The Absorption Process *Revealed*

Until a few years ago, most Air Conditioning and Refrigeration Service Engineers had never seen any type of Absorption Equipment, much less today's sophisticated 2-Stage Direct Fired Absorbers. Some of us had the opportunity to work on these strange devices back in the seventies, before their popularity waned. Only a handful of individuals continued to work on them. For the most part, Refrigeration and Air Conditioning Service Engineers do not like Absorption Units. Why? I think that all of us pride ourselves in our ability to understand and perhaps predict the way the equipment we work on behaves. We like compressors. We can take them apart and rub our hands over the shafts and bearings. We can determine if the clearances are correct. We can predict (most of the time) how they are going to work, and if they don't we take them apart and we fix them. We understand conventional refrigerants and oils.

Absorption units are not so different. The condenser and the evaporator behave much the same as the condensers and evaporators we are used to dealing with. The refrigerant is water, but it does behave in the same manner as our so-called conventional refrigerants, just at much lower pressures. Steam tables are really no different than the refrigerant tables we are used to using.

The big problem lies in the phenomenon that the name of the unit so aptly proclaims. Absorption! What exactly is absorption? How does it work? What makes it malfunction? Many of our fears about Absorption Units are based on the fact that we really don't understand how the absorption process works. We have been told to accept the fact that salt absorbs water and that's about the extent of the knowledge that most of us enjoy.

For a better understanding of the Absorption Process, it makes more sense to look at it in detail.

The Absorber section of an Absorption unit receives refrigerant vapor at a very low pressure. The average pressure in the Absorber is 5.6 mm Hg absolute. The pressure in the Evaporator is somewhat higher, otherwise there would be no flow of the refrigerant vapor through the mist eliminator into the absorber. The refrigerant vapor is created by refrigerant liquid boiling in the evaporator at 6 mm Hg absolute (39°F). Other than the fact that the refrigerant is water and is sprayed over the tubes, there is not much difference between the absorption unit evaporator and a conventional R-11 or R-123 evaporator. They both operate in a vacuum, although the absorption unit operates under a much deeper vacuum. The big difference is where the refrigerant vapor goes when it leaves the evaporator. In a conventional air conditioning system there is a compressor waiting to compress the refrigerant vapor. In an absorption system we must rely on the absorber to collect the refrigerant vapor so that we can reprocess and reuse it.

Absorption takes place as the refrigerant vapor that is created in the evaporator diffuses into the LiBr solution that is sprayed down over the tubes in the absorber. Diffusion is a term that is used when a substance tends to move from an area of greater concentration to an area of lesser concentration. An example of diffusion within air would be opening a bottle of perfume at one end of a room and eventually smelling it at the other end of the room. Many of you could probably think of similar examples. The diffusion of refrigerant vapor into liquid LiBr solution is almost the same. It happens because the vapor pressure of the LiBr solution is lower than the vapor pressure of the refrigerant. The vapor pressure of the LiBr solution is directly related to the amount of refrigerant present in solution with the LiBr salt and the solution temperature. When the solution has only small amounts of refrigerant in it (higher concentration of LiBr) and its temperature is reasonably low, its vapor pressure is also low and the refrigerant vapor has a great desire to diffuse or dissolve into the solution. The greater the difference in vapor pressure between the solution mixture and the refrigerant vapor, the greater the desire to merge and so on. Two simple rules govern the rate of absorption. (1)The lower the solution mixture temperature, the lower the vapor pressure of the solution. (2) The higher the concentration, the lower the vapor pressure of the solution. Therefore, the lower the solution temperature and the higher the concentration, the greater the rate of absorption. The relationship of concentration, solution temperature and vapor pressure can be obtained from a Dürhing Diagram.

