greater propensity for fouling.

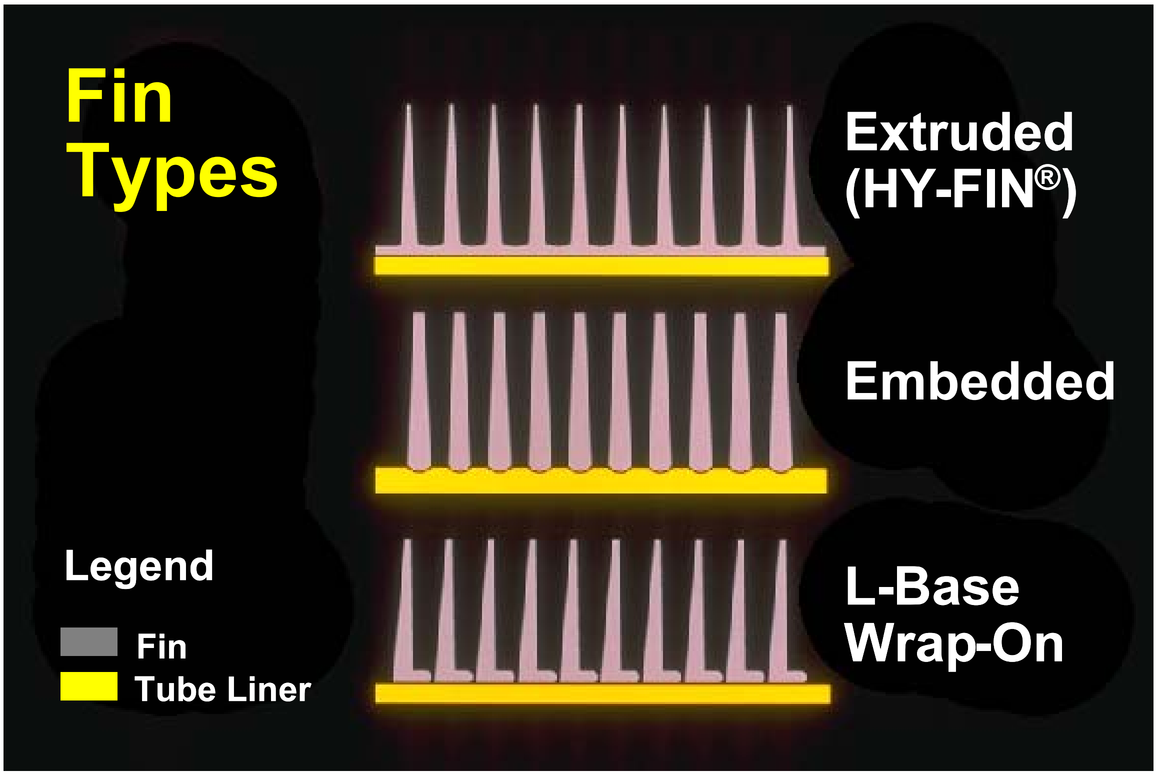

Figure 10. Basic types of ACHE fin tubes

Clean the fin tube bundle: One of the most effective ways to boost ACHE duty is to physically clean the tube bundle. Depending on the ACHE location, the top and bottom rows can be plugged with a myriad of organic and inorganic debris. This material does two things 1) coats the fin surface and acts as an insulator and 2) plugs the space between the fins increasing airside static pressure with a corresponding decrease in airflow. Depending on the condition of the fins, duty increases of anywhere from 5% to as much as 50% (in extremely fouled bundles) can be achieved. There are several methods for cleaning fin tube bundles ranging from high or low-pressure water washes, foam cleansers and even dry ice impingement. A biodegradable foam cleaner followed by a low-pressure deluge rinse with clean, de-mineralized water is normally the most effective and is least likely to damage the fins themselves.

