13th IEA Heat Pump Conference
April 26-29, 2021 Jeju, Korea

Active humidity control for refrigeration applications

Jacob Zerby[a], Bamdad Bahar[a]*

[a]*Xergy, Inc., 299A Cluckey Dr., Harrington DE 19952, USA*

Abstract

According to the Food and Agriculture Organization of the UN, approximately 1.3 billion tonnes of food is wasted per year around the world [1], leading to excess energy requirements and greenhouse gas emissions. It is important to control all aspects of spoilage, including food storage during refrigeration. Maintaining adequate humidity levels during the storage of foods is essential to increasing their shelf life. In this paper we describe a solid-state method of humidity control based on an electrolysis cell, a derivative technology of fuel cells. The technology operates by interacting with moisture in the air, leading to a novel method of simple and accurate control of humidity levels inside an enclosure such as a refrigerator. It requires no maintenance, is quiet, and takes up very little space in a refrigerator. Current technology is limited to one-way operation, either as a humidifier or dehumidifier, and requires either a drain of liquid water for dehumidification or a source of water for humidification. The system can work in conjunction with a heat pump to manage moisture levels inside a refrigerator. Real life, in-situ performance data is provided.

Keywords: Active Humidity Control; Electrolysis; Refrigeration;

1. Introduction

There are many foods stored in a refrigerator that require different levels of humidity to increase their shelf life. In some instances, like vegetables, the foods may off-gas moisture during storage, which can lead to saturated environments. These saturated environments lead to pooling off water and subsequent rotting of food.

Current methods to avoid this issue include vents that allow the moisture to be pulled out of the container and the use of pervaporative membranes, which only allow moisture to pass through based on a humidity gradient. These are methods of passive control and their effectiveness depends on the food and conditions within the refrigerator. An electrochemical humidity control device allows for both humidification and dehumidification at precise levels, something no other technology can do.

Several years have been devoted to the development of these systems to assist standard refrigeration in the preservation of food. As depicted in Figure 1, 5 Generations of systems have been manufactured and implemented, each with increases in performance and decreases in cost from the previous generation [5].

---

[*] Corresponding author. Tel.: +1 (302)-629-5768. *E-mail address:* bamdad.bahar@xergyinc.com

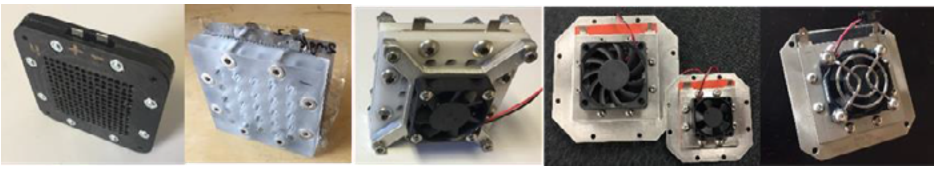

Fig. 1. The development of electrochemical humidity control systems over five generations

For the humidity control system, half of the electrochemical cell operates like the anode of a proton exchange membrane (PEM) water electrolyzer (PEMWE), and the other half of the cell operates like the cathode of a PEM fuel cell (PEMFC). Figure 2 details the operation of all three systems.

The PEM is coated with catalyst on both the anode and cathodes, and then sandwiched by gas diffusion layers (GDL) to assist in electrical conductivity and gas/liquid diffusion to and from the membrane. In PEMWE, water is introduced at the anode side of the system and broken down to oxygen and protons. The protons transport across the membrane to the cathode and react to form hydrogen. In PEMFC, hydrogen is introduced at the anode and reacted to form protons. The protons transport across the membrane and react with oxygen at the cathode to form water and energy.

The PEM humidity control system takes moisture out of the air and reacts that moisture at the anode to generate protons and oxygen. The protons transport across the PEM to the cathode and react with oxygen to reform water. If the anode is interfaced with the chamber then dehumidification is performed, if the cathode is interfaced with the chamber then humidification is performed.

Table 1. PEM water electrolysis technology reaction pathways

PEMWE	PEMFC
$Anode: H_2O \rightarrow 2H^+ + \frac{1}{2}O_2 + 2e^-, E^0 = 1.23V$ $Cathode: 2H^+ + 2e^- \rightarrow H_2, E^0 = 0.00V$ $Total: H_2O \rightarrow \frac{1}{2}O_2 + H_2, E^{0,total} = 1.23V$	$Anode: H_2 \rightarrow 2H^+ + 2e^-, E^0 = 0.00V$ $Cathode: 2H^+ + \frac{1}{2}O_2 + 2e^- \rightarrow H_2O, E^0 = -1.23V$ $Total: H_2 + \frac{1}{2}O_2 \rightarrow H_2O, E^{0,total} = -1.23V$
PEM Humidity Control	
$Anode: H_2O \rightarrow 2H^+ + \frac{1}{2}O_2 + 2e^-, E^0 = 1.23V$ $Cathode: 2H^+ + \frac{1}{2}O_2 + 2e^- \rightarrow H_2O, E^0 = -1.23V$ $Total: Moisture\ Transfer, E^{0,total} = 0.00V$	

