E. Baffle Tray Column (or, Termin Shower Deck, No Holes, Caps, or Other Contact Devices)

For counter flow, gas flowing up a column through a falling shower film of liquid, Fair’s correlation\(^2\) of collected data is to be used as a guide:

\[
S \frac{U}{H} = 0.111 G^{0.14} L^{0.5} \tag{10-284}
\]

See Fair’s reference given previously for nomenclature. For baffle trays, the coefficient equation given under packed columns, the values of \(m = 1.18\) and \(n = 0.44\) with \(C_1\) depending on the system. For example, for a nitrogen/absorption oil system, \(C_1 = 0.00250\). See the reference and Table 10-48 for more details.

Air-Cooled Heat Exchangers

Air-cooled heat exchangers are very seldom, if ever, finally designed by the user company (or engineering design contractor), because the best final designs are prepared by the manufacturers specializing in this unique design and requiring special data. This topic is presented here to aid the engineer in understanding the equipment and applications, but not to provide methods for preparing final fabrication designs.\(^{106, 206, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265}\) Standard 661, 3\(^{rd}\) Ed., American Petroleum Institute, “Air Cooled Heat Exchangers for General Refinery Services” is a good basic reference.

Air-cooled exchangers use atmospheric air on the outside of high-finned tubes (except bare tubes are used in a few applications) to cool or condense fluids flowing through the inside of the tubes.

This type of exchanger is used to reject heat from a fluid inside the tubes (and associated headers) directly to ambient air.\(^ {251}\) To be effective, the air must flow in forced convection to develop acceptable transfer coefficients. Figures 10-174, 10-175, and 10-176 illustrate the two types, designated by the type of air movement, induced draft or forced draft.

The advantages and disadvantages of forced and induced draft fan operation on the performance of the unit as presented by Hudson Products Corp.\(^ {251}\) are used by permission in the following discussions.

Induced Draft.

Advantages:

1. Better distribution of air across the bundle.
2. Less possibility of hot effluent air recirculating into the intake. The hot air is discharged upward at approximately 2.5 times the intake velocity, or about 1,500 ft per min.
3. Better process control and stability because the plenum covers 60% of the bundle face area, reducing the effects of sun, rain, and hail.

![Figure 10-174. Two types of air-cooled heat exchangers. (Used by permission: © Hudson Products Corporation.)](image1)

![Figure 10-175. Typical forced draft air-cooled exchanger showing two exchanger sections and one fan. (Used by permission: Yuba Heat Transfer Division of Connell Limited Partnership.)](image2)
4. Increase capacity in the fan-off or fan-failure condition, because the natural draft stack effect is much greater.

Disadvantages and limitations:

1. Possibly higher horsepower requirements if the effluent air is very hot.
2. Effluent air temperature should be limited to 220°F to prevent damage to fan blades, bearing, or other mechanical equipment in the hot airstream. When the process inlet temperature exceeds 350°F, forced draft design should be considered because high effluent air temperatures may occur during fan-off or low air flow operations.
3. Fans are less accessible for maintenance, and maintenance may have to be done in the hot air generated by natural convection.
4. Plenums must be removed to replace bundles.

**Forced Draft.**

Advantages:

1. Possibly lower horsepower requirements if the effluent air is very hot. (Horsepower varies inversely with the absolute temperature.)
2. Better accessibility of fans and upper bearings for maintenance.
4. Accommodates higher process inlet temperatures.

Disadvantages:

1. Less uniform distribution of air over the bundle.
2. Increased possibility of hot air recirculation, resulting from low discharge velocity from the bundles, high intake velocity to the fan ring, and no stack.

Hudson^254^ states that the advantages of the induced draft design outweigh the disadvantages.

Although most units are installed horizontally, inclined, Figure 10-177, and vertical units are also in service. Figures 10-178 and 10-179 show typical assemblies for tube bundles with fabricated or cast end headers and also with flanged cover plates.

The tube bundle is an assembly of tubes rolled into tubesheets and assembled into headers. See Figures 10-175, 10-176, 10-178, 10-179 and 10-180. The usual headers are plug and cover plate but can accommodate U-bend types if the design so dictates.

