Medical Air Dryer Technologies

The Basics of Dryer Technologies for Medical Air

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Notes on Using this Pamphlet:

This pamphlet seeks to simplify understanding the technologies now in use or likely to be in use soon for medical gas drying.

This pamphlet is intended to be used in conjuction with the NFPA 99 standard, which should be obtained from:

National Fire Protection Association
1 Batterymarch Park
Quincy, MA 02269-9101
Phone 1-800-344-3555
Internet www.NFPA.org

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Comments on this booklet or on any aspect of medical gases are welcome and encouraged. Please send to mallen@beaconmedical.com

Quiz: What is the single most common problem reported with Medical gas systems?

The answer : Water in Medical Air.

Far and away the most common problem which facilities struggle to solve with their medical gas systems is water in the medical air. In some facilities, water in air is a low grade nuisance. Sometimes it's seasonal, in other facilities continuous. It may get bad enough to cost money for ventilator or blender maintenance and repair (and once you're on that road, it can quickly cost a *lot* of money.) At it's apocalyptic worst, it presents a real risk of drowning patients.

Given this risk, it is perhaps not surprising that in many facilities, the medical staff no longer uses the air outlets. Either they modify their technique and use more oxygen, blend in room air, or spend lots of money to buy portable air sources or onboard compressors with their ventilators. All of which are inferior to using the piped air for reasons of cost, cleanliness or purity.

What they don't understand is that water in air is a problem which can be solved. The greatest obstacle to solving it is a basic understanding of what's going on.

This article won't try to explore the physics of water vapor, or study in detail the engineering involved in good system design. These things are crucial to preventing water from accumulating in the pipelines, but are also hard to change in a standing system. In this article, we'll cut to the chase and talk about air drying - why we do it and some of the technology options available to accomplish the job. The reader is cautioned that the best dryer in the world may fail to solve their problem if the system is badly designed or feeds the dryer improperly preconditioned air. Although these subjects are outside the scope of this article, don't let them be overlooked in your search to end your dew point issues.

A water in air problem is often reported during testing as a "high dew point". Dew point is merely a reasonably convenient way to express how much water vapor is in the air. We have all become dew point conscious because NFPA has chosen to peg our alarm as a dew point. The fact is however, we really don't care about the dew point as such - the goal is to prevent liquid water from forming in the lines. This is a key point - although we *measure* the success of our drying efforts using dew point, the actual goal is simpler - *no liquid water*. If we can achieve no liquid, we don't have to be over worried about the actual dew point reading (provided of course that it is below the alarm set point of 39°F.)

Dew point as discussed in the NFPA 99 is a guide, not an absolute. This is most obvious to the facility with OK dew point readings, but which still has water in their air. Areas with cold winters, facilities with exposed piping or air piping run near chilled lines might experience this phenomena. Local conditions therefore may require that the dew point actually be much lower to achieve no liquid.

Where does the water come from? It may seem surprising, but the accumulation of liquid water in air lines is not necessarily related to the compressor type (liquid ring compressors or water seal screw compressors do not necessarily have more water-related problems than other types). An elevated dew point is a natural consequence of compressing air with water vapor already in it. This is why elimination of water at the intake is often very helpful in reducing dew point. Examples of this are facilities who reduce dew point by drawing their intake air from air conditioning ducts. If your water in air problems are seasonal, this is a result of the same phenomena (lower humidity in winter.)

Since no liquid water is the goal, our choice of drying technologies should be weighed against this basic concern. After all, over-specification can result in a higher bill than we want to pay, and under-specification can result in a higher liability than we are willing to accept.

We will look closely at three dryer technologies: Refrigerant Dryers, Regenerative Desiccant Dryers, and an emerging technology, Diffusion Dryers. Each of these uses a different underlying principle to remove water vapor, each has a distinctive performance across it's operating range, and each has it's distinctive strengths.

