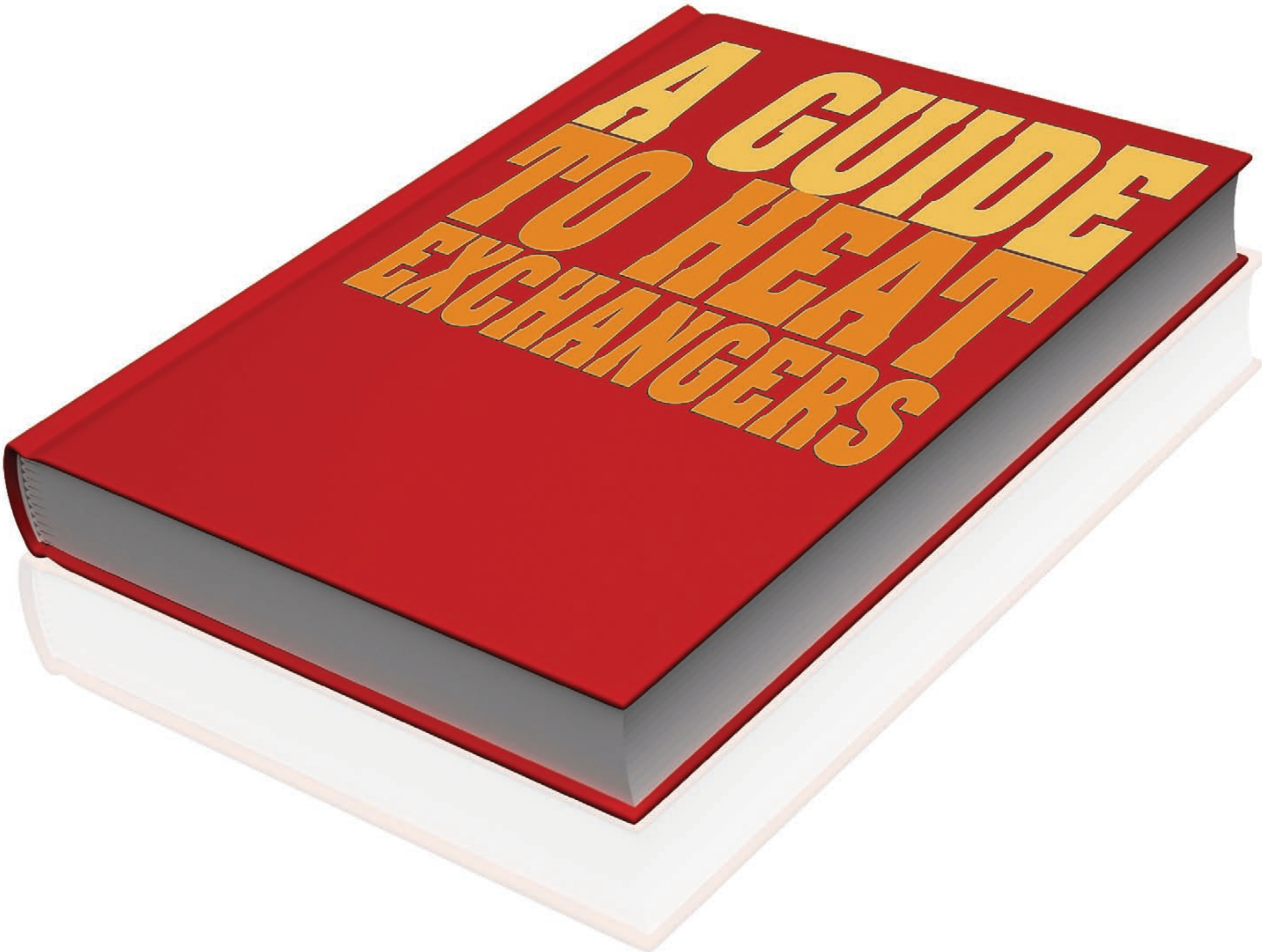


Marc Ellmer, GEA Airflow Services SAS, France, provides a practical guide for identifying and solving air cooled heat exchanger performance problems in the field.

