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Application of Thermo-Pur Manufacturing Technology to Air Cooled Condensers

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Abstract

Taking advantage of the superior heat transfer qualities of cross-corrugated heat exchangers (HXs) and its proprietary manufacturing process, Thermo-Pur Technologies has designed an air cooled condenser (ACC) bundle that produces a 300% increased heat transfer coefficient over current designs for the same face area and fan power while reducing ACC bundle weight 60 to 78%, bundle cost 25 to 56% and ACC module cost 20% or more. A Thermo-Pur ACC module may also reduce structural steel cost 15 to 30%, shipping up to 70%, installation 20% or more, and overhead and contingency by 20% or more.

Introduction

Thermo-Pur Technologies has pioneered a new automated process for the production of corrugated plate heat exchangers constructed of thin, high tensile strength foil. The process employs high speed laser welding and rapid superplastic profiling to form corrugated plate HX cores constructed of 0.1-0.3mm thick Type 304 stainless steel (SS304). Thermo-Pur's manufacturing technology enables the fabrication of the low cost cross-corrugated stainless steel plate heat exchangers. This paper describes the advantages of substituting Thermo-Pur plate heat exchangers for finned tube heat exchangers in existing air cooled condenser (ACC) designs.

Current ACC design

A detailed description of the modern ACC is given in "Air-Cooled Condenser Design, Specification, and Operation Guidelines" issued by the Electric Power Research Institute (EPRI) in 2005.[1]

ACC manufacturers assemble the ACC "in-house". At the power station site the ACC is installed and connected to other equipment. The photo below shows an ACC block consisting of 4 modules. Each module consists of heat exchanging bundles arranged in an "A" shape heat exchanger. The ACC block depicted in Figure 1 below was manufactured by GEA and weighs 460 tons (each ACC module weighs 115 tons). This ACC module weight value will be used throughout this paper for further estimation.

Figure 1

Taking into account the size and weight of the ACC block, its transportation and installation appears to be rather complex and expensive operation.

The typical ACC component cost breakdown is given at page 5-4 of the referenced EPRI report. The total cost of a 10 bundle ACC module is $600,000. The ACC bundles comprise 32% of the total cost. Consequently, the cost of one bundle may be estimated as $16,000.

Most recent ACC heat exchanging bundle designs use elongated, nearly rectangular flow passages separated by plate fins, referred to as a single row condenser (SRC). The basic element of such bundles is a carbon steel plate tube with aluminum fins. A cross-section of a SRC finned tube is shown at Figure 2.

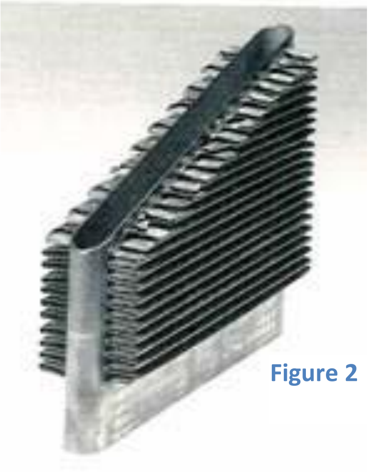


Figure 2

Approximate dimensions of such heat exchanging elements are:

- Inner flat carbon steel tube: wall thickness 1,5 mm; outer short side 19 mm; outer long side 219 mm along the air flow.
- Aluminum fins: .3 mm thick, 200 mm along the air flow, 19 mm height; fin step is 2.3 mm.

The finned tubes are typically about 30–40 ft (9–12 m) long, and are clustered in bundles typically 8 ft (2.5 m) across.

The weight of carbon steel tubes in such a bundle is approximately 2400 kg. The weight of the aluminum fins is approximately 1300 kg. The total bundle weight is thus approximately 3700 kg.

SRC Module (10 Bundle A-Frame)
Source: EPRI-Technical Report, December 2005

HX Material	% Cost	Est. $
* Heat Exchanger Bundles	32.0 %	$192,000
* Structural Steel	16.0 %	96,000
* Shipping (US Destination)	11.0 %	66,000
Other Material	22.8 %	137,040
* Overhead, Contingency, Profit	18.2 %	108,960
Subtotal Material Cost	100.0 %	$600,000
* Installation Cost Estimate (industry planning factor)	40 % of Material Cost	$240,000

*Elements where Thermo-Pur reduces cost.