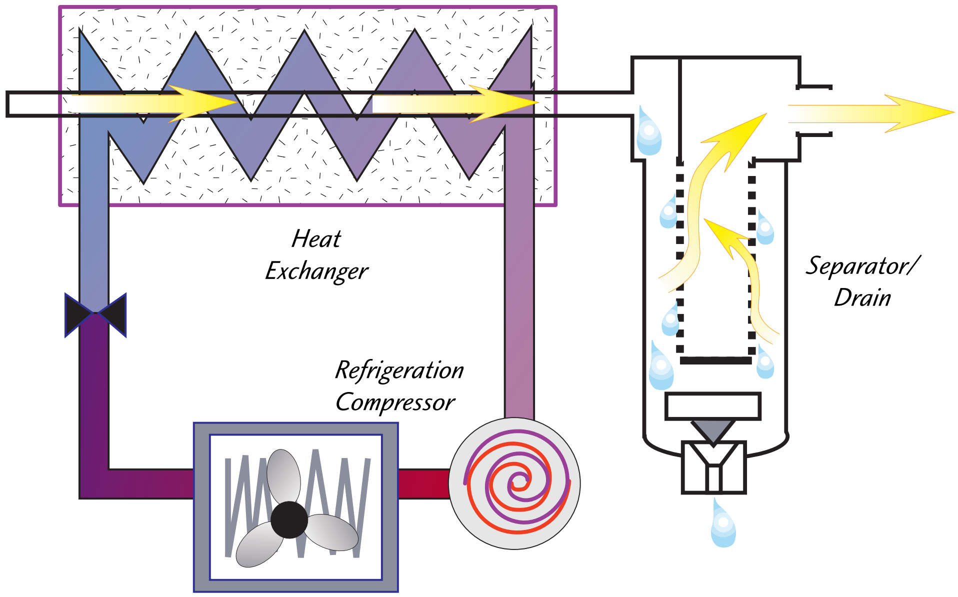

Figure A
A Simplified Refrigerant Dryer

Since the advent of the dew point alarm in the 1987 version of the NFPA 99, one fact has become painfully obvious: the most common cause of persistent dew point alarms is low flow through a refrigerant dryer. When you consider the bulk of North American medical facilities (some 80%) have such dryers, the prevalence of the problem is not too surprising.

The culprit in most facilities is the extreme variation in demand typical of a medical air system. One day the air system may run flat out because a lot of ventilators are in use, and the next day the system may sit idle because those patients have been discharged. This variation in air usage is particularly acute in smaller facilities.

The low flow - high dew point phenomenon is a result of the basic design of a refrigerant dryer (see Figure A). The dryer chills the air using a classic refrigeration cycle. Since the amount of water air can hold is dependant on it's temperature, water vapor in chilled air tends to condense from vapor to liquid. Once a liquid, it is supposed to move through the heat exchanger air tubes, into the separator/drain bowl, and - theoretically - out the drain.

What's the problem?

• *First* : The lowest temperature the heat exchanger in the dryer can be permitted to achieve is 0°C (32°F). Any lower, and the water would turn to ice. In fact, most refrigerant dryers are set to a minimum internal temperature more like 35°F (3°C), which keeps them from freezing under low loads. (Anyone who has suffered a dryer freeze-up will immediately recognize you don't fool with this temperature setting.) 35° is not a particularly low dew point, and moreover is not very far below the alarm dew point of 39°F.

• *Second* : Some dryer designs rely on a steady flow of air to drive the condensate through the dryer. No flow of air, no flow of water.

• *Third* : The separator/drain bowl where the water collects allows water to evaporate back into the air (called re-entrainment). Re-entrainment isn't a problem under nameplate conditions simply because the air flow is high enough to keep the bowl chilled and the water steadily draining out of the bowl. You should have problems with re-entrainment only when the insulation on the bowl is poor or when flows are low. How much flow is low? For the most popular refrigerant dryer models used in the U.S. over the last ten or so years, significant re-entrainment appears to occur at around 20-25% of nameplate flow. You can see how the re-entrainment phenomena effects a refrigerant dryer's dew point performance in Figure D.