Well over 85% of all air cooled heat exchangers (ACHE) in operation do not perform to their specified design values or end user requirements. As a result of this, during hot summer days, the product flow has to be reduced to achieve the required product temperature or pressure in the column.

Production losses during these days can reach levels of as much as 20 - 40%. This can lead to losses amounting to as much as US$ 500 000 - 1 000 000/yr for one single limiting air cooler on a critical unit.

This article will offer a practical guideline enabling organisations to identify basic air cooler problems and offer a few options to get more out of ACHEs without having the need for brand new air coolers or adding new bays.

ACHEs are used mainly in the (petro) chemical, refining, gas and power sectors. The operating principle for an ACHE is fairly simple. Hot process fluid/gas passes inside the finned tubes of the bundle while ambient air flows through the finned tube bundle to cool/condense the process inside the tubes. The process heat is rejected into the air, which in turn will cool/condense the process fluid/gas inside the tubes (Figure 1).

While this seems like a simple concept, it is not always an easy task to identify and maintain proper ACHE performances in the field.

The most common reasons for ACHEs under performances are:

- Process flow and/or conditions may have changed over the years requiring higher heat duty or more surface than was originally needed.
- Too low design ambient air temperature leading to cooling/condensation shortage during hot summer days.
- External fouling of finned tube bundle reducing airflow and heat transfer.
- Internal fouling of finned tube bundle leading to losses in performance.
- Missing air seals.
- Poor air distribution and/or airflow passing through the bundle.
- Reliability issues (mechanical parts).
- Loss of thermal contact between fins and tubes and/or poor conditions of fins (bent, rotten aluminium, etc).
- The ACHE was improperly designed in the first place.
- Hot air recirculation.

Required basic tools for site inspection

- Infrared thermometer.
- Torch light.
- Measuring rod.
- Stroboscope.
- Protractor (to measure pitch angle of blades).
- Thermometer with thermocouple (i.e. PT100, K type, etc).
- A rod with ribbons.
- A pair of working gloves.

Identifying and solving ACHE performance problems

Phase 1: preliminary study

The first thing to do is to compare operating to design conditions. To have a good comparison, manufacturer data sheets must be collected (Figure 2) which cover most relevant ACHE information such as:

- Basic process data.
- Tube side data.
- Air side data.
- Material and construction data.
- Mechanical equipment data.

It is not uncommon to find that the current process data conditions exceed the original equipment design by as much as 20% or more.

This data sheet will also gives an ambient design air temperature that is in most cases lower then a normal hot summer day because:

- Summers are becoming hotter.
- Extra heat generated by the plant as a whole of 3 - 4 ˚C (ovens, heaters, pumps, motors, piping, etc.) was/is often not taken into account when designing air coolers.

Phase 2: field study

The next thing to do is to inspect the unit in the field where the air coolers are actually located.

External fouling

External fouling is a very common problem in air cooler applications. Air side fouling is often caused by matter such as pollen, dust and/or specific fouling related to the plant environment such as an open mine, catalyst losses, other plants in the vicinity (steel mills, petrochemical plants, cement factory, etc.).

In extreme cases, this can virtually plug spaces between the tubes and the fins almost completely, blocking airflow. Applying a proper specialised method of cleaning depending on fouling and air cooler type can solve this problem.

Please note that if a specialised company does not carry this out, there can be limited results and even opposite results leading to additional fouling. A typical case is where the poorly removed fouling (dirt) mixes with the water/chemical resulting in a muddy substance between the fins, which hardens after the ACHE and fan, are started up again after the cleaning. Another problem when inexperienced cleaning companies carry out cleaning can be bent fins.

