AMERCOOL

Basics

of

Air Cooled

Heat Exchangers

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Air Cooled Heat Exchangers – Why are they used?

The Air-cooled heat exchanger is a device for rejecting heat from a fluid or gas directly to ambient air. When cooling both fluids and gases, there are two sources readily available, with a relatively low cost, to transfer heat to…..air and water.

The obvious advantage of an air cooler is that it does not require water, which means that equipment requiring cooling need not be near a supply of cooling water. In addition, the problems associated with treatment and disposal of water have become more costly with government regulations and environmental concerns. The air-cooled heat exchanger provides a means of transferring the heat from the fluid or gas into ambient air, without environmental concerns, or without great ongoing cost.

An air-cooled heat exchanger can be as small as your car radiator or large enough to cover several acres of land, as is the case on air coolers for large power plants where water is not available.

What are the uses for air-cooled heat exchangers?

The applications for air cooled heat exchangers cover a wide range of industries and products, however generally they are used to cooler gases and liquids when the outlet temperature required is greater than the surrounding ambient air temperature.

The applications include:

- Gas compressor packages
- Gas transmission facilities
- Engine cooling
- Condensing of gases (propane, refrigerants, etc.)
- Steam condensers (used in power plants & process applications)
- Industrial uses:
  - Bakeries to preheat ovens and provide steam for other equipment.
  - Hospitals to provide steam for sterilization and for cooling high tech equipment that produces heat.
- Refineries

The only common thread among these users is the need to reject heat from a source into the air. Some of these applications also use the discharge air from the air cooler to help heat buildings or other equipment.

Basic Heat Transfer principles

The basic heat transfer relationships that exist for shell and tube exchangers also apply to the design of an air-cooled heat exchanger. However, there are more parameters to be considered in the design of an air-cooled exchanger.

Since the air-cooled heat exchanger is exposed to changing climatic conditions, problems of control of the air cooler become relevant. A decision must be made as to what the actual ambient air temperature to be used for the design.

Some of the governing factors in the design of the air cooler are:

Tube diameter
Tube length
Fin height
Number of tube rows
Number of passes
Face area
Horsepower availability
Plot area

Since there are many variables, normally there many solutions, however the designer attempts to find the optimum economic design given these factors.

Basic heat Transfer Equations

Q = U * A * MTD

where

Q = Heat load, Btu/hr

U = over-all heat transfer coefficient, Btu/(hr*sq ft * ^{o}F)

A = Surface area, sq ft.

MTD = Mean temperature difference

Normally, this equation is solved for the surface area or A, since the heat load is known, and the over-all heat transfer coefficient and the MTD can be calculated, based on known information.

There are two types of heat load; the sensible heat load or the heat to reduce the temperature of a gas or liquid, and the latent heat, which is commonly called the condensing load. The latent heat is heat generated by the change of phase and is defined as $Q = mh_{fg}$, where,

m = the flow of the fluid or gas in lb/hr.

h_{fg} = enthalpy difference between the liquid and vapor phases at the saturation temperature considered.

To calculate the sensible heat load Q in Btu/hr, the following equation must be followed:

$$Q = m * Cp * (T_i - T_o)$$

Where

m = the flow of the fluid or gas in lb/hr.
Cp = the average specific heat in BTU/LB/oF of the liquid or gas
T_i = inlet temperature of the liquid or gas
T_o = outlet temperature of the liquid or gas

The following formula can be used to calculate the lb/hr of a gas stream given in MMSCFD and the lb/hr of a liquid given in GPM.

lb/hr gas = MMSCFD X Specific Gravity of gas X 3180.662
lb/hr liq = GPM X Specific Gravity of liquid X 60 * 8.333 (weight of 1 gallon water at 70^{o}F)

The mean temperature difference is solved by the following equation:

$$MTD = \frac{(T_{Pi} - T_{Ao}) - (T_{Po} - T_{Ai})}{LN \dfrac{(T_{Pi} - T_{Ao})}{(T_{Po} - T_{Ai})}}$$

where,
T_{Pi} is the process side inlet temperature

T_{Po} is the process side outlet temperature

T_{Ai} is the air side inlet temperature

T_{Ao} is the air side outlet temperature

A correction factor is then added to the MTD to account for different row/pass configurations.

The overall heat transfer rate can be calculated as follows:

U is the reciprocal of an overall resistance, R, which may be defined as follows:

$$R = \frac{1}{h_o} + \frac{1}{h_i} + \frac{f_o}{1} + \frac{f_i}{1} + \frac{t}{k}$$

where

ho = effective outside film coefficient

hi = effective inside coefficient

fo = outside fouling factor (resistance)

fi = inside fouling factor (resistance)

t = resistance to heat passing through the tube wall

k = tube wall conductivity factor

U = 1/R

The effective outside film coefficient, in terms of tube surface, is the true air film coefficient multiplied by the ratio of total surface to tube surface and by fin efficiency.

The inside film coefficient is depends on tube size, velocity of the liquid or gas in the tubes and various physical properties of the fluid, such as the viscosity.

The inside fouling factor is dependent on the dirt or scale characteristics of the liquid or gas in the tubes.

The outside fouling factor, based on tube surface, must be divided by the surface ratio, (bare to finned) which results in a very small figure, negligible in most cases.