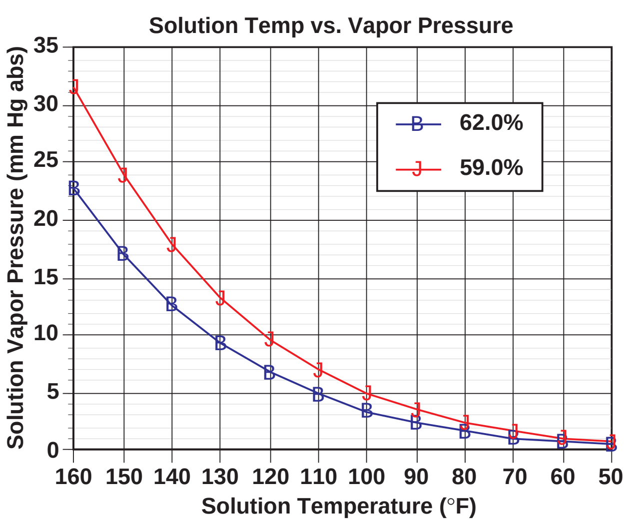
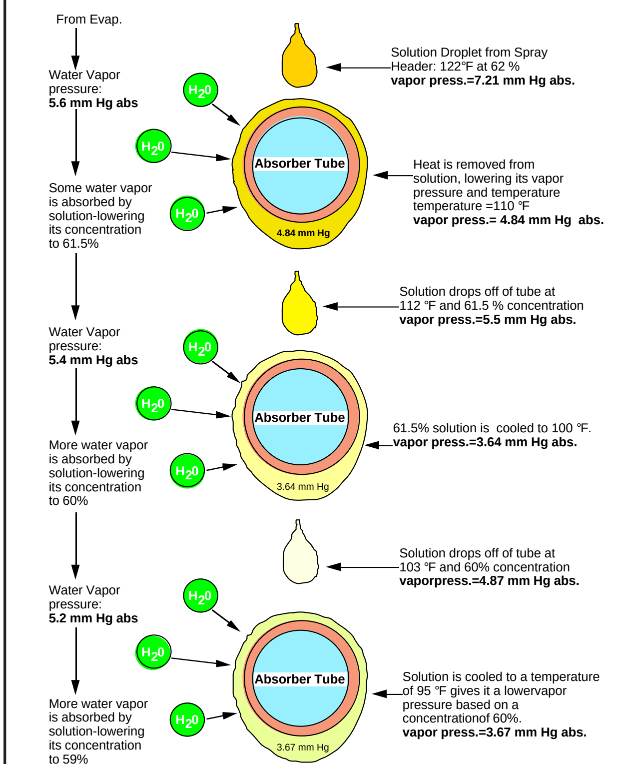


Figure 1

Lets follow a typical droplet of solution through the absorber. In our example, LiBr solution entering the absorber is 62% LiBr by weight. The solution is sprayed into the absorber through spray nozzles. The sprayed solution is directed over the absorber tube bundle. The temperature of the solution entering the absorber is approximately 120°F. Figure 1, which shows the vapor pressure verses solution temperature for 62% LiBr, reveals that at 120°F, the solution has a vapor pressure of slightly less than 7 mm Hg absolute. Since the refrigerant vapor is at a pressure of 5.6 mm Hg absolute, diffusion of the refrigerant vapor into the solution cannot take place. As we stated earlier, in order for the solution to absorb refrigerant vapor, its vapor pressure must be lower than the refrigerant vapor pressure. As the solution from the spray nozzles hits the top layer of tubes, its temperature is lowered by the cooling water passing through the tubes. Our typical droplet lands on one of the tubes in the top row and spreads nicely around the tubes outer surface. The tower water flowing through the inside of the absorber tube at approximately 85°F begins to cool our droplet of solution. When the droplet temperature falls below approximately 100°F, its vapor pressure is lowered below that of the refrigerant vapor. As the solution vapor pressure continues to fall due to the cooling effect of the absorber tubes, the refrigerant vapor with a higher pressure than the solution, is able to diffuse into the solution and absorption takes place. This is actually only the beginning of the absorption process or *mass transfer* as it is called by some absorption lovers. Mass transfer simply means that the solution is gaining mass or weight if you prefer. The mass that it is gaining is refrigerant. Think of it in the classical sense. The absorbent or LiBr solution is like a sponge. As the sponge sucks up the water vapor, it gets heavier and heavier. Without mass transfer, the unit would not function. This is nothing new. Without mass flow through the compressor, a conventional air conditioning system would not function. The secret to mass transfer, is heat transfer. Mass transfer occurs between the refrigerant vapor and the solution. Heat transfer occurs between the solution covering the shell side of the absorber tubes and the tower water flowing through the tubes. There will be no mass transfer without heat transfer and there will be little heat transfer without mass transfer. When the refrigerant vapor was absorbed by the solution on the surface of the top row of tubes in the absorber, heat was generated by the process. But, before the first molecule of refrigerant vapor could be absorbed, enough sensible heat had to be removed from the solution in order to lower its temperature and vapor pressure below the refrigerant vapor pressure. This was a relatively minor amount of heat removal. The largest amount of heat is the heat of condensation that takes place as the refrigerant vapor condenses. This is, of course, the latent heat of condensation. It is roughly the same as the latent heat of evaporation that took place in the evaporator when the refrigerant absorbed the heat from the chilled water and boiled or flashed into a vapor. A third type of heat is created during the absorption process which is unique to the absorption process. When the refrigerant is