Various manufacturers claim that this or that dryer does not have the problem. In fact, different refrigerant dryer designs *are* more or less subsceptible to re-entrainment, and some can provide reasonably satisfactory service at low flows. The best appear to have directly attacked the problems described above. If you are looking to stay with this 'fridge technology, take the time to understand exactly how the dryer you're considering deals with these issues. If the explanation you're given sounds a little like a repeal of the laws of thermodynamics, buy elsewhere.

If 39°F isn't low enough for your local conditions, don't fool around with a 'fridge dryer. It simply can't get you any lower. Another technology may be necessary simply for this reason.

The next technology appropriate to medical air use is the adsorbtion or desiccant dryer. This technology has been gaining popularity dramatically in recent years, especially with facilities who have suffered with low flow refrigerant dryer problems. Their performance curve is the opposite of the refrigerant (see Fig. D.) in that under low flows they simply produce drier air. This characteristic makes them especially attractive in those medical applications where loading varies dramatically day to day or hour to hour.

Desiccant dryers (Fig. B) operate on the adsorption principle - a material with particular affinity for water (a desiccant) is packed into a cylinder (or tower) and mounted in tandem with a second identical tower. As the air passes through the first tower, water "sticks" to the surface of the desiccant and the air leaving the tower is dry. On a timed cycle, air flow is switched from one tower to the other, and a fraction of the dry air is vented back

Why a 39°F Dew Point?

The dew point alarm setting in NFPA was not set because of some significant medical need for a dew point of 39°F - it was set there because a properly operating refrigerant dryer should be able to maintain it. In fact, in the first standard to require dew point monitoring, the 1987 version, there was none stipulated. The requirement was simply a dew point lower than the "minimum ambient temperature to which any portion of the medical air piping can be exposed" (still a useful rule of thumb.)

Is there a medically significant dew point? Not really, although some respiratory therapists are reluctant to see the air be ***too*** *dry. Consider though, that medical oxygen is typically at a dew point less than -48°C(-55°F). Any gas a patient breathes should already be re-humidified with sterile water as a normal practice.*

