Potential of R-32 for Use in Agricultural Dehumidifiers

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January 2022

Executive Summary

Dehumidification in controlled environment agriculture is an emerging and fast-growing application helping to ensure the world's food supply and production of crops requiring controlled horticulture. While R-410A is the current U.S. industry standard refrigerant for use in such vapor compression systems, R-32 is a viable alternative. A comparison between both fluids, including the benefits and limitations of R-32, and results of analysis conducted on an agricultural dehumidifier application comparing the alternative refrigerant R-32 to R-410A are discussed herein. The analysis was based on thermodynamic calculations, vapor compression system modeling, and life-cycle climate performance evaluations. Use of R-32 in an agricultural dehumidifier would result in a 10% reduction of dehumidifier runtime due to improved rated capacity, as well as a charge reduction of 25%. These benefits, along with the lower GWP of R-32, translated to a reduction of total CO_2 emissions from 11-16%, dependent on location. The U.S. EPA does not currently list R-32 as a substitute for this emerging market segment, however, R-32 appears to meet the policy goals for phasing down HFCs.

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Introduction

The American Innovation and Manufacturing (AIM) Act of 2020, which became law at the end of 2020, gives the U.S. Environmental Protection Agency (EPA) authorization to regulate hydrofluorocarbons (HFCs). The AIM act complies with the Kigali Amendment to the Montreal Protocol. The transition to next generation refrigerant technologies driven by the AIM act includes a 15-year phase down of HFC production and consumption; allows the EPA to establish standards for HFC refrigerants, and to enact sector-based use restrictions on substitute refrigerants. In addition to the AIM Act, the EPA's Significant New Alternatives Policy (SNAP) Program implements section 612 of the amended Clean Air Act of 1990 and evaluates substitutes for ozone-depleting substances in various industrial use sectors. The HVAC&R industry must, in turn, adapt by evaluating substitute refrigerants and redesigning systems and components. The selection of alternative refrigerants requires consideration of multiple characteristics, most notably: thermodynamic performance, Ozone Depletion Potential (ODP), Global Warming Potential (GWP), flammability, and toxicity.

Currently, the EPA's Refrigeration and Air Conditioning sector includes 16 subsectors including industrial process refrigeration and air conditioning, residential and light commercial air conditioning and heat pumps, and residential dehumidifiers, among others. As of this writing, there is no EPA sector for commercial/agricultural dehumidification which is an emerging market segment with expectations of significant growth.

Dehumidifiers play a key role in controlled environment agriculture (CEA). The global CEA market is expected to grow from $75 billion in 2020 to $172 billion in 2025, representing a compound annual growth rate of 18.7%[2]. Typical CEA crops include "tomato, cucumber, peppers, cannabis, lettuce and leafy greens, strawberries, and others"[3]. Cannabis is a highly energy intensive crop with significant energy demand for lighting and closely controlled microclimate, which requires air conditioning and additional dehumidification. Carbon dioxide (CO_2) emissions in the United States due to the cannabis energy demand in 2012 were estimated to be equivalent to 3 million average U.S. automobiles[3].

R-32 Background

R-32 (difluoromethane / HFC-32) is a pure fluid with no glide or issues with fractionation, is readily available, and can be reclaimed and recycled easily. It has an ODP of zero and a GWP of 675[4], which is 68% lower than R-410A. Manufacture of refrigerants also results in indirect

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[2] KD Market Insights. 2021. *Controlled Environment Agriculture Market - By Crop, By Growing Method, By Component & Global Region - Market Size, Trends, Share & Forecast 2020-2025*. KDMI-2480.

[3] Mills, E., 2012. *The Carbon Footprint of Indoor Cannabis Production*, Energy Policy, Volume 46.

[4] Pachauri, R.K. and Reisinger, A., 2007. *IPCC Fourth Assessment Report (AR4)*. IPCC.

emissions of greenhouse gases. According to the International Institute of Refrigeration's (IIR) LCCP working group[5], R-410A manufacture results in 10.7 kg CO2-eq./kg produced compared to 7.2 kg CO2-eq./kg for manufacture of R-32, representing a 33% decrease.