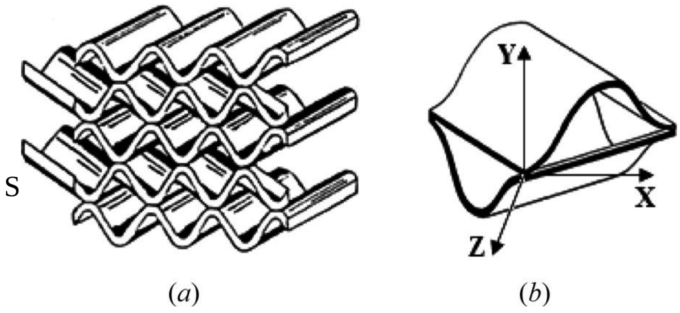
Advantages of Cross Corrugation

To improve heat transfer we need to reduce the primary resistance to heat flow: the thermal boundary layer. Usual methods are to reduce the distance between hot and cold flows and to increase the heat flow by turbulization.

The Thermo-Pur manufacturing process enables low cost fabrication of a well known heat exchanger design: cross corrugated plates utilizing thin stainless steel (0.05-0.3mm). Stainless steel allows for the thinnest wall construction, has the best corrosion resistance, the highest operating temperature, and is the least expensive.

The high tensile strength of SS304 allows the formation of a durable corrugated profile on the plates that maximizes turbulization of both the hot and cold flows.

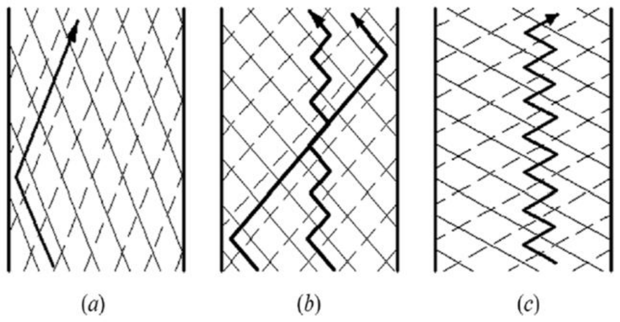
Cross corrugated plates (a) and single sinusoidal cell (b): [2]



(a) (b)

Figure 3

Flows follow multiple intersecting paths creating intense turbulization:



(a) (b) (c)

Figure 4

Steam flow depiction:

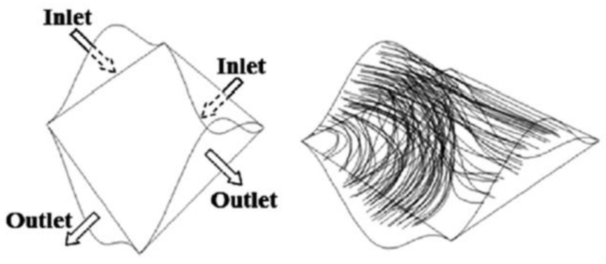


Figure 5

Thermo-Pur ACC Heat Exchanger Design

In order to evaluate the advantages of TPT technology application in ACCs we have designed a new bundle based on TPT plate SS heat exchangers. This new bundle is fully interchangeable with existing ACC bundles.

The basic element of the TPT bundle is an envelope made of two corrugated plates welded at the perimeter. The steam duct is inside the envelopes while the cooling air duct is outside the envelopes.

The envelope view is shown in Figure 6.

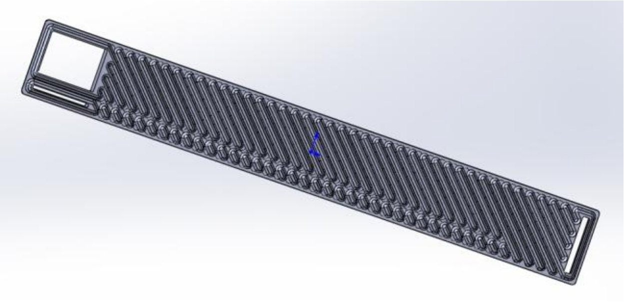


Figure 6

The envelope has three portholes – steam inlet and non condensed gases exit portholes at one end of the envelope and water exit porthole at the other end of the envelope. The steam path has asymmetric “U” form.