In order to properly determine whether a finned tube bundle is fouled externally, a visual inspection should be carried out at the bottom rows of the finned tube bundle. Please keep in mind that bundle fouls from the bottom only and should therefore also be inspected from the bottom using a torch. The dirt will start on the second row and will gradually ‘grow’ up to the first row clogging the bundle (Figure 3).

Please note that specialised air cooler service companies are capable of precisely measuring degree of external fouling by measuring airflow and static pressure and comparing this with design values.

Gains in heat duty after a proper external cleaning can be tremendous as illustrated in Figure 5, which illustrates gains in heat duty obtained at a French Refinery after proper external cleaning of the finned tube bundle.

Internal fouling

This problem can occur when products are viscous or the process has solids inside. Internal fouling can be traced by the following methods:

- Measure pressure drop across bundle and compare to design.
- Inspect for bent/warped tubes (Figure 6), as one plugged tube will be 'colder' then a tube containing hot product resulting in different thermal expansions.
- Use of infrared camera for bundle overview (Figure 7).
- Measuring outlet process temperatures of nozzles using infrared thermometer and non reflective paint (also for points of reference). If there are large differences from one bundle to the other (provided amperage is the same on all fans), chances are there are internal fouling problems (Figure 8).

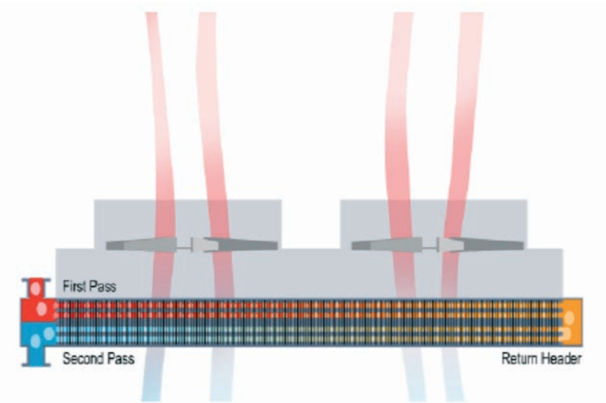
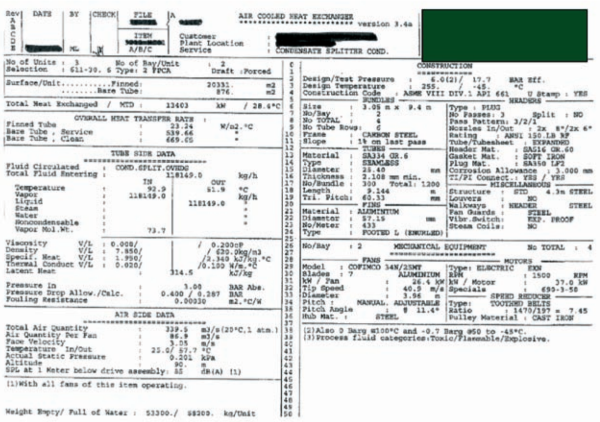


Figure 1. ACHE operating principle.



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AIR COOLED HEAT EXCHANGER version 3.4a

Customer : [redacted]
Plant Location :
Service : CONDENSATE SPLITTER COND.

[redacted]

No of Units : 3 No of Bay/Unit : 2
Selection : 611-30. 6 Type: 2 FPCA Draft :Forced
Surface/Unit..........Finned: 20331. m2
........Bare Tube: 876. m2
Total Heat Exchanged / MTD : 13403 kW / 28.4°C

OVERALL HEAT TRANSFER RATE :
Finned Tube : 23.24 W/m2.°C
Bare Tube , Service : 539.66 "
Bare Tube , Clean : 669.65 "

TUBE SIDE DATA
Fluid Circulated : COND.SPLIT.OVHDS
Total Fluid Entering : 118149.0 kg/h
IN OUT
Temperature : 92.9 51.9 °C
Vapor : 118149.0 kg/h
Liquid : 118149.0 "
Steam : "
Water : "
Noncondensable : "
Vapor Mol.Wt. : 73.7

