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# A REVIEW OF LITERATURE ON THERMAL DESIGN OF FORCED DRAFT COUNTER TO CROSS FLOW AIR COOLED HEAT EXCHANGER

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## ABSTRACT

Heat exchangers are equipment that transfers heat from one medium to another. An air cooled heat exchanger, or ACHE, is simply a pressure vessel which cools a circulating fluid within finned tubes by forcing ambient air over the exterior of the tubes. In cross flow exchangers, the hot and cold fluids move perpendicular to each other. Some actual heat exchangers are a mixture of cross flow and counter flow (Known as Counter to Cross Flow Heat Exchangers) due to design features. The proper design, operation and maintenance of heat exchangers will make the process energy efficient and minimize energy losses. Heat exchanger performance can deteriorate with time, off design operations and other interferences such as fouling, scaling etc. It is necessary to assess periodically the heat exchanger performance in order to maintain them at a high efficiency level. This section comprises certain proven techniques of monitoring the performance of heat exchangers, coolers and condensers from observed operating data of the equipment.

A major problem constantly faced by heat exchanger designers is to predict accurately the performance of a given heat exchanger or a system of heat exchangers for a given set of service conditions. The problem is complicated by the fact that uncertainties exist in most of the design parameters and in the design procedures themselves. The design parameters that are used in the basic thermal design calculations of a heat exchanger include process parameters, heat-transfer coefficients, tube dimensions (e.g., tube diameter, wall thickness), thermal conductivity of the tube material, and thermo physical properties of the fluids. Nominal or mean values of these parameters are used in the design calculations. However, uncertainties in these parameters prevent us from predicting the exact performance of the unit. The effect of the uncertainties is mostly in the performance degradation in service. Hence, there is an imperative need to consider all the uncertainties and to critically evaluate them and correctly predict the thermal performance of a heat exchanger. This is particularly true for critical applications. In thermal design of heat exchangers there are presently many stages in which assumptions in mathematical solution of the design problem are being made. Accumulation of these assumptions (e.g. use of mean values) may introduce variations in design as large as the uncertainties introduced in heat-transfer and flow friction correlations. The designer needs to understand where these inaccuracies may arise, and strive to eliminate as many sources of error as possible by choosing design configurations that avoid such problems at source. Heat Exchanger Thermal Design Problem referred to as the rating and sizing problems.

**KEYWORD:**Thermal Design, Counter to cross flow heat exchanger, thermal design problems, uncertainties in design**.**

## INTRODUCTION

An air cooled heat exchanger, or ACHE, is simply a pressure vessel which cools a circulating fluid within finned tubes by forcing ambient air over the exterior of the tubes [9]. A heat exchanger is a heat-transfer devise that is used for transfer of internal thermal energy between two or more fluids available at different temperatures. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. In many heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or leak. Heat exchangers are used in the process, power, petroleum, transportation, air conditioning, refrigeration, cryogenic, heat recovery, alternate fuels, and other industries. Common examples of heat exchangers familiar to us in day-to-day use are automobile radiators, condensers, evaporators, air pre heaters, and oil coolers. To increase the heat transfer area, appendages may be intimately connected to the primary surface to provide an extended, secondary, or indirect surface. These extended surface elements are referred to as fins. Thus, heat is conducted through the fin and convected (and/or radiated) from the fin (through the surface area) to the surrounding fluid, or vice versa, depending on whether the fin is being cooled or heated. As a result, the addition of fins to the primary surface reduces the thermal resistance on that side and thereby increases the total heat transfer from the surface for the same temperature difference. Fins may form flow passages for the individual fluids but do not separate the two (or more) fluids of the exchanger. These secondary surfaces or fins may also be introduced primarily for structural strength purposes or to provide thorough mixing of a highly viscous liquid.

**Types of Heat Exchanger-**
There are three basic configurations based on the direction o f the fluid flow within the heat exchanger. These are:

1. **Parallel flow**. The two fluids streams in the heat exchanger flow in the same direction.

2. **Counter flow.** The direction of the flow of one of the fluids streams are opposite to the direction o f the other fluid.