Mass Transfer Process

absorbed into the solution, the solution become more dilute or less concentrated. This is due to the refrigerant vapor condensing into it. During this dilution process, heat is given off and the temperature of the solution increases. This type of heat is the result of the concentrated LiBr salt solution becoming more dilute and is sometimes referred to as the heat of absorption or the heat of dilution. This heat is also much less than the latent heat that results from the refrigerant vapor condensing in the solution. The total heat created by the absorption process in the absorber is approximately 1.35 times the heat removed from the chilled water in the evaporator. Therefore, if you know the chilled water flow rate and the temperature drop through the evaporator, you can calculate the expected temperature rise of the tower water through the absorber, providing you know the tower flow rate.

Let's get back to our droplet of solution, which is hanging on the outside of a tube somewhere in the top row of tubes in the absorber. Before any additional absorption can occur, the temperature of this droplet of solution must once again be lowered so that its vapor pressure is below that of the refrigerant vapor pressure present in the absorber shell. The droplet of solution falls from the top row of tubes to the next lower row of tubes and settles on the surface of that tube. As this droplet of solution wets the new tube surface, its temperature is once again lowered which lowers its vapor pressure below that of the surrounding refrigerant vapor and once again absorption occurs. As the mass transfer proceeds, the heat of condensation and the heat of dilution is removed again and again by the cooling water passing through the absorber tubes while the droplet of solution absorbs more and more refrigerant on its way to the bottom of the absorber.

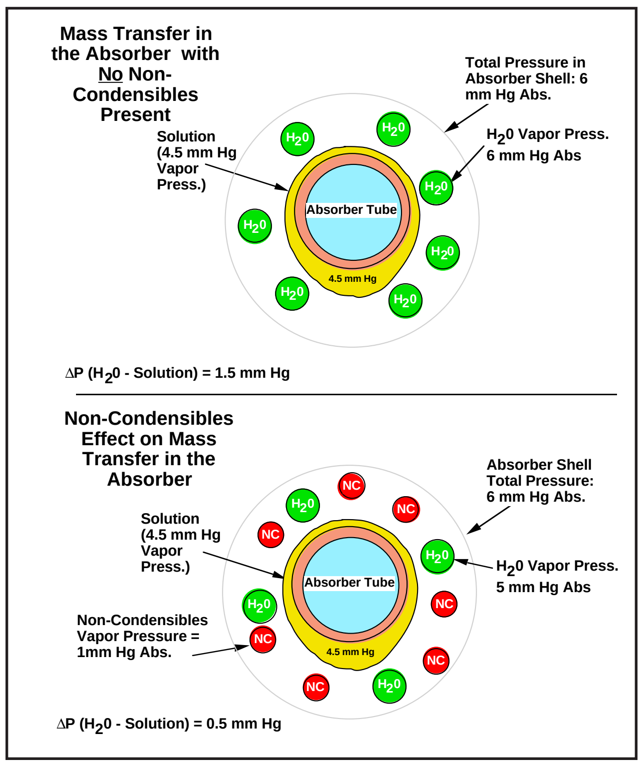
To sum it all up, the solution gains mass as it continues to absorb refrigerant while it falls toward the bottom of the absorber tube bundle. The refrigerant vapor flowing from the evaporator loses mass as it flows toward the bottom of the absorber. Any non-condensables that are present will be swept toward the bottom of the absorber tube bundle by the flow of refrigerant vapor. What is a non-condensable, you say? Non-condensables are the demons of the absorption world. They hang around the absorber and cause untold number of problems. Everything we just talked about, can be affected and even stopped completely by non-condensables.

Non-condensables fall into two categories. The first type is created in the absorption unit itself. Hydrogen and Oxides of Nitrogen are some of the results of corrosion and inhibitor reaction within the unit. Providing the unit is relatively leak free, the amount of these types of non-condensables will be small. Non-condensables will be generated in larger quantities within a new unit, but as the unit gradually ages this quantity should be reduced to a very small amount.

The second type of non-condensable is the most common and probably the single biggest problem found with LiBr units today. This type of non-condensable results from an air leak. Air leaks are difficult to find due to the negative operating pressure of the system. Careful monitoring of the purging frequency is necessary to ascertain when an air leak is present. Air leaks should be found and repaired immediately, or severe problems can be expected down the road. Non-condensables will tend to collect in the bottom of the absorber or around the bottom row of uncovered tubes if the solution level is higher than normal for some reason. If the solution level is low enough in the absorber, the non-condensables will be collected by the purge header and be carried via the solution vortex to the high side of the system. The purge pump may also be effective at removing the non-condensables through the purge header when the liquid level is below the header.