The refrigerants R-404A, R-407A, R-407C, and R-410A are mixtures with R-32 as a constituent and have been used in applications for years. Widely used in HVAC&R applications, including dehumidifiers, R-410A is a 50/50 blend of R-125 and R-32, has a GWP of 2090[4], and has industry use dating back to 1995. Under implementation of the AIM Act, HFC refrigerants with high GWPs, including R-410A, will be phased down.

"R-32 is an attractive alternative to R-410A because it offers an excellent balance of cost, performance, and low environmental impact" – Scot Swan, Global Market Manager at Arkema[6].

R-32 is classified as mildly flammable with lower toxicity (A2L). This rating indicates that R-32 is non-toxic in concentrations less than or equal to 400 ppm, and has burning velocity less than 10 cm/s.

R-32 has been approved by EPA as a substitute refrigerant in new, self-contained HVAC equipment with limits on the amount of charge, however, at the time of this writing, R-32 has not been approved by EPA specifically for use in residential or commercial/agricultural dehumidifiers.

According to Daikin, "more than 100 million R-32 units are operating safely around the world in chillers, packaged rooftops, VRF, residential splits and window air conditioning units"[7] with "20 million more coming online every year"[8].

Advantages of R-32

Besides the 68% reduction in GWP of R-32 compared to R-410A, R-32 potentially offers benefits in terms of performance increases and refrigerant charge reduction. Minimal system redesign, by using R-32 in place of R-410A, is highly attractive to manufacturers. From

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[5] IIR LCCP Working Group. 2016. *Guideline for Life Cycle Climate Performance v1.2*.
[6] Turpin, J. R., 2020. *Manufacturers Eye R-32 To Replace R-410A*.
[7] R32reasons.com
[8] Daikin, 2020. *The Global Stance on R-32*.

a thermophysical perspective, R-32 can be used in compressors and heat exchangers designed to operate with R-410A.

Past case studies have been conducted using R-32 as a drop-in replacement for R-410A in heat pumping and air conditioning applications; yielding results "varied from essentially equivalent performance, to claims of up more than 6% improvement in COP"[9]. In contrast to past studies, the analysis herein considers an agricultural dehumidifier application, comparing R-32 to R-410A based on thermodynamic calculations, vapor compression system modeling, and lifecycle climate performance (LCCP) evaluation.

Concerns & Limitations of R-32

As mentioned previously, R-32 has been classified as a mildly flammable refrigerant (A2L). Researchers Kim and Sunderland at the University of Maryland subjected R-32 and three other A2L refrigerants to 15 different ignition sources including heated nichrome wire, open flames, smoldering cigarette, friction sparks, and other household electric devices which generate heat[10]. The 740°C nichrome wire and the open flames from a butane lighter or safety match were the only viable sources of ignition. Their study found that halocarbon refrigerants can act either as fuels or as suppressants. In tests with slowly increasing refrigerant concentration the refrigerant acted as a suppressant, extinguishing the candle and butane flames. Eleven additional ignition sources including a smoldering cigarette, butane lighter, electric arcs, and heating elements in common household appliances at 540°C did not produce flames.

Manufacturers who intend to produce equipment using low GWP, flammable refrigerants need to comply with UL 60335-2-40.[11] The section of the standard "Safety - Part 2-40: Particular Requirements for Electrical Heat Pumps, Air Conditioners and Dehumidifiers" details safety requirements including those for testing, maximum charge size, minimum allowed room area, ventilation, usage space requirements, hazard warnings and markings, and user manuals.

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[9] Nasuta, D. and Radermacher, R., 2016. *An Evaluation of R32 for the US HVAC&R Market*. Optimized Thermal Systems.

[10] Kim, D.K. and Sunderland, P.B., 2021. *Viability of Various Sources to Ignite A2L Refrigerants*. Energies, 14(1), p.121.

[11] Federal Register. 2021. *Protection of Stratospheric Ozone: Listing of Substitutes Under the Significant New Alternatives Policy Program*. 86 FR 24444.

While less attractive from the standpoint of market-readiness, other refrigerants such as hydrofluoro-olefins (HFOs) and natural refrigerants exist with GWPs orders of magnitude lower than R-32. Compared to R-32, these alternatives drive specific challenges for dehumidifier manufacturers requiring system redesign including compressor design and displacement, increased refrigerant mass flow rate, increased heat exchanger tubing size and/or increased number of circuits to offset pressure loss penalties. Additionally, the market acceptance and availability of these refrigerants lags behind that of R-32. At this point in time, R-32 should be considered a viable alternative which delivers reduced emissions, and avoids significant burden on the dehumidifier industry, and potential negative impact to the market.

