

Moisture in Compressed Air

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Because of the wide spread occurrence of water vapor in compressed air, attention should be given to the special terminology that has evolved. Unfortunately, a great deal of confusion exists, so care should be exercised to avoid misleading or inaccurate terminology. There is a well-defined, maximum amount of water that a gas is capable of holding at any fixed temperature and pressure. If the temperature is increased, it is capable of holding more water. If the pressure is increased it will hold less water. If compressed air containing an arbitrary amount of water vapor is cooled at constant pressure, some water will eventually deposit as liquid (i.e., condense). The temperature at which condensation begins is called the saturation temperature, and the compressed air at these conditions is said to be saturated.

Saturation temperature must always be accompanied by a system's pressure. For the special case where the air pressure is equal to atmospheric pressure, the saturation temperature is called the dew point. However, some people use the term dew point synonymously with saturation temperature; hence, it is always a good practice to include a statement of pressure with dew point temperature. It avoids confusion. In many subzero Fahrenheit dew point systems, the user is measuring atmospheric dew point from a sample expanded to atmosphere from the compressed air system. The result is significantly lower than that which would have resulted at pressure. The user then thinks that he is achieving an adequate dew point, when the dryer on line may be operating at 30 – 40°F above the rated performance. When pressure does not accompany the dew point information, atmospheric dew point is assumed.

For engineering calculations, humidity is usually written as the weight of water per unit weight of the moisture free compressed air (e.g., 0.001 pounds of water per pound of dry air). Because these numbers are frequently very small decimal fractions, it is more convenient to express them as parts of water vapor per million parts of dry air, since conversion to PPM by weight merely involves moving the decimal point six places. But again, care must be exercised. Most constituents of an air sample are analyzed on a volumetric basis; hence, chemists often report water and contaminant as PPM by volume.

The *Percentage Relative Humidity* (%RH) is 100 x the ratio of partial pressure of water vapor to the vapor pressure of water at the stated temperature. Many people confuse *Percentage Relative Humidity* with *Percentage Saturation* (which sometimes is called *percentage humidity*). Percentage saturation is 100 x the ratio of the existing weight of water vapor per unit weight of dry air to the weight of water vapor that would exist per unit weight of dry air if the air were saturated at the existing temperature and pressure.

There are other means of expressing water or water vapor content such as grains of water per standard cubic foot of air. One pound of water equals 7,000 grains. You can also express the water content as pounds of water per unit of compressed air such as 1,000 scf or 1,000,000 scf. Water can be damaging to production equipment of its own. We also must remember that water is a carrier. Most other contaminants are dependent on water to transport them through the system. One of the most problematic is acid gas, a common airborne constituent in most industrial atmospheres. When mixed with water in the cooling stages after compression they form acids such as hydrochloric and sulfuric acids. Many oils and particulates are also transported in the system by water. Without water, most of these materials cannot work their way into the system.

There are many methods for removing water from compressed air. Mechanical methods employ centrifugal separation or porous-media which usually remove liquid, mist, and water droplets only.

These are very velocity dependent in order to function properly. Too high or too low a velocity will result in performance degrading.

Refrigeration drying is limited to the saturation moisture content of the air at the refrigerant temperature. All of the moisture will condense down to the airside heat-exchanger temperature in the refrigerant-to-air heat exchanger. The balance of moisture present will exist saturated at the discharge temperature from the dryer. You must also provide a mechanical separator to remove the liquid condensate, which results from this process. The efficiency of the dryer is dependent on the efficiency of the separator. Many separators in dryers are 80 to 95% efficient in moisture removal. The balance of the water not removed in the separator will be absorbed into a vapor state in the air stream in the reheat cycle of the refrigerant dryer which will result in higher than intended pressure dew point. The efficiency of the separator is largely dependent on the ability to isolate the separated liquid from the air stream so that it cannot be re-entrained. This is why most 35°F dew point refrigerated dryers perform much better than those rated for 40° to 42°F.