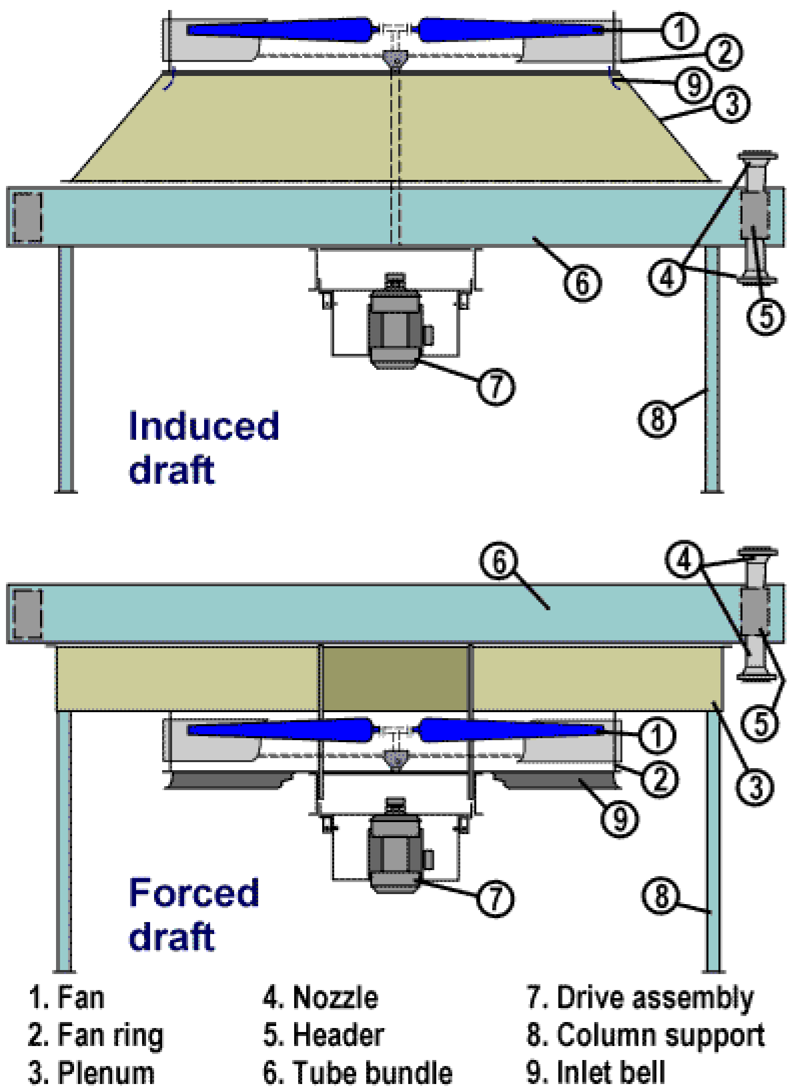
The thickness of the tube is normally small enough with sufficiently high conductivity that this factor is almost negligible.

Air Cooler Components

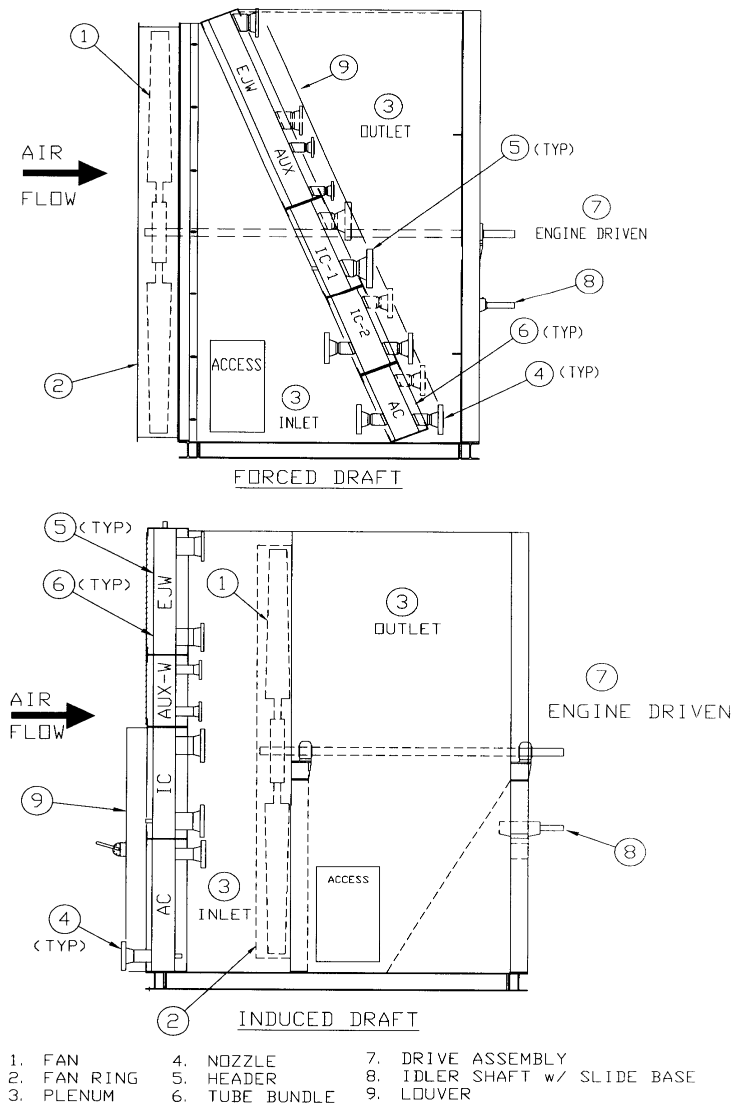
The Air Cooled Heat exchangers consist of the following components:

- One or more coil with heat transfer surface
- Air moving device, normally a fan
- A driver and speed reduction device
- Plenum between the coil and the fan to direct air across the surface area
- Supporting structure
- Guards for rotating equipment & protection of the coil area
- Optional louvers for outlet process temperature control

The components of a typical air cooler are indicated below:



Vertical air cooled Heat exchangers, while shaped differently have the same components as needed on the horizontal air cooler, as indicated in the diagram below:



Types of Air Cooled Heat Exchangers

Air Cooled Heat Exchangers can be built in several configurations, normally controlled by the power available, the installation and customer preferences.
Diagrams of the various types of air coolers are indicated on the following pages. There are many similar configurations by different manufacturers, however most of these are a derivative of one of these types.

