Evaporators

Fundamentals – Part 1

This series of articles by Ramesh Paranjpey covers the fundamentals of evoporators. The articles will serve as a source of reference for newcomers joining the industry as well as for experienced engineers wishing to brush up on fundamentals.

Over the years with the growth of technology and manufacturing techniques, many different types of evaporators have been introduced that have enhanced heat transfer capabilities, compacted the size and reduced costs. These different types, their important features, their application, precautions to be taken while selecting and installation practices will be brought out in future issues of the *Classroom* series to familiarize the reader with the wide variety available today and commonly used.

An evaporator is an important component of the refrigeration system as it performs the primary function of extracting heat from the surrounding air or medium to be cooled, which could be water, brine or any other solid substance, into the refrigeration system.

In order to absorb heat into the refrigeration system, refrigerant is circulated at a temperature lower than the medium to be cooled and at a temperature that varies with the application.

For example, it could be 5 to 7°C in air conditioning applications, 1 to 2°C for chilled water application, around –5°C for fruit and vegetable cold storage, about –10°C for ice plants, –25°C for fish and meat storage, –30°C for ice cream storage and –40°C for blast/plate freezers. Applications can stretch right up to the absolute zero temperature i.e. –273.15°C.

While looking at these applications, it is interesting to note that irrespective of the applications mentioned above, the condensing temperature would be same for all the systems once we decide which type of condenser is to be used, i.e. either air or water cooled or evaporative type. This is due to the fact that condensing temperature is solely dependent on ambient dry and or wet bulb temperature, and not on the type of application. Selection of condenser is therefore much simpler compared to low side equipment i.e. evaporator which is unique for each application. The performance of refrigeration/air conditioning system is therefore largely dependent on the evaporator design since proper design and selection would ensure that the system produces the desired performance.

Before proceeding further into details of the various types of evaporators, let us brush up on some basic principles and equations that will help in understanding technical parameters when we come across them subsequently.

Figures 1 and *2* show the basic refrigeration cycle and the pressure /enthalpy diagram, both of which are needed to understand the function of the evaporator in the refrigeration system

From these figures it can be seen that the refrigerant entering the evaporator is a low temperature, low pressure saturated mixture of liquid/vapour and and when it leaves the evaporator, it is a low temperature, low pressure saturated vapour or superheated vapour.

From the P-H diagram it can be seen that in the evaporator, heat transfer is predominantly a process of latent heat transfer where phase change from liquid to

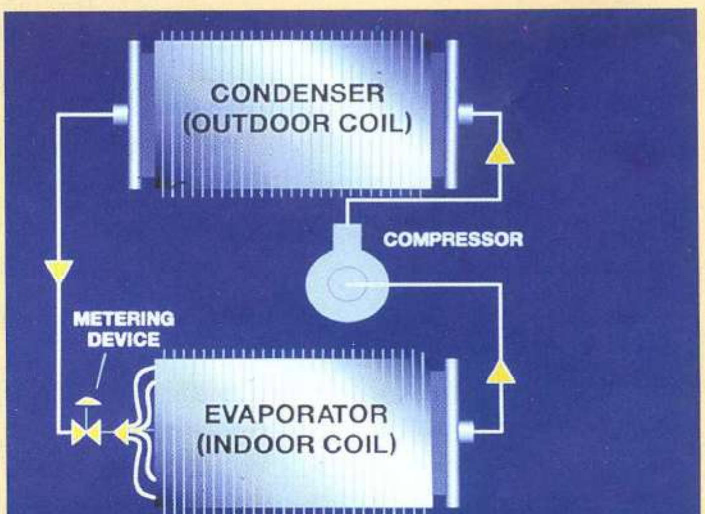

Figure 1 : Basic refrigeration cycle

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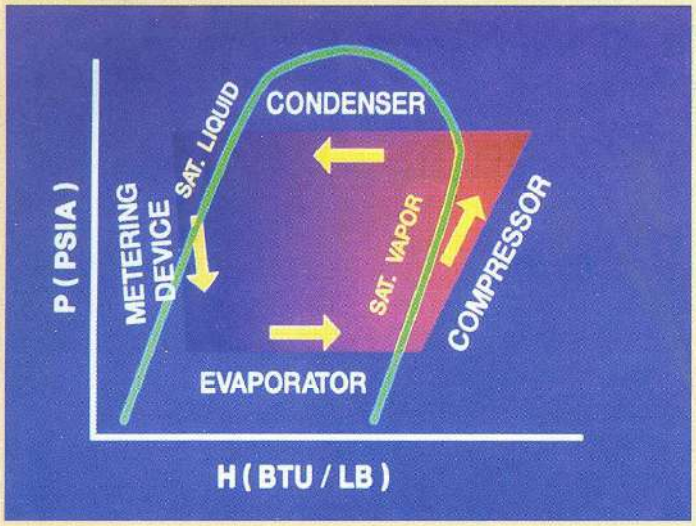


Figure 2 : Pressure-enthalpy diagram

vapour takes place thereby absorbing a large amount of heat in to the system and rapidly extracting the heat from the medium to be cooled. Evaporator performance also improves with sub-cooled refrigerant entering the evaporator.

The basic equations for determining evaporator performance are

$$Q = m \times Cp \times \Delta T \quad (1)$$

- Where m is the mass of substance in lb or kg
- Cp is the specific heat
- $\Delta T = T_1 - T_2$

Where T_1 is the temperature of the medium entering the evaporator in °F/°C and T_2 is the temperature leaving the evaporator in °F/°C

In the FPS system of measurement, this equation is used to determine the capacity of the plant in tons. Alternatively, if the tons of refrigeration is given, we can calculate flow rates of the evaporator fluids i.e. either water or brine solutions like ethylene/propylene glycol or any other low temperature fluid.

We can further simplify the equation for water as:

Q in Btu/hr = 500 × US gpm × ΔT where 500 is the multiplication of 60 minutes × 8.33 lb/gallon in case of water since one US gallon of water weighs 8.33 lbs.

In case of brines we have to multiply by specific gravity and specific heat to arrive at a correct heat load and the equation would then become

Q in Btu/hr = 500 × US gpm × sp.gr. × sp.ht. × ΔT

Q for air is = 1.08 × cfm × ΔT where ΔT is the temperature difference between room temperature minus supply air temperature.

For water both specific heat and specific gravity is unity (1) and hence these are not reflected in the formula

Q in Btu/hr divided by 12000 would give capacity in tons.

In the case of SI system the equation for water would be

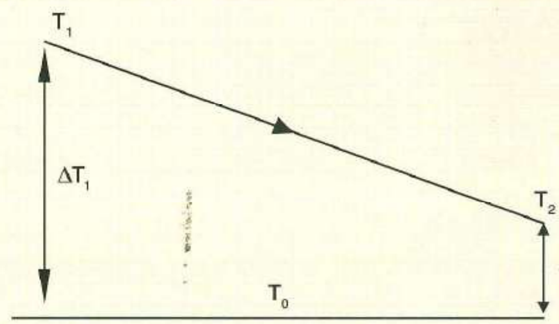
Q in kW = 4190 × (volume flow rate in m^3/s) × (ΔT) where 4190 J/ (kg·K) is the specific heat of water and 1000 kg/m^3 is the density

And for air it is kW = 1.2 × (volume flow rate in m^3/s) × (ΔT). Density of air being 1.2 kg/m^3 and specific heat Cp is 1000 J/ (kg·K)

The second important equation is used to describe quantity of heat exchanged between the refrigerant and the fluid in the tubes:

$$Q = U \times A \times LMTD \quad (2)$$

Where LMTD is the log mean temperature difference between refrigerant and fluid. This can be calculated if we know the fluid entering temperature, fluid leaving temperature and the saturated refrigerant temperature in the heat exchanger.



T_1 - Entering temperature, T_2 - Leaving temperature, T_0 - Evaporating temperature

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\log \Delta T_1 / \Delta T_2}$$

The third important equation used for selection of air cooling equipment for a cold storage is :

$$Q = U \times A \times \Delta T \quad (3)$$

where Q is total heat handled by the evaporator in Btu/hr or W

U is specific coil design heat transfer coefficient in Btu/ft²°F or W/m²°C

$\Delta T = T_{room} - T_0$

T_{room} is the temperature of air entering the coil and T_0 is the saturation temperature of refrigerant corresponding to the evaporator pressure inside the evaporator. The temperature of air leaving the coil would be somewhere in between.

In the next issue we will describe the different types of evaporators.

Credits : 1) Figures 1 & 2 Carrier training material.

2) Learn the factors that affect evaporator performance by Kevin Longe. AC&R News – September 19, 1988.

Evaporators

DX & Flooded Evaporators – Part 2

In the last article we covered some basic formulae required for evaporator selection.

We shall now look at various types of evaporators.

Evaporators are mainly classified based on the method used for control of refrigerant flow through them.

1. Direct Expansion evaporators popularly known as DX evaporators
2. Flooded evaporators

DX Evaporators

In this type the refrigerant flow is controlled so that the refrigerant is wet (mixture of liqid+vapour) at the inlet of evaporator and dry superheated gas at the evaporator outlet as shown in *Figure1*.

The refrigerant undergoes the process as shown in the T/S diagram. As can be seen the saturation refrigerant

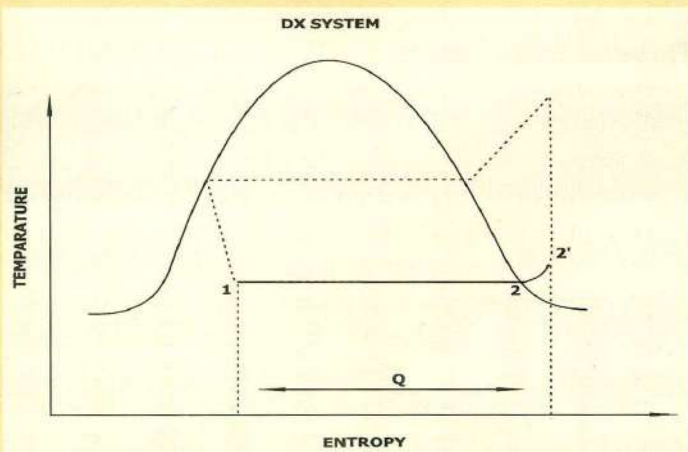


Figure 1 : T/S diagram for DX system.

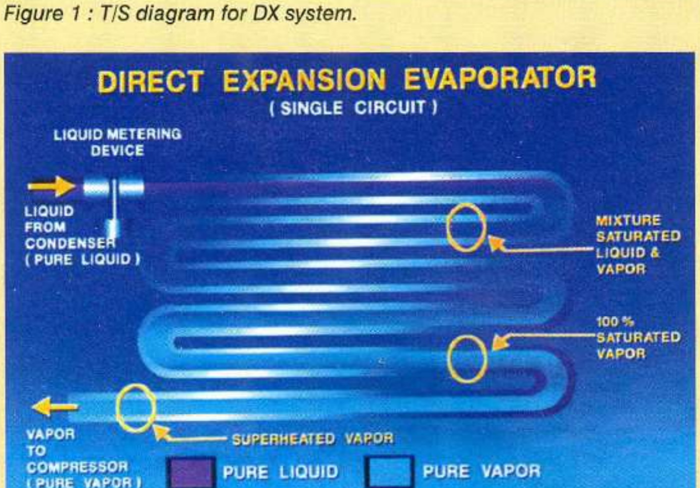


Figure 2

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temperature remains constant during the process of evaporation and as liquid+vapour mixture travels from inlet to outlet (Process1-2) of evaporator, the liquid gets converted to vapour by absorbing heat from surrounding medium. Once the entire liquid is converted to gas, the additional heat increases the temperature of vapour indicating superheat at constant pressure shown by 2-2'. The entire process taking place in the evaporator is thus at constant pressure (neglecting pressure drop in the evaporator due to friction). The refrigerant is mostly liquid with some amount of flash gas (10-15%) at the entry and completely dry or superheated gas at the outlet (*Figure 2*).

Another important point to be noted is that the refrigerant once having entered the evaporator has no possibility of recirculation unless it travels the entire length of the heat exchanger, then onwards to compressor,

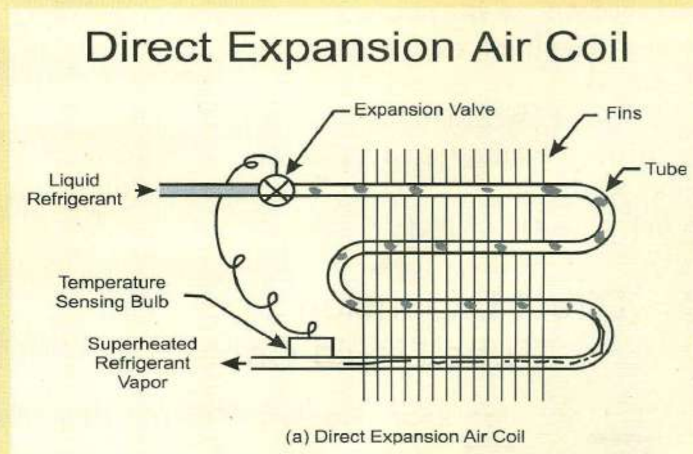

Figure 3

About the Author

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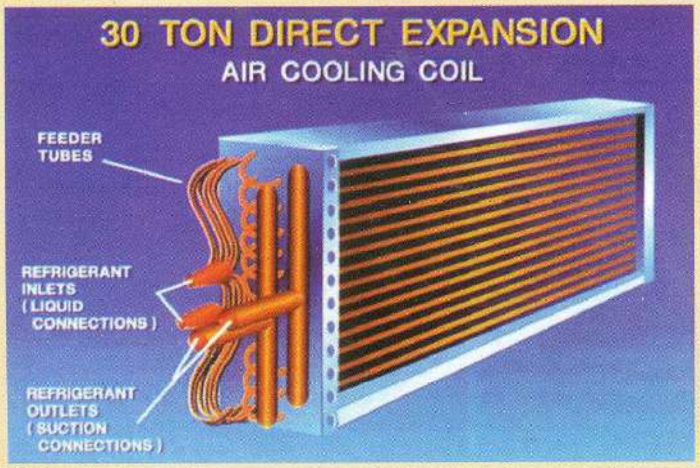

Figure 4

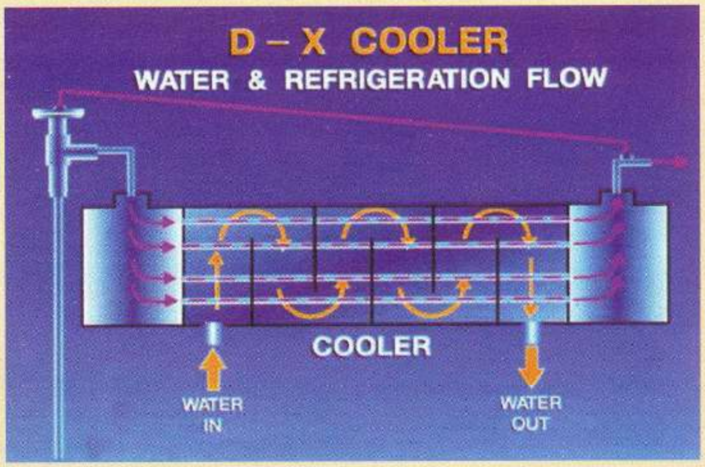

Figure 5

condenser and metering device before it reenters the evaporator. At the inlet of the evaporator, the expansion valve is located and at the outlet is a pipe leading to compressor suction. (*Figure* 3) In DX evaporators the flow is controlled with the help of expansion valve which feeds the exact amount of liquid as needed by the evaporator based on the quantity of liquid evaporated due to heat load. In addition to this the expansion valve is designed to produce about 5 to 6°C superheat to protect the compressor by ensuring that the compressor gets only pure gas free of any liquid droplets.

The various types of DX evaporators used by the industry are:

1. Direct expansion cooling coils for comfort air conditioning applications used in room A/C, split A/C, packaged A/C, as also precision air conditioners for server rooms, telephone exchanges and other applications. (*Figure* 4)

2. Direct expansion chillers used for cooling water or brine solutions used in medium/large capacity reciprocating/scroll/screw chillers for air conditioning as well as industrial process applications.(*Figure* 5 & 6)

3. Direct expansion coolers for cold storages using HCFC/HFC refrigerants for fruits/vegetables and other commodity storage requirements.

4. Evaporator coils submerged in tanks for cooling fluids like water/brine/oil in tank.

5. Natural convection evaporators as used for domestic refrigerators, deep freezers, ice making machines etc.

6. Variable refrigerant flow systems, becoming popular now a days, for comfort air conditioning applications.

Flooded Evaporators

In contrast to DX evaporators, the flooded evaporator provides for recirculation of refrigerant within the evaporator by incorporating an additional vessel called "accumulator". The mixture of liquid and vapour refrigerant coming out of the expansion device, instead of entering the evaporator directly is first admitted to the accumulator, where liquid and gas portion of the refrigerant is separated and only liquid refrigerant enters the evaporator at condition 1' as shown in *Figure* 7 & 8.

The refrigerant is thus wet at the inlet as also wet at the outlet of the evaporator. Unevaporated liquid is once again re-circulated while the vapour is removed from the

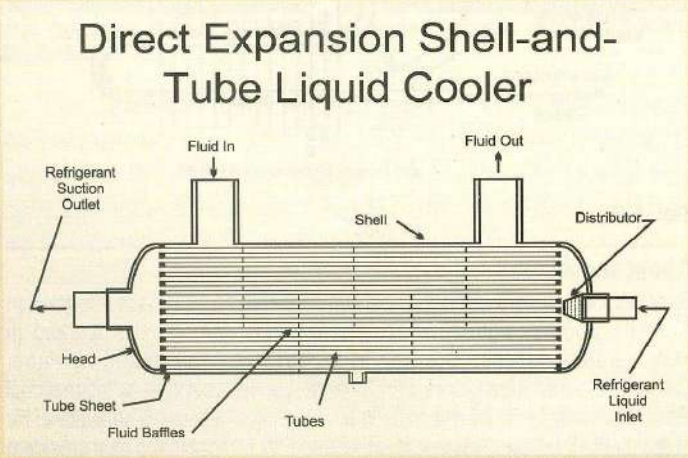

Figure 6

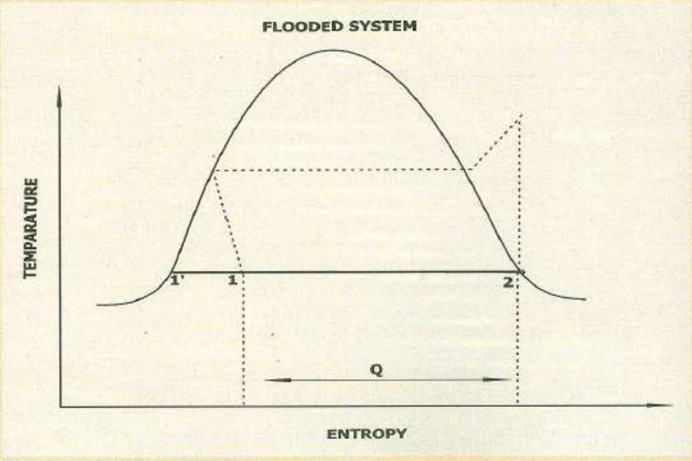

Figure 7 : T/S diagram for flooded system.

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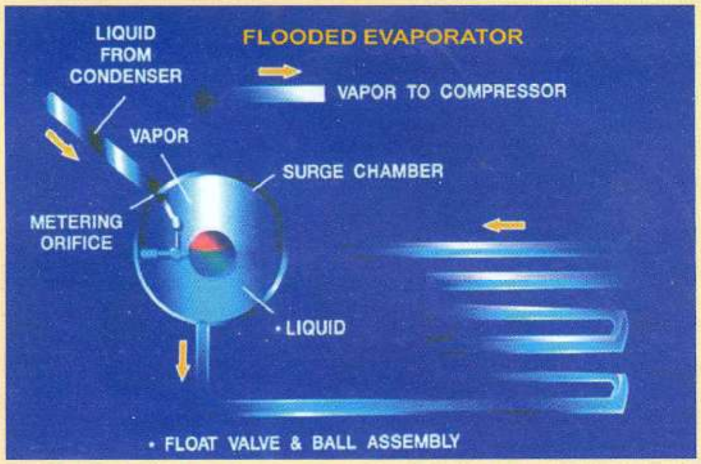

Figure 8 : Flooded evaporator with accumulator or surge chamber.