The headers may be:

1. Cast box type, with shoulder or other plugs opposite every tube. The shoulder plug is generally considered best for most services. The hole of the plug provides access to the individual tubes for (a) cleaning, (b) rerolling to tighten the tube joint, and (c) plugging the tube in case of singular tube leaks.
2. Welded box type, same features as (1).
3. Coverplate type using flat or confined gasket. This type provides complete access to all tubes upon removal of bolted coverplate. This is used for fouling or plugging services where frequent cleaning is necessary.
4. Manifold type, which is used in high pressure and special applications.\(^{16,18}\)

For heat transfer performance, horizontal baffles to isolate tube-side passes in horizontal bundles are preferred over vertical baffles that isolate groups of tubes in vertical columns. The expansion of capacity by adding more tube bundles or sections in parallel is easier, and the MTD is better with the horizontal pass plates. The fan drive may be by any of the available means, including:

1. Direct electric motor or with belts.
2. Two-speed electric motor with belts or gears, gear or fluid coupling.
3. Steam turbine direct or with gear or fluid coupling.
4. Gasoline engine with belt, gear, or fluid coupling.
5. Hydraulic drive (see Figure 10-181).

Gears should be specified as American Gear Manufacturer’s Association (AGMA) requirements for cooling tower service in order to ensure an adequate minimum service factor rating of 2.0. The spiral bevel type is probably used a little more often than the worm gear. It is also cheaper. When gears are used with induced draft applications, the
maximum temperature of the exit air must either be limited by specification, or the gears must be rated at the expected air temperature surrounding the case. Remote lubrication should be provided for gears, bearings, etc., to prevent shutdown of the unit.

For V-belt drive, the type of belt section and maximum number of belts may be specified, as well as the minimum number—usually 3. B-sections are most common. V-belts are not considered for drives over about 50–60 hp, and a minimum service factor of 1.4 should be specified for continuous duty. Belts should not be used in any conditions where the surrounding temperature is greater than 160°F, with or without fans operating. This is of particular importance in induced draft conditions where belts might be in the exit air stream.

For general service, the fans are axial flow, propeller type with 2–20 blades per fan which force or induce the air across the bundle. Four blades are considered minimum, and an even number of blades (2–20) are preferable to an odd number (for emergency removal of blades to obtain balance for continued partial operation.)

Fan diameters range from 3–60 ft. The blades may be solid or hollow construction, with the hollow design being the most popular.

The blades are usually fixed pitch up to 48-in. diameter with applications for adjustable pitch above this size. Fixed pitch is used up to 60-in. diameter with aluminum fan blades when direct-connected to a motor shaft. Variable pitch is used with belts, gears, etc., between the fan shaft and the driver to allow for the possibilities of slight unbalance between blades due to pitch angle variation. Aluminum blades are used up to 300°F, and plastic is limited to about 160°–180°F air stream temperature.

Air noise is usually less with multibladed fans (4 or more) than with 2 or 3 blades. In general, noise is not a real problem when associated with other operating machinery and when the frequency level is low and nonpenetrating. When
these units are isolated, the associated noise would be immediately noticeable but not objectionable unless confined between buildings or structures where reverberation could take place. The noise level is usually limited to 75 decibels maximum at 50 ft from the fan, and the blade tip speed is limited to 11,000–12,000 ft per min \((= \pi \times \text{blade dia. in ft} \times \text{rpm})\). This may run higher for units below 48-in. dia.

Figure 10-175 illustrates the assembly of a typical forced draft unit with electric motor and gear drive. Note that walkways and access ladders are necessary to reach the exchanger connections where valves are usually installed. If designs require a pipe inlet or outlet at each end of the tube bundle, walkways may be required at each end. Pipe layout studies are necessary when multiple sections (exchanger bundles) are placed in the same service.

The structural parts can be galvanized or pickled and painted to prevent rusting of the steel. The specifications will depend upon local requirements and experience.

Hail guards of stiff hardware cloth mounted in a removable frame are used to prevent hail damage to the relatively soft fins in hail-susceptible areas. If damaged just slightly, the performance is not impaired.
Figure 10-180. Typical construction of tube bundles with plug and cover plate headers. (Used by permission: Bul. M92-3003MC 10/94. ©Hudson Products Corporation.)
Fan guards of wire grating or hardware cloth are mounted below the fan to prevent accidental contact with the moving blades and to keep newspapers, leaves, and other light objects from being drawn into the fan. The use of a wire fence around the entire unit is good to keep unauthorized individuals away from all of the equipment; however, a close fan guard, Figure 10-182, will prevent blade contact by the operators.