3. **Cross flow**. In a cross flow heat exchanger, one fluid flows though the heat transfer surface at a 90 degrees angle to the flow path of the other fluid.

**Types of Draft in 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. [9]

**Forced Draft ACHE**
The most economical and most common style of air cooler is the forced draft ACHE, uses axial fans to force air across the fin tube bundle. The fans are positioned below the bundle thus not exposing the mechanical sections to the hot exhaust airflow. The forced draft air cooler also simplifies future plant expansion by providing direct access to bundle for replacement. Structural disassembly is not required **.**Forced Draft – fans are positioned below the tube bundle and force air across the fin tubes [6]. Forced draft coolers offer easy access to the tube bundle and lower horsepower. 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 for process fluids with high viscosities and/or high pour points. [9]

**Induced Draft ACHE**
The second most economical and most common style air cooler is the induced draft ACHE. This design uses axial fans to pull air across the fin tube bundle. The fans are positioned above the bundle thus offering greater control of the process fluid and bundle protection due to the additional structure. Lower noise levels at grade are another benefit. The induced draft air cooler does require some structural disassembly if bundle replacement is required. Induced Draft – fans are positioned above the bundle and pull across the fin tubes . Induced draft coolers offer improved air distribution and protection of the tube bundle from the elements. [9]

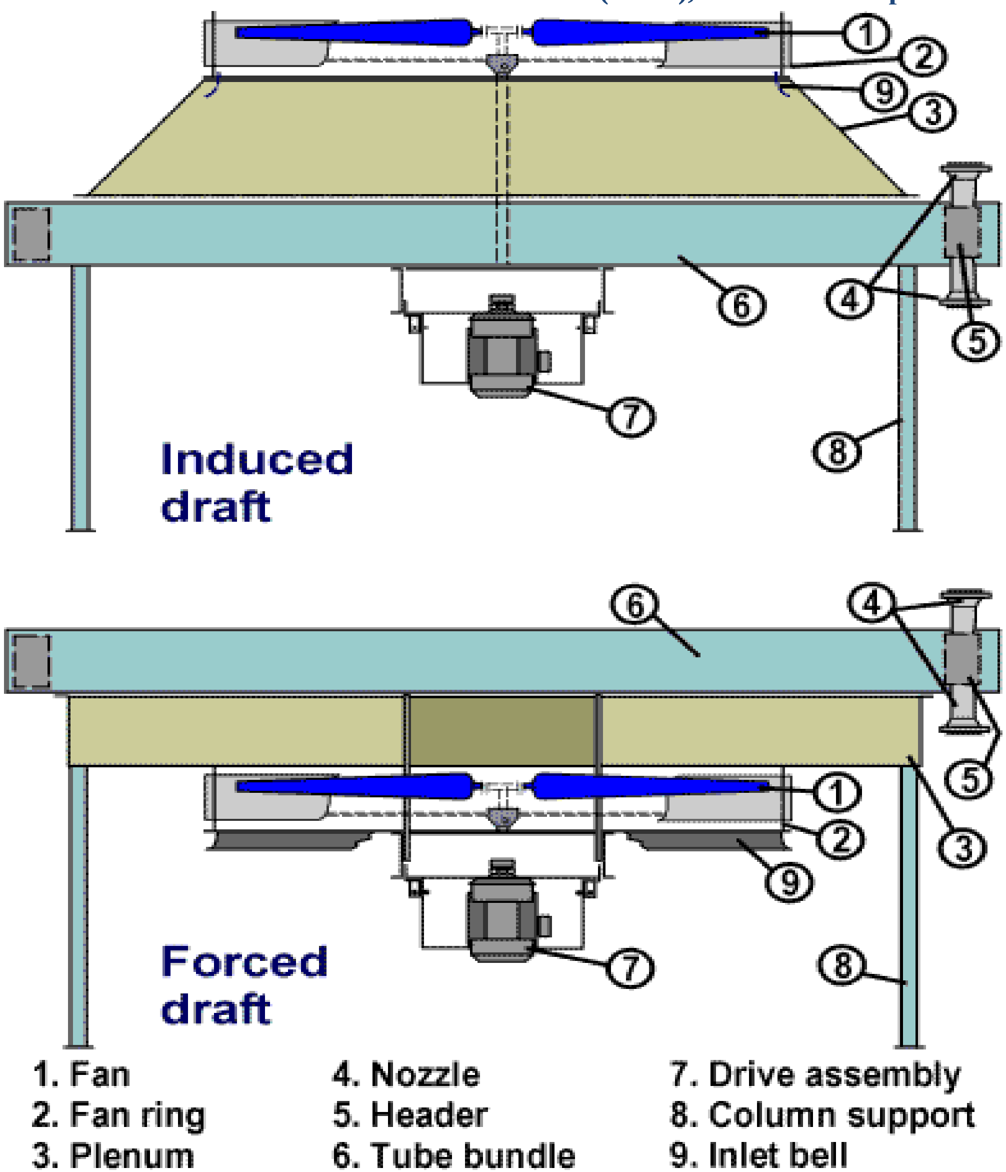
Some of the advantages and disadvantages of each model are listing below:

**Induced Draft**
**Advantages**
- Better distribution of air across the bundle.
- 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 feet per minute.
- Better process control and stability because the plenum covers 60% of the bundle face area, reducing the effects of sun, rain, and hall.
- Increased capacity in the fan-off or fan failure condition, since the natural draft stack effect is much greater.

**Disadvantages and limitations**
- Possibly higher horsepower requirements if the effluent air is very hot.
- Effluent air temperature should be limited to 220°F to prevent damage to fan blades, bearings, or other mechanical equipment in the hot air stream. 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 operation.
- Fans are less accessible for maintenance, and maintenance may have to be done in the hot air generated by natural convection. Plenums must be removed to replace bundles

**Forced Draft**
**Advantages**
- Possibly lower horsepower requirements if the effluent air is very hot. (Horsepower varies inversely with the absolute temperature.)
- Better accessibility of fans and upper bearings for maintenance.
- Better accessibility of bundles for replacement.
- Accommodates higher process inlet temperatures.

**Disadvantages**
- Less uniform distribution of air over the bundle.
- Increased possibility of hot air recirculation, resulting from low discharge velocity from the bundles, high intake velocity to the fan ring, and no stack.
- Low natural draft capability on fan failure.
- Complete exposure of the finned tubes to sun, rain, and hail, which results in poor process control and stability.




***Photograph by Hudson Product Corporation***

**Which is better forced draft or induced draft?**

It depends. The majority of air-cooled exchangers is of forced draft construction. Forced draft units are easier to manufacture and to maintain. The tube bundle is mounted on top of the plenum, so it can be easily removed and replaced. The fan shaft is short, since it does not have to extent from the drive unit through the tube bundle and plenum to the fan, as in an induced draft design. Forced draft units require slightly less horsepower since the fan are moving a lower volume of air at the inlet than they would at the outlet. If the process fluid is very hot, the cooling air is hot at the outlet. This could cause problems with some fans or fan pitch actuators if the fan is exposed to very hot exhaust air. Since forced draft coolers do not have the fans exposed to hot exhaust air, they are a better choice in such cases. (API 661 offer some guidelines for this.)

However, induced draft units have some advantages, too. A common problem with forced draft coolers is accidental warm air recirculation. This happens when the hot exhaust air is pulled back in to the fans. Since a forced draft cooler has a low air velocity at the exhaust from the bundle and a high velocity through the fan, a low pressure area is created around the fan, causing the hot air to be pulled over the side or end of the bay. For this same reason, there should never be a small space between the bays of a bank of forced-draft cooler. Induced draft cooler have a high exhaust air velocity through the top-mounted fan, and a lower velocity into the face of the tube bundle below. This tends to minimize the probability of accidental air recirculation. Also an induced draft plenum does not have to support the tube bundle so some weight can often be saved in this area.

The advantages of forced and induced draft types are -
a. Induced-draft units should be used whenever hot-air recirculation is a potentially critical problem.
b. Forced-draft units should be used whenever the design requires pour point protection, or winterization. However, consideration of possible summer recirculation must be accounted for in sizing the fans to minimize this effect.