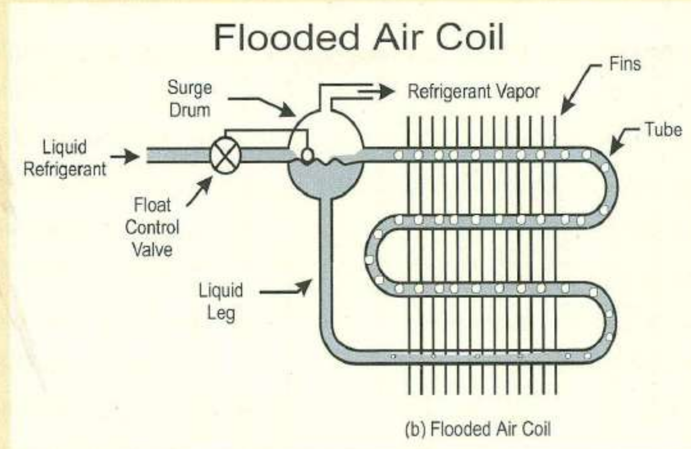

Figure 9

accumulator by the compressor suction action.

In flooded evaporators a constant liquid level is always maintained by use of mechanical float valve also working as an expansion device (*Figure* 9). Many installations also use a combination of external level controller with hand expansion valve and solenoid valve instead of directly installed mechanical float valve.

Since the evaporator is always filled with liquid refrigerant, the vapours coming out of the evaporator are not superheated and are in saturated condition as shown by point 2 in *Figure 7*. Point 1, indicates proportion of flash gas (1-1') separated in the accumulator and liquid portion (1-2) and only liquid part is admitted at point 1'

The evaporating surface is constantly kept coated with liquid refrigerant film under all load conditions and thus gives higher heat transfer rates leading to more efficient cooling than direct expansion evaporators of the same size.

Flooded evaporators are more popular in all applications using ammonia refrigerant. Some of the major applications are listed hereunder :

1. Conventional block and flake ice making plants

2. Cold storage product coolers, blast freezers using ammonia refrigerant

3. Industrial process fluid coolers for water and brine cooling (*Figure 10*)

4. Pump circulation systems

5. Plate heat exchangers used in fisheries and other applications

6. Centrifugal water/brine chillers using R134a/R123 and other refrigerants

7. Water chillers used for air conditioning using reciprocating/screw compressors (*Figure11*)

The major difference as can be seen from these shell and tube heat exchangers is that the fluid is inside and the refrigerant is outside the tubes for flooded coolers whereas for DX coolers the refrigerant is inside and fluid is outside on the shell side.

The advantages of flooded evaporators in comparison with DX evaporators are :

1. The evaporator surface is used more effectively and more effective latent heat transfer takes place. No surface is wasted for superheating (approx.10-15%)

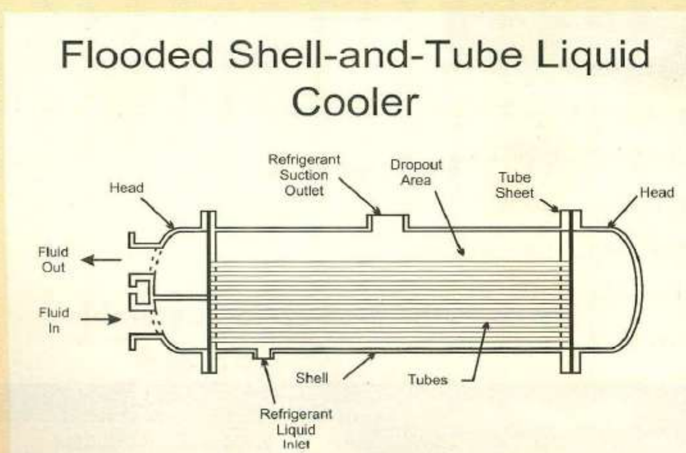

Figure 10

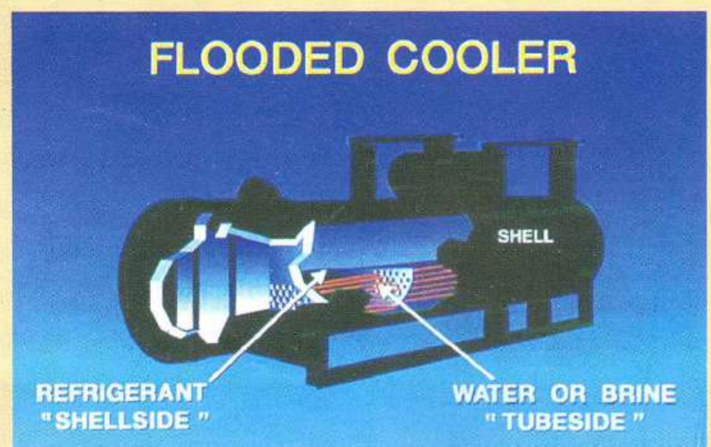

Figure 11

2. The refrigerant distribution design is less complicated. In DX evaporators, coil circuiting to ensure uniform distribution of liquid+gas mixture in all tubes is a challenge. Similarly in shell and tube DX evaporators the tube distribution per pass and no of passes to ensure required velocity all load conditions requires design expertise.

3. In a flooded design saturated vapours enter the suction line, compared to superheated vapours in DX evaporator systems. This means suction gas entering the compressor is at a lower temperature in flooded systems, thus reducing the corresponding compressor discharge temperature. This is important for ammonia installations since higher discharge temperatures can lead to adversely affecting lubricating oil properties and endangering compressor operation.

4. Tube cleaning is easier in flooded S & T coolers. In DX the fluid is on the shell side and difficult to clean manually.

5. Trouble shooting analysis for flooded systems is easier since one can monitor the liquid level and temperature in an accumulator by installing sight glass and temperature probe. In DX system it is difficult and generally not done; hence no valid indication of quality of refrigerant entering the evaporator is available.

The disadvantages of flooded evaporator systems are:

1. Initial cost of plant is higher. More expensive controls required to monitor and control liquid levels.

2. Quantity of refrigerant required is much higher as it has not only to fill up the evaporator but also has to maintain constant liquid level in the accumulator up to at least 50% height. For HCFC/HFC refrigerants this is a very significant factor since cost of these refrigerants is very high compared to ammonia refrigerant.

3. The oil recovery with use of HCFC/HFC refrigerant is again a major challenge as oil tends to separate in the evaporator and does not easily return to the compressor. Many times a separate oil recovery system needs to be installed.

4. Defrosting of low temperature coolers needs more sophisticated controls for top or bottom feed evaporators using both gravity flooding or pump circulation systems.

In the next article we shall discuss DX evaporators used in room air conditioners and split systems for air conditioning applications. ❖

Evaporators

Direct Expansion (D-X) Cooling Coils – Part 3

This series of articles by Ramesh Paranjpey covers the fundamentals of evoporators. The articles will serve as a source of reference for newcomers joining the industry as well as for experienced engineers wishing to brush up on fundamentals.

Direct expansion cooling coils are used in most unitary products like room air conditioners, split air conditioners, packaged air conditioners, ductable splits, and in central air handling units (AHU'S) even up to 150 ton capacity. D-X coils are also used in various types of fan coil units such as wall mounted, floor mounted and roof cassette types. Indoor units of variable refrigerant flow systems (VRF) also use such evaporators.

The direct expansion coil works with the principle of refrigerant (R-22/ R-134A/ R-404a/ R-407C or R-410A) flowing inside the coil. Heat transfer between the warm air to be cooled outside the coil and the low temperature, low pressure liquid refrigerant inside the coil takes place. Heat for boiling the liquid refrigerant is supplied by the air and in the process the air gets cooled to around 11 to 13°C. The saturation refrigerant temperature in the coil remains around 5 to 7°C. The liquid refrigerant evaporates inside the coil and the superheated vapours emerge at the coil outlet. Therefore the D-X coil is also called an evaporator. Most of these coils provide sensible cooling and dehumidification of air simultaneously.

Due to pressure drop inside the coil, the pressure and saturation temperature at the outlet is somewhat lower than the inlet and the refrigerant is also superheated (5-6°C) by using some 10-15% portion of coil area for such superheating, the major area 85-90% being used for boiling purpose, which is the latent heat transfer process. The superheating is important to ensure stable operation of the system and in protecting the compressor from entry of liquid refrigerant.

Selection of D-X coils

For unitary products, the selection is limited due to face area(size) of the unit, where as for central AHU'S the selector has a wider choice of selecting the coil length, height, rows deep, number of fins, circuiting etc.

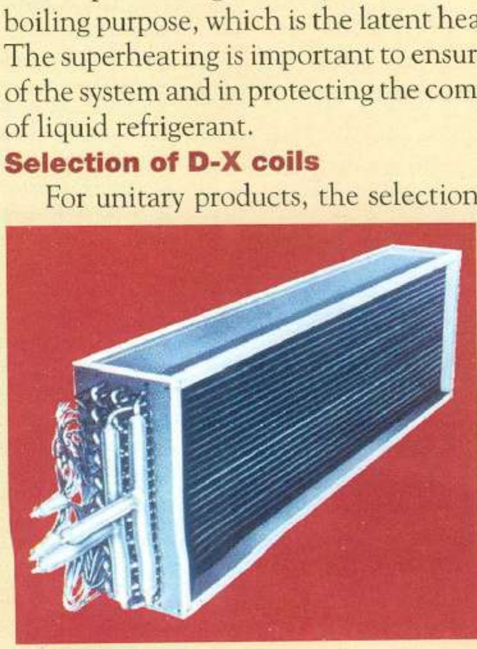

Figure 1 : D-X coil.

The standard formula as indicated in an earlier part used for selection is :

Coil capacity = 'U' x A x (Tr-Tc) where

Tr is the room temperature or return air temperature or coil air-on temperature.

Tc is the average temperature of the coil or refrigerant boiling temperature or the coil ADP (aptaratus dew point).

'U' is the coil specific design heat transfer coefficient.

A= coil surface area.

Btu/degree TD (where TD = Tr–Tc) is the normal representation of coil capacity in the manufacturer's catalogues on 'Y' axis & face air velocity over the coil on 'X' axis for different diameters of tubes/rows deep and number of fins used.

A sample format is shown in *Figure 2*.

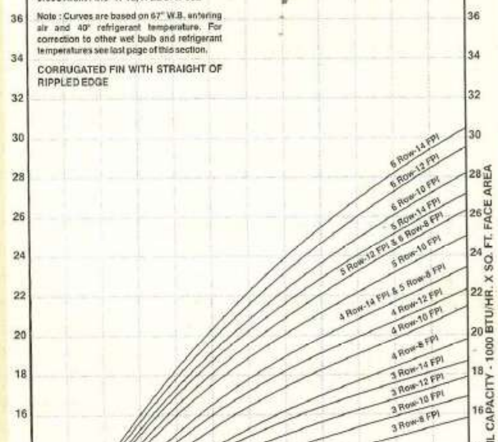

Figure 2 : Evaporator capacity.

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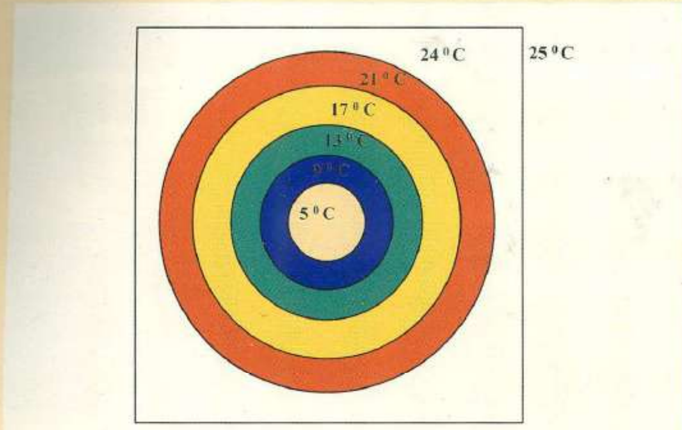


Figure 3 : Cross section of a plate fin DX coil showing temperatures on the tube surface and fins at different distances.

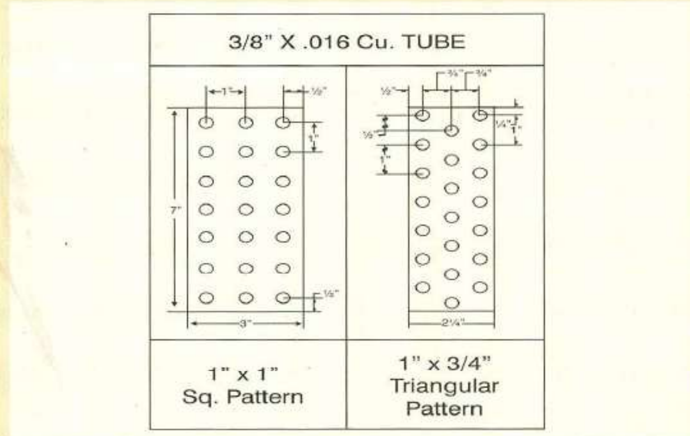


Figure 5 : Different fin patterns.

Looking at the equation it is important to note that the application engineer or system designer can only select coil surface area A, Tr and Tc. On the other hand the coil designer has control over heat transfer coefficient 'U' by selecting different diameters of tubes, type of its internal surfaces, number of fins per inch, type and thickness of fins, its material and surface treatment, horizontal and vertical spacing of tubes, its circuiting etc. Fins are available in various designs so as to increase the fin surface area and allowing air to remain in contact with the fin surface more intimately.

Once the system designer decides to use a particular manufacturer's coil all these designer's options are not available to him as he has to make selection of area required based on the available coil design.

Prime Surface v/s Extended Surface

Normally, only primary surface coils or bare tube evaporators are not used in comfort air conditioning applications. The coil's effective surface is extended by mechanical attachment of fins to the coil tubes. The tube area is called primary area 'Ai' whereas fin area is called secondary area 'Ao'. Providing secondary area gives greater heat exchange per unit area of coil exposed to the air stream, thus making the coil compact and economical.

It should however be noted that the primary area is the most effective area for heat transfer as the temperature gradient or potential difference is the highest between copper tube and the air passing over it. As one moves away from the inner tube towards outer fin surface, effectiveness of each subsequent area for heat transfer diminishes and becomes less productive as can be seen from *Figure* 3, which explains why primary tube area is more important compared to secondary fin area.

The designer's objective therefore is to design a coil which has maximum primary area i.e. more number of copper tubes and less fin area for the given dimensional limitations. The current trend is to use 3/8" copper tubing through which refrigerant flows, thus increasing Ai/Ao ratio. Earlier in the 70's, engineers were using 7/8" or ¾" tubing. These were replaced by 5/8" and ½" in the 90's and now a days most manufacturers use 3/8" tubing though the latest trend is to use 5/16" tubes. The automobile industry has gone a step further and used extruded aluminum tubing with very small tube holes and thus further increased the Ai/Ao ratio.

Tube spacing. Tube spacing in the tube sheet ranges

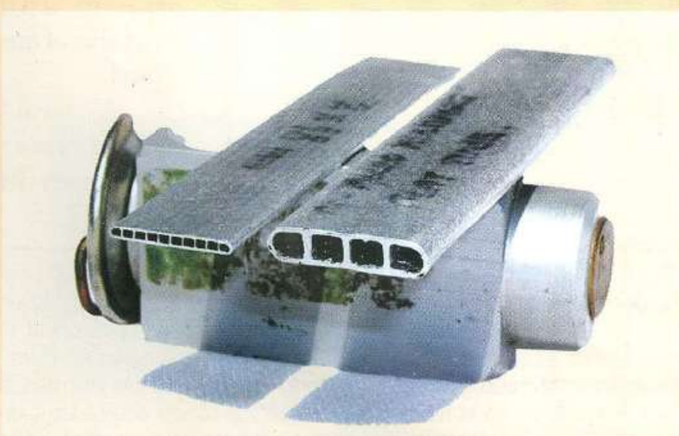


Figure 4 : Photograph of extruded tubing in a car air conditioner's evaporator.

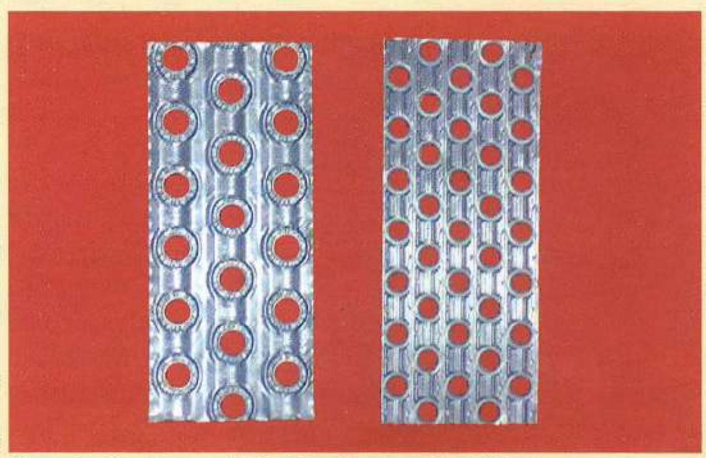


Figure 6 : Fin pattern with 18×3/8 tubes and 37×5/16 tubes.

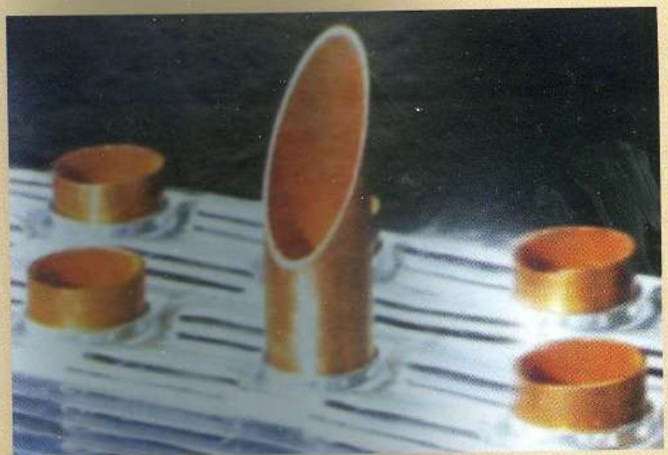


Figure 7 : Internally grooved tube.

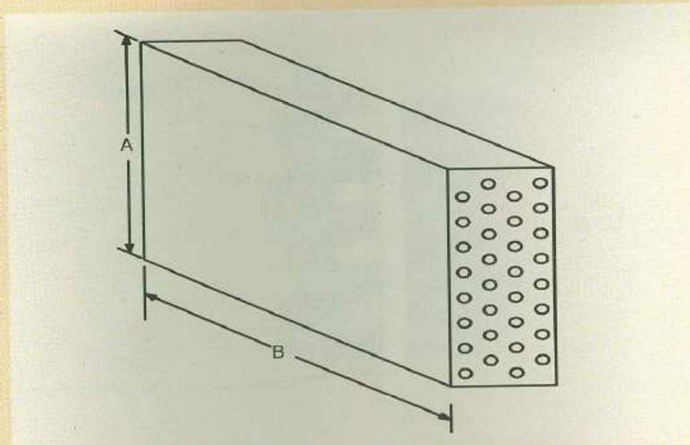


Figure 9 : Coil geometry.

from 0.6" to 3" on equilateral (staggered) or rectangular (in-line) centers depending upon width of individual fins and other performance considerations. The number of fins can vary from 4 to 18 fins per inch.

As can be seen in *Figure* 6, for the same foot print of 6.5 cm width and 15.8 mm length we can only accommodate 18 no. 3/8" tubes whereas in the same foot print we can accommodate 37 no. of 5/16" tubes thus providing more primary area to secondary area ratio and making the coil more compact/efficient as well as more economical. This however does not mean that for each application a smaller tube diameter selection is the best option as when the tube diameter reduces, for the same length of refrigerant travel the pressure drop increases, lowering the saturation suction temperature selection which means requiring more compressor capacity and penalty on power consumption. The effect of these negative factors can also be balanced by the coil designer by suitable judicious adjustments in other parameters.