The most common type of air cooler is the horizontal coil with horizontal fan and vertical air flow. This type is typically driven by an electric motor drive attached to the fan through v-belts to allow for speed reduction between the motor and the fan. This model can also be driven by hydraulic motors, air motors and even from an engine with special right angle gear drive arrangements.

The normal application for these models are in plants or refineries where electric power is available, and where the cooler is installed away from other equipment to allow adequate air flow around the air cooler.

This model is built in both induced draft and forced draft configurations. Depending on the application, and the installation site, there are advantages and disadvantages to both models. Some of the advantages and disadvantages of each model are listing below:

Forced Draft

Advantages

1. Lower horsepower requirements due to lower inlet air temperatures.
2. Better accessibility of fans and bearings.
3. Better accessibility of bundles for re-placement.
4. Accommodates higher process inlet temperatures.

Disadvantages

1. Less uniform distribution of air over the bundle.
2. Increased possibility of air recirculation.
3. Low natural draft capability on fan failure.
4. Exposure of coils to sun, rain, etc.

Induced Draft

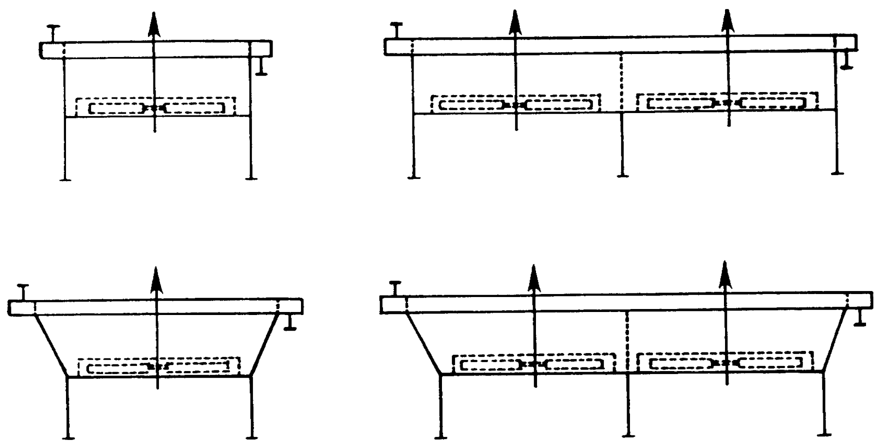
Advantages

1. Better distribution of air across the bundle.
2. Less possibility of hot air recirculation.
3. Better process control since plenum covers 60% of bundle face area, blocking it from sun and rain.
4. Increased capacity with fan off due to natural draft stack effect.

Disadvantages

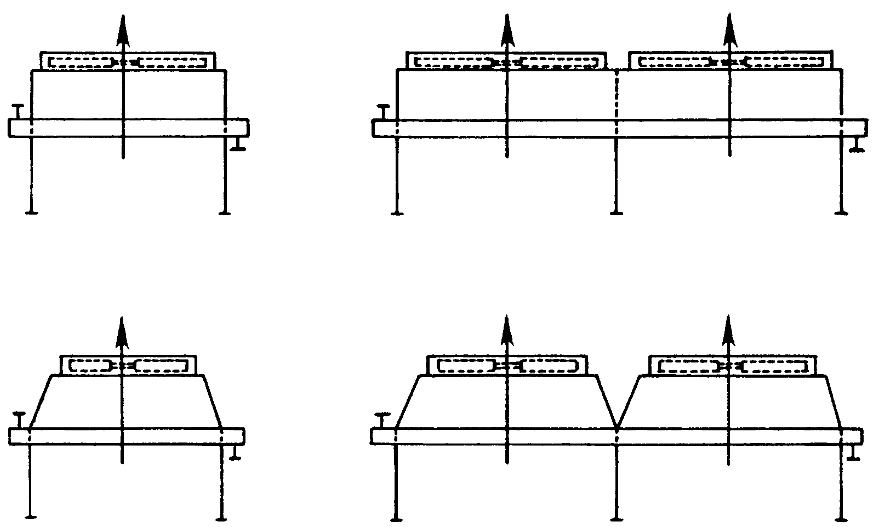
1. Higher horsepower since fan is in outlet air stream.
2. Mechanical equipment subjected to higher temperatures.
3. Fans are less accessible for maintenance.
4. Plenums must be removed to replace bundles.

Horizontal Coil Configurations



(Number of Fans or Bays Not Limited)

FORCED DRAFT — HORIZONTAL



(Number of Fans or Bays Not Limited)

INDUCED DRAFT — HORIZONTAL

Another common configuration of air cooler is the vertical air cooler. This model typical consists of bundles stacked vertically, with a vertical fan, and intake air flow from a horizontal direction. Different models may have air flow turning to discharge vertically, air flow horizontal, or bundles mounted at an angle to the fan.

This model was developed for applications where the fan was driven from an engine and the cooler was skid mounted with other equipment. This is the typical application for engine driven skid mounted gas compressors and generator sets. It is common for the cooler to be utilized, not only as a radiator for the engine, but to include gas or air cooler for the compressor.