Viscosity V/L : 0.008/ / 0.200cP
Density V/L : 7.850/ / 620.0kg/m3
Specif. Heat V/L : 1.950/ /2.340 kJ/kg.°C
Thermal Conduct V/L : 0.020/ /0.100 W/m.°C
Latent Heat : 314.5 kJ/kg
Pressure In : 3.00 BAR Abs.
Pressure Drop Allow./Calc. : 0.400 / 0.287 BAR
Fouling Resistance : 0.00030 m2.°C/W

AIR SIDE DATA
Total Air Quantity : 339.5 m3/s(20°C,1 atm.)
Air Quantity Per Fan : 86.9 m3/s
Face Velocity : 3.05 m/s
Temperature In/Out : 25.0/ 57.7 °C
Actual Static Pressure : 0.201 kPa
Altitude : 90. m
SPL at 1 Meter below drive assembly: 85 dB(A) (1)
(1)With all fans of this item operating.

Weight Empty/ Full of Water : 53300./ 58200. kg/Unit

CONSTRUCTION
Design/Test Pressure : 6.0(2)/ 17.7 BAR Eff.
Design Temperature : 255. / -45. °C
Construction Code : ASME VIII DIV.1 API 661 U Stamp : YES

BUNDLES
Size : 3.05 m x 9.4 m
No/Bay : 2
No TOTAL : 4
No Tube Rows: 6
Frame : CARBON STEEL
Slope : 1% on last pass

TUBES
Material : SA334 GR.6
Type : SEAMLESS
Diameter : 25.40 mm
Thickness : 2.108 mm min.
No/Bundle : 300 Total: 1200
Length : 9.144 m
Tri. Pitch: 60.33 mm

FINS
Material : ALUMINIUM
Diameter : 57.15 mm
No/Meter : 433
Type : FOOTED L (KNURLED)

HEADERS
Type : PLUG
No Passes: 3 Split : NO
Pass Pattern: 3/2/1
Nozzles In/Out : 2x 8"/2x 6"
Rating : ANSI 150.LB RF
Tube/Tubesheet : EXPANDED
Header Mat. : SA516 GR.60
Gasket Mat. : SOFT IRON
Plug Mat. : SA350 LF2
Corrosion Allowance : 3.000 mm
TI/PI Connect.: YES / YES

MISCELLANEOUS
Structure : STD 4.3m STEEL
Louvers : NO
Walkways : HEADER STEEL
Fan Guards : STEEL
Vibr.Switch: EXP. PROOF
Steam Coils: NO

No/Bay : 2 MECHANICAL EQUIPMENT No TOTAL : 4

FANS
Model : COFIMCO 34N/25MT
Blades : 7 ALUMINIUM
kW / Fan : 26.4 kW
Tip Speed : 40.9 m/s
Diameter : 3.96 m
Pitch : MANUAL. ADJUSTABLE
Pitch Angle : # 11.4°
Hub Mat. : STEEL

MOTORS
Type: ELECTRIC EXN
RPM : 1500 RPM
kW / Motor : 37.0 kW
Specials : 690-3-50

SPEED REDUCER
Type: TOOTHED BELTS
Ratio : 1470/197 = 7.45
Pulley Material : CAST IRON

(2)Also 0 Barg @100°C and -0.7 Barg @50 to -45°C.
(3)Process fluid categories:Toxic/Flammable/Explosive.

Figure 2. Illustration of ACHE manufacturer data sheet.

Figure 3. Steps one and two of air side fouling.

Air seals

Air seals are used to eliminate air leaks that can exist between the bundle and the plenum chamber. They consist of simple pieces of metal that function as seals.

The loss in airflow generated by missing air seals can be considerable. To estimate the loss in airflow caused by missing airflow, the surface opening should be multiplied by 14 m/s, which is the average speed at which the air will go through an opening without any resistance.

Air seals should be inspected for air leaks between the bundles, under the bundle, etc.