Tube and Fin material

Aluminum sheets for fins and copper tubes are the most popular combination although some applications for harsher climatic conditions (such as salt laden sea air) warrant use of copper tube and copper fins. Similarly, all automobile air conditioners use exclusively aluminum tubes and aluminum fins due to its light weight, compactness and special use of extrused sections.

Copper tubes are either plain or internally grooved to improve that internal heat transfer coefficient. The fins can be straight, wavy, slotted, and ridged or many different patterns to improve air side heat transfer coefficient without putting undue penalty on air side pressure drop. In order to drain condensed water on the coil easily most of manufacturers use hydrophilic coating on fins. Copper tube/copper fin heat exchangers can also be tin plated by hot dipping to improve its life. The selection of tube and fin material would depend upon the type of environment, expected life of equipment and the price customer is willing to pay.

Coil Geometry

Some of the common terminologies used in connection with D-X coils are explained hereunder :

Face area. The face area of the coil is the area in sq.ft. (sq.m.) i.e. length x height (BxA).

Tube Face. The number of horizontal tubes in the first row is called tube face. These could be 10/12/14 or more depending on dimension 'A' i.e. height of coil

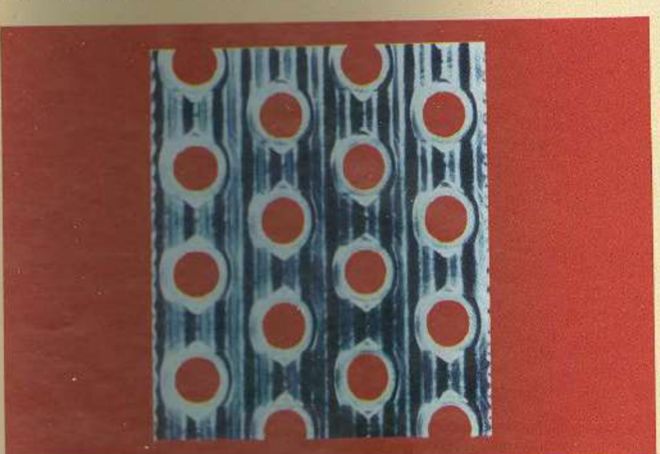


Figure 8 : Aluminum fin.

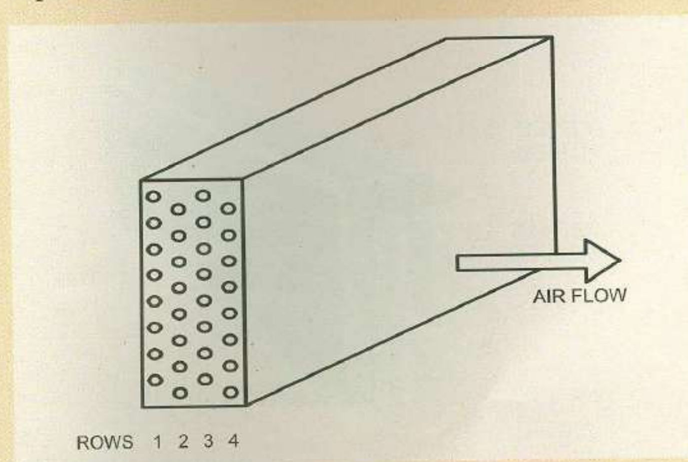


Figure 10 : Rows deep.

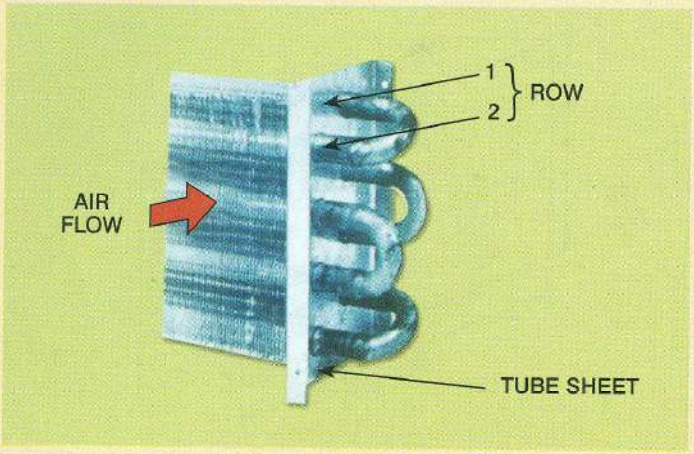


Figure 11 : Tube sheet and tube bundle.

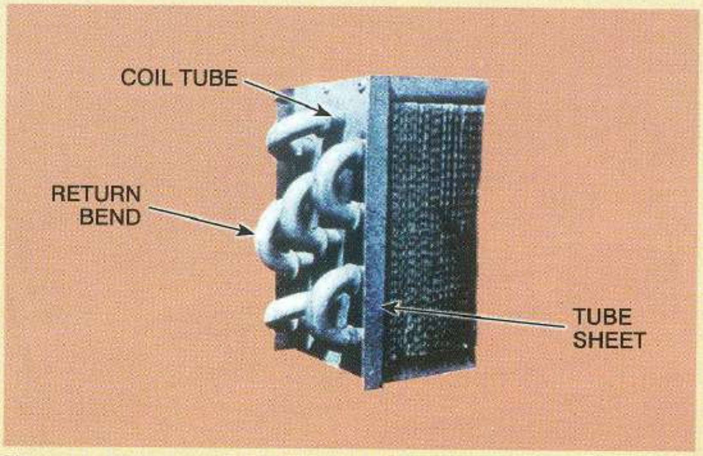


Figure 13 : Return bends / passes / coil circuits.

Rows Deep. The tubes of the coil are arranged in rows across which the air flows. The direction of air flow is perpendicular to the coil face area in most of the cases though inclined coils are also used. The rows are numbered starting from 1st row where air enters the coil. The coil can be single row or 2/4/6//8 rows deep depending upon the application. In unitary products it is seldom more than 4 rows deep.

Tube sheet/Tube bundle. The coil tubes pass through the coil casing at each end supported by the end plates. These end plates are called tube sheets. They provide structural support for the tubes and the total number of tubes supported by the tube sheets is called tube bundle.

Return Header. The refrigerant exits the coil from the end through an enlarged vertical pipe turned horizontally at the bottom which is then connected to the compressor suction. This pipe is therefore called suction or return header.

Feeder Tubes / Distributor. The liquid + vapour mixture, containing predominantly liquid and some flash gas formed during expansion process in the expansion valve needs to be equally distributed in all tubes on the coil face. This is achieved by selecting a proper distributor, nozzle orifice and proper length of feeder tubes so that pressure drop in each circuit is the same. The length of each refrigerant circuit from the expansion valve distributor feed tubes up to the suction header, is therefore kept equal. This ensures that top tubes receive the same proportion of liquid + vapour mixture as the bottom tube. If there is an error in designing this combination of distributor and feeder pipes, one may experience that the top tubes would get only vapours making them less effective where as the lower end tubes mostly would receive higher density liquid. This can be easily verified by mapping temperature profile on the coil face. If it is not uniform then it means liquid distribution is not proper.

Return bends / passes / coil circuits. The refrigerant travels in the coil from entry to exit in various paths. To accomplish this, the tube bundle needs to be interconnected by return bends. These could be separate bends or by bending the tube in hairpin bends of 180 degree angle thus saving brazing operation at one end of the tube sheet and thus reducing joints and possible leakage areas/labour and internal contamination.

The refrigerant enters at one end through the feeder tubes, then travels the length of copper tube in one direction before turning through 180 degrees and again

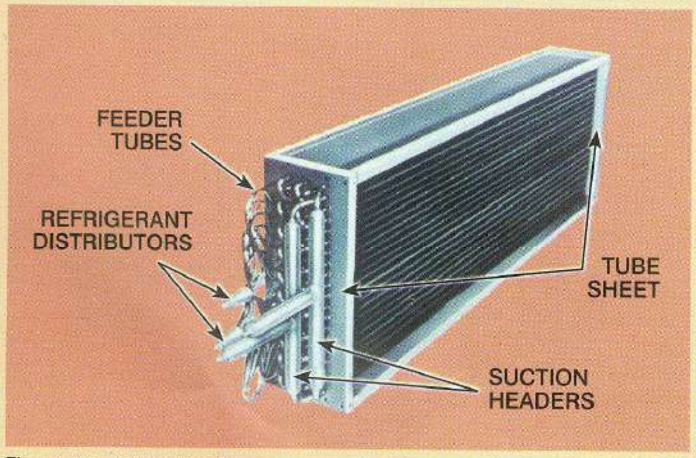


Figure 12 : Return header.

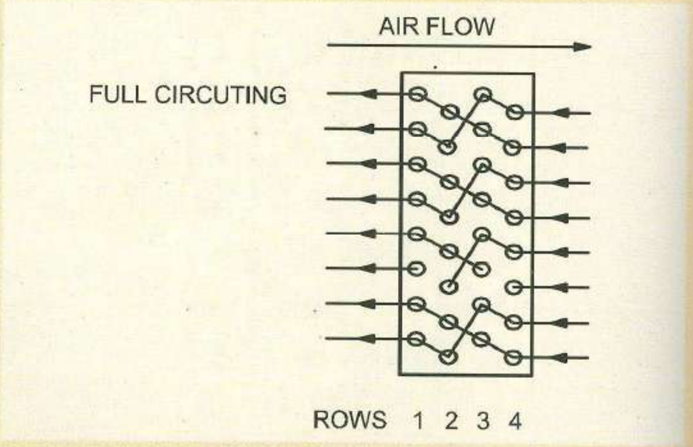


Figure 14 : Full circuiting.

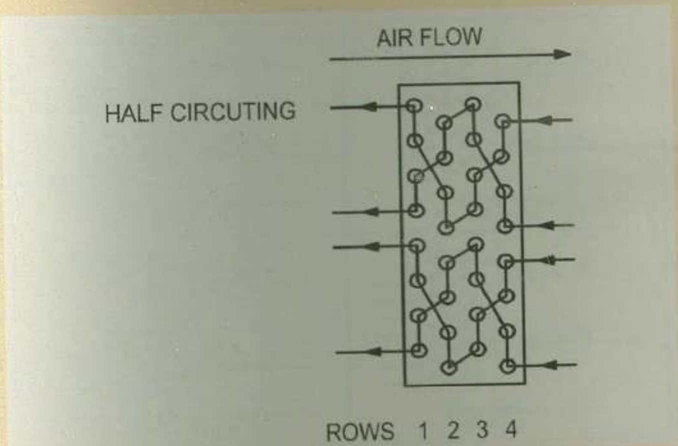


Figure 15 : Half circuiting.

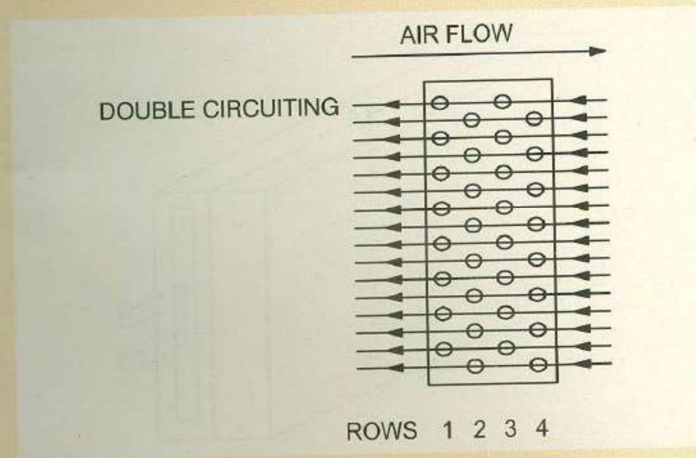


Figure 17 : Double circuiting.

travels in the reverse direction in the copper tube. Each such traverse of coil is called a "pass".

The return bends or hairpins are arranged so that refrigerant in the tubes can make one or several passes before it leaves the coil and joins the return header.

The path traveled by refrigerant from inlet to outlet header is called as one coil circuit. In coils, more than one circuit operates in parallel to provide the required capacity.

By varying the return bends and hairpin turn arrangement several circuiting types are possible for the same tube bundle.

Circuiting of Coils

Full Circuiting

The liquid refrigerant enters in the last row in each circuit and completes 4 pass travels along the length before exiting. As can be seen from the diagram that there are a total of 8 circuits. See *Figure 14*.

Half Circuiting

As can be seen from the diagram, the tube bundle is the same as that of full circuiting but every alternate tube is fed with liquid refrigerant. The fluid, thus is, now making 8 passes, meaning that the liquid travel is doubled than in the earlier case which means liquid remains in contact with the air for a longer duration. The number of circuits is reduced to 4 only, in this case. See *Figure 15*.

Quarter Circuiting

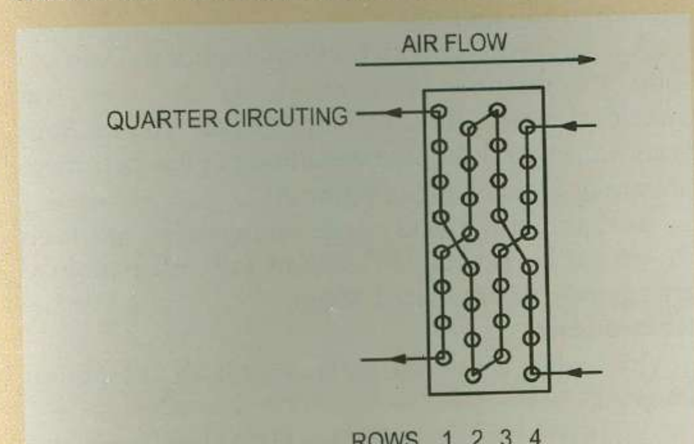
Every 4th tube of the last row is fed with liquid refrigerant resulting in 2 circuits and 16 passes. See *Figure 16*.

Double Circuiting

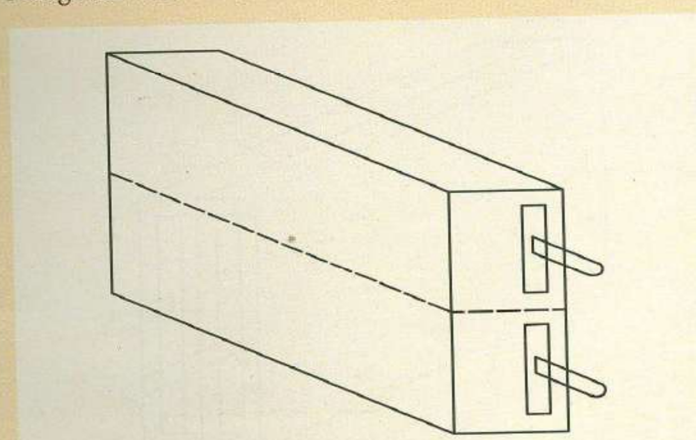
In this case every tube of the last two rows is fed with liquid refrigerant. This means only 2 passes, i.e. length of liquid travel is the least and number of circuits is increased to 16. See *Figure 17*.

From above it can be noted that different methods of connecting the same tube bundle in various circuit arrangements alters the coil performance. For a given heat removal capacity, longer the liquid travel (more passes and less circuits) the better is the heat absorbed by the liquid refrigerant due to higher velocity, leading to improvement in heat transfer coefficient , but it also leads to a higher pressure drop on the refrigerant side resulting in lowering the suction pressure/ saturation temperature.

Instead if the number of passes is reduced (2) and more circuits (16) are provided, it would mean more refrigerant quantity is being fed to the coil but in each circuit the refrigerant travels least. The pressure drop/velocity is



Slide 16 : Quarter circuiting.



Slide 18 : Horizontal split coils.

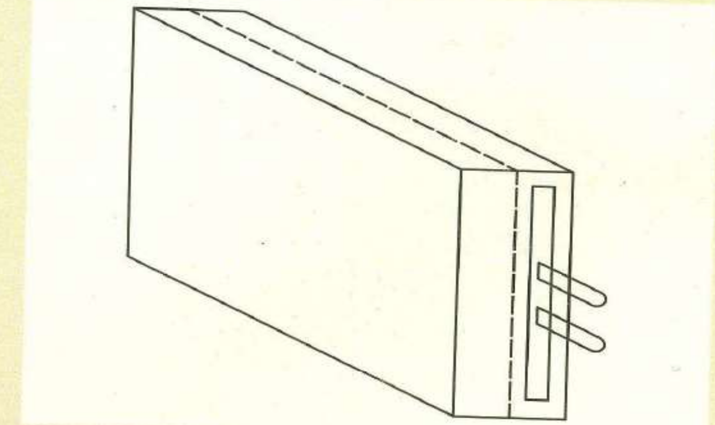


Figure 19 : Row split.

low, so also a lower heat transfer coefficient, but a higher saturated suction temperature/pressure.

The coil manufacturer decides the circuiting based on application, required temperature drop across the coil and the tube geometry. Many times, more than one combination may satisfy the requirements.

Coil Splits

Many times, coil splits are provided to meet part load requirements and for other reasons like operational stability/enhancement and for better oil management.

The coil split is also required due to limitations of expansion valve operation at low load limit, distributor nozzle low load limit and evaporator circuit low load limit to maintain minimum velocity for proper oil return.

As mentioned above, D-X coils are designed with a number of circuits each having many passes. These circuits need to be further grouped into splits for most of the commercial projects above 20 ton capacity. The advantage of a split circuit is to match coil capacity with compressor loading steps. For example a compressor having 4 cylinders with one solenoid valve for capacity control will have 2 steps of 50% and 100% and the coil then can be split in two parts so that when the load reduces less

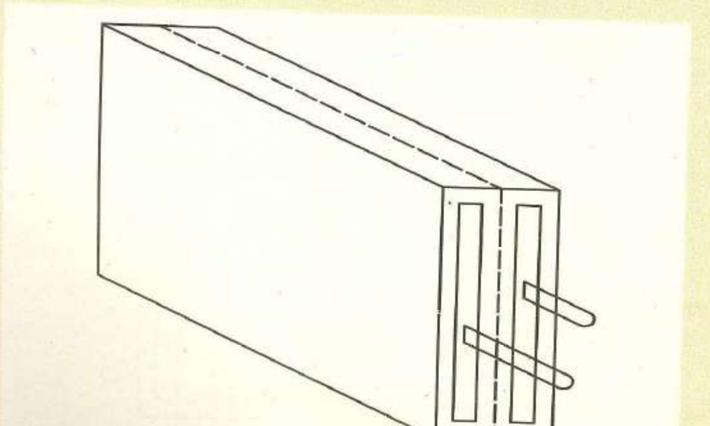


Figure 20 : Interlaced circuit coils.

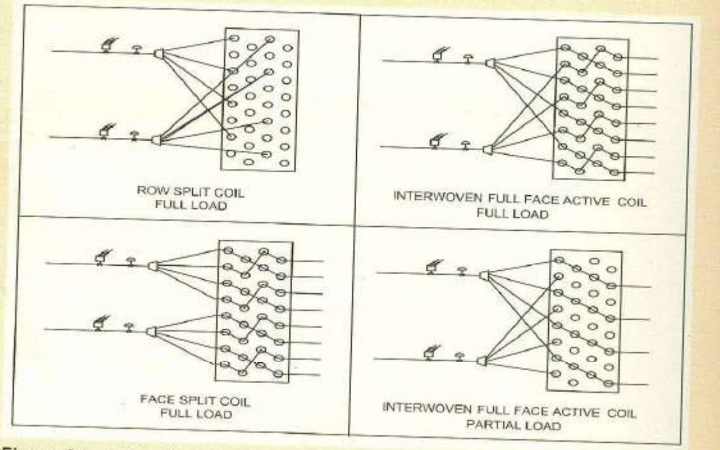


Figure 21 : D-X coil.

than 50% one circuit can be switched off by the solenoid valve and the compressor also unloads by 50%. Thus the compressor and coil capacity matches as required by the load pattern and optimum use is made ensuring proper oil return to compressor. Such a circuiting would also have two expansion valves, two solenoid valves. Similar possibility also exists with use of multiple compressors with single coil having equal number of splits to match each compressor.