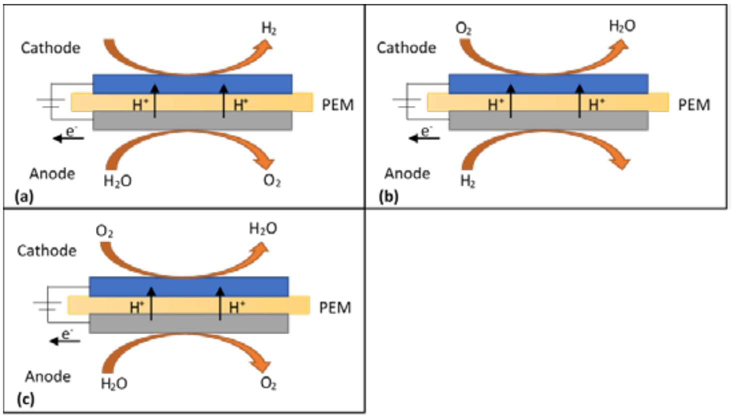

Fig. 2. Operation of (a) a PEMWE for hydrogen generation, (b) a PEMFC for power generation, and (c) a PEM humidity control system for oxygen removal

2. Testing and Results

Single cell MEAs were sandwiched between current collectors and housings to conduct performance testing. Several membranes were then tested to characterize the performance and determine feasibility of a water-vapor-based humidity control system. Testing was carried out in a 20 L container, while monitoring cell current, temperature, and humidity.

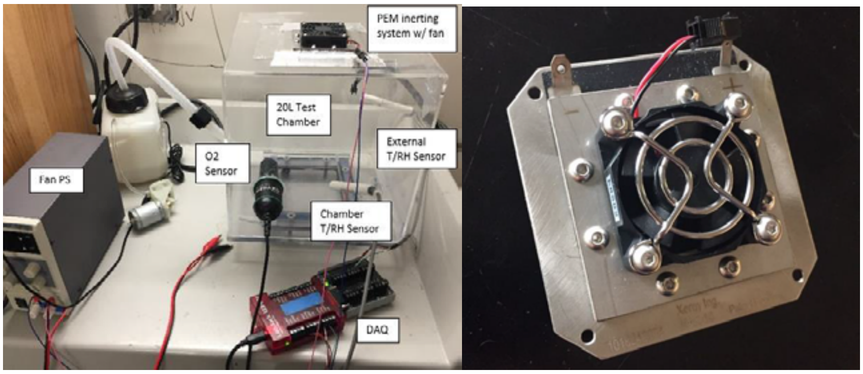

Fig. 3. Humidification testing set up (left); Sample commercial humidity control cell (right)

Membranes of various thicknesses were tested to determine the effect of thickness on moisture transfer rate. The test was terminated when the target relative humidity level, 15% RH, was reached. Membrane A was the thinnest membrane, while membrane C was the thickest membrane. As, as seen in Figure 4, membrane thickness increases the moisture transfer rate increase. However, the increase in thickness comes with an increase in cost, so it is essential to balance the two variables for a commercially viable moisture control system. Although membrane C reached the target relative humidity the fastest, its thickness left it cost prohibitively expensive and membrane B was selected for further testing and production.

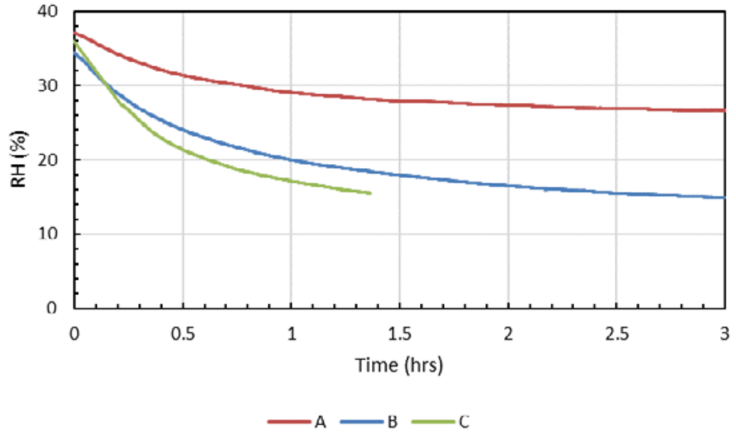

Fig. 4. Humidity control performance of membranes A, B, and C

A cell was run with and without a fan system to determine the improvement to the overall system (Figure 5) [2]. At the low external humidity conditions during testing, 30% RH at 18°C, the moisture transfer rate was 1.65 g/day and 8.5 g/day for the system without a fan and with a fan, respectively. Running solely on moisture available in the air makes this technology simple and compact but does limit the capacity to humidify and dehumidify. Improving the mass transfer of water molecules to the system has shown to improve rates by upwards of 5 times. Any increase in performance equates to a decrease in size, so the improved fan system allows for a 5 times reduction in size, leading to less catalyst and membrane, and makes the electrochemical humidity control system commercially viable.

