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Engineered Systems

Liquid Desiccant Dehumidification For Challenging Environments

In our second look at liquid desiccants this year, a veteran industry author and consultant reviews the technology and its application to difficult loads and environments. Review his cost-benefit analysis, supplemented by brief case studies ranging from a nursing home and a clean room to food and candy processing and a warehouse.

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Liquid desiccants may be among the most valuable HVAC technologies of this young millennium. Some leading researchers and mechanical engineers — and a growing number of large facility owners with significant humidity control challenges — are betting on it. As reported recently, liquid desiccant dehumidification is "an approach to effectively manage humidity under challenging conditions," including facilities in humid climates with high outdoor air (OA) requirements, applications with precise humidity control needs, and wet industrial applications including food manufacturing.[1]

The main advantage of liquid desiccant systems is that they remove humidity with far less energy input than either conventional cooling coils or solid desiccant approaches. According to the National Renewable Energy Laboratories (NREL) in Golden, CO, desiccant cooling and dehumidification is a thermally driven air conditioning technology and a "valuable tool in the industry's arsenal of space conditioning options."[2]

The benefits of desiccant systems over vapor-compression units are twofold: a fundamentally more efficient humidity-removal process and the potential to use low-temperature waste heat, solar thermal energy, or natural gas — or a combination of these energy sources — to regenerate the desiccant. These approaches reduce primary electrical consumption and allow endusers to reduce peak electrical demand. They also use less ozone-depleting refrigerant.

Yet there's an additional advantage in effectiveness of humidity control, which has attracted the eye of HVAC engineers and facility owners dealing with requirements for low humidity, such as ice rinks or supermarkets, or outsized humidity loads caused by high ventilation air needs or very wet occupancies (such as swimming pools and manufacturing processes). Even the food-processing industry, with its energy-intensive steamers and cookers and daily washdowns, has proven quick to adopt liquid desiccant technology. Appreciable operating cost reductions have been calculated as compared to solid desiccants and vapor compression systems.

However, one might ask, why liquid desiccant? It's a fair question, best addressed by focusing on recent experience and independent testing.

In fact, the moisture removal effectiveness and system efficiencies of packaged liquid desiccant dehumidification systems have been well established. A report by QinetiQ North America, an independent testing lab in McLean, VA, concluded that liquid desiccant systems have operating costs that tend to be about 50% less than those of other, comparable dehumidification systems (Table 1). The QinetiQ study also noted that new packaged dehumidification systems are made from corrosion-resistant materials, so the systems no longer suffer from carryover and other corrosive effects of the lithium chloride solutions used.[3]

Within these novel packaged systems are new designs of liquid-to-air contactors that contain desiccant liquids without using mist eliminators. According to NREL's Eric J. Kozubal, a researcher in distributed thermal energy technologies, "This is a critical advance that eliminates the maintenance traditionally associated with liquid systems, making possible their broad application as packaged systems." In addition, the packaged units allow for independent cooling and dehumidification in a single HVAC component, which can simplify and reduce system costs. Lastly, says Kozubal, many liquid desiccant systems are being integrated

Liquid Desiccant Performance: Sample installation for 50,000-sq-ft facility

Average performance across various humidity removal conditions.*

Assumes 24/7 hour operation throughout year

(in thousands)	First cost	Annual operating cost	Annual maintenance cost	10-year operating cost
Liquid desiccant (two packaged systems**)	90	20.7	10	397
Solid desiccant wheel	124	44.4	25	818
Vapor compression	75	37.6	20	651

*per Foster-Miller/Qinetiq report
**2 DuTreat system

TABLE 1. Calculating costs for original installations of twin packaged liquid-desiccant systems and a solid desiccant wheel — and then adding associated costs for operating energy use and typical maintenance — has allowed a comparison of the needed annual and 10-yr operating investment.

with combined-heat-and-power (CHP) systems to use excess waste heat during off-peak periods to heat and regenerate the desiccant solution.[4]

NEW SCIENCE FOR LONGSTANDING CHALLENGES

"Liquid desiccant has been used in building HVAC systems since the 1930s, mostly in industrial situations where it has always vied with solid desiccants," said Dr. Andrew Lowenstein, president of the R&D laboratory AIL Research (Princeton, NJ) and inventor of a plate contactor array for liquid desiccant systems.

Liquid desiccant air conditioning removes moisture (latent heat) from airstreams by means of a solution of lithium chloride (LiCl) or halide salts, according to Lowenstein. Concentrated, cooled desiccant flows into an absorber and through a mass transfer surface while counterflowing air passes through the same surface, transferring heat and moisture out of the air into the desiccant liquid. As the desiccant dilutes and passes out of the absorber, the moisture collected is transferred to the regenerator. This can be accomplished either by transferring the entire desiccant liquid volume to the regenerator, or, in some cases, more efficiently by simply allowing the excess moisture to migrate to the regenerator using diffusion-driven process. In the regenerator, the solution is heated and flowed onto another mass transfer surface, losing moisture to another counterflowing airstream.