Typically, these coolers are v-belt driven from a natural gas or diesel engine, however most manufacturers also build this model with electric motor drivers.

Again, this configuration is available in both forced and induced draft, with both models having advantages and disadvantages dependent on the application.

Forced Draft

Advantages

1. Lower horsepower requirements due to lower inlet air temperatures.
2. Better accessibility of fans for maintenance.
3. Less possibility of hot air recirculation.
4. Center of gravity of cooler is closer to the center of the cooler, making it easier to lift.

Disadvantages

1. Less uniform distribution of air over the bundle.
2. Accessibility of bundles for replacement is difficult
3. Discharge air is at a lower velocity, since it comes off of the coils.
4. Exposure of coils to sun, rain, due to slope of bundles.

Induced Draft

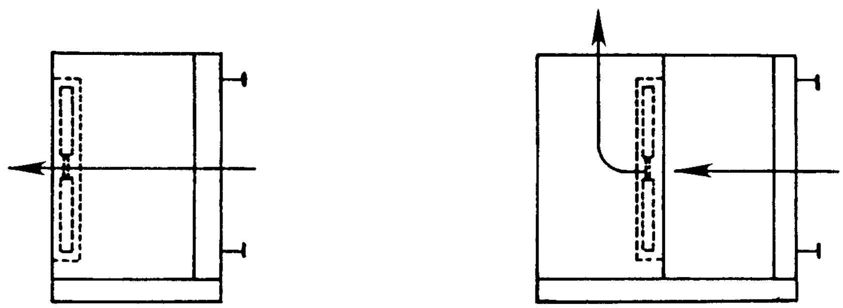
Advantages

1. Better distribution of air across the bundle.
2. Easier accessibility of bundles for replacement.
3. Discharge air is at a higher velocity.
4. Easier accessibility to louvers for process control.

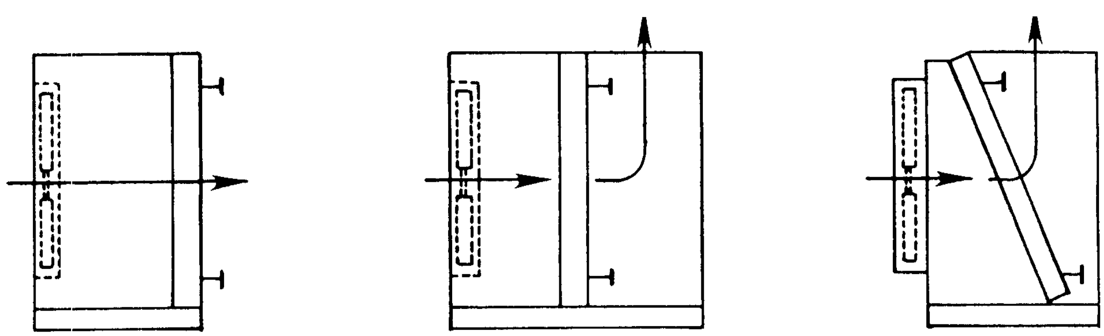
Disadvantages

1. Higher horsepower since fan is in outlet air stream.
2. Lifting is difficult since all of the weight is in the front of the cooler.
3. Fans are less accessible for maintenance.
4. More susceptible to hot air recirculation due to lower intake air velocity.

Vertical Coil configurations



INDUCED DRAFT — VERTICAL

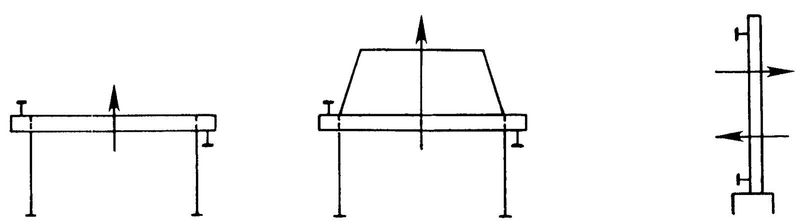


FORCED DRAFT — VERTICAL

In applications where power is not available, Natural draft coolers can be utilized for some applications. This design is based on the air cooler bundle generating it's own air flow, either from natural crosswinds, or from the air flow created when the hot air rises from the bundle, and the cooler air replaces it.

Natural draft coolers can be built in a variety of configurations, including models with horizontal coils, vertical coils and units utilizing stacks to provide additional means of generating air flow across the coils.