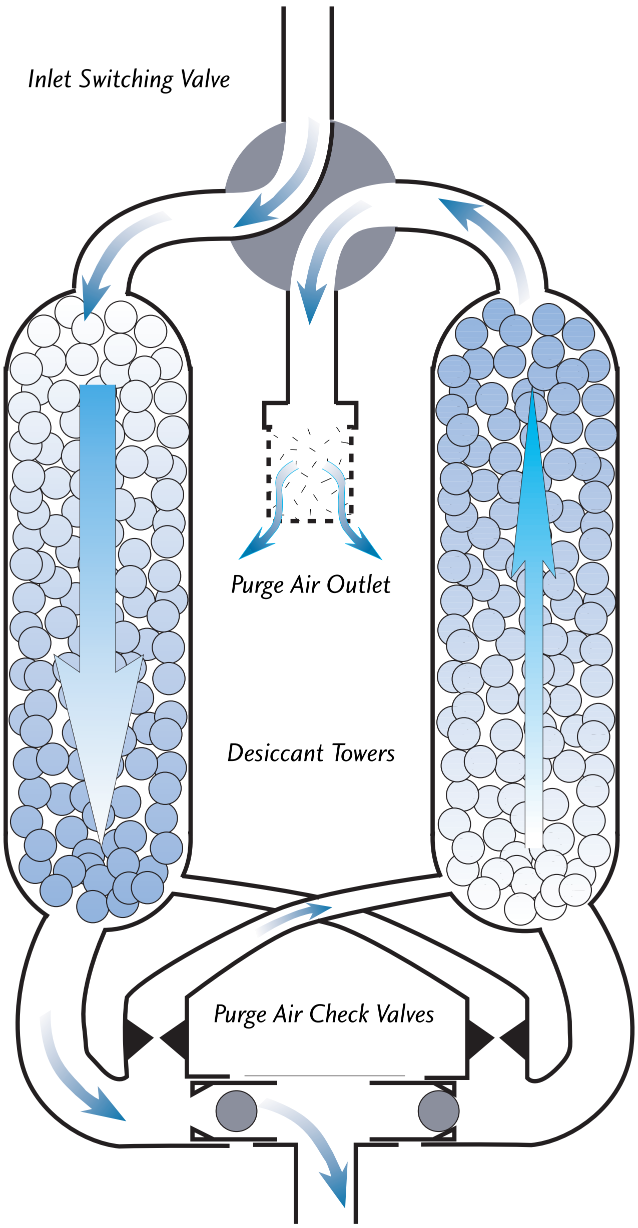

Figure B
A Simplified Desiccant Dryer

through the off line tower to regenerate the desiccant (i.e. *remove* the water from the desiccant surface). By switching back and forth, one tower drying the air and the other regenerating, a kind of perpetual drying machine is created.

Desiccant dryers never change the phase of the water (water vapor is never converted to liquid). Instead, they handle the water entirely in vapor phase (liquid water in a desiccant dryer is a sign of dryer collapse.) Because they work at the molecular level they can achieve very low dew points. A typical off the shelf desiccant dryer is nameplated at -40°, and most can get much lower when operated at flows below nameplate. (See Fig. D.)

This trick of regeneration uses some air. The amount used in a stock dryer is a fixed volume determined by the dryer size and operating conditions, which works out typically to about 15% of nameplate. However, put an oversized dessicant dryer on the system, and the amount of air used for regeneration will be higher as a percentage of system capacity.

Some users object to this purge, seeing it as a "waste" of air. Purge loss is the trade-off for the dryer's other benefits, but intelligently designed medical desiccant dryers also include purge controllers. Purge control adjusts the purge to the air used by the patients, rather than a fixed amount based on the dryer size. Less air used, less purge used. In medical systems, with their enormous variability in demand, purge control can represent a dramatic savings (a 60% reduction in purge loss over time is not unusual)

The technology of purge control varies, with equivalent variation in the cost, effectiveness and reliability. Since we are required by code to monitor dew point, a well designed medical air system can be purge controlled relatively simply. Nevertheless, purge control will also rapidly bring your dryer to it's knees if it doesn't work correctly. If you elect to use this technology, check out the mechanism used, because some purge control techniques are not suited to intermittent demand, and others simply don't work. At it's most subtle, a purge control failure will simply cause your compressors to work too hard (no purge savings). The other end of the spectrum is a failure which causes dryer collapse (a complete failure of the dryer). Don't buy a dryer for medical use without purge control, but take the time to understand the purge control principle involved in any dryer you're considering.

After the purge use, the most common knock against desiccants is the valving. The drying/purging cycle requires a desiccant dryer to have a lot of simple valves, or fewer but more complex valves. Every valve adds a potential point of failure and a potential maintenance headache.

Another concern with desiccant dryers is replacing the desiccant. Desiccant is subject to breakdown from the hammering it takes from the pressurize and depressurize cycle, and it can also be ruined by liquid water or oil. How difficult is replacing the desiccant and how often must it be done?

In evaluating a desiccant dryer, weigh these three considerations:

• *First :* How has the manufacturer dealt with the issue of switching the towers? What is the life of those valve(s) and how much maintaining do they need? Remember, your satisfaction with the dryer is directly related to how much you'll have to fuss with it. Get one which won't need too much.

• *Second :* What is the cost of replacing the desiccant? Don't let anyone tell you you won't have to - desiccant has a finite life and you should plan on changing it every few years (probably every 5) to maintain good dryer performance. Desiccant *material* is much the same between dryers and should be cheap. You need to understand the *labor* involved.

• *Third :* Is the dryer fitted with a purge control? If so, how does it work? Since we don't need a precision dew point, we can save ourselves a lot of money by going with a simpler control mechanism, but many dryers only have purge control options intended for high end industrial control (read: expensive and maintenance intensive).