Deliquescent drying involves chemicals – usually in tablet form – which absorb the airborne moisture in the compressed air stream. The air is usually forced through a path of deliquescent tablets, which is made up of primarily salt and desiccated urea. It absorbs the water into the tablet which in turn converts in a phase conversion to a liquid brine solution which drops out to the bottom of the holding tank. It is then removed with a timer or solenoid operated drain valve arrangement. This type of dryer is typically capable of 20 – 40°F dew point reductions at pressure. One of the problems associated with this approach is the highly corrosive nature of the tablets and the brine. Another is the bed geometry. As the dew point is dependent on the relative geometry to the saturation temperature and mass flow of the compressed air, as the bed dissolves in its normal functioning, the dew point reduction degrades proportionally. Obviously, maintaining the bed geometry or desiccant level is critical to the operation of the dryer. This involves topping off the dryer with tablets.

As simple as this may seem, this is a pressure vessel. It must be isolated from the system and depressurized in order to add desiccant. If it is isolated with a bypass valve arrangement, there will be gross water dropping out when this occurs every few days. Without this approach, the system will have to be shut down if possible. What really happens is that bed refill seldom occurs but a few times a year when the moisture content of the air is so high that there are substantive complaints from production. Another problem with this approach is that this type of desiccant will absorb lubricant from the air stream and reject the water in the air stream. For this type of drying to function, it is very important to provide excellent pre-filtration to remove all lubricant liquids and aerosols prior to drying.

Adsorption or regenerative dryers are the third predominant form of dryers. These dryers are typically twin tower where one tower is drying, while the other dryer is regenerating. Adsorption is generally preferred over absorption because it is not corrosive, does not require the frequent refills, and can easily produce dew point of – 20°F and lower pressure dew points consistently. It is possible to produce pressure dew points below – 100°F when properly applied and engineered. Adsorption is a phenomenon whereby vapors are attracted to, and condense on the enormous interior surfaces of solid materials or tablets which contain literally millions of submicroscopic pores and cavities often referred to as angstroms (although this is actually a unit of measure). Once a bed is saturated, the desiccant bed must be stripped of the moisture. The approach towards doing this is to switch the bed when it is saturated with liquid so that the air stream for the system flows through an alternate dry bed. The stripping process can be performed with dry air, which reabsorbs the moisture from the bed. This is called heatless or air reactivation. This approach uses a portion of the dry air produced from the drying tower to regenerate the wet tower. In a typical – 20 to –40°F pressure dew point dryer, the quality of air consumed for this process is 14.7% of the rated capacity of the dryer at pressure. If the pressure is higher, the purge flow will be higher. If the pressure is lower, you may not make the dew point desired. Dew points lower than –40°F will require a higher purge rate sometime approaching 25 – 30% of the dryers rated performance. Usually the drying cycle for tower changes is approximately 5 minutes.

The other approach towards stripping this type of dryer bed is with heat. This can be accomplished internally or externally. The internal approach typically uses cal rode heaters, which are installed in the bed. They heat up for regeneration. Typical drying temperatures can approach 450°F. This is generally not a good idea if the compressors use lubricant. Most compressor lubricants have flash points well below this temperature.

Another approach is external heats where the heater elements are not in the bed. This can be accomplished with electricity or generally steam. External heater dryers first costs are significantly more expensive than internally heated or heatless dryers. The operating cost from type to type of heater dryers doesn't vary much. These types of heater dryers also require some air purge in order to function. Generally the purge amounts to approximately 6% of the dryer capacity. It is important to understand that when we say a percentage of dryer capacity, we are not referring to the mass being processed. If the dryer is rated at 1,000 scfm, we will use the purge percentage, whether we are flowing 10% or 100% of the dryer's capacity.

Another type of heater desiccant dryer is heat of compression. In this approach, the heat of compression is used to regenerate the dryer. The hot flow of the compressor upstream of the aftercooler is channeled first to regenerate, through the aftercooler where moisture is condensed and removed, and then to the dry side desiccant bed. This type of dryer can be a twin tower arrangement or a heat wheel. This type of dryer is by far the most economical of all forms of dryer. The draw back is that you must be able to maintain bed temperatures. If the amount of air or the temperature is too low, the dryer will not work correctly. We have seen many of these types of dryers that have been misapplied. Like everything in the system, good ideas poorly applied don't work. One draw back to all heat regenerated dryers is the bed temperature. The results of this involve discharge temperatures into the system immediately following tower switching of 200°F or more. The air temperature will reduce 100°F in time before the towers switch again. You need to be very careful to check to see if this cyclical temperature swing effects any part of the production process. Remember that the weight flow of the air at 200°F at 100 psig is 0.470 lb/cf while the same cubic foot weights 0.551 lb/cf at 100°F at 100 psig. 15% less density at the elevated temperatures may have an adverse effect on the process.