Horizontal Split Coils

In this case the coil area is split horizontally, parallel to the direction of air flow. Such splits are used where uneven air temperatures are acceptable, but where uniform coil leaving temperature is essential; the top split is normally switched off first otherwise condensed water from the top coil will run down on the fins of the lower coil and this moisture may enter the air path of lower split. See *Figure 18*.

Row Split

Here the coil is split vertically in a plane perpendicular to that of air flow. Such coils give uniform air leaving temperature regardless of load. The disadvantage of such a design is the coil capacity in each row is not uniform. The row nearest to air entry shares more load compared to subsequent rows. See *Figure 19*.

Interlaced Circuit Coils

A combination of both horizontal splits and vertical splits removes most of the drawbacks mentioned for individual design. With this arrangement the full face becomes active and load distribution per row gets more uniformly distributed. See *Figure 20*.

In *Figure 21* full load circuit arrangement has been shown for horizontal/vertical and full and part load arrangement for interlaced design.

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Evaporators

Direct Expansion (DX) Fluid Coolers – Part 4

In the last article we covered terminologies and other design aspects for direct expansion air cooling coils

This article we will cover direct expansion shell and tube evaporators known as fluid coolers.

The use of such heat exchangers in the air conditioning and refrigeration field is for cooling water and brines.

The water coolers are used for chilled water applications in factory built packaged chillers working with halocarbon refrigerants and using positive displacement compressors such as reciprocating or screw type.

The brine coolers are used for low temperature process cooling applications in industry using fluids such as, ethylene glycol, propylene glycol, calcium chloride, methylene chloride, methanol water and many other fluids.

The direct expansion chillers are of shell and tube design with refrigerant in the tubes and fluid to be cooled on the shell side.

This series of articles by Ramesh Paranjpey covers the fundamentals of evaporators. The articles will serve as a source of reference for newcomers joining the industry as well as for experienced engineers wishing to brush up on fundamentals.

Working

The direct expansion evaporator receives a mixture of liquid and vapour refrigerant at the entry having predominantly liquid and some percentage of flash gas from the outlet of the thermostatic expansion valve. The refrigerant entering the evaporator tubes is at a low pressure and low temperature. The operating saturation evaporating temperatures and corresponding pressures are based on the end use requirement. The liquid to be cooled is on the shell side and circulates in a zig-zag manner perpendicular to the tubes so that its direction is repeatedly reversed with the help of a baffle arrangement. Heat transfer takes place in which the liquid gets cooled to the desired temperature and the refrigerant liquid traveling in the tubes evaporates. The heat required for evaporation is provided by the warm fluid. Thus it basically works on latent heat transfer process. The refrigerant leaving the evaporator is in the superheated form and this is ensured by the setting of the thermostatic expansion valve which is normally factory set to ensure 4 to 7°C superheat at the outlet. The superheat is required to ensure that chances of liquid refrigerant going to the suction line and thereafter to the compressor are eliminated or minimized.

The shell and tube evaporator normally uses 3/4 inch copper tubes with internal or external extended surfaces. There are a number of such small diameter straight tubes accommodated in one large tube referred to as a "shell". The cluster of tubes is called a "tube bundle". The tubes are fixed at the ends on two tube sheets which are on both the ends of the tube bundle and are welded to the shell. Some evaporators using fluids which need frequent cleaning on the outside, use only one tube sheet with a removable tube bundle.

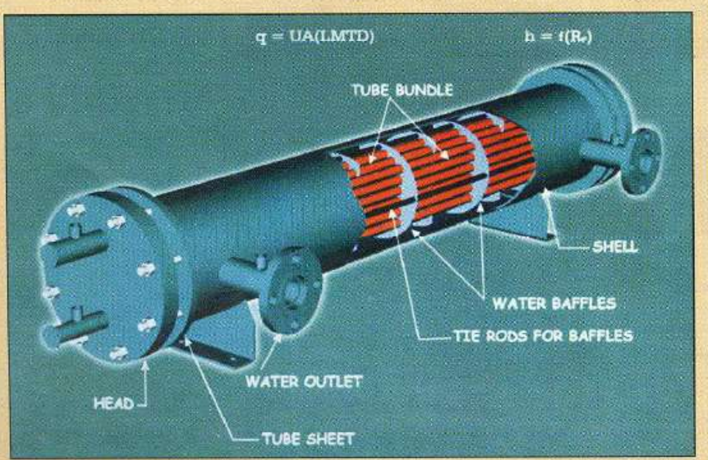

Figure 1 : Shell and tube fluid cooler.

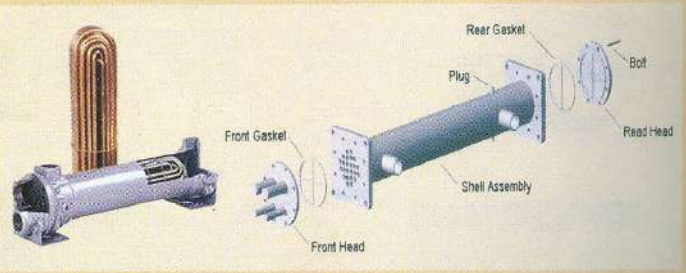

Figure 2: Fixed and removable bundle heat exchanger.

About the Author

Ramesh Paranjpey is a mechanical engineer with an M.Tech in refrigeration from IIT Bombay with over 35 years experience. He has worked in very senior positions starting with Kirloskar Pneumatic in Pune, Carrier Transicold in Bangalore and Singapore as well as Voltas-Air International Pune. Presently he works for himself as a technical advisor & consultant. He is an ASHRAE Fellow, past president ASHRAE W.I. chapter and past president ISHRAE Pune chapter. He can be contacted at *pramesh@vsnl.com*

Baffle Spacing

The baffle arrangement increases the velocity of the fluid, thereby increasing the rate of heat transfer because of higher heat transfer coefficient. The velocity of fluid flowing over the tubes in a perpendicular direction is maintained in the range of 0.6m/s to 3m/s maximum by altering the baffle spacing form closer to wider distance, depending upon the fluid characteristics.

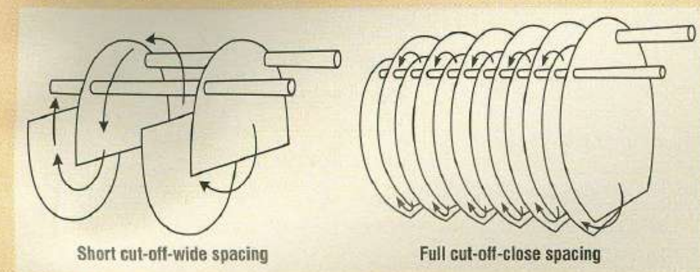

Figure 3: Baffle arrangement.

A typical baffle spacing and cut out provided by one manufacturer for a 20 inch shell dia. evaporator is given below to understand this aspect

	Baffle spacing in inches			Baffle cut out in inches		
20"shell dia. 252 tubes	K	L	M	K	L	M
	2.3	3.6	5.8	3.0	3.6	5.5

Refrigerant Distribution

Refrigerant distribution is critical in the shell and tube evaporator so as to get the best results. It is essential that the quantity of liquid + vapour mixture is equally distributed in all the tubes. A distributor at the inlet is sometimes provided for this reason. If the liquid distribution is unbalanced it would lead to poor performance of the evaporator.

Normally heat exchangers are provided with multiple pass arrangement to reduce the length of the cooler. This however requires proper design and distribution of tubes per pass as the percentage of gas goes on increasing in the subsequent passes as can be seen from

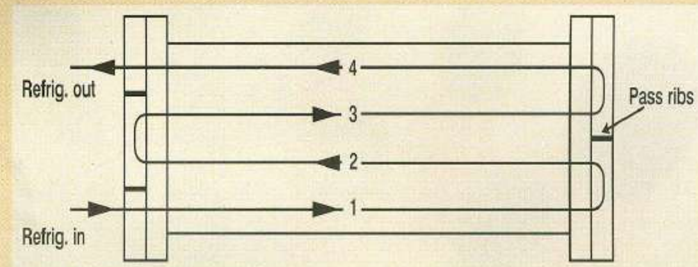

Figure 5: Tube side - pass arrangement.

the table below. A single pass evaporator would require evaporating the entire liquid refrigerant before it reaches the opposite end requiring very long length of tubes and the heat exchanger.

The percentage of number of tubes in different passes as given by one manufacturer is as under:

4 pass	13%	19%	28%	40%	-	-
6 pass	9%	11%	13.5%	20.5%	22%	24%

The Heat Transfer Process

The basic heat transfer formula Q = U × A × LMTD also holds good for these direct expansion shell and tube evaporators.

Let us now analyze each term and its meaning.

1. Q = Total capacity in tons of refrigeration

2. U = Overall heat transfer coefficient

Resistances to heat flow are created by the refrigerant film, effect of oil in the refrigerant, tube wall material and its thickness, fouling deposits on water/brine side and fluid film.

$$U = \frac{1}{Rr + Rm + Rf + Rb}$$

Where:

1. Rr is the thermal resistance on the refrigerant side in - hr×sq.ft×°F/Btu
2. Rm is the metal tube coefficient in - hr×sq.ft×°F/Btu
3. Rf is the fouling coefficient in - hr×sq.ft×°F/Btu
4. Rb is the brine/water side film coefficient based on tube inside surface in - hr×sq.ft×°F/Btu

The heat transfer coefficients if based on outside tube surface area need to be converted to the basis of inside tube surfaces by using surface area ratio Ao/Ai

3. A = Area

Ao is the external area of the tube and Ao is the internal area of the tube. To make the heat exchanger compact and to improve the heat transfer rate by enhancing the heat transfer coefficient, several types of tubes are

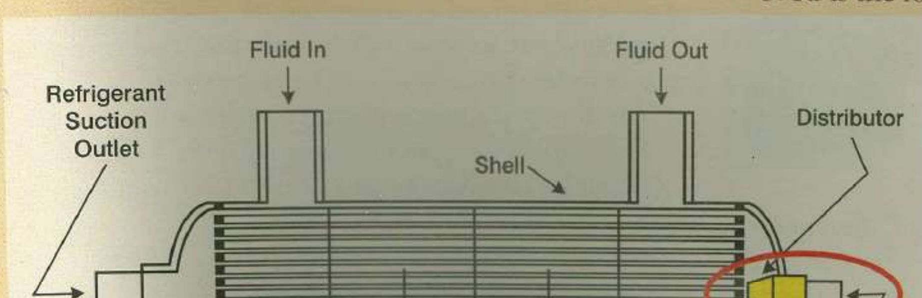

Figure 4: Evaporator with distributor.

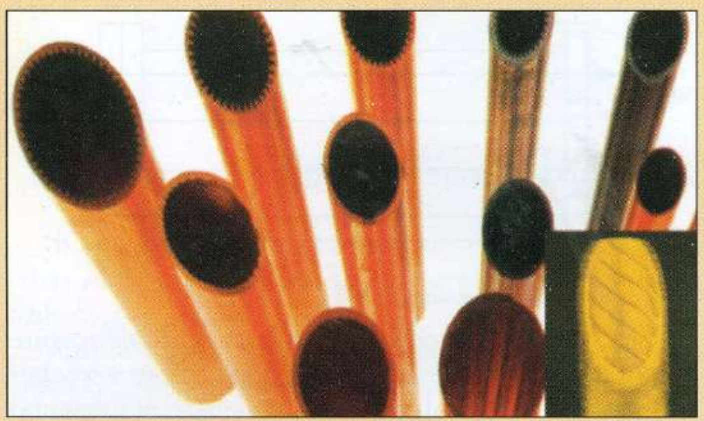

Figure 6: Extended surface tube samples.

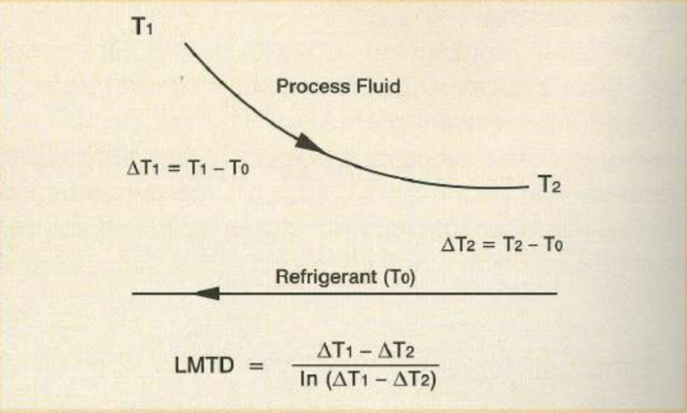

Figure 8: LMTD shown graphically.

available from various manufacturers. These tubes are with external as also internal extended areas. The enhancement on the inside surface is through rifling, cross hatching, micro finning and enhancement outside of the tube is generally by finning using 19,26, or 40 fins per inch.

Some of the leading manufacturers are Wolverine USA, Wieland –Germany, Yorkshire Imperial from UK, Hitachi from Japan and many more.

The improvement of heat transfer coefficient also leads to reduction in temperature difference between fluid leaving and evaporation temperature thus leading to power savings.

There are many manufacturers using inserts to enhance tube side heat transfer coefficient and also use plain tubes without internal or external finning for various other applications.

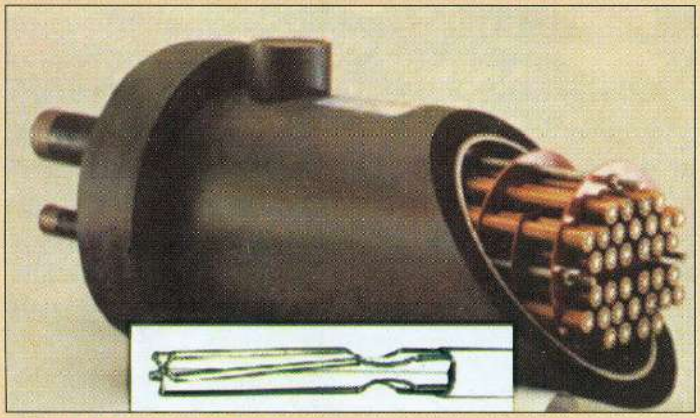

Figure 7: D-X chiller with star inserts.

4. *LMTD - Log Mean Temperature Difference*

The temperature difference between the refrigerant and the fluid is the driving force that overcomes the resistance to heat transfer. Heat is added to refrigerant at a constant pressure and corresponding constant saturation temperature which results in change of state from liquid to vapour and is known as latent heat of vaporization.

It is difficult to develop a single relation to describe heat transfer performance for evaporation inside the tubes due to a series of changing vapour-liquid flow patterns; therefore selection of direct expansion chiller is generally done from a manufacturer's catalogue or software.

The selection procedure guidelines for shell and tube evaporators are given below:

Generally the customer gives the desired flow rate of fluid required and the temperature at which the process requires this fluid.

Based on this data the selection of appropriate brine is made.

The total amount of heat exchanged equals:

$Q = W \times Cp \times \Delta Tb$

Q= quantity of heat exchanged in Btu/hr

W= Weight of fluid circulating in lb/hr

ΔTb= Temperature difference between fluid entering and fluid leaving the heat exchanger in °F known as "range"

The same equation can also be expressed in the following form:

$$\text{Load} = \frac{\text{gpm x } \Delta Tb \times \text{sp.gr.} \times \text{sp.ht.}}{24}$$

Load is the tons of refrigeration and in order to arrive at the weight of fluid we need to multiply flow rate in gpm by specific heat and specific gravity of fluid being used. In case of water these values will be unity i.e. 1

An illustrative example is given hereunder:

Flow rate 800 usgpm to be cooled from 20°F to 10°F

Based on this data brine selected is ethylene glycol with 35% concentration by weight

Normally concentration should be selected so that the freezing point of the solution is at least lower by 15°F than the brine leaving temperature

In this case with 35% concentration the freezing point is minus 5°F

Basis of selection :

1. Brine type- ethylene glycol
2. Brine concentration-35% by weight

3. Brine entering temperature = +20°F
4. Brine leaving temp. as required by process= +10°F
5. Specific heat- 0.83 Btu/lb F
6. Specific gravity- 1.056
7. Brine temperature drop –10°F (20-10)
8. Mean brine temperature +15°F (20+10)÷2=15
9. Refrigerant used –R22
10. Evaporating temperature +1°F

Refrigeration capacity in tons is calculated using the above formula works out as:

(800 ×1.056 x0.83 x10)÷24 = 292.16 Ton

While selecting the sizes, following factors play an important role :

1. Velocity of fluid over the tubes
2. LMTD
3. Approach-brine leaving temperature – saturated evaporating temperature
4. Range-brine inlet temperature – brine leaving temperature
5. Baffle spacing closeness
6. Pressure drop and length limitations

Construction Details

1. The evaporator is generally designed as per ASME Code Practices-Section VIII Div.1
2. The tube layout pattern and designs are as per TEMA standards-(Tubular Exchanger Manufacturers Association)
3. The shell side design pressure is generally minimum 150 psi or more as the case demands based on chiller installation location.
4. The tube side (refrigerant) design pressure is 200 psi.
5. The test pressures are 1.25 times the design pressure
6. The tubes used are generally ¾" with 0.028" wall thickness-hard drawn copper with internally and externally extended surfaces
7. The tube sheet thickness is normally 1¼" using IS 2062 steel
8. The baffles are generally 5 mm thick and can be either HDPE material or steel
9. The evaporators are generally with two circuits so that when the load reduces less than 50%, one circuit can be switched off through a liquid line solenoid valve. Many times chillers with four circuits are also manufactured if the system uses four independent compressors.
10. Number of refrigerant passes are generally even 2, 4 or 8, so that both liquid refrigerant inlet and outlet connections are on the same side, making the connections of superheat sensor bulb as well as piping simpler.
11. End covers are normally of cast iron IS210 grade with $1^1/_8$" thickness
12. Fouling factor on the fluid side, if it is water, is considered as 0.00025 h.ft^2.°F/Btu or more depending on water quality
13. Testing is done as per ARI standard 550/590-2003 for the entire water chilling package using either reciprocating/screw compressors

As mentioned in earlier articles, the design and selection of an evaporator is unique for each application and there are innumerable varieties of different evaporators. The success of any refrigeration and air conditioning plant is predominantly dependent on the evaporator selection, whereas selection of condenser or condensing unit is comparatively much simpler as it has to do the job of only rejecting the heat absorbed by the evaporator. How efficiently an evaporator absorbs heat from air or product or any other fluid therefore depends on evaporator design and selection.

Direct expansion evaporators are also used in a variety of other applications besides those discussed in this and the previous article and we shall cover some of the applications like tank and coil evaporators, oil coolers, milk coolers, plate heat exchangers etc. in the next article.

Evaporators

Special Contsruction Direct Expansion Cooling Coils – Part 5

This series of articles by Ramesh Paranjpey covers the fundamentals of evoporators. The articles will serve as a source of reference for newcomers joining the industry as well as for experienced engineers wishing to brush up on fundamentals.

In Part 3 we covered direct expansion evaporator coils for comfort air conditioning application and in Part 4 shell and tube coolers for fluid cooling for comfort air conditioning as well as for process cooling applications.

Although the principle of operation of DX evaporators remains same, for every application there is some unique feature which makes the evaporator more suitable for that particular duty compared to other type of DX evaporators.

We shall discuss some more commonly used spcial construction applications of DX evaporators in this part.

Plate Coil Evaporators

Plate coil evaporators are fabricated from two metal sheets, either rigid or flexible, and depending on the end use, either one or both plates are embossed to provide a channel path for refrigerant to flow. Laser welding technology is used for bonding the plates.

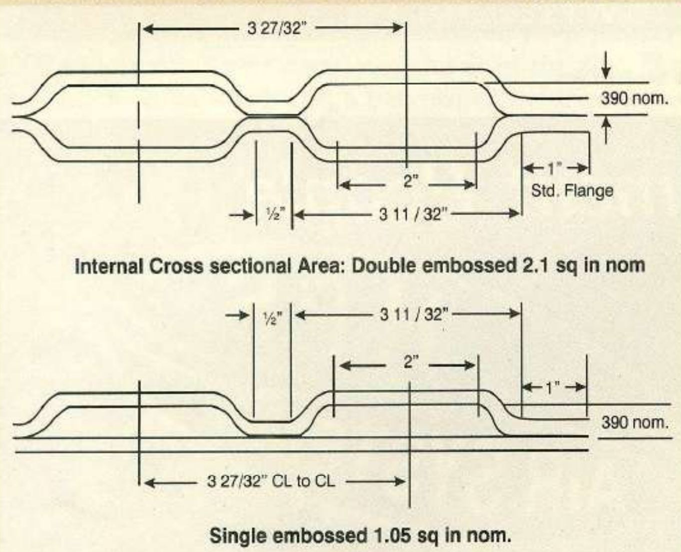

Figure 1: Single & double embossed plate coils.