Clean inside the tubes: Sometimes the most fouling is inside the tubes. This is most common in viscous process coolers or with fluids that precipitate out solids or waxes when the temperature falls below the minimum design point. Chemical flushes, high temperature / high pressure steaming and pigging are the most common forms of cleaning. Unlike with airside fins, viscous coolers benefit most and condenser normally least from tube cleaning. As with airside cleaning, tube side cleaning can improve ACHE duty anywhere from 5 to 50%.

Retube the bundle: If the condition of the fin tubes has significantly degraded due to overheating or excessive corrosion (Figure 11) retubing the bundle with equivalent or higher-grade fin types will be required. Extruded fins typically have the highest ability to transfer heat and by their construction can maintain that high level over a sustained period of years. Embedded fins, while having comparable heat transfer coefficients to that of extruded fins and less expensive, will degrade faster over time, especially in corrosive environments and when sprayed with water. Additionally, embedded fin tubes require process tubes that are nominally one gauge heaver in wall thickness to account for the mechanical fin groove. This will increase the tube side pressure drop and may exceed existing process limits. L-Base fins are the cheapest but also the most susceptible to damage due to thermal upsets and airside corrosion. Serrated fins will normally provide 15% to 33% increase in the airside heat transfer rate over non-serrated fins. However, this comes at the expense of increased pressure drop and will sometimes require motor and drive upgrades to maintain current airflow rates. Overall, a 10 to 50% increase in ACHE duty can be achieved depending on the level of fin tube deterioration.

Figure 11. Effect of water spray on L-Base fins

Replace the bundle: If the fin tube corrosion is severe it is sometimes an indication that the headers and bundle frame may have also reached their useful life. Schedule is also a factor. Given today's compressed turnaround schedules it is sometimes cheaper to replace the entire bundle with a new one. This affords the end user with the ability to sometimes add tube rows, modify tube pitch or upgrade fin type to increase the amount of duty without increasing footprint. As with retubes, 10 to 50% increases in ACHE duty can be achieved.

Step 5 – Retest
Now that you have completed Step 4 by installing one or more of the upgrades, it is always good practice to retest the unit to confirm the increase in ACHE thermal duty achieved. But this last step is sometimes skipped as operational data from the process control can, with good accuracy, show the performance increase. Unfortunately, there will be situations when no amount of upgrades will allow you to reach your thermal duty goal. In those instances sometimes the most cost effective way to get more cooling is to just add more coolers if plot or pipe rack space is available.

SUMMARY

As presented above, an end user can in most cases optimize ACHE performance by following a five-step process:

1. Determining original design performance and determining current needs.
2. Detailed mechanical inspection and repair of the units to standard.
3. Determine current ACHE performance base line via airside testing.
4. Install upgrades.
5. Re-test to confirm performance improvement goal has been achieved.

Expected improvements and relative costs are as follows:

Upgrade	Improvement	Cost
Blade Pitch	More Airflow	Low $$
Fan Speed	More Airflow	Low $$
Tip Clearance	2 – 5% More Airflow -0.50 dBA Noise	Low $$
Inlet Bell	2 – 3% More Airflow -1.0 dBA Noise	Low $$
Seal Disc	2 – 3% More Airflow	Low $$
Belts & Drives	3 – 4% More Drive Efficiency	Med $$
High Efficiency Fans	25 – 40% More Airflow	Med $$
Clean Fins	5 – 50% More Duty	Med $$
Clean Tubes	5 – 50% More Duty	Med $$
Retube Bundle	10 – 50% More Duty	High $$
Replacement Bundle	10 – 50% More Duty	High $$

Table 3. Summary of upgrade improvements and relative cost

The above process can take several avenues depending on the condition of the ACHES and the performance improvement desired. Also, while changing one or two things will normally improve unit performance, a total system approach to optimization, not just simply a retube or a bundle cleaning or a fan retrofit by themselves, usually provides the best overall value for your capital upgrade dollars.

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