Natural draft configurations

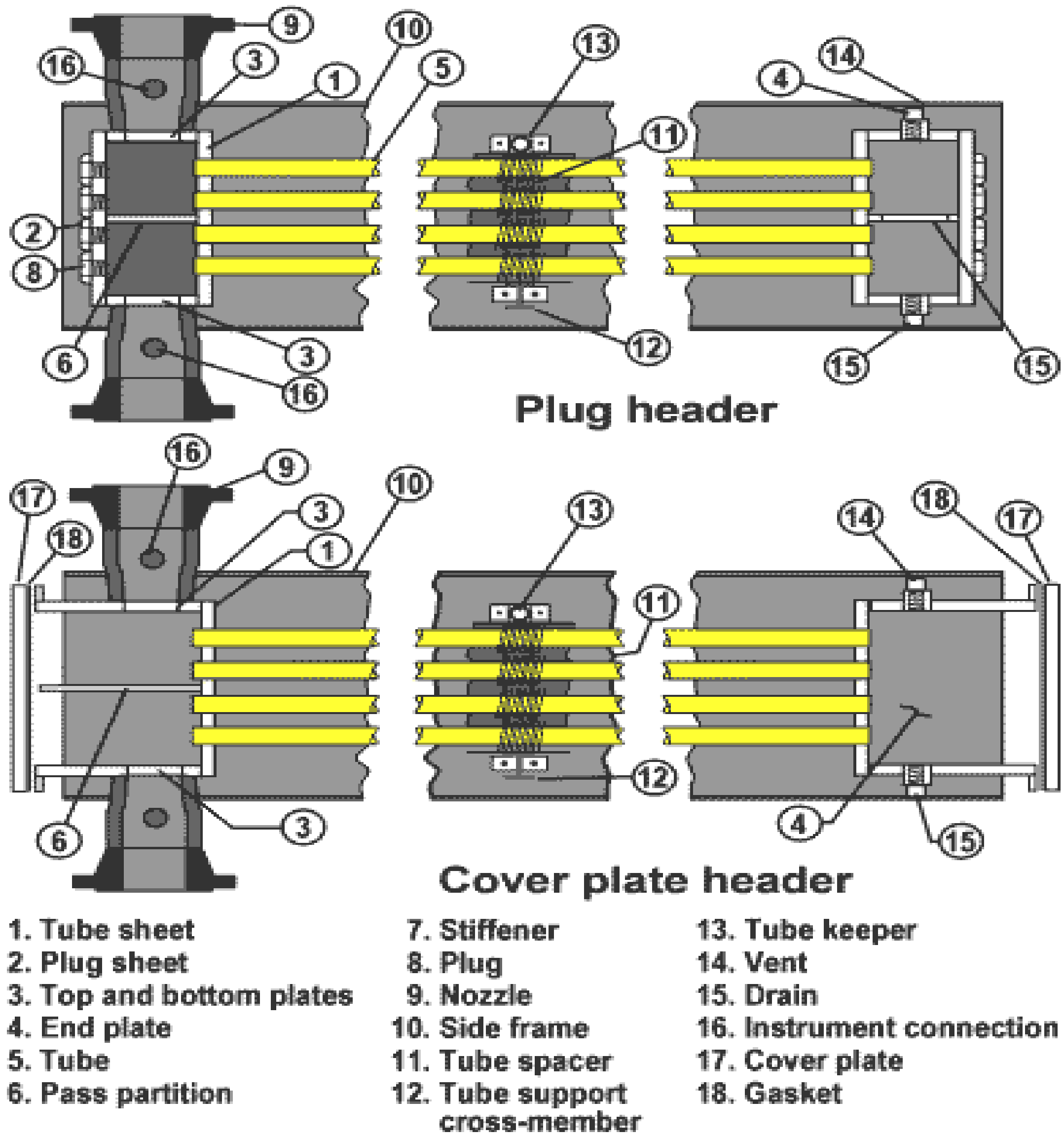


NATURAL DRAFT — HORIZONTAL   NATURAL DRAFT — VERTICAL

Tube bundle or Coil components

The tube bundle or coil is designed and manufactured as an assembly of tubes, headers, tube supports, and side frames that assembled allowed the entry and exit of the fluid or gas into a series of tubes for cooling purposes. Usually, the tube surface has aluminum fins to added extended surface area to compensate for the low heat transfer rate of air at atmospheric pressure.

A typical tube bundle is shown below with the different components shown:



Coil or Bundle design and construction

The coil or bundle in the air-cooled heat exchanger is an assembly of tubes, headers, side frames and tube supports as shown in the figure on the next page. Usually the tube surface exposed to the passage of air has extended surface in the form of aluminum fins to compensate for the low heat transfer rate of air.

The box header is normally fabricated from plate, and consists of a tube sheet, plug sheet, top and bottom wrappers, and end plates. In a standard box header configuration, holes must be drilled and tapped in the plug sheet opposite each tube to allow maintenance of the tubes. A plug, normally a shoulder plug with a gasket, is threaded into each hole to seal under pressure, but allow access when required.

Partitions, or pass plates are welded into the headers to establish the tube side flow pattern. The tube side flow pattern is determined by maximizing the inside tube velocities; within the pressure drop limits imposed. Pass plates can also be used as structural stays of the tube and plug sheets, in some configurations.

Within practical limits, the longer the tubes and the greater the number of rows, the less the surface area cost per square foot. One or more bundles can be combined on a common structure, assuming all bundles have the same airside static pressure loss.

The bundles must be designed with at least one floating header to allow for thermal expansion of the tubes. Failure to provide for thermal expansion, could result in problems with the tube-to-tube sheet joint, since the thermal expansion will attempt to push the tube into the header box, loosening the expanded tube-to-tube sheet joint.

Tubes are generally expanded into the holes in the tube sheet of the header box. The expansion process can be done utilizing a grooved tube sheet hole or a smooth inside tube sheet hole. In high pressure or high temperature applications, the grooved tube sheet hole is preferred due to the additional strength provided. The expanded tube-to-tube sheet joint has been utilized in services up to 15,000 psi design pressures. In some cases, welded tube-to-tube sheet joints may be required.

Once installed in the bundle, the tubes must be supported to prohibit intermeshing of the fins, and “bunching” of the tubes, which allows for openings in the tube that allow channeling of the airflow. Several means of tube support are utilized dependent on manufacture.