Figure 2: Clamp-on flexible plate coils.

The plate coil thus formed can be bent, rolled or formed into virtually any shape and thus has inherent flexibility. The material used for the plates could be carbon steel, stainless steel or any other material like monel, nickel and a variety of other corrosion resistant materials.

The various applications of such plate coil evaporators are described hereunder:

Direct Cool Domestic Refrigerators

The evaporator coil formed from two aluminum sheets is bonded together and has 5/16" or 3/8" wide channels for the refrigerant to flow. The overall inflated height of such tube–ways is 0.18". The plate coil is then bent in to a shape of a box and located inside at the top of the refrigerator cabinet. Such coil evaporators normally use a capillary tube as the expansion device.

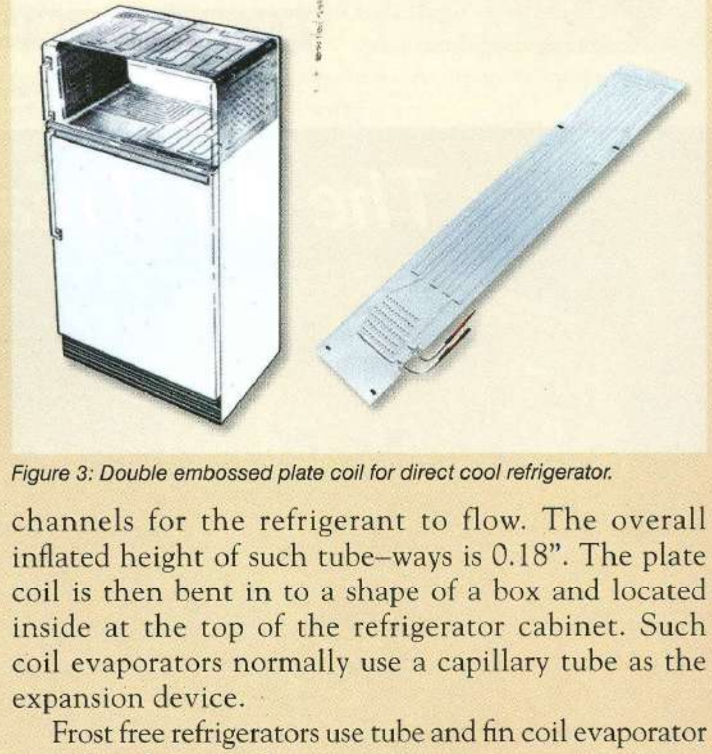

Figure 3: Double embossed plate coil for direct cool refrigerator.

Frost free refrigerators use tube and fin coil evaporator with forced air circulation.

About the Author

Ramesh Paranjpey is a mechanical engineer with an M.Tech in refrigeration from IIT Bombay with over 35 years experience. He has worked in very senior positions starting with Kirloskar Pneumatic in Pune, Carrier Transicold in Bangalore and Singapore as well as Voltas-Air International Pune. Presently he works for himself as a technical advisor & consultant. He is an ASHRAE Fellow, past president ASHRAE W.I. chapter and past president ISHRAE Pune chapter. He can be contacted at *pramesh@vsnl.com*

Figure 4: Cube ice machines use special DX evaporators.

Ice Cube Machines

Some ice cube manufacturer's designs use two plates bonded in such a manner that the upper plate remains flat whereas the lower plate is formed (embossed) and then both the plates are bonded. The low temperature refrigerant flow in the channels thus formed keeps the temperature of the plates below freezing so that it helps in ice formation on the upper plate. The water trickles down on the flat surface and gradually builds in to a sheet of ice. Once the desired thickness is reached, the refrigerant flow is stopped. The plate is normally inclined so the sheet of ice thus formed slides down and falls on the electrically heated wire heater grid and gets cut into ice cubes. These cubes are collected in the tank located below and the cycle repeats.

Baudelot Coolers

These types of coolers are used for chilling water to near its freezing point (0.5°C) without the risk of freezing. Such water is required for many industrial applications, food processing and dairy plants. The fish processing industry also uses such coolers to produce water required for glazing the fish after IQF processing. Other common users are beverage coolers, abattoirs and other liquid cooling applications. The coolers are also used to quickly chill warm beer to the ideal dispensing temperature of 2–3°C.

The design consists of multiple vertical plates, inside which refrigerant circulates and the fluid to be chilled circulates over the outside of the vertical plates in a thin film. The advantage of such a design is that the plates are easier to clean from outside. The coolers use common HFC/HCFC refrigerants in direct expansion using thermostatic expansion valves. In case ammonia refrigerant is used then these coolers are generally of flooded refrigerant design.

Figure 5: Falling film chiller using a double embossed rigid plate coil.

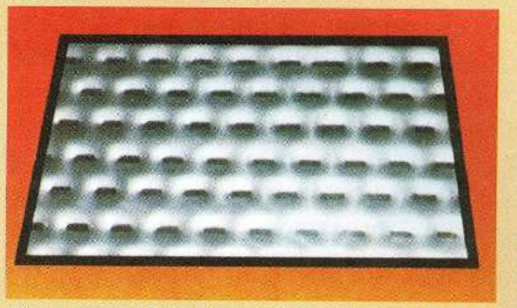

Figure 6: Cad/Cam designed SS plate coils for fluid cooling.

The latest construction technique uses Cad/Cam methods to design & generate outside surface to give the highest possible outside heat transfer coefficient. The plate surfaces are different to suit different fluids and applications (see *photo*) and normally of stainless steel material in various sizes. Multiple plates are assembled in a pre-insulated cabinet which supports the plates. The fluid distributor manifold is located on top and the collecting tank can be either S.S. or PVC.

The flexible design of plates is used to maintain temperatures in the tanks by wrapping the coils externally to the tank. The flexibility allows coils to be curved to even small diameters of 12 inch tanks or pipes.

Rigid as well as flexible plates can be manufactured to ASME Section I Div VIII standard or to ISO 9001 Standard and can be tested to 300 psig pressure and up to 750°F temperature.

Bulk Milk Coolers

Fresh milk must be stored on the farm for some duration before it is sent to the dairy plant. The bulk milk cooler is therefore another major used of plate coil evaporators. Cooling tanks are made of stainless steel AISI 304 grade, with sandwich design using PUF as insulation between the inner and outer sheets and the inner tank surface consists of a laser welded plate-coil design working on direct expansion principle with thermostatic expansion valve. These coolers come in sizes from 200 liter to 5000 liter capacity.

The cooler cools milk from approx. 37°C to 4°C. The direct expansion technique allows milk to be cooled by direct contact with the evaporator. Large temperature differences accelerate milk cooling. Also an agitator helps in providing high speed and turbulent motion of milk along the wall improving heat transfer rate. Anti freezing protec-

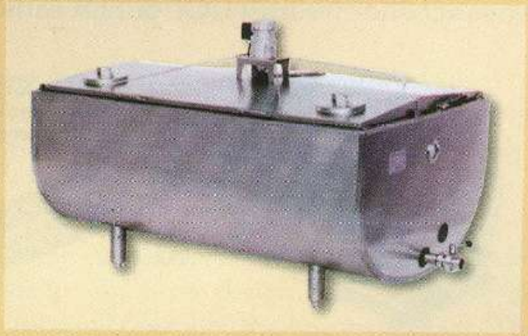

Figure 7: Bulk milk cooler with a semi-cylindrical tank and a built-in DX evaporator.

tion is provided to ensure that the milk doesn't freeze.

The larger size rectangular milk coolers use tube and fin evaporators.

Tank and Coil Coolers

A tank and coil cooler is a tank containing fluid to be cooled with a simple coiled tube through which refrigerant circulates. This type of cooler has the advantage of cold fluid storage to offset peak demand loads. The tank can be also opened for cleaning. Such type of industrial coolers to produce drinking water are used in railway stations where peak demand exists only when a train arrives. For such applications hygiene is important and the DX cooling coils are soldered on to the SS tank from the outside, leaving the inside of tank easy to keep clean. Some other designs use a coil attached to the tank from inside, either with or without agitator to churn the fluid in the tank and thus improve heat transfer. These types of tank and coil coolers are also very popular on fishing boats to cool and maintain the catch at a low temperature before the processing / freezing process is undertaken on the shore.

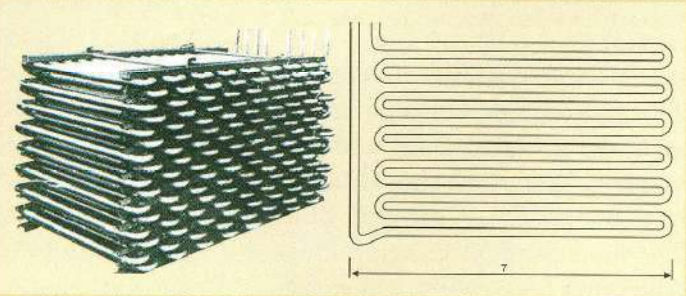

Figure 8: A typical DX coil mounted inside a tank.

Coaxial Evaporators

The tube-in-tube heat exchanger uses an outside tube with inner convoluted tubing. Convolutes are formed having 4, 5, 6 or 8 leads & thus generate higher heat transfer area per unit length. The convoluted surface also imparts turbulence to both water and refrigerant flows while offering large prime surfaces. This yields superior evaporator heat transfer while maintaining low water and refrigerant side pressure drops. The heat exchangers are compact and give high COP & EER without sacrificing space. The heat exchangers can be installed in both horizontal as also vertical manner as per requirement of the package. This heat exchanger can be used as a DX evaporator or condenser in various compact fluid cooling applications.

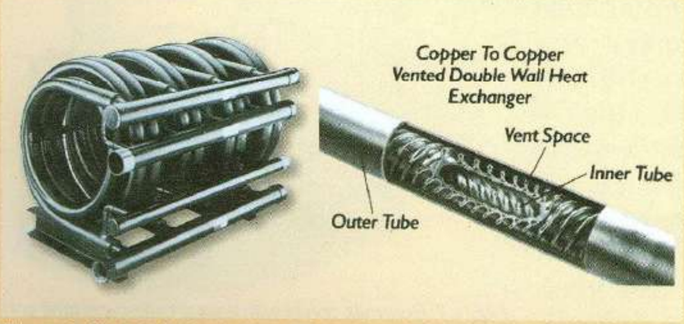

Figure 9: Co-axial tube-in-tube DX evaporator.

Shell and Coil Design Oil Coolers

Such heat exchangers are generally tubular type and consist of a sheath of pipe through which the hydraulic oil flows between the gap of tubular evaporator and the wall of outer tube. One end is fixed whereas other side is bolted.

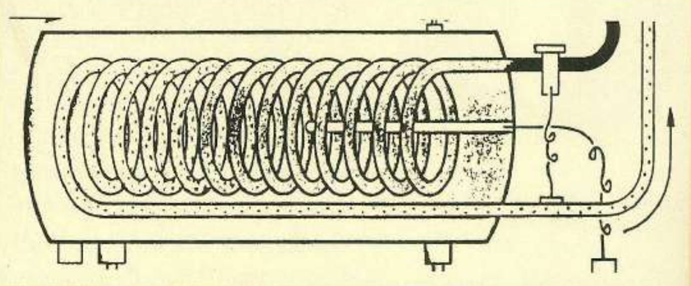

Figure 10: Shell & coil cooler with externally finned copper coils.

Coolants and lubricants, if used at lower temperatures have a remarkable favorable effect on tool life and accuracies. Oil coolers for hydraulic systems used in machine tools in any factory require oil cooling. The heat generated during machining of components needs to be taken away by the coolant.

If the oil which is re-circulated is not cooled it leads to premature ageing of hydraulic oil, leading to increased wear and tear of components. Efficient cooling is therefore vital and the compactness is also very important as the cooling system has to be fitted within the machine. A machine having 10 hp spindle drive normally uses 100 liter capacity cooler whereas 25 hp machine uses 200 liter and large machines of 35 to 50 hp drives use 350 liter capacity coolers. The oil is cooled from 60 to 70°C to 32 to 34°C whereas coolants are maintained at 18-20°C. The refrigeration capacity of such units varies between 1 ton to 5 ton maximum though most popular size is 3 ton capacity. For hydraulic oil cooling, shell and coil or PHE coolers are used but for cutting oil, shell and coil or tube and coil designs are preferred.

Since tube-in-tube design described earlier is currently not manufactured in India, many manufacturers use a finned tube evaporator in a coiled form and insert this in a shell. The refrigerant flows inside the tube and oil flows between the coil and shell. The clearance between shell and OD of coil has to be controlled with precision so that oil flows over the entire coil surface without bypassing. The finned tube is generally with 14 to 16 fins per inch with 1.5 to 2 mm fin height.

The advantage of such a cooler is its ease of maintenance, as the coil and shell can easily be separated. This is essential since the coolant carries metal contaminants choking the passage between evaporator coil and shell, the pressure drop increases rapidly thus endangering flow of coolant. Highly efficient filtration is therefore essential before the coolant enters the cooler.

DX Evaporators for Passenger Cars

The most widely used DX evaporator of special construction is in the automobile industry.

The design of evaporators for automobile air conditioners have some very unique requirements and features.

The evaporator blower assembly is normally under the dash board in front of the co-passenger sitting next to the driver and is invisible to occupants. The frontal area is limited and it becomes necessary to increase the depth of the evaporator.

The design considerations are:

1. The evaporators have to be extremely compact and light weight to fit in the available space decided mainly by styling considerations.

2. The evaporator has to meet the initial fast cool down load which can be as high as 2 to 3 times more than the normal stabilized load.

3. The evaporator has to work with 100% outside air to be cooled from ambient temperature to the supply temperature.

4. The coil should not get iced when running in the recirculation mode and should have a freeze-up protection thermostat.

5. Coil water drainage should ensure that the water spray is not carried to passenger compartment as well as lead to odour problems. This is important since the frontal area is less, it tends to increase the face velocity in full air flow conditions and chances of water carry over increase.

6. Since normally there are no filters provided in order that the evaporator does not get choked, maximum allowable fin spacing has to be provided with minimum air side pressure drop.

7. The refrigerant to air flow should be "counter flow", i.e., the refrigerant should be circuited to flow from back to front as air flows from inlet face to exit face of the evaporator, to get optimum efficiency and uniform face temperature distribution

These evaporators use thermostatic expansion valves which are known as block valves since they do not have bulb and capillary but have an inbuilt superheat control arrangement. Some cars also use an orifice tube to reduce cost.

The basis of design of automobile evaporators is as under:

- Air inlet temperature 43.3°C (such high temperature is due to engine heat pick up over which air flows before it is admitted at the inlet)
- Air outlet temperature 11 to 13 °C.
- Evaporating temperature- minus 1.7°C.
- Pressure drop approx. 0.6" water.

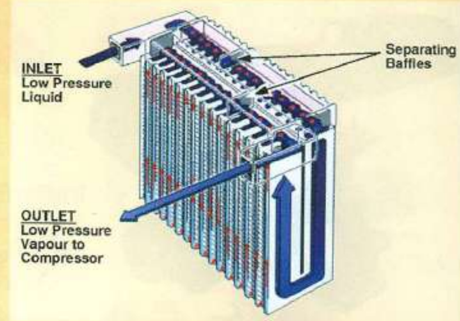

Figure 11: Plate & fin evaporator design for automobiles.

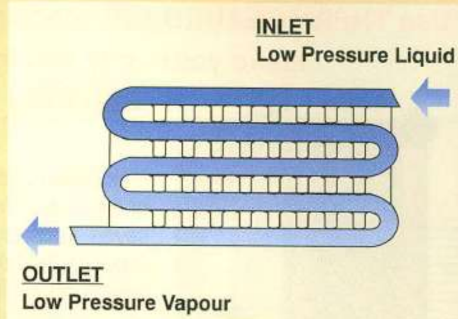

Figure 12: Serpentine evaporator design used in passenger cars.

After considering all these aspects the choice of selecting evaporators for automobile application is limited to the following types

- Plate fin evaporators
- Serpentine
- Tube and fin type

The performance expectations from such design demands the following results while testing

1. Open door test(fresh air mode) – in 10 minutes average grill temperature drop w.r.t. ambient should be 15°C minimum when ambient is 40°C and RH 30 to 60%

2. Closed door test – (recirculation mode) – in 10 minutes average grill temperature should be reduced to less than 10°C.

The plate fin type is the most efficient of the lot (maximum loading i.e. max. kcal/hr/sqm/°C) and the performance increase over the serpentine design is as much as 20%. Some manufacturers in India are using this design.

Many times however other considerations like cost make serpentine selection a preferred choice. Most of the Indian manufactured cars use serpentine type evaporators where as use of tube and fin evaporator is now out dated.

The serpentine evaporator construction uses extruded aluminum tube in serpentine design. The aluminum fins are brazed to tube in controlled arc brazing furnace. The extrusion section enhances primary to secondary area

Evaporators

Plate Heat Exchangers – Part 6

This series of articles by Ramesh Paranjpey covers the fundamentals of evoporators. The articles will serve as a source of reference for newcomers joining the industry as well as for experienced engineers wishing to brush up on fundamentals.

In the last 5 parts we covered direct expansion evaporators mainly for air and water/brine cooling. Other popular heat exchangers which are Plate Heat Exchangers (PHE) were not touched upon since PHE's are not used extensively for direct expansion application and the majority of them are used in flooded system designs. None the less, the direct expansion evaporator series would remain incomplete if we do not discuss these widely used heat exchangers. While doing so, we shall also cover some more important aspects of this type of heat exchanger.

Plate Heat Exchanger (PHE) are so versatile that one can make use of them in any one of the following system designs:

a. Direct expansion system design
b. Gravity flooded system design
c. Forced pump circulation over feed system design

Construction Details of PHE

The plate heat exchanger consists of a number of plates assembled together with two different fluids flowing on either side of the plates. The plates are corrugated with herringbone pattern, which increases the plate rigidity, allowing use of thinner gauge plate material leading to faster heat transfer. This also substantially increases the heat transfer area making them very compact and generating turbulent and counter current flows in opposite channels and thus further improving heat transfer characteristics. The turbulent flow also ensures that there are no stagnant areas which considerably reduce fouling tendencies. The flow pattern geometry of each plate depends on the application and is based on computerized design and manufacturing techniques to give the highest heat transfer with minimum pressure drops due to optimum geometry through which the fluids flow. The plates can be manufactured in a variety of materials to suit fluids handled. AISI316 Stainless Steel is standard material but Titanium, 254SMO, AISI 317 or Hastelloy C, Hastelloy D, Nickel-200, Incolloy material plates are also available.

Types of Plate Heat Exchangers

1. Gasketed Plate Heat Exchangers
2. Semi Welded Plate Heat Exchangers (SWPHE)
3. One piece fully Brazed/Welded Plate Heat Exchangers

In this last category, there are two versions as under

a. Brazed Plate Heat Exchangers (BPHE) – copper brazed, stainless steel fusion bonded and nickel brazed

b. Automatic All Welded Plate Heat Exchangers (AWPHE)-Either stainless steel or titanium

Only semi welded twin plate heat exchangers (SWPHE) can be opened on gasketed side for inspection and cleaning.

Which type of PHE to use from the above options depends upon the application. For halocarbon refrigerants normal brazing of edges is sufficient but for ammonia, either nickel brazing or welding is essential.