Poor air distribution and/or airflow passing through the bundle

One of the main causes for poor performance of existing air coolers is caused by poor air distribution across the bundle. This lack in airflow versus design can be caused by a variety of small causes adding up, which in turn creates a problem. Therefore it is important to run through these pointers for each fan. It can be surprisingly beneficial to increase heat duty of an air cooler by simply increasing airflow as illustrated in Table 1.

Checklist for site inspection of fans stopped

- How large is the distance between the tip of the blade and fan ring (tip clearance)?

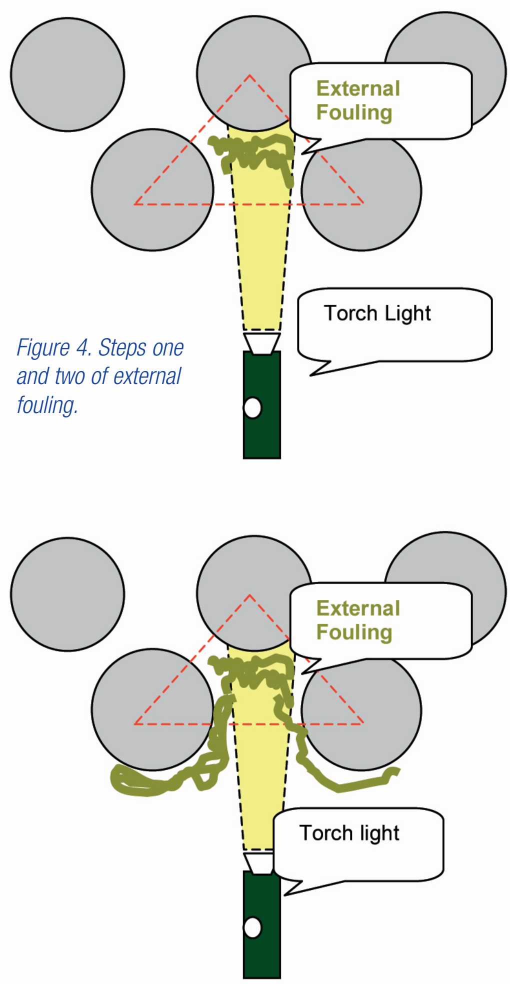

Figure 4. Steps one and two of external fouling.

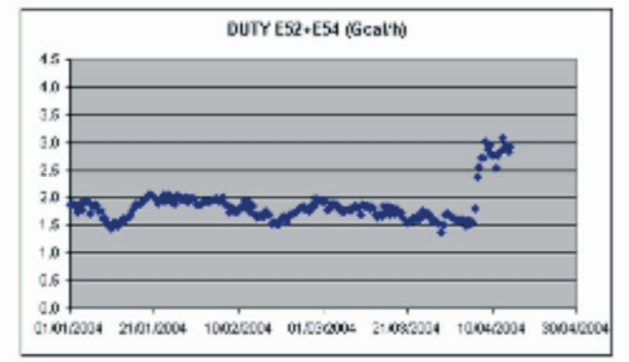

Figure 5. Illustration of possible gains in heat duty after cleaning.

Figure 6. Bent/warped tubes in African refinery.

Table 1. Illustration of possible gains in heat duty for 10% increase in airflow

Process service	Increase in heat duty	
	Minimum	Maximum
Condenser	3%	8%
Light product cooler	2%	4%
Heavy product cooler	0%	0.5%

- Is the fan equipped with a seal disc in the middle of the fan?
- Does the fan ring have inlet bells for smoother inlet conditions?
- Is the fan running inside the fan ring?
- Is the fan running the proper direction (mostly clockwise)?
- Is the fan pitched under 22° (measured at the tip of the blade)?
- Are all the blades pitched at the same angle (+/- 0.2° tolerance)?
- Are there variable chord fans?

Checklist for site inspection of fans running

- Is the fan running at the design fan RPM?
- Is there any negative airflow at the tip or centre of the fan using a rod with ribbons?
- Does anything stick to the fan guard?