The use of a liquid allows engineers and operators to further boost system efficiency by incorporating heat exchangers, heat pumps, or cooling coils. These components help balance heat transfer and mass transfer, ensuring input energy is distributed as efficiently as possible. Being able to simultaneously dry and cool the treated airstream may provide an increase in efficiency over solid desiccant rotors, which carry heat from the regeneration process back into the airstream that may need to be cooled to a desired temperature range.

APPLICATION OPPORTUNITIES

The effectiveness of liquid desiccant A/C systems for deep drying, precise humidity control, and highly saturated conditions have made them particularly appealing for industrial end uses.[5]

"For inherently wet processes and operations, you need to determine what humidity you're going to get from their process to calculate those loads," said Wayne Montgomery, P.E., a senior mechanical engineer at Food Facility Engineering, Yakima, WA. "Often a piece of dehumidification equipment can save money on the cooling and refrigeration equipment required." Effective dehumidification can also help with downtime needed to control excessive condensation or water vapor.

In the past, process manufacturers typically employed HVAC equipment types for process environmental control, such as direct expansion (DX) systems or chilled water systems. These have effectively dealt with temperature variations within the plants, but for humidity they have proven ineffective or costly due to the low temperatures required to extract moisture — generally at temperatures much lower than those needed for space cooling. A further challenge awaits this scenario according to Montgomery. "This means the engineers have to oversize the refrigeration evaporators to handle the humidity load," he says. "Often it also requires use of a defrost cycle because frost forms on the coils, so they're using heaters and shutting down the refrigeration units for defrosting." Liquid desiccant systems have shown an alternative to this kind of inefficient humidity extraction and defrost cycling.

The systems have also been successfully applied for a range of commercial and institutional projects as well, say engineers, ranging from nursing homes to cleanrooms.

COMMERCIAL AND INDUSTRIAL CASE STUDIES

A few examples demonstrate how liquid desiccant HVAC systems have been employed to boost plant energy efficiency while also benefiting public health, corporate sustainability and occupant safety and comfort. These include both industrial and commercial applications of a variety of types.

- Regents Park Nursing Home. This South Florida facility faced serious condensation problems, odors, and air quality concerns in two large cafeterias. Using conventional air conditioning systems made the interiors too cold for elderly residents and increased the risk of microbiological growth

Reasons to Apply Liquid Desiccant Dehumidification for Food Processing

Building or Process Challenge	Liquid Desiccant Life-Cycle Feature
Deep, precise drying	High dehumidifying potential
Inherently wet processes, washdowns and CIPs	Captures excess water vapor
High-humidity OA	Reduced ventilation
Low-temperature environments	Low-dewpoint moisture removal
Frost and ice formation	Reduces/eliminates frost conditions
Poor air quality, microbials	Helps remove particulates and airborne pathogens
Cost of HVAC systems	Allows downsizing of conventional A/C
First (capital) costs	Novel packaged units

on cooling coils. Packaged liquid-desiccant dehumidification systems were installed in the large common areas, eliminating the condensate and associated problems within hours.

- Huawei cleanroom. Manufacturing telecommunications equipment in a clean room facility requires precise control of humidity levels and IAQ, and Huawei Technologies — located outside of warm, humid Shanghai — sought a cost-effective solution for their plant. The company's engineers considered a standard HVAC solution that would have used about 45 kW to chill water, 29 kW to reheat air to the design point, and 11 kW for other system needs. By contrast, the pair of packaged liquid desiccant units ultimately selected by Huawei consumes only 53 kW, yielding 62% energy cost savings and a brisk 16-week payback.
- Europlast food processing. Europlast's meat plant was beleaguered by air quality and humidity issues due to the hot, wet process conditions. The production hall was cooled but relative humidity levels reached 85% during summer months, putting the facility at a high risk of mold and mildew growth. Production was halted to allow for a retrofit to improve ambient conditions. Europlast considered an oversized vapor-compression system as well as solid and liquid desiccant options and settled on a packaged liquid desiccant dehumidifier with a built-in heat pump, which maintains mandatory environmental conditions of 71°F and 50% rh regardless of weather conditions.
- Duty Free Americas Miami warehouse. For a warehouse facility in southern Florida owned by Duty Free Americas, sensitive goods such as cosmetics, tobacco, watches, and chocolate required cool and dry conditions. The existing HVAC system could cool the air but not remove enough humidity to be effective. Two liquid-desiccant units were added and integrated with the existing air-handling system to maintain ideal constant conditions of 76° and 52% rh.
- Confectionery plant. As part of a demonstration project to confirm energy savings and effectiveness, operators of a candy and gum factory in a subtropical climate tested a liquid desiccant dehumidification unit with a heat pipe, retrofitted to an existing AHU, to condition supply OA to a gum production area. The new liquid-desiccant system cost about 28% less to purchase and install than a comparable desiccant wheel system and cut associated cooling power loads from 37,800 kWh per month to about 27,000 kWh per month for the single unit.
- Meat processing facility production areas. To address the humidity, mildew, and mold generated by continual cleaning of production areas — which also caused slip dangers — engineers at this food company demonstrated how waste heat from a process biofuel incinerator could be used to power new liquid desiccant dehumidifiers. For the dehumidification system's heat sink, the team tapped into an existing cooling tower, actually reducing necessary chiller capacity even though additional cooling was achieved. The six new rooftop packaged dehumidification units slashed HVAC energy costs by 40%, and airborne particulate levels (5 microns or greater) dropped by about 75%, while almost 95% of microorganisms were eliminated. This helped address concerns about listeria, salmonella, and E. coli bacteria.