Don't allow a desiccant dryer to see liquid water or oil in any form. The desiccant is ruined by liquid water or oil, and must be replaced if exposed to it. Proper prefiltration and liquid water separation is absolutely essential to keep the dryer in good working order.

The good news is that technologies are available to resolve these issues with desiccant dryers in medical air applications. This fact, combined with the very desirable elimination of low flow issues have elevated the desiccant dryer to it's position as today's technology of choice.

Is there a middle ground between the refrigerant dryer and the desiccant? One possible answer lies in an emerging dryer technology, the *Diffusion* dryer (Fig. C). Diffusion Dryers are based on the technology of the gas selective membrane, originally used in industry for the generation of nitrogen.

A polymer membrane is formed into a tiny tube, typically some three feet long (a *microtubule*). Internally, a coating is then applied which makes the membrane selective for water. Hundreds of these tiny tubes are bundled together inside the dryer, which then provide an enormous surface area. The "wet" air is passed through the inside of the tubes, and the water vapor diffuses through the membrane to the outside (hence the name Diffusion Dryer). Once on the outside of the membrane, the vapor is "swept" away by a continuous flow of air bled off the "dry" end of the tubes.

The mechanism is elegant and has the terrific advantage of being based on a simple physical principle. Neither valves nor refrigeration are needed. Indeed, Diffusion dryers use no power at all, and there is no way to service one.

Sound's too good to be true? Is there a downside? Unfortunately, at this time there are several. First, let's look at the ones which are easily dealt with:

• *First :* They are very sensitive to dirt - you can imagine that with these tiny tubes it wouldn't take much dirt to block them up - and they will be ruined by oil. This is easy to deal with, and a responsible manufacturer will only sell them with adequate prefiltration.

• *Second :* They do not achieve a dew point as low as a desiccant, but since they have a similar performance curve (see Fig. D), they effectively eliminate low flow dew point problems. In fact, the dew point they do produce is more than adequate for medical use where the objective is simply No Liquid Water. Typically their dew point performance is much lower than a refrigerant.

• *Third :* Like desiccant dryers, they expend a portion of the air for "sweeping" the outside of the membrane. This sweep air consumption may be lower or higher than a similarly sized desiccant, but under the best conditions it is still considerable, and as of this writing purge control is not available for them (technically it is a much more demanding purge control application).