Dehumidification Applications

Dehumidifier performance is typically measured using pints/day for moisture removal capacity and liter/kWh for energy efficiency. Residential dehumidifiers (Figure 1) have moisture removal capacities (rated capacities) of up to 130 pints/day, while commercial/agricultural (Figure 2) dehumidifiers have moisture removal capacities of up to 875 pints/day[12], which translates to an equivalent cooling capacity of a 21.7 kW (>6 ton) HVAC system. Using R-410A, a typical residential dehumidifier will have a refrigerant charge of approximately 454 g (16 oz) and commercial/agricultural dehumidifiers will have a refrigerant charge up to 3700 g (130 oz)[13].

Figure 1: Residential Dehumidifier

Figure 2: Indoor Agricultural Dehumidifier

[12] https://www.questclimate.com/product/quest-876/
[13] https://www.anden.com/products/anden-710/

Thermodynamic Analysis

Vapor compression cycle applications necessitate refrigerants with thermophysical properties suitable for certain operating conditions. The optimal refrigerant for dehumidifier applications is not necessarily the same as that for air conditioning, heat pumping, or low temperature refrigeration applications.

Thermodynamic analysis was performed to compare the theoretical performance of an agricultural dehumidifier with R-410A and R-32 refrigerants. In the analysis, operating conditions including saturation temperatures, compressor efficiency, and capacity were held constant, and mass flow rate, compressor displacement, compressor power, and coefficient of performance (COP) were calculated. The evaporating temperature was assumed to be 6°C (43 °F) and the condensing temperature was assumed to be 42°C (107 °F). Results are given in Table 1, normalized against R-410A values.

Table 1: Normalized Results from Thermodynamic Analysis

Refrigerant	Normalized Mass Flow Rate (-)	Normalized Displacement (-)	Normalized Compressor Power (W)	Normalized COP (-)
R-410A	1.00	1.00	1.00	1.00
R-32	0.68	0.94	1.00	1.00

With R-32, the refrigerant mass flow rate was 32% lower, compressor displacement 6% lower, and compressor power and COP equivalent to that of R-410A.

Vapor Compression Cycle Modeling

Detailed vapor compression cycle modeling was conducted using the proprietary software tools CoilDesigner® and VapCyc® with information provided by a major manufacturer of agricultural dehumidifiers. The heat exchangers were modeled in CoilDesigner® and used in the VapCyc® cycles along with 10 coefficient compressor models. Compressors were selected for use with R-410A and R-32 having the same displacement. In contrast to the thermodynamic analysis, the vapor compression cycle model calculated the capacity, compressor efficiency, and condensate removal rate in addition to the COP, power, and mass flow rate. The performance of the systems operating with both R-410A and R-32 is summarized in Table 2, along with the percent differences for R-32 compared to R-410A.

With R-32, cooling capacity increased 7% and compressor power increased 1% leading to a COP increase of 6%. The refrigerant mass flow rate was reduced by 26% and the charge by 25% with R-32. The dehumidifier performance metrics of rated capacity and rated efficiency increased 10% and 9%, respectively, with R-32. In summary, the use of R-32 leads to improved performance over the current R-410A. This can be explained by the higher heat capacity of R-32 which provides higher cooling capacity for the same compressor displacement.

Table 2: Results from Vapor Compression Cycle Models with R-410A and R-32.

	R-410A	R-32	Unit	% Difference R-32 to R-410A
Cooling Capacity	10,795	11,543	W	7%
COP	5.57	5.92	-	6%
Power	1.938	1.949	W	1%
Mass Flow Rate	0.056	0.041	kg/s	-26%
Charge	0.548	0.411	kg	-25%
Rated Capacity	331	362	pints/day	10%
Rated Efficiency	3.362	3.663	liter/kWh	9%

Life Cycle Climate Performance

In addition to the thermodynamic cycle analysis, high-level life cycle climate performance (LCCP) analysis was completed to identify the differences in lifetime emissions for agricultural dehumidifiers operating with R-410A and R-32 refrigerants. The lowest GWP does not necessarily yield the lowest LCCP as total emissions consist of both direct emissions, such as leaks of refrigerant; and indirect emissions, which are driven primarily by lifetime energy consumption. In this analysis other sources of emissions, such as component materials and decommissioning impacts, have not been included as they are negligible.