In standard ACC designs there are primary and secondary modules which may have different bundle designs. In the primary bundles the flow directions of steam and condensate film are the same providing higher heat transfer properties during condensation. In the secondary bundles steam is moving up together with non-condensed gases contrary to the direction of condensate film movement. In the TPT envelope both functions are superposed. Therefore all bundles are identical, eliminating the need for secondary bundles.

The envelope is made of SS foil with initial thickness .10 mm. The length of the envelope is 800 mm; the width of the envelope along the air flow is 100 mm.The envelope thickness is 10 mm.

The corrugated walls of the envelope form the channels inside the envelope for the steam and condensate and channels between the envelopes for the cooling air. The envelopes are welded together at the edges of the portholes to form the heat exchanger core.
The heat exchanging process may be optimized by modifying the step and the height of the corrugations and by changing the angle between them.

The choice of corrugation parameters ensure maximal steam condensing inside the envelope and condensate draining.

The relative concentration of non-condensed gases is growing during steam condensation process, and as a result the condensation temperature is decreasing. Therefore the removal of the steam saturated by non-condensed gases is provided along the coldest part of the envelope.

At the same time the air side of the heat exchanging surface has the best properties – the highest heat exchanger coefficient for a given fan power consumption.

The ACC heat exchanger unit formed by welding of 106 envelopes by porthole’s edges is shown in Figure 7 below where the volumes inside the portholes form the inlet steam, exit gases and exit water headers.

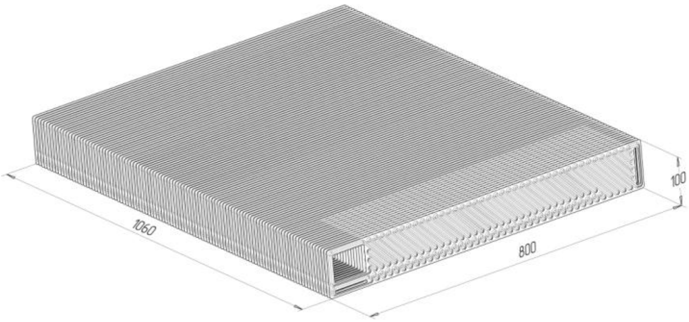


Figure 7

The heat exchanging units are installed in the frame comprised of steam distributing manifolds. The separate frame and the frame with 30 heat exchanging units (two rows with 15 units in each) are shown in Figures 8 and 9 below.

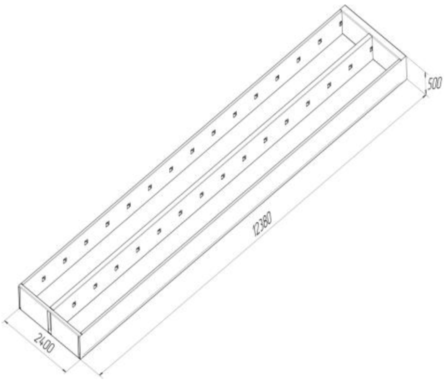


Figure 8

Figure 9

The frame design provides steam supply to each unit as well as condensate draining and non-condensable gas removal. The frame weight is estimated as 400 kg. Thirty units in one frame form the bundle. The steam is supplied from both sides to each unit, the same as water draining and gas removal. The total TPT bundle weight is estimated as 800 kg (400 kg carbon steel frame weight and 400 kg total SS units weight).

TPT variant of ACC bundle was designed for the same bundle cross section and operating conditions as the existing ACC bundle.

The plate heat exchangers have primary surface. Therefore the overall heat transfer coefficient differs for only a small amount from the heat transfer coefficient at the air side. The finned tubes have additional thermal resistances: fin resistance and wall resistance. Wall resistance in tube/fin design is 80 times greater than in TPT design because the wall is 20 times thicker and the tube walls surface is 4 times smaller. At the steam side the heat exchanging surface is 4 times larger in the TPT design.

The main advantages of the TPT bundle design was achieved due to excellent heat transfer properties of the cross corrugates surfaces and reduction of thermal resistance relative to existing tube/fin design. The overall heat transfer coefficient appeared to be 4 times greater than in tube/fin design and, therefore the heat transfer surface value at the air side was taken 4 times smaller.

The total TPT bundle cost is estimated to be reduced by 25 to 56%.