A similar test was conducted for the humidification at low external humidity conditions, 22% RH at 18°C, and the moisture transfer rates were 1.2 g/day and 1.7 g/day for the system without a fan and with a fan, respectively. Note: at higher humidity conditions the membrane will exhibit a higher conductivity and the moisture transfer rate increases. The increase in humidification is less than that for dehumidification at these reduced moisture levels due to an overall decrease in membrane conductivity; the fan system only improves the performance by around 1.5 times.

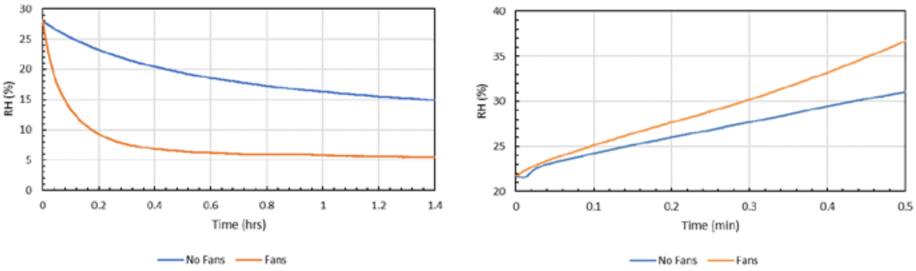

Fig. 5. Results of humidity test

After selecting the appropriate membrane thickness and fan system, the modules were tested in a fridge. Typically, temperature has a negative impact on chemical reactions, so it is essential to prove feasibility at the temperatures experienced in a fridge. As seen in Figure 6, the system was able to both humidify and dehumidify around the humidity level inside the fridge at temperatures between 8°C and -1°C.

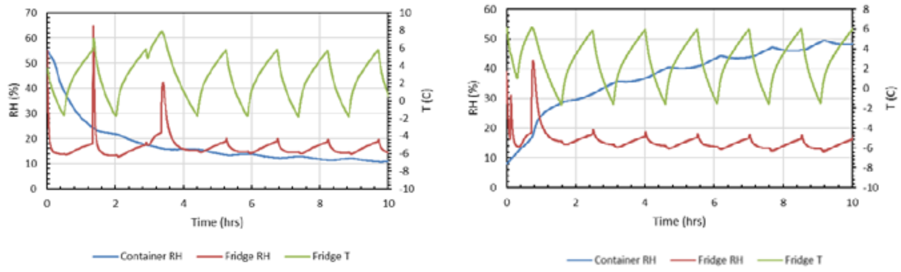

Fig. 6. Dehumidification (left) and humidification (right) testing in a refrigerator

3. Conclusions

Electrochemical cells have successfully been developed and demonstrated to provide both humidification and dehumidification, with the target of improving food preservation and aiding in refrigeration. Performance and cost targets have been met to make this product commercially viable for appliances and reduce the burden for heat pumps used in refrigeration. The proposed system is able to humidify a 35 L enclosure from 30% to 80% RH in less than 3 hrs or dehumidify the same enclosure from 80% to 30% RH in the same amount of time. There are many other applications for this technology including in controlling humidity in museum displays, and moisture/condensation sensitive optics and electronics applications.

4. Nomenclature

Table 2. Acronyms and abbreviations, defined

Term	Definition	Term	Definition
GDL	Gas Diffusion Layers	PEMFC	Proton Exchange Membrane Fuel Cell
MEA	Membrane Electrode Assembly	PEMWE	Proton Exchange Membrane Water Electrolyzer
PEM	Proton Exchange Membrane	RH	Relative Humidity

Acknowledgements

The technologies outlined in this paper are protected by US Patents referenced [2]. Certain aspects of this technology were originally developed under US DOE SBIR funding sponsored by the Building Technologies Office. This publication is a part of a 10-paper series to commemorate Xergy's 10-year anniversary, bringing advanced membrane technology to the global HVAC industry.

References

[1] Food and Agriculture Organization of the United Nations. "Key facts on food loss and waste you should know!" *Save Food: Global Initiative on Food Loss and Waste Reduction*. http://www.fao.org/save-food/resources/keyfindings/en/. Accessed 6 May 2019.

[2] US Patent Applications: 20190192806, 20190100844