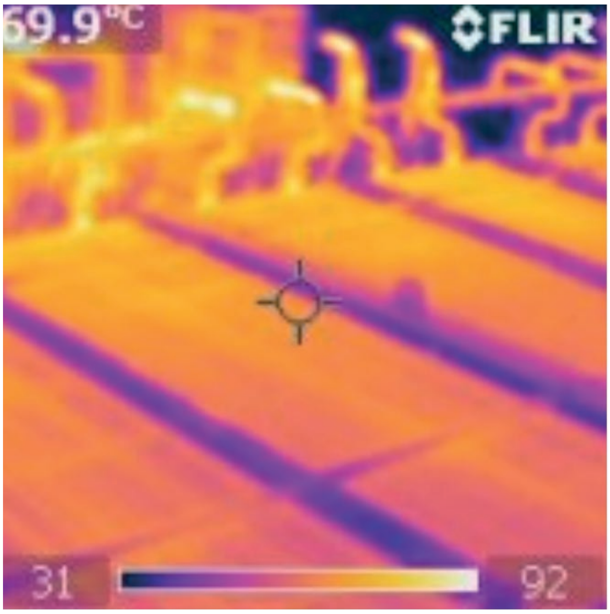

Figure 7. Scan of bundles with IR camera.

Explanation of checklist fans stopped

- Tip clearance (distance between the tip of the blade and the fan ring). Too much distance at the tip will cause air recirculation problems; too little distance at the tip can cause rubbing, or tipping, during high winds. According to API661, tip clearance should be as illustrated in Table 2.
- A good fan should be equipped with a seal disc to stop recirculation at the centre of the fan. Fans should therefore be checked to see whether they are equipped with a seal disc (Figure 10).
- Inlet bells should be installed at the inlet side to create smoother inlet condition and not to starve the fan at the tip of the blade (vena contracta) (Figure 11).
- At mid radius (0.25 D), tangential velocity is only 25% of the velocity at the tip. To compensate for this decrease in velocity, the chord width and twist must be increased. This is the reason for the increased efficiency and more uniform airflow from a tapered (=variable chord) blade. Figure 12 illustrates the difference between a tapered twisted blade and straight chord blade. The straight chord blades are not performing as desired.

Explanation of checklist fans running

Using a rod with ribbons indicates whether a fan is running well or not and will pinpoint the problems (Figure 13). When a fan is not functioning well (poor selection, cavitation/stalling of fans, etc.) it is very common to have recirculation at the tip of the blade for forced draft units and at the centre of the fan for induced draft units. A rod with ribbons will tell if a fan has recirculation problems.

A working glove can also be used to see whether air velocities are sufficient. The glove should at least stick to the fan ring on a forced draft unit. If not, the air velocities

Table 2. Illustration of tip clearance according to API 661		
Fan diameter	**Minimum clearance**	**Maximum clearance**
3 - 9 ft	6 mm	13 mm
9 - 11ft	6 mm	16 mm
> 11ft	6 mm	19 mm

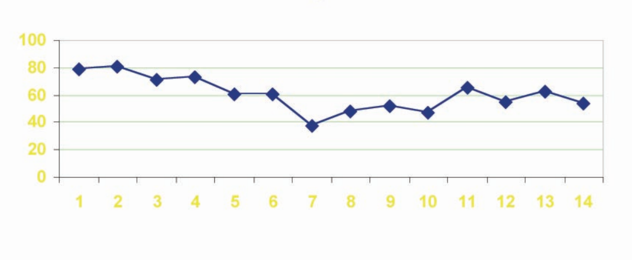

Figure 8. Difference in measured process outlet temperatures.

Figure 9. Missing air seals.