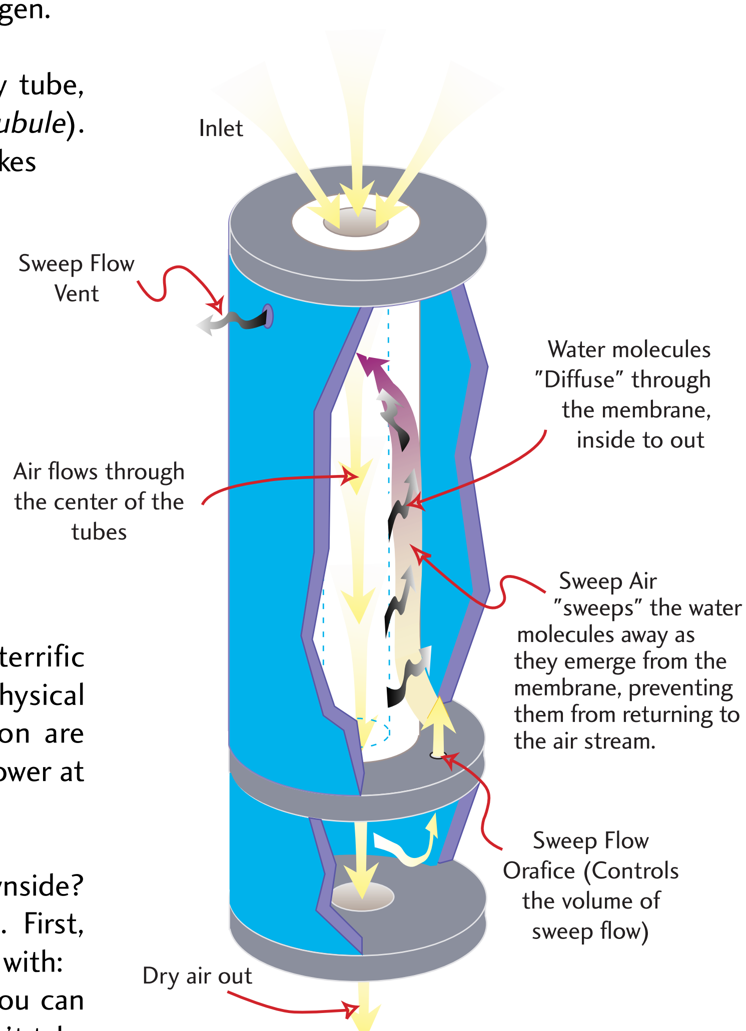

Figure C
A Simplified Diffusion Dryer

Back to 'Fridges

Back to Desiccants

Back to Diffusions

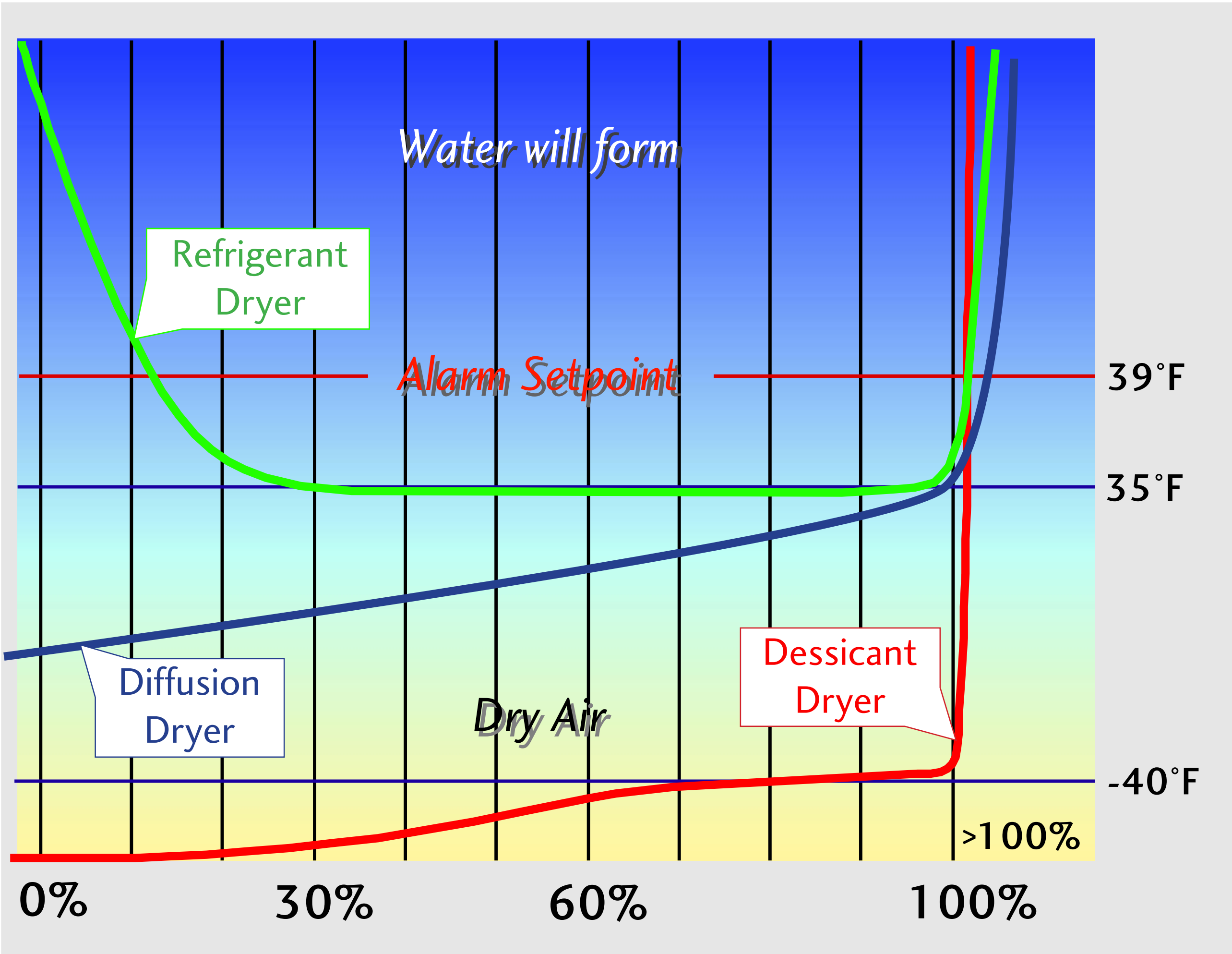

Figure D
Typical Dryer Performance Curves

• *Fourth :* Their heritage is gas separation - removing oxygen from air. Some makes still do. If you elect to try one, be sure to get a certificate from the manufacturer that your prospective dryer is of the correct type for breathing air service - those which deplete oxygen are definitely *not* suitable for medical applications.

These faults can certainly be worked around or lived with. Potentially more serious is:
Fifth : They have appear to have limited life. The membranes are themselves delicate, and the stresses of high internal pressures and the abrasive effects of flowing air limit how long the microtubules will last. They are also very easily damaged by liquid water. This is a paradox, since one benefit claimed for them is their ability to recover unharmed from a dousing. The explanation is simple enough - if you *pour* water into them, they apparently can recover without damage. However, if the water is shot into them at the pressure and velocity found in an air stream, the abrasive effect is devastating.

In the current state of the technology, it appears that they will last roughly three to five years when properly installed and prefiltered (but note that this life can vary greatly in different circumstances). A typical symptom of failure is excessive purge flow as the microtubules fracture and allow air to vent to atmosphere. Suprisingly, they maintain good dew points even when quite far gone, but the compressor will have to work overtime. Eventually of course the compressor won't be able to keep up at all.

Diffusion dryers are limited in size, so larger capacity dryers end up being made of several smaller dryers. This multiplexing has some advantages of it's own and is perfectly acceptable, but you should be aware that it is likely to occur if you require a larger capacity dryer.