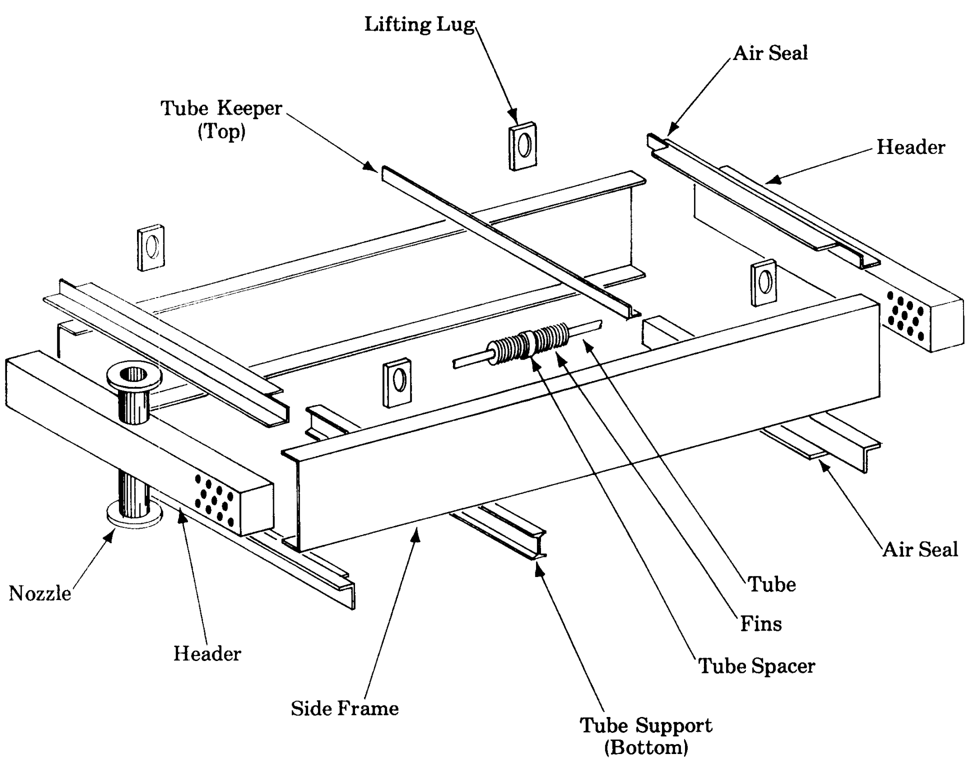
The most common tube support is provided by a “wiggle strip” that is place between each row, and runs between each tube. This method allow for support of the tube from the fin tip and is susceptible to movement in the bundle during transportation.

Another common method, utilized by some manufacturers, is to wrap aluminum strips around the perimeter of the tube at designated spots along the length. These strips are stapled to prohibit them from loosening. Again, this provides support from the tip of the fin.

A third method is the scalloped channel. This method provides a strip, normally fabricated from aluminum that cradles each tube and runs the entire width of the bundle. The scalloped channel is formed to provide both supports from the fin tip, and to the tube wall. Based on the configuration, it is not able to move after inserted, and also provides a means of keeping the tubes spaced properly.

Tube support can also be provided by cast zinc collars. This method requires a zinc collar to be poured at each support spot on the tube. This method, while providing excellent support, is normally cost prohibitive.

Typical Bundle configuration



Finned Tubes

The tubes are normally round and can be produced to almost any metal suitable for the process. Tube material is selected based on the corrosion, pressure and temperature limitations of the material in the process it is exposed.

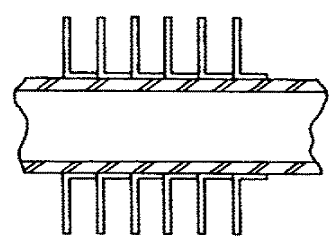
Fins are normally helical wound aluminum fins. Aluminum material is used for reasons of good thermal conductivity and economy of fabrication. The normal aluminum material used is 1100-00 due to its relatively low cost and superior thermal conductivity. Fins can be produced from other materials including copper, steel and stainless steel. Copper is normally used in offshore or marine environments when the airside environment is corrosive enough to justify the cost increase associated with copper material. Steel and stainless steel is normally used for very high temperature applications.

Fin Types

Fins can be attached to the tubes in a number of ways:

L-footed Tension wound

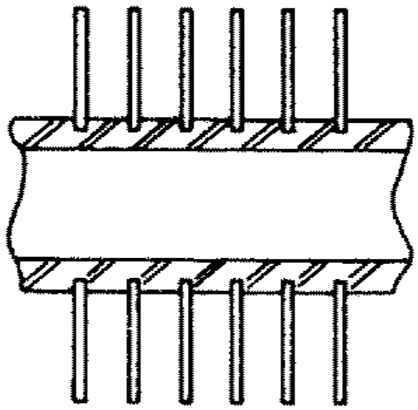
The most common fin type utilized in the air-cooled heat exchanger design is the L-footed tension wound aluminum fin. The fin is produced by wrapping an aluminum strip, that is footed at the base, around the tube. This process is done by holding tension on the fin at all times. The ends of the fins are stapled to prohibit the aluminum fin from unraveling, and loosing the contact between the fin foot and the tube. This contact is critical to the operation of the air cooler, since the heat is transferred from the tube wall, through the fin, to the surrounding ambient air.



L-FOOTED TENSION

The L-footed tension wound fin is normally used in services where the tube wall temperature does not exceed 350 degrees, and air side corrosion is not extremely high. At the higher tube wall temperature, due to the difference in material between the tube and the fin, the fin will not maintain contact with the tube, therefore loosing cooling efficiency of the air cooler. This fin is also susceptible to air side corrosion creating a film between the tube and fin, creating the same problem. Coatings to the fins, or special in material can be utilized to slow this process.

Embedded



EMBEDDED

In high temperature applications, an embedded process is employed to attach the fin to the tube wall. In this process, a groove is actually cut into the tube, the fin strip inserted, and the tube material then "plowed" back against the fin to bond it to the tube. Separation of the fin and tube due to corrosion or temperature differentials are not a factor with the fin type.