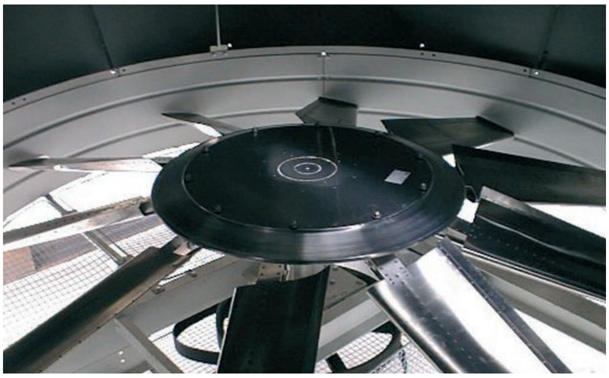

Figure 10. A seal disc.

are mostly too low. Please note that static pressure, motor power, etc. will also affect the air velocities and therefore a glove not sticking to the fan guard will not necessarily mean it is not functioning properly. However, in most cases, the test will just simply do.

Reliability issues (mechanical parts)

As most ACHE's are located on top of a unit above the pipe rack accessible only by ladders, they usually only get looked at when there is a significant mechanical problem. Other than that, they are usually abandoned and ignored.

This is why most air coolers inspected have mechanical problems. Mechanical problems are an underestimated cost as a non-running fan on a critical air cooler in the summer can cost a lot more then just the material cost of small spare items. In fact, it can cause production limitation as one or more fans are not running. Also, it is well known that a breakdown will cost at least 15 times more then a simple planned repair. Therefore, it is important to carry out the following checklists for mechanical inspection when the fan is stopped.

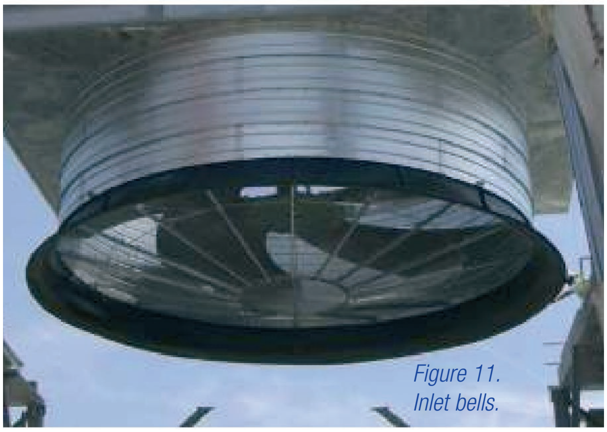

Figure 11. Inlet bells.

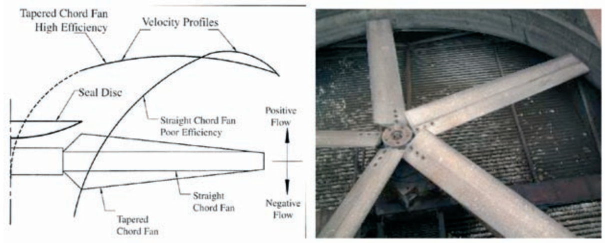

Figure 12. Illustration in airflow for variable chord fan versus straight chord fan.

Checklist for site inspection of fans stopped: mechanicals

- How is the condition of the belt and what type of belt is it?
- Are the sheaves (pulleys) worn down on the grooves? Are they cracked?
- Are the sheaves correctly aligned?

Checklist for site inspection of unit running

- Is the auto variable fan still functioning when switching air supply on and off?
- Are the steam coils leaking? Are they on? It is not uncommon to find steam coils on or leaking heating up the air entering the finned tube bundle reducing drastically heat duty of the air cooler.
- Do the louvers open/close correctly and are they open? Closed louvers in the summer will obviously reduce airflow and thus heat duty.

Explanation of checklist fans stopped" mechanicals

The drive system (belt and sheave) is critical for air fan performance. Slipping of the belt (V drives) can cause the fan RPM to decrease which in turn will decrease the airflow as fan RPM is linear to airflow. Toothed belts (HTD of timing belts) do not have this problem. However, they can have reliability problems if not properly installed and designed. Therefore it is important to ask operators whether there are any reliability issues and take fan RPM while running as a lower fan RPM will affect airflow and therefore ACHE performance.