Thermo-Pur Heat Exchanger Performance

Thin wall construction and intense turbulization enable the Thermo-Pur ACC bundle design to achieve heat exchanging efficiency of 123 W/m^2-K and a total heat rejection of 1062 kW under the generic conditions described in the table below. Different conditions and design goals will result in different configurations and performance outcomes.

	Hot	Cold
Heat carriers	Steam	Air
Inlet temperature	90 – 140 degF	10 – 100 degF
Outlet temperature	90 – 140 degF	
Flow rate	45000 lbs/hour per module	1,500,000 ACFM per module 2-3.5 m/s air face velocity
Pressure	50 – 250 mbara	atmospheric
Pressure losses	5-25 mbara	0.5-1.0 in H2O

ACC bundle performance calculations

1. The steam flow to the bundle is 5.64 kg/s (45000 lbs/hour) /12 = 0.47 kg/s; specific condensation heat is 2300 kJ/kg. Thus the thermal power rejected from the bundle is 0.47 x 2300 = 1081 kW.

2. The air flow to the bundle is 708 m^3/s (1500000 ACFM)/12 = 59 m^3/s; the air density under the given parameters (hot case 100 deg F) = 1.13 kg/m^3; air heat capacity is 1.006 kJ/kg^{o}C. Water equivalent for air is 59 x 1.13 x 1.006 = 67.1 kJ/^{o}C.

3. Air temperature growth at the bundle exit is 1081/67.1 = 16.1 ^{o}C.

4. Inlet air temperature is 37.8^{o}C (100 deg F); steam condensation temperature is 60^{o}C (140 deg F). Maximal possible temperature increase of air in the bundle is 60 - 37.8 = 22.2 ^{o}C.

5. The required heat exchanger efficiency is 16.1/22.2 = 0.7.

6. The Number of Thermal Units (NTU) ensuring such efficiency in the one way cross flow heat exchanger is

1.2 (see “Compact Heat Exchangers” by Kays and London).

7. The required product of heat exchange surface area and heat transfer coefficient **h** is 67.1 x 1.2 = 80.5 kJ/ ^{o}C = 80 000 W/ ^{o}C.

8. Calculation of the heat transfer coefficient **h**:

8.1. The heat-transfer coefficient is determined by following values: **h** = 1/(Rc + Rh + Rm); where Rc - resistance on the cold fluid side; Rh - resistance on the hot fluid side; Rm - resistance of the metal wall.

In our case the heat resistance for the condensing steam Rh and the resistance for the metal wall Rm are negligible and it is enough to specify only the resistance for air - Rc.

Note: When the heat exchanging surface is covered by fins, the steam side resistance and metal resistance (fins resistance) may be of importance. These resistances may reduce the overall heat transfer coefficient relatively to the coefficient of heat transfer for the air side sometimes additionally for 30 - 40 % (basing on our experience). These resistances are not present in the case of cross corrugated surface.

8.2. The coefficient of heat transfer for air side 1/Rc:

8.2.1. The full cross section of air flow (given in initial data) is 40 x 8 sq. feet = 320 sq. feet = 30 m^2.

8.2.2. The part of the cross section which is occupied by steam distributing manifolds and steam and water headings inside the units is 4.6 m^2, another part of this area is occupied by envelopes with steam - 11.9 m^2. The effective area of the heat exchanger front for the air flow is 30 - 4.6 - 11.9 = 13.5 m^2.

8.2.3. The average air velocity between the envelopes is 59/13 .5 = 4.4 m/s.

8.2.4. Equivalent diameter of the heat exchanging surface is chosen equal to 8.5 mm (.0085 m); the angle between corrugations is chosen 90 degrees. The choice of these two main parameters is made basing on our experience.

8.2.5. Kinematic viscosity = 16.95 mm^2/s.
Re number = 4.4 x 1000 x 8.5/16.95 = 2200.

8.2.6. **Nu** number. We use experimental data determining dependence between **Re** number and **Nu** number for cross corrugated surfaces. These data were received in Soviet Union in 70-ies and published in Russian. Later they were verified while creating industrial heat exchangers in Russia (such as gas turbine recuperators and others). These data correlate also well with numerous experimental data received by other researchers later in Europe and US. One of the most important parameter for cross corrugated surfaces is the angle between the corrugations. In case of the zero angle (parallel corrugations), the surface degenerate into smooth channels and **Nu** value becomes equal to 10 - the same as for the flow inside round tube for **Re** number = 2300. When the angle between the corrugations increases up to 90 degrees (our case) then the **Nu** number reaches 40.