Tubes, Figure 10-183A and 10-183B, are usually finned with copper, aluminum, steel, or a duplex combination of steel inside with copper or aluminum fins outside. Other combinations are used to suit the service with the ratio of
finned to bare tube surface of 15:1–20:1. Common sizes are 3/4-in. and 1-in. O.D. with 1/2-in. to 5/8-in. high fins, although 1 1/2-in. O.D. as well as small sizes are available for a specific design.

The minimum number of the tube rows recommended to establish a proper air flow pattern is 4, although 3 rows can be used.265 The typical unit has 4–6 rows of tubes, but more can be used. Although more heat can be transferred by increasing the number of tubes, the required fan horsepower will be increased; however, this balance must be optimized for an effective economical design. Tubes are laid out on transverse or longitudinal patterns; however, the transverse is usually used due to the improved performance related to pressure drop and heat transfer.265 The tube pitch is quite important for best air-side performance. A typical representative tube arrangement for design optimization is for bare-tube O.D., finned-tube O.D., and tube pitch;256

1-in. / 2-in. / 2.375 in.
1-in. / 2.25 in. / 2.625 in.

For 1-in./2-in. (bare tube O.D./finned tube O.D.) the usual range for tube pitch is 2.125–2.5. For a 1-in./2.25-in tube, the pitch range would be 2.375–2.75. Reference 265 presents an interesting comparison of the effects of tube pitch on the heat transfer coefficient and pressure drop.

Tube lengths vary from 5 ft to more than 30 ft. Units for some heavy lube oils have been installed without fins due to the poor heat transfer inside the tube, i.e., the fins could not improve the overall coefficient above plain tubes. Economical tube lengths usually run 14–24 ft and longer. The performance of the tubes is varied for a fixed number of tubes and number of tube rows by varying the number of fins placed per lin in. on the bare tube. The usual number of fins/lin. ranges from 7–11, with the lower number giving less total finned surface, ft² per lin ft of tube. Available extended or finned surface may be increased by changing the height of the fins from the usual 1/2-in. to 5/8-in.

When the fluid in the tubes yields a low film coefficient, the amount of finned surface area is adjusted, as suggested, to provide an economical and compatible area. A high ratio of outside finned surface to bare tube surface is of little value when the outside air and inside fluid coefficients are about the same. The tubes are usually on 2-in. or 1/2-in. triangular (60°) spacing. Fin thickness usually varies from
0.016–0.014 in. The effect of mechanical bond on heat transfer resistance is discussed by Gardner.50

It is helpful to the manufacturer for the purchaser to specify any conditions that are peculiar to the plant’s warehouse stock of tubes or process controlled preferences:

1. Preferred bare tube O.D. and gage, giving minimum average wall thickness.
2. Seamless or resistance welded base tube.
3. Fin material preferred from atmospheric corrosion standpoint.

General Application

Air-cooled units have been successfully and economically used in liquid cooling for compressor engine and jacket water and other recirculating systems, petroleum fractions, oils, etc., and also in condensing service for steam, high boiling organic vapors, petroleum still vapors, gasoline, ammonia, etc. In general, the economics of application favors service allowing a 30–40°F difference between ambient air temperature and the exchange exit temperature for the fluid. These units are often used in conjunction with water-cooled “trim” coolers, i.e., units picking up the exit fluid from the air-cooled unit and carrying it down to the final desired temperature with water. In some situations, the air-cooled unit can be carried to within 20–25°F of the dry bulb air temperature if this is the desired endpoint rather than adding a small trim cooler. Kern72 has studied optimum trim cooler conditions. As the temperature approach to the ambient air decreases, the power consumption increases rapidly at constant exchanger surface. This balance of first cost vs. operating cost is one of the key comparisons in evaluating these units.

Because surface area affects the first cost much more than the normally required horsepower (driver), the selection of the proper unit is a function of the relative change in these two items for a fixed heat duty. The optimum design gives the lowest total costs (first, operating, and maintenance) over the life of the unit, taken in many instances as 15 years or longer. Fan horsepower runs 2–5 hp per 106 Btu/hr.65 First costs range from 25–150% of cooling tower systems with an average indicated at greater than 30%.115

Although these units find initial application in areas of limited water, they have not been limited to this situation. In many instances they are more economical than cooling tower systems and have been successfully applied in combination with cooling towers (see Figure 10-184). Economic comparisons should include such items as tower costs, basin, make-up facilities, water treatment, pumps for circulation, power supply, blow down, piping, etc. For small installations of air-cooled units, they should be compared

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**ILLUSTRATION OF SUMMER AND WINTER OPERATION OF THE COMBINAIRE (R)**

**SUMMER**

1. Relatively small quantity of water required, with no treatment necessary. Salt water may be used.
2. Cooled water may be used for other cooling purposes.
3. Because of elevated temperature, air leaving Combinaire is undersaturated with water vapor, thus preventing spray carryover or misting.