## CONSTRUCTION OF HEAT EXCHANGERS

**A** heat exchanger consists of heat-exchanging elements such as a core or matrix containing the heat-transfer surface, and fluid distribution elements such as headers or tanks, inlet and outlet nozzles or pipes, etc. Usually, there are no moving parts in the heat exchanger; however, there are exceptions, such as a rotary regenerator in which the matrix is driven to rotate at some design speed.

### Heat Exchanger Thermal Design Problems

From the quantitative analysis point of view, there are a number of heat exchanger thermal design problems. Two of the simplest (and most important) problems are referred to as the rating and sizing problems.

**Rating Problem.** Determination of heat transfer and pressure drop performance of either an existing exchanger or an already sized exchanger (to check vendor's design) is referred to as a rating problem. Inputs to the rating problem are the heat exchanger construction, flow arrangement and overall dimensions, complete details on the materials and surface geometries on both sides, including their non dimensional heat transfer and pressure drop characteristics ( j or Nu and f vs. Re), fluid flow rates, inlet temperatures, and fouling factors. The fluid outlet temperatures, total heat transfer rate, and pressure drops on each side of the exchanger are then determined in the rating problem. The rating problem is also sometimes referred to as the performance or simulation problem.

**Sizing Problem.** In a broad sense, the design of a new heat exchanger means the determination/selection of an exchanger construction type, flow arrangement, tube/ plate and fin material, and the physical size of an exchanger to meet the specified heat transfer and pressure drops within all specified constraints. However, in a sizing problem for an extended surface exchanger, we will determine the physical size (length, width, height, and surface areas on each side) of an Heat exchanger. [27]

## UNCERTAINTIES IN THERMAL DESIGN OF HEAT EXCHANGERS

A major problem constantly faced by heat exchanger designers is to predict accurately the performance of a given heat exchanger or a system of heat exchangers for a given set of service conditions. The problem is complicated by the fact that uncertainties exist in most of the design parameters and in the design procedures themselves **.** The design parameters that are used in the basic thermal design calculations of a heat exchanger include process parameters, heat-transfer coefficients, tube dimensions (e.g., tube diameter, wall thickness), thermal conductivity of the tube material, and thermo physical properties of the fluids. Nominal or mean values of these parameters are used in the design calculations. However, uncertainties in these parameters prevent us from predicting the exact performance of the unit. The effect of the uncertainties is mostly in the performance degradation in service. Hence, there is an imperative need to consider all the uncertainties and to critically evaluate them and correctly predict the thermal performance of a heat exchanger. In this section, various uncertainties that influence the thermal performance and a method to account for these uncertainties in the design calculations are presented. [28]

### Uncertainties in Heat Exchanger Design

Various uncertainties and their reasons are:
1. Fluid flow rates, temperatures, pressures, and compositions vary from the design conditions.
**2.** Temperatures of cooling water and air used to cool process fluids vary with seasonal temperature changes.
**3.** Physical properties of the process fluids are often poorly known, especially for mixtures.
4. Heat-transfer and pressure-drop correlations from which one computes convective heat transfer coefficients and pressure drop have data spreads around the mean values.

5. Manufacturing of heat-transfer tubes and other component dimensions influencing thermal performance does not produce precise tube dimensions.
6. Manufacturing tolerances in equipment lead to significant differences in thermo hydraulic performance between nominally identical units.
7. Fouling of heat-transfer surface is poorly predictable.
**8.** Miscellaneous factors influence the thermal performance.
   a. Uncertainty in process conditions
   **b.** Uncertainty in the physical properties of the process fluids
   **c.** Flow non uniformity
   **d.** Non uniform flow passages
9. Bypass path on the air side of compact fin-tube exchangers
**10.** Non uniform heat-transfer coefficient
11. Uncertainties in fouling
12. Miscellaneous effects

**Uncertainty in Process Conditions**
Heat exchangers are designed for a nominal set of operating conditions chosen to represent a relatively ideal state of a system. In general, a heat exchanger will not operate under the ideal design conditions. Process stream flow rates, compositions, and temperatures can all be expected to vary during the lifetime of the exchanger, and seasonal changes in weather constantly change cooling water and air temperatures.