8.2.7. Air heat conductivity is 0.027 W/m ^{o}C. The coefficient of heat transfer for air = 40 x 0.027/0.0085 = 127 W/m^2 ^{o}C (.0085 m is equivalent diameter).

8.3. Coefficient of heat transfer for heat transfer surface is accepted equal to the coefficient of heat transfer for air = 127 W/ m^2 ^{o}C.

9. The required value of the heat exchange surface = 80,000/128 = 625 m^2.

10. The air part of heat exchanger core volume is 625 x 0.0085/4 = 1.33 m^3.

11. Heat exchanger core size along the air flow (core thickness) =1.33/13.5 = 0.09 m (13.5 m^2 is the surface determined in 8.2.2).

12. Hydraulic resistance of the air side.

12.1. Dynamic pressure at the air side 1.13 x 4.4^2/2 = 10.9 Pa (1.1 mm H_2O).

12.2. Inlet resistance of the core is roughly accepted equal to the dynamic pressure = 1.1 mm H_2O.

12.3. Exit resistance of the core is roughly accepted equal to the dynamic pressure = 1.1 mm H_2O.

12.4. Resistance of the core.

12.4.1. Friction factor: we use experimental data defining the relationship between Re number and Friction factor for such surfaces, similar data for **Nu** number. One of the most important factors for these surfaces is the angle between the corrugations. In case of the zero angle the surface degenerate into smooth channels and Friction factor becomes 0.07 - the same as for flow inside round tube at **Re** number = 2300. When the angle between corrugation increases up to 90 degree (our case), then Friction factor reaches 0.7.

12.4.2. Core resistance coefficient = 0.7 x 0.1/0.0085 = 8.2.

12.4.3. Core resistance = 8.2 x 1.1 = 9 mm H_2O.

12.5. Full resistance for the air side = 1.1 + 1.1 + 9 = 11.2 mm H_2O.

13. Design solution: the heat exchanger is divided into 30 equal units with 22 m^2 of heat transfer surface in each.

14. Steam distributing manifolds inside the units have cross section .005 m^2. Each unit has two entrance portholes. Steam flow is 0.0078 kg/s for each entrance porthole. Steam density is 0.17 kg/m^3, volumetric flow - 0.046 m^3/s, and accordingly maximal steam velocity for the hot case is 0.046/0.005 = 9.2 m/s; under the cold conditions the vapor density would be 5 times smaller, Thus the steam velocity in the inlet portholes will increase up to 46 m/s. The estimated steam velocity inside the envelopes is 2 - 10 m/s.

Thermo-Pur Weight and Cost Comparison

	Current Technology	**Thermo-Pur**
HX Material	CS tubes; Al fins	Corrugated SS304 plates
Bundle weight (kg)	3,700	800

Thus the application of TPT technology for ACC module manufacturing may reduce ACC bundle weight 60 to 78%, and bundle cost 25 to 56% and ACC module cost 20% or more. A Thermo-Pur ACC module may reduce structural steel cost 15 to 30%, shipping up to 70%, installation 20% or more, and overhead and contingency by 20% or more.

Conclusion

Thermo-Pur’s manufacturing innovation creates new design possibilities for ACCs and reduces their material, construction and maintenance cost. Until now, the use of stainless steel, with its superior tensile strength and corrosion resistance in massive heat exchangers such as ACCs has been cost prohibitive. Thermo-Pur’s manufacturing process enables the cost effective joining and profiling of thin, high tensile strength metals to form plate heat exchangers that take advantage of the well known performance properties of cross corrugation, dramatically reducing the mass of an ACC while improving its performance.

Notes

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2. Figures 3-5 are found in “Numerical Simulation of Heat Transfer in Primary Surface with Corrugations Recuperators.” by Liu Hanpeng, Liu Xuedong, and “Influence of Corrugation Profile on the Thermalhydraulic Performance of Cross-Corrugated Plates.” by Zhou Ling and in Lei Zhanga.

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