Gasketed Plate Heat Exchangers

This plate heat exchanger consists of a pack of single plates mounted and compressed in a frame. The plates are assembled with the herringbone pattern pointing alternately upwards and downwards. Each individual plate is separated with a one piece molded gasket, secured in the gasket groove around the edge of the plate and around the porthole areas. The gaskets are arranged so as to direct the flow of the medium into alternate channels, usually in countercurrent flow. This is the most widely used variety as it can be used for any two fluids flowing in alternate plates

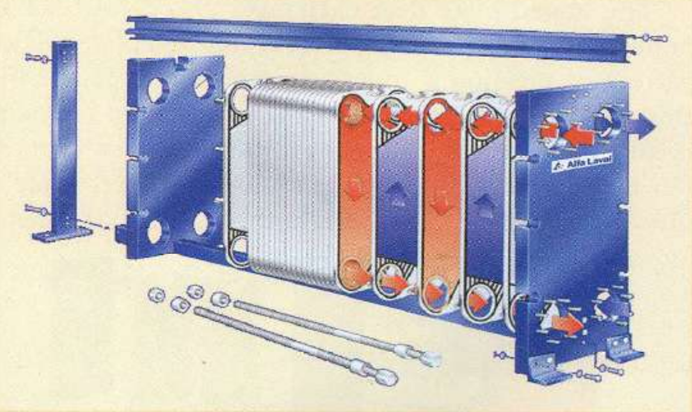

Figure 1: Gasketed plate heat exchanger.

About the Author

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like a milk cooler in which milk flows on one side and on the other side is chilled water. The other applications are oil cooling, heat recovery, electro-painting and other numerous applications. The major advantage of this type is that both sides can be cleaned by loosening the plates and creating gap in-between for cleaning.

Semi Welded Plate Heat Exchangers

In semi welded gasketed heat exchangers, the two plates are seam welded with computer precision so that it creates a hermetically sealed cavity for fluid to flow. One fluid flows through this sealed twin plate assembly and the second, not so critical fluid, passes through the gasketed path transferring heat. Thus, there is a strict separation between two fluids and chances of leakage from one to other are eliminated. The heat exchanger assembly is formed by bolting together pairs of sealed plates. The construction has confined gasketed passage for other fluid and there is a small circular gasketed joint. When the plates are assembled the refrigerant flows through this circular passage to the next pair. Such design helps in dismantling the assembly to clean the liquid side surfaces should they be fouled. It is not necessary to remove the plates from the bolts and the plates can be loosened to make space for cleaning. It is however essential to remove refrigerant before dismantling as the round holes through which the refrigerant flows become exposed to air.

These heat exchangers are used in dairy, brewery, marine, and slaughterhouses, chemical and pharmaceutical industry and for ammonia evaporators and condensers and other applications in ammonia refrigeration systems.

Brazed Plate Heat Exchangers

The brazed plate heat exchanger also consists of a number of parallel stainless steel corrugated plates. The pattern of pressing is inverted on alternate plates. In this way, the ridges on adjoining plates form contact points. Between each pair of heat transfer plates, copper foil is inserted. The complete assembly is then loaded into vacuum brazing oven. In this oven, due to the high temperature, the copper melts and accumulates at the contact points and edges. It solidifies and a compact copper brazed heat exchanger is formed. The complete heat exchanger thus consists of many plates brazed together resulting in a compact, strong heat exchanger.

These are used in direct expansion evaporators using HFC/HCFC refrigerants, food, pharmaceutical, marine, power, textile and other industries.

Automatic All Welded Plate Heat Exchangers (AWPHE)

All welded plate heat exchangers are similar to brazed plate heat exchangers except that it is formed by laser welding at the edges of plates assembled together. In contrast to normally sealed brazed units, the unit remains immune to more aggressive and clean media. These heat exchangers are preferred for high temperature and pressure applications where gasketed heat exchangers cannot be used.

Direct Expansion Plate Heat Exchangers

In direct expansion evaporators, the two fluids flow in pure counter current through alternate channels. The flow of liquid is downward, whereas, refrigerant flow is upward; counter flow to the liquid. The refrigerant enters at lower right end portion and flows upward whereas remaining refrigerant passes through subsequent pairs. In the end pair, the refrigerant flows upward and joins the streams from other pairs finally leaving the evaporator in the upper right corner. The liquid (single phase media) enters at the upper right port and gets cooled down and leaves from the bottom right port. This arrangement ensures that the refrigerant is super heated.

Although the PHE's can be used as direct expansion evaporators, they are better suited for flooded systems with surge drum or forced/pumped liquid overfeed applications. The reason being, to achieve uniform refrigerant flow through all pairs becomes difficult in direct expansion design. As in air coolers, after the expansion valve a distributor is provided with feeder tubes to each circuit

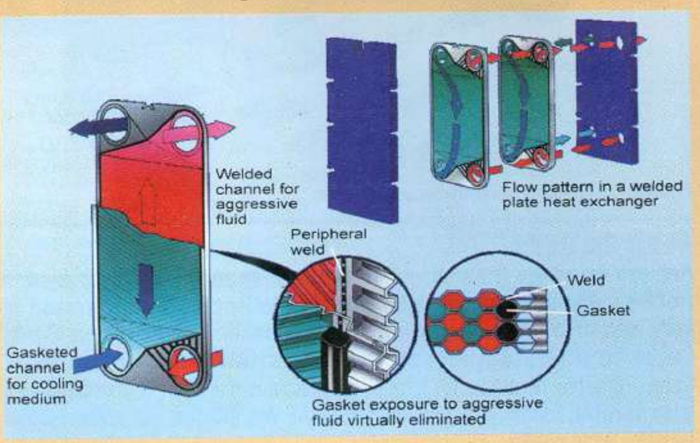

Figure 2: Semi welded plate heat exchanger.

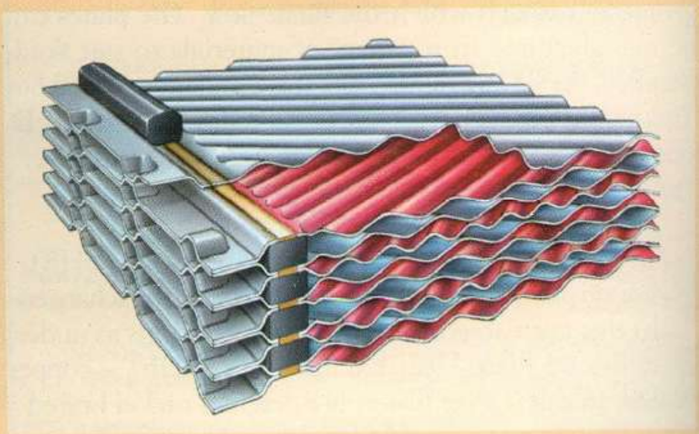

Figure 3: Aggressive media on one side.

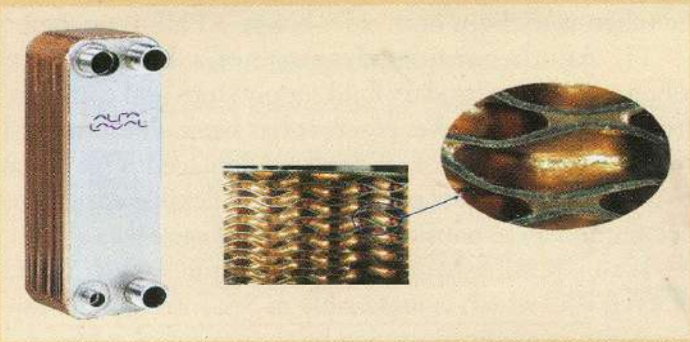

Figure 4: Brazed heat exchanger.

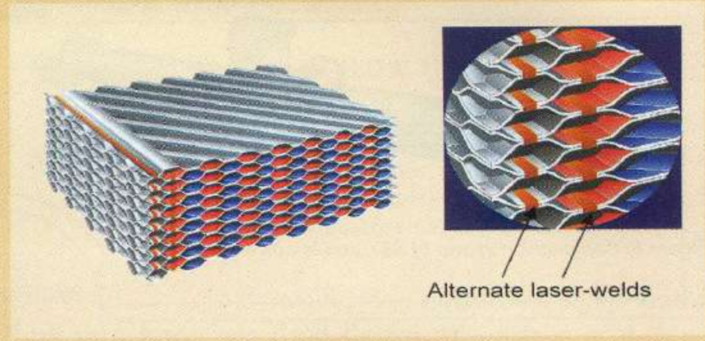

Figure 5: Welded plate heat exchangers.

for ensuring equal distribution of liquid plus gas in each circuit. A similar arrangement is also essential if PHE is used as direct expansion evaporator. At low nozzle refrigerant velocities, there is a risk that the vapour and liquid emerging from the expansion valve gets separated and enters different channels. If the velocity is high, then there is chance of unequal distribution from channel to channel. To overcome this, different distributing devices are used. The most common one is to insert a pipe in the lower refrigerant path with drilled holes, usually one for every alternate channel. The diameter of this hole increases with the distance from the entrance. This helps in improving the distribution by providing uniform quantity of liquid plus vapour in each refrigerant channel. The other types of distributors are shown in *Figure 7*.

GEA uses patented technology known as mister refrigerant spray, which distributes a fine gas/liquid mixture over the entire flow path surface.

When the PHE is used as direct expansion evaporator, it is essential to take the following precautions:

1. The plate heat exchanger should be mounted in vertical position
2. A short straight pipe between evaporator and expansion valve with no bends, valves or vessels in between is preferred.
3. The pipe diameter should not be larger than the exit diameter of the thermostatic expansion valve.
4. There should always be enough liquid on the high pressure side whether receiver is used or not.
5. A difference in height between high side and evaporator is desirable to ensure liquid at the inlet of expansion valve, if no receiver is used. The valve stem should be in horizontal position, since an inline valve might have much larger inside bend which is not desirable.
6. Over sizing the number of plates in evaporator with the purpose of increasing the evaporation temperature to get more capacity involves the risk of poor distribution of refrigerant flow. The evaporator therefore, is not the deciding component in a system; it can only boost the performance by operating at higher evaporating temperature. It is the compressor capacity which decides the amount of cooling achievable *Figure* 6.

Salient features of PHEs and why they are so popular and are replacing other types of heat exchangers, wherever opportunity arises, are:

1. The function of the evaporator is to transfer heat from the cooling medium to the refrigerant. Smaller temperature differences between the two mediums enhance the refrigeration cycle efficiency and save energy. Plate heat exchangers do this better than any other type of heat exchanger.
2. In comparison with shell-and-tube heat exchangers, the size and geometry of PHE makes them suitable for installation within compact framework and are thus, ideal

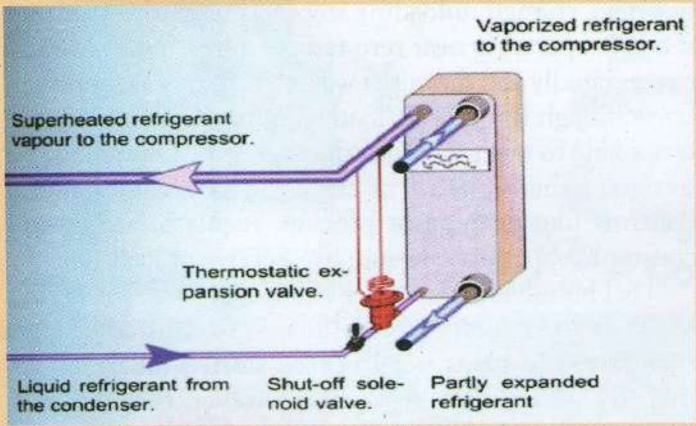

Figure 6: Direct expansion plate heat exchanger evaporator.

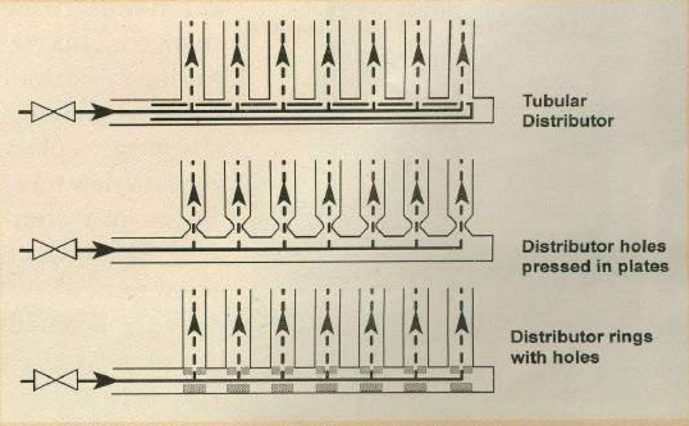

Figure 7: Different arrangements of liquid line distributors.

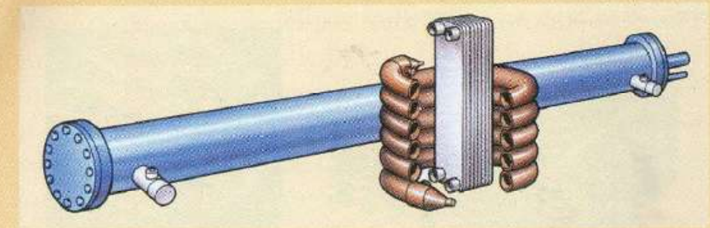

Figure 8: Comparision in size of S&T, coil-in-coil and PHEs.

where space restriction exist. *Figure* 8.

3. It is possible to install both the condenser and evaporator in one frame to save space, weight and cost of installation.

4. The compact execution and the small internal volume means extremely low weight compared to other exchangers.

5. Due to the low internal volume, a low charge of refrigerant is required. A typical relation to systems with conventional exchangers is that the PHE requires only 1/7th the quantity of refrigerant.

6. Semi welded gasketed PHE can easily be opened for inspection, cleaning and maintenance while plates are still inside the frame.

7. Chemical cleaning is very effective due to high turbulence in the channels formed in the corrugated plates. They also require less chemical cleaning solution and shorter circulation time.

8. Increase or decrease in capacity can be easily achieved by adding or removing plates.

9. The corrosion resistant properties of S.S. material are far superior compared to steel which is standard in shell-and-tube (S&T) designs.

10.In the unlikely event of leaks, it is almost always an external leak and therefore, easy to detect. A gasket failure cannot result in internal leakage and danger of cross contamination between two fluids. Only the ring joint gasket needs to be changed. Thus, repairing by expanding tubes, welding, plugging, replacing with new tubes which are common maintenance issues in S&T designs are avoided, in case of PHE's. The only precaution that needs to be taken is to drain both sides before a PHE is opened.

Figure 9: In case of freezing of a PHE, plates and gaskets do not get damaged.

11. Another major advantage of a PHE is, even when water or secondary fluid supply stops and complete freezing of a PHE takes place, it has been demonstrated that the plates and gaskets don't get damaged. This is due to the construction of plates which are flexible enough to accommodate expansion on freezing. *Figure* 9.

12. It is possible to get water temperatures as low as 1°C or even 0°C which is impossible in S&T design. For low temperature applications one has to use glycol solutions.

13. In applications, demanding consumption of secondary fluid like water such as in concrete cooling or fisheries, the temperature drop from normal temperature of water of 25 to 30°C to such low temperature of 1°C is difficult in S&T designs, whereas in PHE high temperature drops can easily be achieved. The production of low temperature water of 0°C using PHEs has been successfully demonstrated in the construction of the 38 km long Euro-tunnel.

14. In case of sub zero applications requiring glycol solutions, with PHE use, the solution concentration can be much weaker compared to S &T heat exchangers as one can select a concentration very near to freezing point, thus saving pumping cost.

15. In Ammonia pump circulation systems, the circulation rate can be kept as low as 1.2 to 1.5, which is enough, thus requiring smaller pumps. The surge drum or low pressure vessel size can also be much smaller compared to other designs.

16. Lower internal volume of PHE compared to S&T design sometimes is a disadvantage, as the system does not have enough inertia and hence, is very sensitive to load fluctuations. As we all know, in refrigeration systems, part load is very common and if proper flow rates in PHE on either side are not maintained the performance deteriorates rapidly.

17. When the load on the system reduces, with constant flow designs, the inlet temperature starts dropping and thus, suction pressure also drops. If the compressor does not have enough unloading steps to match the load and if one is operating near zero temperatures, a part of PHE freezes rapidly and the outlet water temperatures shoots up. Even though the process load requirement is lower, one is not able to meet the same due to this phenomenon. To overcome this drawback of PHE, one has to install costly controls like evaporator pressure regulators to ensure constant evaporator pressure irrespective of load.

18.The advantage of a PHE is that it starts giving required fluid temperatures in a very short time and therefore, the plant need not be started much earlier than the process requirement. However, this acts as a disadvantage in case the plant stops abruptly as there is

continued on page 110

Evaporators

Flooded Ammonia Unit Coolers – Part 7

This series of articles by Ramesh Paranjpey covers the fundamentals of evoporators. The articles will serve as a source of reference for newcomers joining the industry as well as for experienced engineers wishing to brush up on fundamentals.

In the first and second part of the Evaporator series, we covered the basics of operation of an evaporator, the part it plays in the refrigeration system, some useful formulae as well as differences between Direct Expansion and Flooded evaporators together with their advantages and disadvantages.

From part 2 to 6, we then discussed various types of Direct Expansion evaporators for comfort air conditioning as well as fluid cooling applications using HCFC/HFC refrigerants.

Having covered almost all D-X evaporators, we shall now discuss Flooded evaporators used for air cooling using ammonia refrigerant.

Since ammonia and oils are immiscible at all temperatures, it can be easily drained from various equipments, like oil separators, condensers, receivers and evaporators. Ammonia evaporators are therefore, predominantly of flooded design, as this is more efficient in operation than D-X evaporators.

One of the most primitive designs of ammonia flooded coolers can be seen, especially in the eastern part of the country like Bihar/West Bengal, where one would notice cold storages with ceiling coils, popularly known as "bunker coils". These coils have no fins and no defrosting methods. The building of frost reduces the coil's heat transfer ability and a lowering of suction pressure. This leads to higher compressor power consumption. Oil draining is also difficult. These are now getting replaced by forced circulation air coolers.

The flooded air coolers currently being used, can be further classified as gravity circulation design or force feed pump circulation design. The basic mechanical design of an evaporator cooler is the same in both the cases, but the system design is different.

Gravity Flooded Air Coolers

The ammonia flooded evaporators for air cooling are normally called "product coolers" or "unit coolers" since they are used in food preservation cold room applications.