**Uncertainty in the Physical Properties of the Process Fluids**
Correlations for heat-transfer coefficients and pressure drops, and the heat-transfer rate equation, require values of one or more of the following physical properties: density, specific heat, viscosity, thermal conductivity, latent heat, etc.

**Flow Non uniformity**
To obtain maximum thermal performance, the flow should be uniform across the entire frontal area of the core. However, the flow may not be uniform due to unfavorable header design, nozzle location, and non uniform flow passages in the case of tube-fin and plate-fin heat exchangers.

**Non uniform Flow Passages**
For high-surface-density compact heat exchangers like tube-fin and plate-fin units with parallel fins, the identified non uniform flow passages are due to(1) non uniform fin spacing, (2)re curved fin, and **(3)** open fin. For mechanically bonded tube-fin cores, there is ample scope for bunching of fins due to deficiency in bullet expansion, thermal fatigue, and cracking of fin collars. [28]

**Basic Thermal and Hydraulic Design Methods.** Based on the number of variables associated with the analysis of a heat exchanger, dependent and independent dimensionless groups are formulated. The relationships between dimensionless groups are subsequently determined for different flow arrangements. Depending on the choice of dimensionless groups, several design methods are being used by industry. These methods include e-NTU, P-NTU, MTD correction factor, and other methods. Inputs to the thermal and hydraulic procedures are the surface heat transfer and flow friction characteristics (also referred to as surface basic characteristics), geometrical properties, and thermo physical properties of fluids, in addition to the process/design specifications.

**Thermal and Hydraulic Design Problem Solution.** Solution procedures for rating and sizing problems are of an analytical or numerical nature, with empirical data for heat transfer and flow friction characteristics and other pertinent characteristics. Due to the complexity of the calculations, these procedures are often executed using commercial or proprietary computer codes. Since there are many geometrical and operating condition–related variables and parameters associated with the sizing problem, the question is how to formulate the best possible design solution (selection of the values of these variables and parameters) among all feasible solutions that meet the performance and design criteria. This is achieved by employing mathematical optimization techniques after initial sizing to optimize the heat exchanger design objective function within the framework of imposed implicit and explicit constraints.

**Heat Exchanger Pressure Drop Analysis**

Fluids need to be pumped through the heat exchanger in most applications. It is essential to determine the fluid pumping power required as part of the system design and operating cost analysis. The fluid pumping power is proportional to the fluid pressure drop, which is associated with fluid friction and other pressure drop contributions along the fluid flow path. [27]

**Importance of Pressure Drop**

The determination of pressure drop in a heat exchanger is essential for many applications for at least two reasons:
(1) The fluid needs to be pumped through the exchanger, which means that fluid pumping power is required. This pumping power is proportional to the exchanger pressure drop.

(2) The heat transfer rate can be influenced significantly by the saturation temperature change for a condensing/evaporating fluid if there is a large pressure drop associated with the flow. This is because saturation temperature changes with changes in saturation pressure and in turn affects the temperature potential for heat transfer.

The pressure drop associated with a heat exchanger is considered as a sum of two major contributions: pressure drop associated with the core or matrix, and pressure drop associated with fluid distribution devices such as inlet/outlet headers, manifolds, tanks, nozzles, ducting, and so on. The purpose of the heat exchanger is to transfer thermal energy from one fluid to the other; and for this purpose, it requires pressure difference (and fluid pumping power) to force the fluid flow over the heat transfer surface in the exchanger. Hence, ideally most of the pressure drop available should be utilized in the core and a small fraction in the manifolds, headers, or other flow distribution devices. However, this ideal situation may not be the case in plate heat exchangers and other heat exchangers in which the pressure drop associated with manifolds, headers, nozzles, and so on, may not be a small fraction of the total available pressure drop. If the manifold and header pressure drops are small, the core pressure drops dominates. This results in a relatively uniform flow distribution through the core. All heat transfer and core pressure drop analyses outlined here that the flow distribution through the core is uniform. A serious deterioration in performance may result for a heat exchanger when the flow through the core is not uniformly. The core pressure drop is determined separately on each fluid side. It consists of one or more of the following contributions, depending on the exchanger construction:
(1) frictional losses associated with fluid flow over the heat transfer surface (this usually consists of skin friction plus form drag),
(2) momentum effect (pressure drop or rise due to the fluid density changes in the core),
(3) pressure drop associated with sudden contraction and expansion at the core inlet and outlet, and
(4) gravity effect due to the change in elevation between the inlet and outlet of the exchanger. The gravity effect is generally negligible for gases. [27]