HEALTH CHALLENGES IN INDUSTRY

The risks of microbiological contamination for food processors are vast. The recent E. coli outbreak in Germany cost the nation's farmers at least $600 million in the first weeks, and Spanish exporters lost $200 million per week. According to FDA, a food manufacturer's risks of microbiological contamination — and worker health dangers such as Legionella — are directly proportional to the levels of wetness and humidity in production areas. Listeria, for example, can exist on persistently damp surfaces even in refrigerated areas of plants. "Humidity control is becoming more and more important for these reasons," says Montgomery.

In fact, the prospect of an outbreak is so financially disastrous that food manufacturers are adamant about keeping floors dry and conducting powerful daily deep cleaning at least once per day, with high-temperature, high-pressure washdowns on every surface in production areas, says Gunawardena.

After cleaning, processing spaces resemble massive steamrooms, which must be vented and dried before resuming production. In addition, Kozubal points out that today's industrial and commercial buildings have tighter enclosures that improve efficiency but also tend to cause humidity and condensation challenges. "This reduces the thermal loads and so the standard air conditioning systems often don't operate sufficiently to control humidity, which can be the most energy-intensive load in the building," he explains.

Liquid desiccant systems can improve humidity management, removing moisture without cooling air to saturation, keeping the relative humidity of supply air below 70%. In this way, supply-air ducts remain dry, helping to reduce mold and bacterial growth.

Dehumidifiers also reduce condensation on cooling coils as well as water accumulation in drain pans, both of which can be breeding grounds for bacteria. In addition, the scavenging action of liquid desiccant systems can improve IAQ by removing airborne contaminants.

APPLYING LIQUID DESICCANT

With increased safety requirements, many HVAC challenges can be addressed with liquid desiccant dehumidification, says AIL Research's Lowenstein. Common situations ideal for liquid desiccants include:

- Where the facility has to overcool and reheat the air to maintain comfort conditions — a common scenario in all but the most arid climates.
- Where dewpoints lower than 40° make it very difficult for a vapor compression system to dehumidify without risk of freezing.
- Where recoverable heat is available at between 140° and 220°.
- Where waste heat or thermal energy is available, the already considerable energy savings from liquid dehumidification units can be even greater.

"Liquid desiccants are cheap cooling storage devices, requiring three to five times less volume than comparable ice energy storage systems," says Kozubal. Confirming the benefits, in a recent article John Dieckmann described how "a desiccant system integrated with a CHP system could generate strong desiccant during off-peak times when excess waste heat is available and store strong desiccant to provide cooling capacity during periods of peak electric demand."[6]

In humid environments, the energy savings are most pronounced, says Dieckmann. The liquid desiccant handles the primary latent load, avoiding the need to overcool the OA supply, decreasing reheat needs and allowing interior cooling to handle ambient interior moisture. In this way, the A/C chiller system operates at optimal desiccant.[7] With dryer interior conditions, another benefit is that indoor temperature setpoints can be higher by as much as 5°, without any perceived change in occupant comfort. Dieckmann concludes that new-generation liquid desiccant systems used as a DOAS in warm, humid climates can achieve significant energy savings.

COMPARING SOLUTIONS

Liquid desiccants have similar moisture-absorbing properties as solid desiccants, but they absorb the humidity portion of a typical air conditioning load without adding the heat, says Hugh Williams, a mechanical engineer and industrial department head for KGS Group, Winnipeg. "Getting around heating requirements for using solid desiccants is a huge challenge," Williams adds, referring to the heat needed to regenerate solid desiccant wheels.