Since the fin does not employ a "foot", this leaves the tube totally exposed to airside corrosion factors. In addition, due to the groove cut into the tube, a thicker tube wall thickness must be used to avoid over-pressuring the tube.

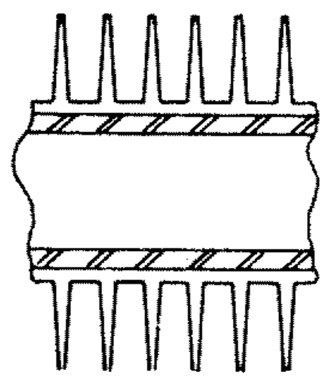
The embedded fin is normally used for services greater than 350 degrees and less than 750 degrees F.

Extruded

For applications where atmospheric corrosion is critical, the extruded fin tube provides the best protection.

The extruded fin is produced by inserting the tube into an aluminum sleeve and then extruding the fins from the aluminum sleeve. Since the tube is totally covered by the aluminum sleeve, the tube wall is protected from outside corrosion, and the bond between the fin and the tube remains tight.

The extruded fin tube is good for tube wall temperature up to 650 degrees F. This is the most expensive fin tube to produce.

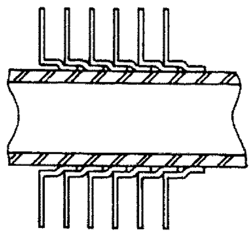


EXTRUDED

Others

There are several other types of fin that are similar to the above fin types:

Double L-footed fin:



OVERLAPPED FOOTED TENSION

This fin is similar to L-tension in that it is produced in much the same manner. In this process, a foot is formed on both sides of the upright portion of the fin, providing an overlapping of the fin. This provides a higher protection for the tube against atmospheric corrosion. This fin type is also referred to as an overlapped fin.

Knurled L-footed fin:

Again, this process is very similar to the L-footed tension wound fin, but utilizes knurling wheels that actually knurl the fin foot into the tube. This allows for a tighter bond between the tube and the fin, and reduces the likelihood of a corrosion film between the two.

L-footed fins with slits cut into the fin:

By cutting a slit into the fin, more air turbulence can be created, due to the interruption of the air boundary layer. This in turn increases the airside heat transfer coefficient with a modest increase in the airside pressure drop and the fan horsepower.

Fans and Air Movers

The air-cooled heat exchanger is controlled by two factors, the tube bundle size and configuration, and the ability to move air across the surface area that the bundle provides. Therefore, a major consideration of air cooler manufactures is not only the selection of the proper fan, but also the design of plenums to force the air across the surface area.

The common means of moving air across the air cooler bundle is an axial flow, propeller type fan that either pushes (forced draft) the air across the bundle or pulls (induced draft) it across.

Even distribution of the air across the tube bundle is critical for uniform heat transfer. this is normally achieved by adequate fan to bundle coverage and controlling the static pressure loss across the bundle. A good design practice, and API661 requirement, is to maintain a forty percent (40%) coverage of the face area of the tube bundle to the area of the fan. Coverage's of less than this will allow for lower airflows on the outer surfaces of the tube bundle, and can result in poor performance.

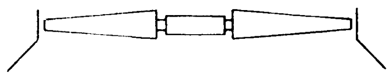
In addition, the distance from the fan to the coil can be critical. Again, good design practice requires an air dispersion angle of forty five percent (45%). The angle is measured from the outlet side of the fan ring to the center of the depth of the coil. This distance will allow the air to disperse, rather than channel directly through the bundle in front of the fan.

In horizontal configurations, the face coverage and air dispersion angle control the plenum size. On vertical configurations, many times the forty five percent dispersion angle is more difficult, since the overall size of the cooler is affected. Therefore, the designer must compensate for this design flaw by other means. This can be accomplished by additional air flow from the fan, resulting is more air flow than required directly in front of the fan, with the outside surfaces at the design velocity. It can also be accomplished by adding additional surface area to the coils affected.

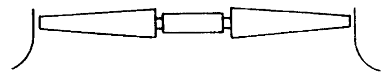
On vertical coolers with vertical air discharge, the designer also has to deal with the problem of discharging the air from the cooler, without causing additional pressure losses to the fan. Careful design of the size of the discharge plenum must be undertaken to assure the air can discharge the cooler.

Fan ring design varies among manufacturers. The common configurations for fan rings are indicated on the following page. Due to the cost of manufacture, the eased or taper fan rings are generally not utilized in standard products, however are available when required for special applications.

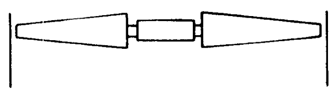
FAN RING TYPES



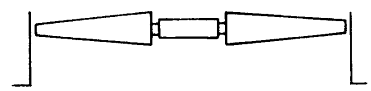
TAPERED INLET
FIGURE 6A



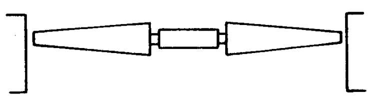
EASED INLET
FIGURE 6B



STRAIGHT
FIGURE 6C



FLANGED INLET
FIGURE 6D



CHANNEL

Tapered or Eased Rings

The tapered inlet and eased rings both allow for a more uniform exit of the air from the fan ring. Most fan design programs will indicate slightly less horsepower required for this configuration. In addition, these fan rings allow for better air dispersion since the air is directed when it leaves the ring.

In most air-cooled heat exchangers, the cost of producing this configuration outweighs the increased savings in horsepower, or in airflow efficiency.