**Assumptions made for the pressure drop analysis-**

The following are the major assumptions made for the pressure drop analysis-
1. Flow is steady and isothermal, and fluid properties are independent of time.
2. Fluid density is dependent on the local temperature only or is treated as a constant (inlet and exit densities are separately constant).
3. The pressure at a point in the fluid is independent of direction. If a shear stress is present, the pressure is defined as the average of normal stresses at the point.
4. Body forces are caused only by gravity (i.e., magnetic, electrical, and other fields do not contribute to the body forces).
5. If the flow is not irrotational, the Bernoulli equation is valid only along a streamline.
6. There are no energy sinks or sources along a streamline; flow stream mechanical energy dissipation is idealized as zero.

**Computational Software for Using Thermal Design of Air Cooled Heat Exchanger**

Reflecting the growing trend of using computers for design and teaching, recent heat transfer texts incorporate computer software for the design and optimization of heat exchangers. These software are written to reinforce fundamental concepts and ideas and allow design calculations for generic configurations with no reference to design codes and standards used in the heat exchanger industry. For actual engineering applications, most heat exchangers are designed using commercially available software such as those developed by co-operative research organizations such as Heat Transfer and Fluid Flow Service (HTFS) and Heat Transfer Research Inc. (HTRI) and by computer service companies such as B-JAC International. These programs offer design and cost analysis for all primary heat exchanger types and incorporate multiple design codes and standards from the American Society of Mechanical Engineers (ASME), Tubular Exchangers Manufacturers Association (TEMA) and the International Standards Organization (ISO). These are user-friendly computer software developed for the thermal and hydraulic design of heat exchangers. [19]

## OBJECTIVES OF LITERATURE REVIEW

1. The main objective of this master thesis is to give the idea for thermal design of Forced Draft Counter to Cross Flow Air Cooled Heat Exchanger, as there are lots of problems associated, while designing an Air Cooled Heat Exchanger
2. To identify the best possible method of thermal design of Forced draft counter to cross flow Air Cooled Heat Exchanger
3. To discuss various parameters considered for Forced draft counter to cross flow air cooled heat exchanger Design.
4. To highlight various uncertainties keep in mind while designing a counter to cross flow Air Cooled Heat Exchanger.
5. To discuss the importance of pressure drop in heat exchanger performance
6. To discuss various assumptions while designing counter to cross flow air cooled heat exchanger
7. To give the basic thermal design & hydraulic design procedure of ache.
9. To discuss the various challenges while designing the Counter to Cross Flow Heat Exchanger.
10. To give an idea about forced draft he & induced draft Air Cooled Heat Exchanger type.
11. To give the brief perspective of counter to cross flow Air Cooled Heat Exchanger.

## CONCLUSION & OUTCOME

For accurate calculation of thermal design, the various computing software are available such as Heat Transfer and Fluid Flow Service (HTFS) and Heat Transfer Research Inc. (HTRI) and by computer service companies such as B-JAC International etc which precisely calculate the data of Air Cooled Heat Exchanger thermal design, because it was a very complex & cumbersome work for calculating these data manually & manual calculation may lead to miscalculation of Air Cooled Heat Exchanger Design .Uncertainties & thermal design problems like rating problem ,sizing problem etc that were discussed above should also be kept in mind while designing counter to cross flow Air Cooled Heat Exchanger

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