When non-condensables are present with an absorber liquid level above the purge header, the non-condensables have no where to go. They will collect around the coldest and quietest portion of the absorber which will be the lower rows of uncovered tubes. Their presence impedes absorption, by exerting a partial pressure which effectively subtracts from the available vapor pressure of refrigerant vapor.

Understanding how non-condensables affect absorption requires that you forget about conventional air conditioning and refrigeration purge systems. The quantities of non-condensables in an absorption system that will cause absorption problems do not cause a general increase in absorber pressure. There is far too much volume and far too few non-condensables for the partial pressure to be measured on a conventional gauge. In order to understand the effect of the non-condensables, you must think of the area surrounding a single tube as a separate pressure vessel. This small area within the larger area of the absorber has the same overall pressure as the absorber itself, but if non-condensables are present around the tube, their partial

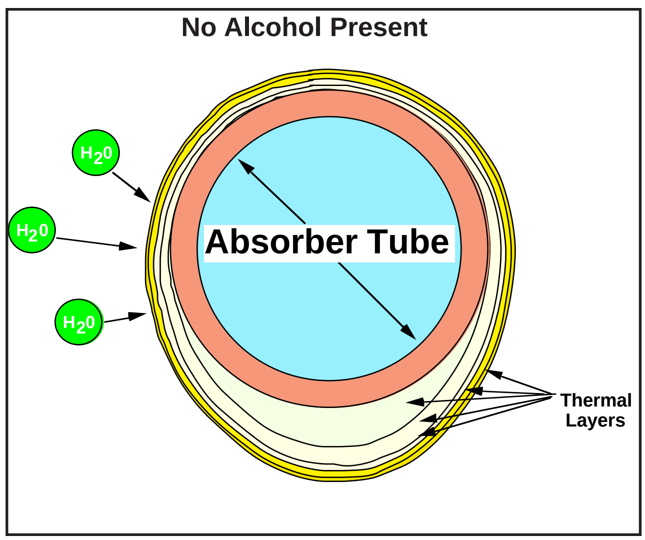


pressure subtracts from the overall available refrigerant vapor pressure. For example, suppose the refrigerant vapor pressure in the absorber was 5.5 mm Hg absolute and the solution flowing over the absorber tube had a vapor pressure of 4 mm Hg absolute. The net difference in vapor pressure would be 1.5 mm Hg, providing a fair rate of absorption.

Now, if some non-condensables were to be present around the tube and they exerted a partial pressure of 1 mm Hg, this would make the refrigerant vapor pressure in that local area around the tube only equal to 4.5 mm Hg, since the sum of the two pressures must equal the total pressure in the shell which is 5.5 mm Hg. The net vapor pressure difference between the refrigerant vapor and the solution has now been reduced to 0.5 mm Hg. The rate of absorption with this small of net differential would be drastically slowed. For the purist, yes, there is a very, very, small increase in the overall shell pressure due to the presence of the non-condensables. As I said before, this will not be measurable on any conventional pressure indicator. This small pressure increase has no significant effect on the areas of the absorber where there are no non-condensables gathered. Only in the areas where non-condensables are present, is a decrease in mass transfer seen.