Loss of thermal contact between fins and tubes and/or poor conditions of fins (bent, rotten aluminum, etc.)

The air cooler consists of two vital parts, which are the fins and the fans. Fins are used to increase heat transfer surface. As a rule of thumb, the ratio between bare tube and finned tube surface is approximately 20 times, meaning that it is important to have the fins in good condition.

There are a few things that will occur with finned tubes during operation, namely:

- Depending on type of fin, spraying or not of water and the environment (marine, corrosive, etc.), the bimetallic (mostly aluminium/steel) interface, through which the heat must be transferred from process fluids/gas within the steel tubes to the air flowing over aluminium fins can severely be degraded over time. This will then lead to a permanent loss in thermal capability by as much as 50% if the fins have no function at all.
- By carrying out measurements such as airflow and associated air temperature difference across the bundle, the user is able to accurately measure the amount of heat rejected into the air and thus the heat duty of the existing air cooler.[1] By using a heat transfer simulation program such as HTRI® loss in thermal conductivity of the finned tube bundle can be estimated.
- When inspecting the fins for conditions, it is important to have a good picture in mind of what type of fin is being looked at and what characteristics these fins have (Figure 13).

The ACHE was improperly designed in the first place

If the inspection reveals that all is well and the air cooler does still not comply to its check rating can be carried out to see whether the air cooler was properly designed in the first place. It is not so uncommon to see under rated air coolers in the industry.

Hot air recirculation

Hot air recirculation occurs when some of the warm exhaust air from a cooler is drawn back into the intake side or it is (through wind) drawn back into the intake side of another air cooler. Smoke bomb can be a solution (Figure 15). When designing a plant, it is useful to have a CFD modelling in order to detect possible hot air recirculation problems.

PHASE 3: Upgrading of the air cooler

The most cost effective way to increase air cooler performance is by increasing airflow rate going through the bundle as illustrated in Table 1. Airflow can be increased by relatively small means that can still have a great impact on cooling/condensing capacity. The other option is modifying the exchanger surface, which is more costly.

Figure 13. Rod and ribbon indicators.

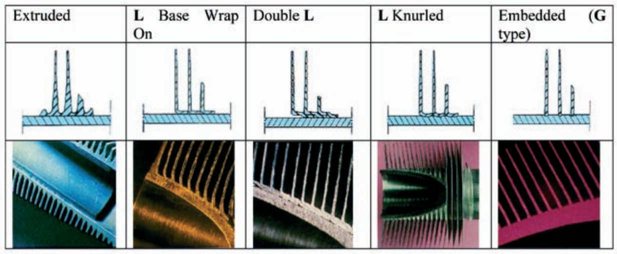

Figure 14. Illustration of different types of fin.

Figure 15. Smoke test bomb on offshore rig.

Figure 14 is an overview of the possible 'tools' for air cooler performance with budget costs for an average size of five rows consisting of two bundles (5 m wide x 10 m deep) with CS tubes and plug type header boxes equipped with two 12ft (3m67) fans and 22 kW motors in a European climate with design temperature of 28 ˚C.

References

1. Qair = (Cpair) * M * ΔTair where,
   Qair = Heat Duty in W
   Cpair = Specific Heat of Air J/kg-C
   M = Air mass (airflow in m^3/s * density in kg/m^3
   ΔTair = TairOUT - TairIN in ˚C
2. American Petroleum Institute 'Air Cooled Heat Exchangers for General refinery Service,' API Standard 661, 5th edition, March 2002.
3. Brochure GEA BTT Nantes, p.10.
4. Hudson Products Corporation, 'The Basics of Axial Flow Fans', 2000, p.22.
5. GIAMMARUTI. R., 'Performance Improvement to Existing Air-Cooled Heat Exchangers', February 2004.
6. Brochure Hudson Products Corporation entitled 'Finned tubes'.