**WINTER**

1. No water required.
2. Shutters may be made automatically responsive to air temperature, thus automatically controlling percentage of air pre-cooled.
3. No possibility of icing as encountered in winter operated cooling towers.

(R) TRADEMARK, HUDSON ENGINEERING CORP.

Figure 10-184. Combined system using cooling tower and air-cooler units. (Used by permission: Hudson Products Corporation.)
with the prorata share of such cooling facilities unless the
specific plant account of costs dictates otherwise.

The overall economics of an air-cooled application
depends upon the following:

1. Quantity and quality of available water.
2. Ambient air and water temperature.
3. Fluid inlet as well as exit temperatures.
4. Operating pressure.
5. First costs.
6. Maintenance and operating costs.
7. Physical location and space requirements.

Mukherjee\textsuperscript{265} presents an interesting examination of fac-
tors that can influence operating problems with air-cooled
heat exchangers.

Advantages—Air-Cooled Heat Exchangers

1. Generally simple construction, even at relatively high
pressure and/or high temperatures. Amount of special
metals often is reduced.
2. No water problems, as associated with corrosion, algae,
treating, scale, spray, etc.
3. Excellent for removing high level temperatures, partic-
ularly greater than 200°F.
4. Maintenance generally claimed to be \( \frac{1}{3} \) or less than
water coolers. Clean fins by compressed air and
brushes, sometimes while operating.
5. Lower operating costs under many conditions, depend-
ing upon the type of water system used for comparison.
6. Ground space often \( \leq \) cooling towers; can also serve
dual purpose by mounting air-cooled units above other
equipment or on pipe ways or roofs of buildings. Vibra-
tion is no problem.

Disadvantages

1. Rather high limitation on outlet fluid temperature.
2. Generally most suitable only for liquids or condensing
vapors in tubes, with limited application for gas cooling
due to low inside coefficient.
3. First capital costs may range from only 25–125\% above
water-cooled equipment for same heat load. Each situ-
ation must be examined on a comparative basis.
4. Fire and toxic vapor and liquid hazard, if leaks occur to
atmosphere.
5. Not too suitable for vacuum services due to pressure
drop limitations but are used in application.

Chase\textsuperscript{24} lists these factors affecting the overall costs:

1. Exchanger Sections
   a. Tube material and thickness.
   b. Fin material size, shape.
   c. Fin bond efficiency.
   d. Header type and pressure.
   e. Type of piping connections.
2. Air Moving Equipment
   a. Power source (electricity, gas, etc.).
   b. Power transmission to fan (direct, gear, belt, etc.).
   c. Number of fans.
   d. Fan material and design.
3. Structure
   a. Slab or pier foundation.
   b. Forced or induced draft.
   c. Structural stability.
   d. Ladders, walkways, handrails.
   e. Type of construction.
   f. Belts, reducing gears, shaft and fan guards.
4. Controls
   a. Temperature control instruments.
   b. Power.
   c. Louvers, rolling doors.
   d. Mixing valves.

Factors to consider in evaluating the selection between
induced and forced draft include the following:\textsuperscript{23}

1. Induced Draft
   a. Recirculation of air is less (exit air velocity 2–3 times
      forced draft).
   b. Air distribution over exchanger is better.
   c. Sections are closer to ground and easier to main-
      tain, provided driver mounted below cooler.
   d. Maximum weather protection for finned tubes
      (rain, hail, freezing).
   e. Few walkways needed, mounting easier overhead.
   f. Connecting piping usually less.
2. Forced Draft
   a. Mechanical equipment more easily accessible.
   b. Isolated supports for mechanical equipment.
   c. Simpler structure.
   d. Easier to adapt to other than motor drives.
   e. Fan horsepower less for same performance (due to
      difference in air density).
   f. Exchangers are easier to remove for repairs.

Bid Evaluation

Manufacturer’s specification sheets, Figure 10-185, are
important for proper bid evaluation, and purchaser’s speci-
fications may be offered on a form as in Figure 10-186.

Optimum design is not often achieved in all respects;
however, the fundamentals and application cost factors of
Nakayama\textsuperscript{87} are of real value in selecting goals and design
features.

In addition to the items listed on the specification sheets
and in other paragraphs of this section, it is important for