One major drawback of early-generation liquid desiccant systems was an effect known as carryover, in which lithium chloride desiccant would become entrained in cross air flows, causing corrosion in downstream ductwork.

According to NREL's Kozubal, newer liquid-desiccant dehumidifier and A/C designs available on the U.S. market employ advanced liquid-to-air contactors that contain the desiccant without mist eliminators. The mass-manufactured contactors require a minimal pressure drop as compared to desiccant wheels, and represent "a critical advance that eliminates the maintenance traditionally associated with liquid systems," allowing broader application of the packaged systems. Liquid desiccant systems also allow a number of application benefits that are unachievable with solid desiccant technology, including integration with CHP systems:

- Making effective use of low-temperature waste-heat sources, as well as thermal energy from fuels cells and solar collectors.
- The ability to physically separate the A/C and regeneration functions. This allows the liquid desiccant to be piped to a useful humid location and then piped back to a heat source for regeneration.
- The option to store regenerated desiccant solution, which allows flexibility in the timing of the regeneration function — for example, it can occur when waste heat is available. Desiccant storage — essentially accumulated chemical energy with A/C potential — can be more efficient than thermal energy storage.

Lab testing supports assumptions made in the field. QinetiQ conducted a economic analysis of packaged liquid desiccant units and two alternate dehumidification approaches: a solid desiccant wheel for dehumidification followed by a vapor compression unit use for the removal of sensible heat from the process airstream; and a vapor compression unit used for dehumidification followed by sensible heating (reheat) of the process air to the final desired delivery temperature.[8]

As shown in the Table 1, the liquid desiccant systems perform competitively when compared to other conventional dehumidification equipment types — on operating costs and maintenance costs as well as on a first-cost basis, QinetiQ concluded. (For details on the study,

How Liquid Desiccant Systems Work

Liquid desiccants work by means of a solution that acts as a drying agent, typically a brine of lithium chloride or halide salts, that works in absorption and diffusion.

Absorption occurs when brine is sufficiently salty — about 30 to 40% salt concentration — to capture water molecules from the air. This effect occurs in nature as well: the Dead Sea, for example, constantly pulls moisture out of the air.

To make this desiccant action useful, a dual-reservoir system is employed to absorb moisture on one side and then exhaust it through the other. When quantities of the brine absorb enough water vapor, they migrate through simple diffusion to the regeneration reservoir to be actively heated, typically above about 120°F. This reverses the absorption process, desorbing and ejecting a significant amount of water vapor and, in this way, regenerating the system to allow for further humidity capture.

To pass supply air near the liquid desiccant, typical systems use a mass transfer surface, such as a packed bed or corrugated medium. A small pump circulates desiccant to the top of the media bed and it flows down in a filmlike fashion, against a counterflow of supply air. The desiccant absorbs moisture from the air, and the moisture captured migrates to another packed medium where moisture is rejected to and picked up by a counterflowing scavenger airstream.

A temperature differential of at least 45° must be maintained between the absorption and regeneration reservoirs. A heat source of 140° to 150° is typically sufficient for the regeneration side, which can be waste heat or solar thermal power. On the absorber side virtually any heat sink, such as groundwater, can be employed. Some standalone systems use a heat pump to transfer heat out of the absorber directly into the regenerator — making them very easy to deploy in any facility.

see the sidebar, "A Cost Comparison of Dehumidification Approaches.") For unconditioned process air treated to acceptable supply air at several test conditions, operating cost savings for the liquid desiccant system ranged from 27% to as high as 55% per unit. These implied significant reductions in operating costs, in part due to the elimination of process heat inputs.

CONCLUSION: BENEFITS FOR INDUSTRY

A growing number of facilities with challenging humidity conditions are employing liquid desiccant dehumidification systems, some saving up to half of its outlays for operating HVAC dehumidification. Experience at food plants shows that liquid desiccant systems can maintain tight tolerances for demanding process environments, such as preventing excessive condensation. The most significant benefit of using liquid desiccant systems is the potential for reduction in maintenance and total operating costs — in some cases cutting energy requirements by half. Liquid desiccant systems have also been shown to improve IAQ by reducing humidity loads as well as airborne microbiologicals. The liquid-based systems also require little maintenance.

Just as important, liquid desiccant systems can be implemented using creative approaches to heat-recovery, CHP, and even renewable energy solutions such as solar thermal collection. With the energy-efficiency gains of this inherently economical approach, facilities can further reduce greenhouse gas emissions and carbon footprint, making operations not only leaner but also greener. One reason for its effective performance is that liquid desiccant systems cool and dehumidify simultaneously — yet with independent control of each function.

A growing number of industrial and commercial HVAC installations are taking advantage of the resulting efficiencies, increasingly specifying liquid desiccants for hospitals, fitness centers, museums, and storage facilities. **ES**

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CITED WORKS

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