In this analysis, several states within the U.S. and provinces within Canada were identified that have active cannabis production. Each state or province has a corresponding emission factor related to sources used locally for electricity generation[14,15]. The locations selected for

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[14] U.S. EPA. 2021. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019*. EPA 430-R-21-005.

[15] Canada Energy Regulator. 2021. *Provincial & Territorial Energy Profiles*.

representative analysis were the states of California, Michigan, Oklahoma, and Oregon and the provinces of Alberta, British Columbia, and Quebec.

Total lifetime emissions for these states/provinces are shown in Figure 3 for both R-32 and R-410A dehumidification systems. With R-32, the rated capacity improvement translated to reduced runtime and provided a 10% reduction in indirect emissions; and the charge reduction and lower GWP translated to a 76% reduction in direct emissions. Total emissions were reduced 11-16% in locations where indirect emissions were significantly higher than direct emissions. In the provinces of British Columbia and Quebec, where power generation is more than 90% hydroelectric, the major benefit of R-32 was the 76% reduction in direct emissions.

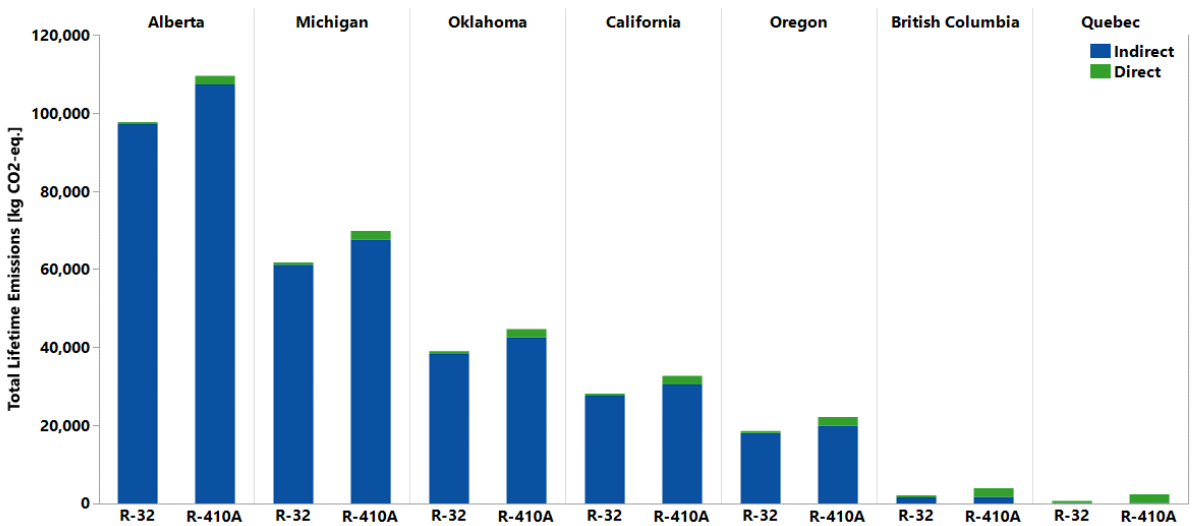

Figure 3: LCCP Emissions for R-32 and R-410A.

Summary

Dehumidification is a fast-growing application due to the emergence of the controlled environment agriculture industry. Analysis based on vapor compression system modeling and LCCP evaluations showed that R-32 resulted in a 10% reduction of dehumidifier runtime due to improved rated capacity, and therefore a 10% reduction in indirect emissions compared to R-410A. Also, with R-32 the 25% reduced charge and lower GWP translated to 76% lower direct emissions. Total CO_2 emissions were reduced from 11-16%, dependent on location, over system lifetime with R-32. Locations heavily reliant on fossil fuels for electricity generation represent the most significant CO_2 emission reduction opportunities. Locations reliant on renewable energy sources also benefit from direct emissions reduction. The U.S. EPA does not currently list R-32 as a substitute for this emerging market segment, however, R-32 appears to meet the policy goals for phasing down HFCs. To avoid significant burden on the dehumidifier industry, and potential impact to the market, R-32 should be considered a viable alternative.