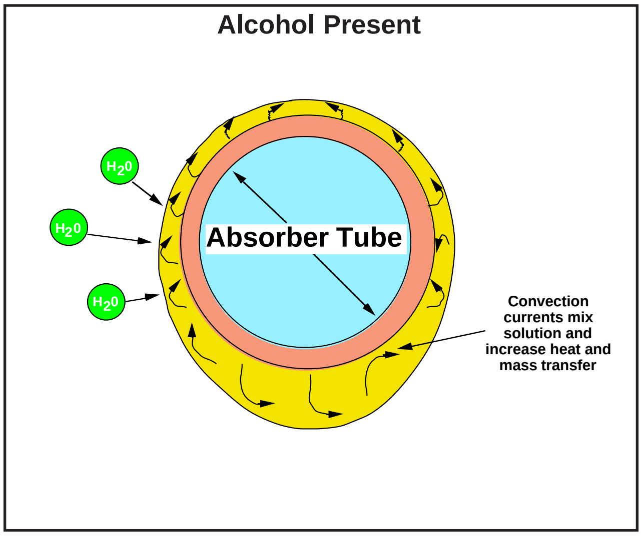
Alcohol is used to enhance the absorption capability of the solution. The correct amount of alcohol in the system will provide an increase in capacity of between 10 and 15 per cent vs. the same unit with no alcohol. Without alcohol, the solution surrounding the absorber tube tends to stratify or develop layers. Anyone who has gone swimming in a pond or lake during the summer has felt the different temperature layers in the water. Scuba divers can relate to the thermocline, which is a very well defined temperature layer in the water. Much the same thing happens to the solution on the outside of the absorber tube without alcohol present. As refrigerant is absorbed into the outer surface of the solution surrounding the absorber tube, the solution reaches equilibrium due to lack of heat transfer. Equilibrium is a scientific way of saying that things have stopped happening. In other words, the heat build- up in the solution on the outer-most layer causes absorption to cease due to the solution temperature rising. Remember what happens to the vapor pressure as the solution temperature goes up. It goes up and when it gets as high as the refrigerant vapor pressure, no more absorption can take place. Some means of stirring up the solution surrounding the tube is needed in order to mix the layers and get the heat from the outer layers to the inner area next to the tube where the heat can be carried away. In that way, absorption can continue throughout all of the solution instead of only the outermost layers. Alcohol provides the means for this stirring up of the layers. This stirring action is a result of convection. The convection is believed to be caused by variations in surface tension of the solution due to the droplets of free alcohol floating on the surface while absorption occurs. The surface tension variation causes convection to occur due to the stretching and pulling on the surface skin of the solution.

This type of convection is sometimes referred to as *Marangoni Convection* named after a 19th century Italian. Many of you may have actually seen Marangoni convection. In a clean absorber with good visibility of the tubes, a shimmering effect can sometimes be



seen on the outer surface of the tubes as this phenomena takes place. In order for the alcohol to work it must be present in the correct quantities. The alcohol York uses is a type of Octyl alcohol called 2-Ethyl 1-Hexanol. Only a small portion of the alcohol dissolves in the solution or refrigerant. Various experimentation has shown that the correct amount of alcohol is approximately 1.0 percent by mass. 15 to 20 percent of the solution surface area should be covered by floating droplets of alcohol.

The correct amount of alcohol is added at the factory or at start-up and therefore it should seldom be necessary to add additional alcohol in the field. Some people believe that alcohol is lost due to purging. The odor of the alcohol will be present in the purge pump exhaust, but very little alcohol is actually lost through purging.



Too much alcohol will cause a decrease in absorption, therefore if there ever is a suspicion that alcohol is needed, a small quantity such as a gallon should be added and the performance of the unit observed. If an increase in performance is evident, another gallon could be added and so on. If no increase in unit performance is observed, do not add any more alcohol.

2-Ethyl 1-Hexanol can be destroyed by other organic material in the solution, such as oil. In fact, part of the alcohol has an affinity for water and the other part has an affinity for oil. Unfortunately, if some foreign organic substance does get into the machine, it usually not only destroys the alcohol and its absorption enhancing qualities, but also retards normal absorption by affecting the surface quality of the LiBr solution.

The ParaFlow Unit has an alcohol trap which separates the alcohol from the refrigerant coming from the condenser and puts it into the solution where it is needed. Alcohol has little, if any, beneficial effect on the refrigerant although there will always be some alcohol present in the refrigerant. This alcohol in the refrigerant may tend to provide better tube wetting in the evaporator. It also lowers the freezing point of the refrigerant as does the small quantities of solution that will be present in the ~~solution~~ refrigerant.

Well, that's about it. All you ever wanted to know about Absorption, but were afraid to ask. We covered Heat and Mass Transfer as the solution is cooled and absorbs refrigerant and is then cooled again and so forth. We talked about the evil Non-Condensables and their detrimental effect to the absorption process. Last, but not least, we discussed Alcohol. Alcohol is like the icing on the cake. It makes the absorption process work so much better by causing convection currents in the solution surrounding the absorber tubes.

Hopefully at this point, you are feeling a bit more confident in your ability to understand the Absorption Process. The rest of the unit, is after all, pretty much old hat. You pump the diluted solution to a couple of generators where you boil out the refrigerant. The refrigerant vapor is condensed in the condenser to a high pressure and temperature liquid. It then returns to the evaporator and is again converted into a vapor by absorbing heat from the chilled water. The strong solution that is left in the generators after the refrigerant vapor is boiled off is returned to the absorber where it will collect more refrigerant vapor. Throw in a couple of solution to solution heat exchangers to gain cycle efficiency and you got it.

J.M.Brillhart-June 9, 1999