Should you consider one? There are places where these dryers work when nothing else will. In applications which challenge a desiccant or refrigerant dryer, such as situations with low inlet pressures, they have been shown to work well. There is a price to pay, and you pay it in two ways: Life, because you can expect to be replacing the diffusion dryers often, and in the sweep air they consume - especially at lower inlet pressures.

The best that can be said for them is that the technology is extraordinarily promising. Wheras today they are probably best reserved as a dryer of last resort, as the technology improves they may come to take a place among the preferred selections for medical air.

The success any facility will have with any dryer will depend partially on the technology, and partially on the way it is applied. Even the best technology badly applied will give unsatisfactory results. Unfortunately, dryers in medical air are most often applied by rote, slavishly following the NFPA 99, typically not even the text but rather Figure 4-3.1.1.9. Unfortunately, this often reflects the lack of engineering savvy as much or more than it reflects a genuine attempt at code compliance - after all, any knucklehead can cobble together an air compressor package from a diagram.

NFPA makes a significant effort to point out that the diagrams are meant as illustrations only, and that alternatives which achieve the intent are acceptable (vis. the Note on the diagram itself). This is a very important point, because NFPA's intent is not to restrict good engineering. In getting the best from your dryers, this freedom is very important, since you may *not* do so by blindly following Figure 4-3.1.1.9. This is not a failure of the standard - NFPA 99 is about the *result* which needs to be achieved - *how* that gets done is the job of the engineer working with knowledgeable suppliers and varies with circumstance and technology.

When Good Dryers Fail - some nuances of Compressor System Design

Obviously, no dryer will work without a source of air. So? Won't any compressor work with any dryer?