Construction

The material used for ammonia coolers is generally mild steel tubing with M.S. fins and the complete assembly is externally galvanized. Some manufacturers use stainless steel tubes with aluminum fins. The advantages of using S.S. tubing are explained in detail in an article published in ISHRAE Journal Oct-Dec 2000 issue by Mr. David B. Young. The major advantages are that it makes the coolers light in weight by 30% compared to M. S. coolers, reduces defrost time, better heat transfer, use of thinner and stronger tubes with smooth surface and corrosion

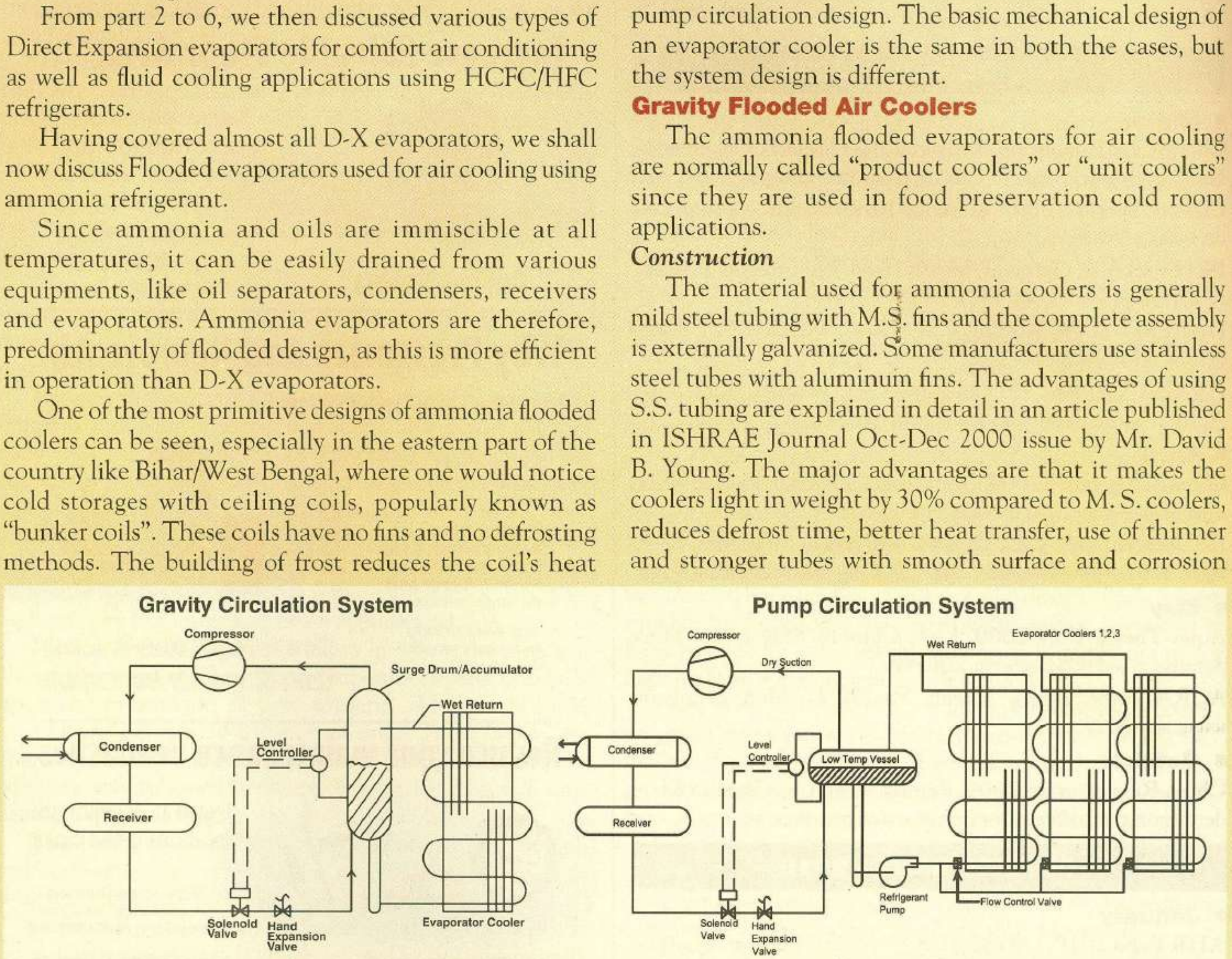

Figure 1 : Comparison of gravity and pump circulation systems

About the Author

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proof as well as hygienic operation. Some manufacturers are also using all aluminum construction, the drawback being that it is difficult to repair at site in case of leaks, and more corrosive and weaker in strength compared to M.S. or S.S. construction.

The cooler consists of a cooling coil and surge drum and the air is circulated over the coil block. The direction of liquid flow in gravity flooded systems is generally upward from bottom to top and in pump circulation systems it could be either top or bottom feed or even cross flow as is the case in plate freezers.

The fans used for air circulation can be standard propeller, or Aerofoil design.

The fans used for air circulation are in the majority of cases, axial fans using single or two speed motors. The Aerofoil multiwing fan impeller has adjustable blades and the angle can be changed.

In a free-flow air pattern, the external static pressure is zero which is normally the case with ceiling suspended unit coolers. In case of blast or trolley freezing applications the blade angle is adjusted to work with a static of up to 12 mm to overcome the pressure drop when air directly passes through the product.

Principle of Operation

This type of evaporator relies on natural convection to circulate more refrigerant through the evaporator than what evaporates. The inside surface of the tubing is thus totally wetted with liquid refrigerant from beginning to end of the coil, thereby increasing the latent heat transfer capability substantially. The vapors formed bubble out through this liquid and then are separated in the surge drum and only vapor flows to the compressor suction.

Instead of a thermostatic expansion valve regulating liquid flow in D-X evaporators, a liquid level controller is used, which admits liquid in the surge drum to replace the quantity evaporated.

The static pressure difference in the liquid leg is greater than the evaporator tube-side pressure drop and this difference in pressure motivates the flow of refrigerant. The location of the surge drum is critical as it decides the liquid leg height and pressure at the bottom of the liquid leg. Since this pressure at the lower end is higher due to liquid column, it increases the boiling point of liquid refrigerant and thereby reduces useful heat transfer area of the evaporator as part of the area is used to overcome this additional sub cooling before the evaporation starts. The balance between higher ΔP in the coil and the force required to motivate circulation is critical. Normally the surge drum bottom should not be at a higher elevation than 6 to 10 inches from top of the evaporator.

In pump circulation flooded evaporators, low temperature liquid from the vessel is pumped through a number of evaporators at a much higher rate than what evaporates.

In a pump circulation system every evaporator, therefore, does not need a separate liquid level controller and surge drum as one common low pressure/temperature storage vessel does the function of supply of liquid to various evaporators.

The performance of the evaporator in well designed systems in both the types is equally effective and the only difference is that in gravity flooded evaporators every evaporator needs oil to be drained and therefore if the system requires more than 3 to 4 evaporators, as generally is the case, with multi-room cold storages, a pump circulation system is preferred.

More detailed information on the effect of pressure balancing and pump circulation systems is given in an article published in this *Journal* elsewhere.

Type of Coolers

Ceiling Mounted Coolers

This type of unit cooler using ammonia refrigerant, is used in cold storages and operates near 0°C saturated evaporating temperatures in case it is used for fruit or vegetable storage applications or several other commodities needing positive storage temperatures as well as low

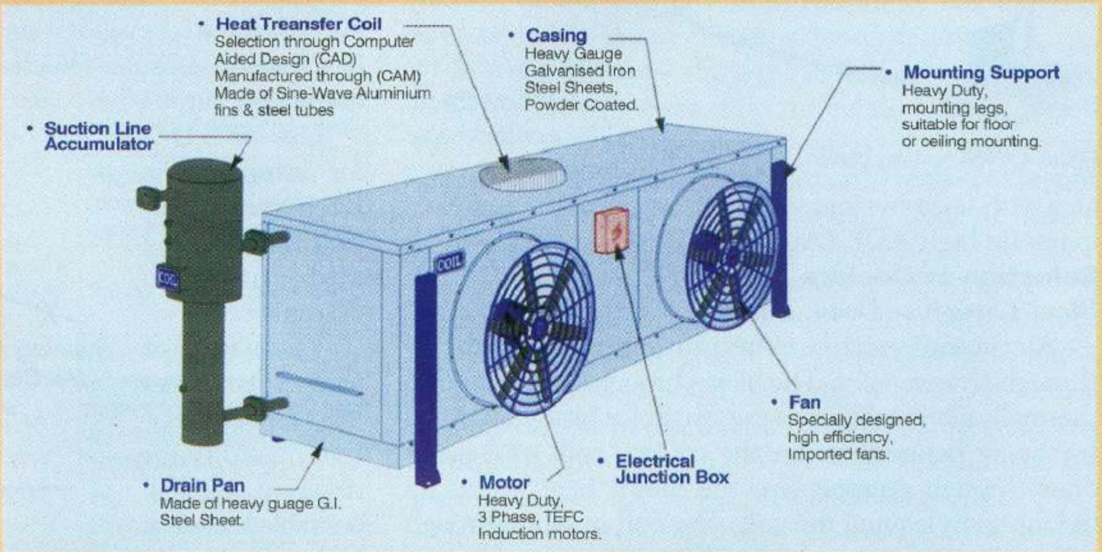

Figure 2: Ceiling suspended cooler

temperatures up to minus 25°C.

The advantage of these coolers is they do not occupy floor space and give good air circulation over the product since cold air tends to move down and warm air rises thus giving additional benefit of natural circulation.

Blast Freezers

Generally these are floor mounted type with coil block below and fan section at the top. The coolers are also used for low temperature applications up to minus 40°C. These coolers have very high air circulation rate and are normally kept in a very small room where batch freezing takes place. The product is kept on trolleys or on racks in front of the cooler up to the coil height and a partition is placed on top of the product. The air coming out at the top from the fans travels horizontally to the opposite wall and is redirected over the product to be frozen and then returns to the coil block. Thus the air envelops the product completely without any short circuit or bypass of circulating air.

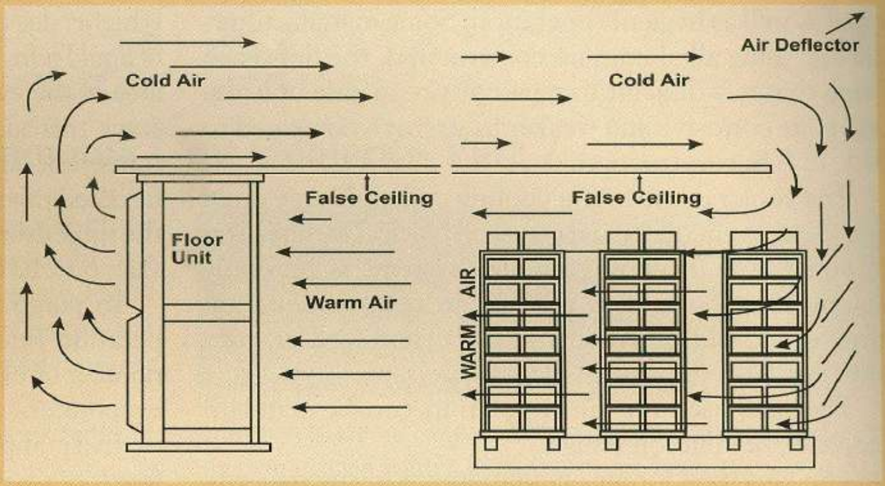

Figure 3: Batch freezing with floor mounted unit cooler

High Humidity Cooling Units

For many applications, especially for fruit and vegetable storage, pre-cooling is required, maintaining high humidity to avoid product weight loss. These units are selected on the basis of very low ΔT or there are chilled water/glycol spray sections after the cooling coil to saturate air coming out of the coil. Thus high sensible heat ratio is maintained. The coolers have much larger face area with less rows and very high air circulation rates to maintain high ADP. (Apparatus Dew Point)


Figure 4 : High humidity cooler

Selection of Coolers

Blow Thrugh or Draw Through

Air circulation can be either in a draw-through or blow-through arrangement. The blow-through arrangement is thermally advantageous as the fan motor heat is absorbed by the air before it enters the cooling coil, whereas in draw-through arrangement the motor heat warms up the air upon leaving the coil. The coil in blow-through design thus operates at higher ΔT and is more effective.

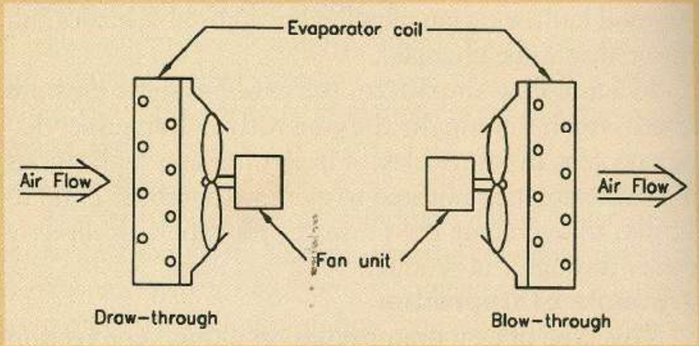

Figure 5: Draw through and blow through evaporator – fan configurations

The advantage of draw-through configuration is the air throw is greater than blow through arrangement. Care however has to be taken to ensure there is no moisture carry over directly into the air stream.

Temperature Difference (TD).

TD-1 "TD" is defined as entering air temperature minus saturated evaporating temperature

TD-2 is for those who select air coolers on MEAN air temperature which is (air entering +air leaving) ÷ 2, minus saturated evaporating temperature. This results in a lower size cooler selection which may not give the desired output.

Use of TD-2 for rating coolers is being phased out as it is misleading and unfair to customers.

The nature of product determines the desirable relative humidity for storage room. The desirable humidity in turn dictates the

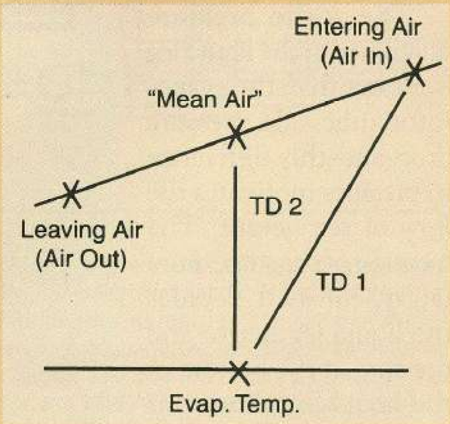

Figure 6: Selection "TD = TD 1"

approximate design TD between the air in the storage room and refrigerant in the cooler. Most manufacturer's catalogues show cooler capacity in Btu/hr for a given air flow rate expressed in cfm and evaporator TD as 10°F. Over sizing the evaporator may reduce TD, but ensuring the refrigerant evaporator pressure, and not allowing it to reduce, is the surest way of maintaining required TD and the relative humidity to prevent product weight loss.

Theoretical RH%	50-65	65-80	80-85	90	95
Design TD °F	17-22	12-16	10-12	7-9	5

Cfm Requirements

The total heat removal capacity of the cooler depends on adequate air flow to ensure rapid pull down temperature and uniform air distribution to achieve uniform temperatures in all the areas of the cold room.

Too little air would lead to wide temperature difference, heavier frosting, and poor air movement in the store leading to hot spots and spoilage of product, and too long a cooling period.

Too high an air flow is also objectionable as it would lead to excessive noise and high power consumption, imposing additional load on the refrigeration system.

Type of Application	Recommended number of air changes	
	MINIMUM	MAXIMUM
Holding Freezer	40	80
Packaged holding cooler	40	80
Cutting rooms	20	30
Meat chill room	80	120
Boxed banana ripening	120	200
Vegetable and fruit storage	30	60
Blast freezer	150	300
Work areas	20	30
Unpacked meat storage	30	60

ASHRAE *Handbook on Refrigeration* gives general guide lines which are reproduced as below:

Low velocity coolers, low fin density	Velocity over the coil face 85-200 fpm	High humidity application, meat, floral walk in coolers
Medium velocity coolers	200-400 fpm	Vegetable preparation rooms, Wrapped fresh meat cooling, Dairy coolers
Standard air velocity	Up to 600 fpm over the coil face & 1000-2000 fpm at discharge	Potato coolers, chili stores
High velocity coolers	600-700 fpm over coil but 200 fpm at air outlet	Blast and tunnel freezers, where products are not likely to be adversely affected by moderate dehydration during rapid cooling
Spray coolers	600 fpm at coil face or less	High humidity chambers like grape coolers

After selecting the cfm, TD, area required, we need to also pay attention to whether to provide more fins and less primary area or to provide less fins and more primary area.

For the selection of number of fins, one may follow the general guide lines given below:

6FPI	Storage rooms above 0 deg C, occasionally also for subzero temperatures where minimum door openings, and product thoroughly wrapped
4 FPI	Low temperature rooms Where not heavy frosting is expected, even for light frosting this is best selection
3FPI	For low temperatures where moisture load is high or where defrosting is infrequent like blast freezers
2 FPI	Use for low temperatures especially for first two rows of coil block and 3 or 4FPI for air leaving side rows. used where moisture load is heavy and frequent defrosting is not possible say within 24 to 48 hours

After taking care of all the above mentioned points it is easy to select a cooler that is appropriate for the application

Defrost

Defrosting the coolers operating at sub zero temperature needs periodic defrosting to keep the coil surface free from frost so that optimum heat transfer efficiency is maintained. The defrosting frequency depends upon the type of product stored, frequency of door openings, weather conditions, insulation, vapor barrier effectiveness and other factors.

The common methods of defrosting are:

1. ***Electrical defrost*** – in this method electrical resistance heaters are embedded in the coil along with the tubes in the fin section so that there is good thermal contact with the coil. Many times, heaters are also inserted in dummy tubes through which refrigerant does not flow. This type of defrosting is used for small to medium capacity coolers especially with HCFC/HFC refrigerants where copper tube with aluminum fins is the normal construction material. The first cost of this method is lower but the running cost is higher due to electricity consumption required by the heater elements during defrosting.

2. ***Water Defrost*** – this is the most widely used method in which water is sprayed on the tubes. The mixture of water and melted frost is collected in the drain pan and through a drain pipe is discharged outside the cold room.

3. ***Hot gas defrost*** – which is most efficient since it is the only method where heat is provided from inside. The hot gas defrost works only when 3 or more coolers are present in the plant and only 1/3rd coolers can be defrosted at a time to ensure enough hot gas is available for defrost. The detailed description of this system is given elsewhere in this Journal. This is the most effective method of defrost but involves complex design and has higher first cost due to various controls involved.

4. ***Reverse cycle defrost*** – The evaporator may be defrosted by reversing the cycle of operation in the

system. When the cycle is reversed, the evaporator acts as condenser and the condenser becomes an evaporator. When evaporator is acting as condenser, it melts the frost on the coil while condensing the hot gas and converting it into liquid inside the tubes. This system requires a four-way valve to reverse the direction of flow.

In order to activate defrost there are again many choices. Some of them usually practiced are:

1. ***Manual on/off*** – in this method either the compressor is stopped or the refrigerant flow to evaporator is stopped until the frost is melted. The major draw back is that it takes a long time to defrost and in the meanwhile temperature in the room gets disturbed.

2. ***Pressure control defrost*** – when frost accumulates on the coil, the pressure drop across the coil increases. The preset pressure sensor activates defrost cycle based on increase or decrease in pressure drop.

3. ***Ice thickness sensor*** – the defrost cycle is activated when ice thickness builds to a certain level. This method is used in defrosting flooded operation ice bank systems or tube ice makers.

4. ***Defrost Timers*** – the defrost cycle will be activated as per preset timing whether the coil is frosted or not. The timing can be adjusted to suit the needs or reset after couple of days when moisture load reduces which occurs while only maintaining the product temperature.

Conclusion

The author suggests the following key issues to be considered to ensure successful application of coolers:

1. Irrespective of product loading temperature and storage temperature, do not select cooler for higher than 6-7°C TD. This should give adequate heat transfer area and faster cool down.

2. Select a cooler with adequate air circulation rate. Many times, if the product is in pre-cooled condition and with good insulation of cold room and long duration of storage, the cooling load is very low, and many engineers tend to select coolers only on the basis of refrigeration tonnage. As this selection leads to a small cooler it's air circulation also is very low and is not enough to ensure that air reaches all stored goods. Hence selection should also be checked for enough air circulation based on room volume. The temperature gradient from one corner to another should not be more than 1 to 1.5°C

3. Ensure that air coming out of cooler is not returned with out enveloping the entire product. Proper stacking and arrangement of stored commodity is very important.

4. Defrosting method and its engineering, piping and controls should be given special attention.

The next issue will be the last in this series on evaporators and will deal with flooded shell and tube fluid coolers.

Evaporators

Flooded Shell-and-Tube Chillers – Part 8 (concluding)

This series of articles by Ramesh Paranjpey covers the fundamentals of evaporators. The articles will serve as a source of reference for newcomers joining the industry as well as for experienced engineers wishing to brush up on fundamentals.

In this last article of the series we shall discuss shell-and-tube flooded chillers for water and brine cooling applications. Such evaporators use ammonia as well as halocarbon refrigerants like R-22 and R-134a.

In Part 2 of this series we have already dealt at length with various advantages of flooded evaporators.

Flooded shell-and-tube evaporators are very popular in screw/centrifugal compressor water cooling packages predominantly used for comfort air conditioning applications. These packaged chillers mostly use R134a refrigerant. Flooded design is popular for its major advantage of ease of tube cleaning on the water side. The other advantage is that the thermodynamic cycle efficiency is much better due to complete wetting of tube surface, leading to better heat transfer performance compared to direct expansion evaporators as discussed in the earlier part. They also work with minimum suction gas superheat and small temperature approach between evaporating temperature and fluid leaving temperature. This improves C.O.P. and leads to reduced power consumption per ton of refrigeration (kW/ton).

In flooded evaporators, the liquid to be chilled passes through tubes which are surrounded by the boiling liquid refrigerant on the shell side and for separating the liquid from vapour before it leaves the evaporator, some fool-proof method of separation needs to be provided. There are two ways in which this is normally done.