Although there are other drying approaches such as microwave and membrane technologies, the above dryers represent the large majority of those commercially used in industry for compressed air for water moisture removal.

Besides the traditional approach towards water contamination of a system, entering with the air in the compression inlet, there are other approaches towards water entry. These are less commonly understood. Leaks, even pinhole types, can be the source of water contamination. The assumption that nothing can get into a pressurized system because pressure inside is greater than pressure on the outside is not true.

There are at least three methods for this intrusion. They are the jet pump effect, shortened diffusion path effect, and molecular flow effect. These effect siphons stagnant contaminants into the system where there are particularly high velocities in the pressurized gas stream passing over a lead, seal or packing. The entry point can be as small as 0.00001" or smaller. The size only needs to be larger than the molecule of moisture or contaminant that is siphoned into the system in what is called a "direct hit". Selection of the piping material will significantly reduce the potential for contaminant from this effect. The shortened diffusion path effect occurs when there is a leak or leaks with an observable out flow from the pressurized system. Diffusion of a molecule from a region of high concentration to a region of low concentration is known as Fick's Law. The hole in the pipe acts as an orifice; hence, the cross sectional area of the jet formed by the leaking compressed air may decrease over a finite distance downstream from the inner edge of the hole where the leak originates. Eddy currents are then formed near the hole. It is possible that the refrigeration effect owing to the expansion of the leaking air may be sufficient to cause water vapor to condense both in the vicinity of and around the edges and sides of the hole. The result is that the actual path length for a water molecule to travel into the system may not be the metal thickness but rather a shorter distance near

the inner edge. If the partial pressure of the water inside the pressurized system is sufficiently lower than the partial pressure of the water in the air outside the system, water vapor will diffuse through a solid pipe wall and enter the system. This phenomena occurs where compressed air systems are operating at sub zero dew points of -40°F or less and the outside-saturated temperature is high. Systems that incorporate -75 to -100°F or lower pressure dew points must use ACR copper or pickled and lined pipe to prevent this diffusion path problem from downstream contaminants. The extreme of these application errors would be the use of compressed air for open blowing where the compressed air is very dry and the atmosphere is quite humid.

The most ludicrous method of contaminating the system is by driving down the dew point of the air to the point where it can wick liquid or vapor, then exposing the gas to a liquid downstream of the drying process. Vapor seeks the lowest vapor pressure. A common problem is regenerative drying of compressed air at the source of a low dew point and then using the air for one of the following applications downstream.

- Sparging any liquid with compressed air.
- Using point of use lubricators to drip or atomize oil into the air stream.
- Agitating sludge or chemicals with air.
- Aspirating oils or liquids with compressed air.
- Spilling a higher pressure, wetter compressed air source into a dryer compressed air source.
- Transporting a slurry with liquid in it by dense or dilute phase using compressed air.

In most systems the effect is most felt where the air is extremely dry, the atmosphere is very wet, or the dry air comes in contact with liquid. The more the extremes between the dry air and the contaminant, the more of a problem you will have. We have seen more molecular diffusion problems than define the real problem; the solution is determined to be to make the air dryer. This, of course, makes the problem worse rather than better.

The compressed air needs to be as dry as needed. Excessive drying usually fixes one problem and creates new ones in the process, not to mention that more drying means more cost.

Reprinted with permission from R. Scot Foss, president of Plant Air Technology, Charlotte, N.C., a company specializing in system auditing and design. This article is based on his book, "Compressed Air System Solution." A portion of the proceeds from sales of the book is donated to children's charities. To order a copy of the book, please contact Southern Corporation.