The answer is no - in fact the condition of the air fed to the dryer is the biggest single factor in the success of any dryer. The compressor system determines four factors critical for dryer operation: pressure, temperature, cleanliness, and water load. Compressor - Dryer interaction is complex enough to deserve it's own paper, but in brief:

A compressor system will output a pressure between the cut in and cut out points. All Dryers are designed to work at 100 psig inlet, and suffer loss of efficiency at lower pressures. One of the easiest ways to boost a weak dryer is to raise it's inlet pressure - if your compressor can make it.

Compressor systems output hot air (because of the heat of compression). Dryers object to being hot, whether from high inlet temperature or high ambient temperatures. Some dryers, desiccants in particular, will simply cease to remove water above certain temperatures. A well designed compressor system removes excess heat before feeding the air to the dryer.

The amount of dirt or oil which comes out of the compressor will effect the dryer's efficiency over time. Diffusion dryers and to a lesser extent desiccant dryers cannot stand dirt. If they are exposed to liquid oil, they are simply ruined. Refrigerant dryers can withstand limited amounts of dirt, and are not damaged by oil, but will lose efficiency over time.

Water load is the amount of water presented at the dryer inlet for the dryer to remove. A well designed system is designed to remove water wherever it can, and not to pass it on to the dryer if it can be removed elsewhere. Good design requires proper placement of traps and drains.

A first and simple example: all dryer manufacturers recommend dryers be prefiltered, irrespective of the technology. Why? Dirt in a refrigerated dryer will over time at least reduce it's efficiency, and in desiccant and Diffusion dryers can ruin the dryer altogether. Despite this, few suppliers include prefilters in their medical air packages - because it is not required by NFPA 99, and because without it they can reduce their bid price.

A second example is where a dryer is located in the system. Some facilities have had success eliminating the low flow dew point problem by simply moving the refrigerated dryer so that it is located between the compressors and the receiver with an intervening check valve. This is sometimes referred to as a "dry receiver" configuration. Conceptually, this works because the dryer responds to the velocity of the air - when the compressor runs the dryer sees the maximum velocity and when the compressor is off it sees no air movement at all. The net sum effect is that the dryer works fine when it *is* working (i.e. when the compressors are running) and is effectively removed from the system when it *is not* working (i.e. because the check valve shuts off flow out of the dryer.) The air accumulated in the receiver is dry and so the system stays dry. The concept is logical and in practice has been shown to help. It is however no panacea. It does not always help, and BE CAREFUL - get the advice of your supplier first, because you can damage the dryer if the inlet air is too hot (some compressors rely on the receiver for all or part of their aftercooling - see the side-bar on compressor systems)

The same "dry receiver" technique has been applied with Diffusion and Desiccant dryers as a way to reduce the purge loss. This arrangement is generally not recommended and should not be attempted without the advice of your dryer manufacturer)

Another concept which may be worth considering is to multiplex the dryers. This cannot be done with refrigerant dryers, but can work very effectively with Diffusion and Desiccant dryers. The basic rule is contained in NFPA 99 1999 4-3.1.1.9 (c) and (g), which states that multiplexing should be done so that the peak system demand can be serviced with the largest single unit out of service. Any number of configurations are possible under this rule using more, smaller dryers to create a system which can dry all the needed air. Again, don't do this without solid advice from someone knowledgeable in dryers - it is easy to do it wrong and end up with a persistent dew point problem or worse.

When the dew point alarm first appeared in the NFPA 99 1987, most of the industry was rocked back on it's heels. Virtually everyone then used refrigerant dryers and the extent of the problem was not understood. A facility which may even have worked around water in the lines for years suddenly found that measuring dew point meant they could no longer ignore the problem. A whole class of facilities which didn't use much air or only used it intermittently found that dew point became an ongoing nuisance they couldn't eliminate. A remarkably large number of facilities, frustrated, simply unplugged their monitors and abandoned the search for a solution which didn't seem to exist.

Ten years on, the problem is better understood. and some excellent technologies are now available. With the savvy to apply those technologies properly, any dew point nightmare can finally be ended.

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