Figure1 shows an arrangement in which the tubes do not fill the entire shell volume. Separation space is provided at the top inside the shell. Tubes normally occupy up to 50% height of the vessel and these are totally submerged in liquid refrigerant. To control the liquid level, an external level controller is used, which regulates the amount of refrigerant getting admitted into the vessel, equivalent to the amount of liquid getting evaporated. Liquid refrigerant is normally admitted in the evaporator at the bottom of the vessel so that it is uniformly distributed under the tubes. The relatively warmer fluid in the tubes heats up the refrigerant liquid surrounding the tubes causing it to boil. Bubbles of vapour rise through the space between the tubes and nearly 50% volume of the shell is occupied by these vapours.

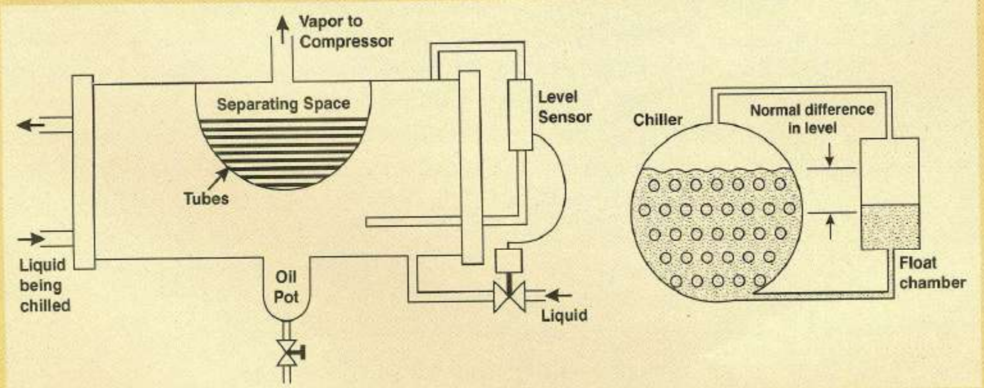

Figure 1: Flooded evaporator with inbuilt separating space

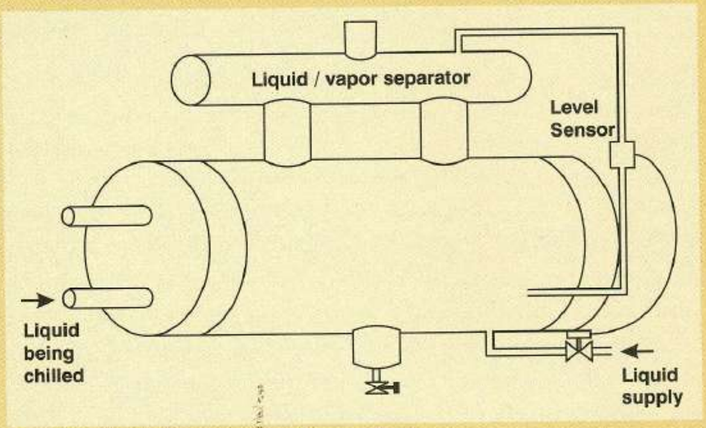

Figure 2: Flooded evaporator with surge drum

Some manufacturers insert "droplet" or "mist" eliminators made of aluminum mesh, right above the topmost layer of copper tubes, to ensure that no liquid droplets enter the suction line to the compressor. This type of arrangement is generally used in factory produced screw or centrifugal chillers using R-134a/R-22 refrigerants.

Another approach for separating the liquid and vapour is to provide a vessel mounted above the shell of the main evaporator. In such a design

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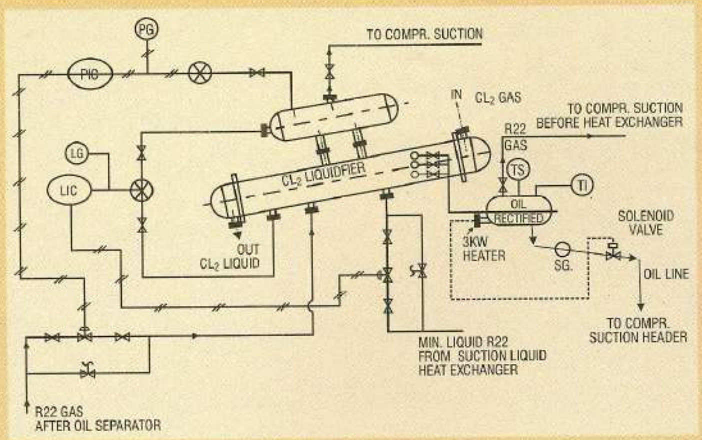

Figure 3: Oil recovery through Oil Rectifier

the entire internal volume of vessel is occupied by the tubes. This type of arrangement is more popular in evaporators using ammonia refrigerant for water and low temperature brine cooling applications. See *Figure 2*.

The diameter of this vessel, popularly known as a surge drum is selected so that the velocity of the liquid droplets slows to a point where they fall back to the bottom of the surge drum. This liquid is then drained back into the main evaporator.

It is essential to ensure that only pure vapour without any liquid mist enters the compressor. This is more important in packaged chillers using reciprocating compressors as reciprocating compressors are less tolerant to liquid compared to other types of compressors. If the liquid separation is not proper, liquid carry over to the compressor may cause accelerated wear or damage.

In both the above designs, the liquid is separated either in the chiller or in the surge drum, by reducing the vapour velocities to a point where the liquid drops out. The calculation of velocity required to decide this is difficult, since all the liquid droplets are not of the same size and vary from extremely small to large. The two forces acting on the droplets are vertical upward drag force exerted due to compressor suction and the other is gravity force pulling it down. When the gravity force is higher than the drag force on any liquid droplet, the droplets will settle down. For design purposes, a velocity between 100 to 200 fpm is suggested though selecting a velocity closer to 100 fpm would ensure much better separation of liquid and vapour.

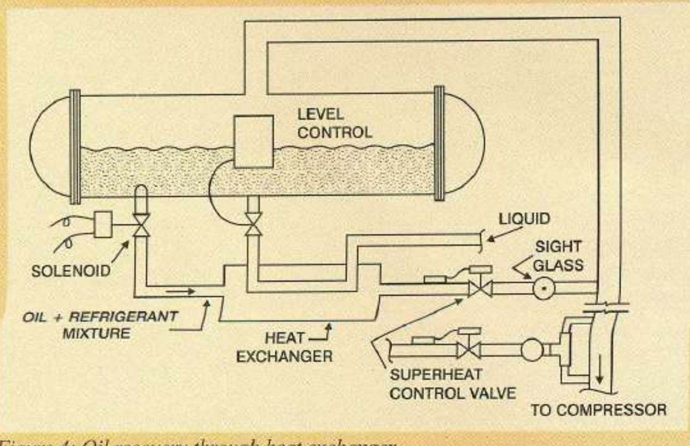

Figure 4: Oil recovery through heat exchanger

Halocarbon R-22 refrigerant and oil miscibility properties are such that when the temperature is reduced, the oil starts separating out from the mixture and in case of flooded design due to low velocity on the shell side, the oil remains back in the evaporator. Vapour velocity above the tube bundle is usually insufficient to return the oil up the suction line and this oil tends to accumulate in the cooler, thereby endangering the compressor lubrication due to inadequate oil in the crankcase and reducing heat transfer performance as tubes get coated with oil which has no cooling ability. This problem is aggravated in low temperature applications for brine cooling or for gas liquefaction applications like chlorine condensation and require some positive means to bring back the oil to the compressor from the evaporator. An oil recovery system needs to be installed by tapping oil and refrigerant R-22 mixture at various levels from the shell side which then needs to be separated with an external heater in the oil pot, as shown in *Figure 3*, or through a suction –liquid heat exchanger, as shown in Figure 4 Refrigerant vapour is sucked back in to the suction line and oil returned to the compressor.

Chillers using R134a refrigerant and POE oil have better miscibility and oil returns to the compressor along with refrigerant vapours. R-22 chillers for water cooling applications are therefore normally of direct expansion type while R134a chillers are flooded type.

Construction

Coolers are normally constructed to comply with ASME Boiler and Pressure Vessel Code, section VIII with design pressures on the shell side as 150/200 psig or standing pressure which ever is higher. The tube sheet layout can have tubes up to 50% height or occupy the entire diameter, if a separate surge drum is installed above the evaporator.

Tubes used are ¾"copper or copper alloys for R-22/R134a evaporators with enhanced surfaces internally as well as externally. This makes the heat exchanger compact, reducing the weight of copper and thus saving in cost as well as improving heat transfer performance.

In case of evaporators using ammonia refrigerant, plain steel tubes are used since ammonia and copper are not compatible. Normally tubes used are 1¼" dia or ¾" dia ERW/ CDW (Electric Resistance Welded/ Cold Drawn Welded) or seamless conforming to BS 3059 grade. ¾" dia tubes are more popular for brine coolers.

Heat Transfer

The boiling heat transfer coefficients for ammonia are substantially higher compared to R-22 or other halocarbon refrigerants as can be seen from the values indicated below

Boiling outside tubes *W/m2.K*	Ammonia *2300-4500*	HCFC-22 *1400-2000*

(W/m2.K x 0.1761=Btu/hr.sq.ft.0F)

Ammonia flooded coolers therefore do not use finned tubes as the heat transfer coefficient on the shell side, outside the tubes, is already high and finning tubes from outside does not give enough advantage compared to the cost of finning. Also, there is possibility of oil film coating the fins affecting heat transfer performance adversely. Chances of oil film sticking to plain tubes are less. Hence, use of plain tubes is the norm in ammonia evaporators.

The heat transfer performance is also dependant on tube side velocity. A minimum velocity on the tube side is maintained around 300 fpm. Higher velocities can also be used if the fluid passing through the tubes is free of suspended abrasives or fouling substances. Higher velocities improve heat transfer performance and reduce fouling but on the other hand increase pressure drop leading to higher power for pumping fluid.

Brine Coolers

The brine or salt solutions used for low temperature process cooling requirements use various mixtures of chemicals depending on the required temperature. The mixture concentration is decided based on the freezing point of the mixture and the selection should ensure that it is at least 10°C lower than fluid outlet temperature. The common brines used by the industry are calcium chloride, sodium chloride, ethylene or propylene glycol, methanol water/methylene chloride or CFC-11 refrigerant.

In case of brine coolers, for low temperature requirements, the concentration of brine used increases. This increases the fluid viscosity and reduces heat transfer coefficient drastically. To improve heat transfer performance, much higher velocities are required to be maintained compared to water coolers. Velocity of minimum 400 fpm is normal. If velocity is lowered, the heat transfer area needs to be increased proportionately and balancing these two aspects is a difficult exercise. The use of smaller diameter tubes solves this problem to a considerable extent as these can maintain much higher velocity and at the same time provide adequate heat transfer area, compared to larger diameter tubes. Increasing the length of evaporator to increase the area, while maintaining the velocity beyond a certain length is impracticable and ¾" tubes are therefore preferred in case of ethylene or propylene glycol flooded coolers.

Duel Circuit Flooded coolers

It is well known that in comfort air conditioning applications, peak load occurs for less than 1% of the time and part load is the norm. In order to meet the full load requirement as well as

Figure 5: Dual circuit flooded chiller

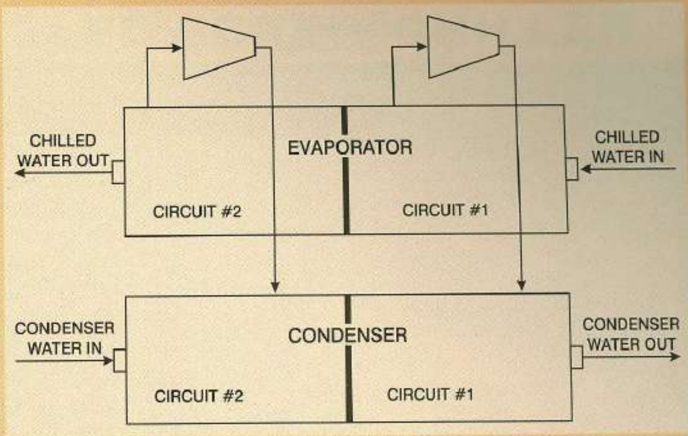

Figure 6: Schematic for dual circuit flooded chiller

to ensure that machines run efficiently, some manufacturers have introduced dual circuit flooded coolers either with single or multi pass arrangement. These chillers use two compressors mounted on a common shell. The evaporator is provided with a vertical baffle half-way in the length, which virtually divides the flooded evaporator in two parts each of 50% capacity. There are two independent circuits on the refrigerant side, where as on the water side it is only one path. When the capacity requirement drops below 50%, one circuit can be shut off including its compressor so that there is a considerable saving in power. The IPLV value with VFD (Variable Frequency Drive) can be as low as 0.340. The dual circuit design is common in DX chillers where two independent circuits with two expansion valves are provided. This concept has now been introduced in flooded coolers as well, as explained above.

Liquid Level Control

There are three refrigerant control devices used by industry for liquid level control in flooded coolers.

Ammonia flooded coolers use a level controller which regulates liquid feed to the evaporator. A combination of hand expansion and solenoid valve regulates high pressure liquid refrigerant flow to the evaporator. When the liquid level goes down below the preset mark, the level controller sends a signal to the solenoid valve which opens and allows liquid to go through the hand expansion valve, which reduces the pressure and temperature of the liquid refrigerant to the desired values. When the liquid level reaches the upper limit, the solenoid valve closes interrupting the liquid flow. This arrangement is also used in R-22/R-134a evaporators by some manufacturers

The second method used by some manufacturers, who make a uni-shell condenser/evaporator is to install a fixed orifice with a float or a movable plate. When the level in the evaporator falls or the level in the condenser side rises, the high side float opens and admits liquid through the orifice to the evaporator.

The latest designs use either thermostatic expansion valves for units above 300 ton capacity or electronic expansion valves up to 300 ton capacity. Electronic expansion valves control suction gas super heat to as low as 0.1°C and thermostatic expansion valve up to 1.0°C. The response time to adjust to

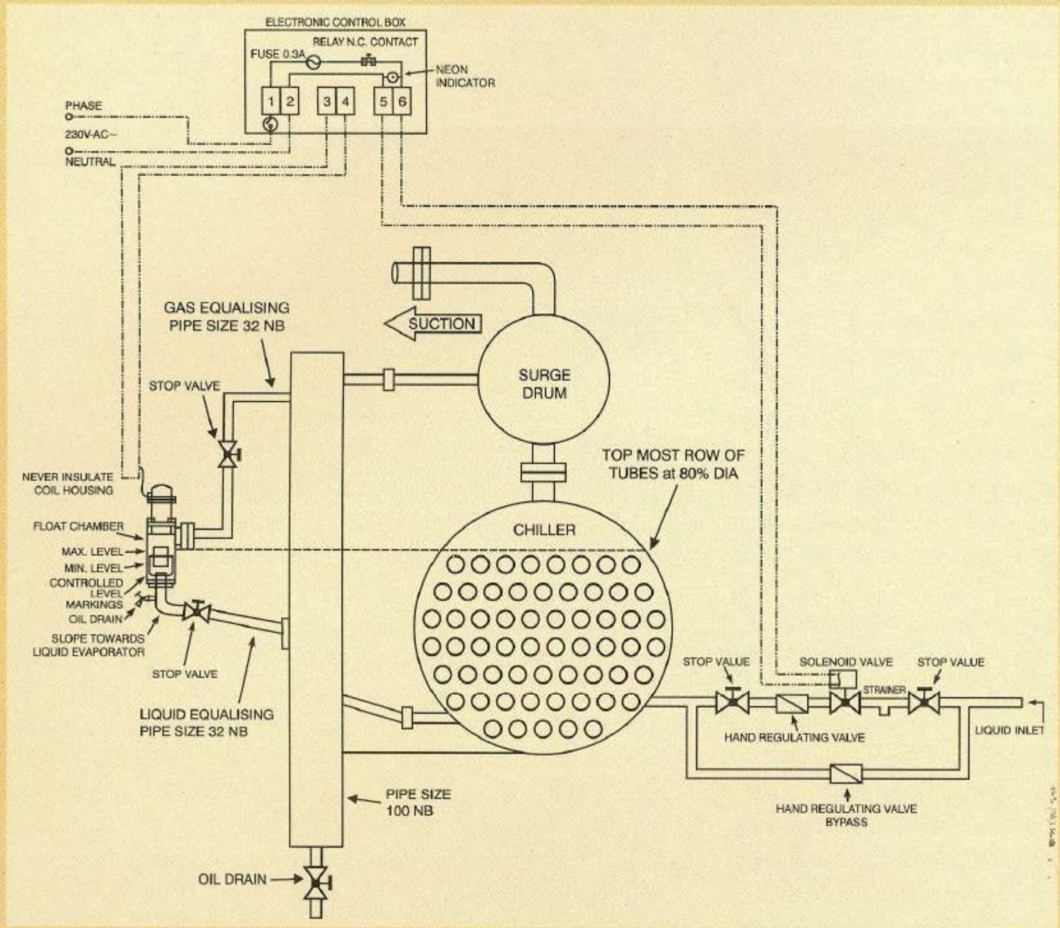

Figure 7: Liquid level control scheme

the load is also very fast and this type of control is becoming more popular. The limitation of use of electronic expansion valves is its non availability in higher capacities.

Spray Type Evaporators

In this type of design, instead of immersing all the tubes in a low temperature refrigerant liquid bath, the liquid refrigerant is sprayed over the tubes by a refrigerant circulating pump. The minimum operating liquid level to be maintained is therefore eliminated. This design is gaining popularity since the refrigerant charge is very much less than in the conventional flooded design. Trane USA uses this concept in their centrifugal chillers. The heat transfer coefficient in this design is equal to or better than conventional design. The spray pattern is arranged so that the tube surface remains completely wetted by liquid refrigerant film all the time and this improves the latent heat transfer rates as the vapours escape easily without any resistance from liquid refrigerant, as it would occur in normal flooded evaporators. An additional pump with stand by pump and spray assembly needs to be incorporated in this type of design. The recommended optimum spray rates are around five times the amount of refrigerant evaporated.

The reduction in quantity of refrigerant is substantial, thus saving cost, especially with HFC refrigerants and increasing safety in the case of ammonia evaporators. The environmental issue, due to leakage of refrigerant is also addressed with these spray coolers due to their extremely low system refrigerant charge.

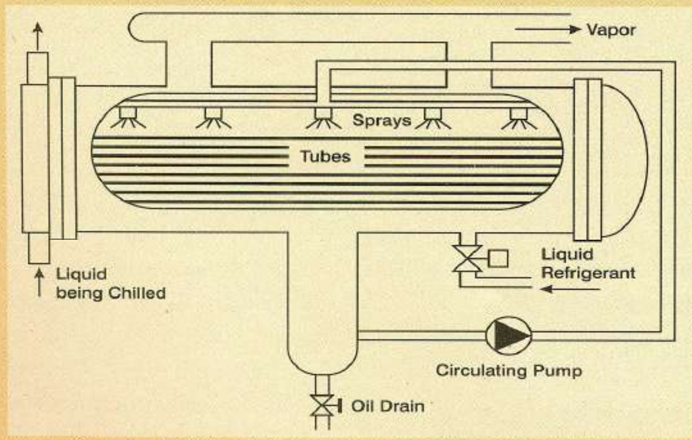

Figure 8: Sprayed tube liquid chiller

Standards

Flooded water chillers with R134a refrigerant using centrifugal or screw compressors are generally factory produced and the performance of these is rated and tested as per ARI Standard 550/590-2003. This Standard gives rating conditions, so that comparison of chiller performance of various manufacturers can be compared on an equitable basis. It allows one to establish full load power consumption, COP, as well as part load power consumption (IPLV/NPLV).

The ASHRAE Standard 90.1-2004 specifies a minimum COP value of 5.5 for water cooled chillers using reciprocating/screw/scroll compressors and 6.10 COP for centrifugal chillers for capacities higher than 300 tons.

The Energy Conservation Building Code 2007 published by the Ministry of Power specifies these values as minimum 5.75 and 6.3 respectively.

This is the last part in this evaporator series and an effort has been made in these eight parts to give as much information as possible on various types of evaporators used in the air conditioning and refrigeration industry, so that practicing engineers and new comers in the field can have ready information available in an easily understandable manner. ❖