Straight, Flanged Inlet or Channel Rings

These are the most common fan rings utilized by manufacturers. This ring is easily produced, and provides good air movement if close tip clearance between the ring and the fan are maintained. The depth of this ring will vary with the fan selected.

Fans

Fans can vary in size from 2 to 20 feet in diameter, and can have from 2 to 16 blades. Common sizes are in one-foot increments, but can be supplied in any diameter desired. Generally the blades are aluminum, but other materials are available, including steel, fiberglass, reinforced plastic and wood.

Normally the blades of the air cooler have a profile that allows an even distribution of air across the length of the blade. This can be accommodated for by a blade that has a wide chord width at the tip, and tapers to a narrow chord at the tip. In addition, most blades have a twist that compensates for the slower velocity at the portion of the blade closer to the center of the fan. This helps produce a more uniform, efficient air velocity pressure.

The necessity for uniform flow and pressure is easily explained:
If certain portions of the blade are not able to develop the pressure necessarily being carried by other portions of the blade, back flow of air at these points will occur. This would be the case around the hub if a typical propeller were used as an axial flow fan.

The number of blades in a fan is not important, but the area of the total blade surface at each radius is vital. Blade widths are generally limited by physical conditions in order to keep the fan from becoming too deep.

Fans may have fixed or adjustable pitch blades. Normally smaller blades (four feet and less) are provided with fixed pitch, while larger diameters are generally adjustable pitch.

Fan Laws

Horsepower

Horsepower of a given fan in a given installation, with increase or decrease in RPM, will vary approximately as the cube of the RPM.

(a) The static pressure will increase as the square of the CFM.
(b) The velocity pressure will increase as the square of the CFM.
(c) Since the velocity pressure and static pressure are additive, the total pressure increases as the square of the RPM.
(d) The volume will increase directly as the speed.
(e) As a result, the horsepower will increase as the cube of the speed, the horsepower being the product of the CFM and the total pressure.

With changes in air density, horsepower for a given volume will increase or decrease in direct proportion to the air density, provided that the static pressure also varies directly with the air density, as is the case in most practical applications.

Air Cooled Heat Exchanger Noise

Environmental noise is becoming an increasing factor in the design and operation of air-cooled heat exchangers. Due to this, the design of a noise efficient air-cooled heat exchanger is a growing concern.

Noise from the air coolers comes from several sources:

- Fans are the largest contributor to the overall noise levels in the air cooler. There are many factors in the fan design and the selection of the proper fan for low noise applications that affect the noise level, however the fan speed has the greatest effect on the overall noise.

- The method of speed reduction is probably the second most significant source of noise in the air cooler. Many methods of speed reduction are available, however due to the constraints of the low noise requirements, many of these do not lend themselves to low noise applications.

- The electric motor is generally much less of a factor in the overall noise than the fan or the drive, however there are steps that can be taken to minimize the noise source.

- Structural vibration and the effects of rotating equipment can have an effect on the air cooler structure, including vibration in panels. A low-frequency noise can be produced from this vibration in the panels, adding to the overall noise level of the air cooler.

In the initial design of the equipment, it is possible to reduce noise in the air cooler and to have an impact on the overall plant noise. Generally, the following are general rules to use in the design of a noise efficient air cooler:

- Fans should be run at slow tip speeds, utilizing wide chord with blades to achieve adequate airflow. Normally this will require reducing the static pressure through the coils, due to the fact that most fans will not overcome high static pressures at low tips speed.

- V-belts, not cog belts should be used to drive the air cooler. Normally v-belts will add very little noise to the overall air cooler package. The use of newer “cog” type belts, including HTD belts will add a significant factor to the noise level.

- Premium efficiency motors are generally quieter than a standard efficiency motors. The motor is very seldom responsible for noise problems, however in the case of extreme noise level requirement, the motor may play a factor.

- The use of thicker panels, and elimination of any members interfering with the inlet airflow should be carefully studied. These two factors, though minor, should reduce low-frequency noise, usually generated by the air cooler structure.

General Air Cooler design practices

1. Static pressures through the coils should be limited to a reasonable number. Normally, this would range from .4” to .7” static pressure.

2. A general rule of thumb for the airside face velocity through the coils is as follows:

3 row coil	800 to 850 FPM
4 row coil	500 to 700 FPM
5 row coil	450 to 600 FPM
6 row coil	350 to 500 FPM

3. On new construction, good design practice would normally restrict the number of tube rows to four. This allows for some modification, if need later, to allow for higher heat load applications. Normally, on gas compressor applications, the air is at such a high temperature after the four rows, that additional cooling from additional rows in minimal.

4. A minimum fan to coil face area of forty percent.

5. Air dispersion angle of forty five percent should not be exceeded, without compensating for this in the design.

6. Fans should be operated in the mid range of the fan performance, this should be applied to tip speed, ability to handle the static pressure, and blade angle.

7. More surface area is always better than more airflow.

Air Cooler Governing bodies

ASME code, Section VIII, Division 1

API661 standard for air-cooled heat exchangers

TEMA (Tubular Exchangers Manufacturing Association)

HTRI (Heat Transfer Research Institute)

AMERCOOL

Amercool Manufacturing Inc. is a full service provider of air-cooled heat exchangers for Gas Compressors, Gas Transmission, Power Generation and General Industrial requirements. Amercool has been producing air cooled heat exchangers for these markets since it's inception in 1987.

The information contained in this booklet is derived from the combined experience of many years in operation, shop and field testing, and joint studies undertaken with fan manufacturers and industry groups.

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