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Longevity of Membrane for Energy Recovery Ventilation: Thermal, Humidity, and Oxygen Stability

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Abstract

The lack of data in the open literature on membrane lifetime, degradation mechanisms, longevity, and durability for polymeric membrane for energy recovery ventilation (ERV) systems has been identified as an area where research is required [1]. In this work, the effectiveness of several factors including heat, relative humidity (RH), and oxygen concentration on the longevity of commercial ERV membranes are evaluated. The degradation of the membranes over a lifetime of several years is simulated by accelerated degradation testing in pressurized vessels. Results show that the membrane failure time depends on both the conditions and the membrane material properties.

1. Introduction

Energy recovery ventilators (ERV) are mechanical air exchange systems that are used for building ventilation, heat and humidity control. An ERV system pre-cools and dehumidifies the air in warm and humid weather, while it pre-heats and humidifies the inlet air in cold and dry weather [2]. Although manufacturers have internal data about ERV longevity, there are few reports of ERV membrane lifetime and durability in the open literature [1]. For polyolefin-based membranes, the primary degradation mechanism occurs due to an oxidative process combining environmental stresses such as temperature, humidity, chemical pollutants, microbial and mechanical effects. The material failure time (MFT) can be calculated from the failure rate under accelerated conditions according to Arrhenius equation [3]. We considered MFT as a function of temperature, activation energy, pressure, humidity, and material properties using a modified version of Arrhenius equation:

$$MFT = A * exp\left[\frac{Ea}{RT} + \left(B + \frac{C}{T}\right) P * D\right] \tag{1}$$

where T is temperature (K), Ea is activation energy (kJ/mol) which is temperature dependent and varied with material, P is the air or O_2 pressure (psi) in the pressure vessel (Fig. 1), D is humidity effect, and R is the gas constant (8.314 J/K·mol), respectively. A, B, C, and D are material constants and expected to vary for different polymers, as well as from one antioxidant to another. In this study, effects of temperature and humidity at controlled pressure of 150 psi for a type of polymeric membrane have been monitored over time. Elongation of membranes (in %) and oxidation induction time (OIT) were measured for samples aged at different conditions to estimate their failure time. Elongation at break (%) is the ratio between increased length and initial length of a polymeric membrane specimen before it breaks ($Elongation\% = 100 \times (L_{break} - L_{initial})/L_{initial}$) at controlled temperature. Fitting Eq. 1 to the experimental failure data for the membranes, materials constants were calculated and membrane performance was evaluated. Accordingly, one would be able to select the material type and potential anti-oxidants for slowing down their oxidative degradation.

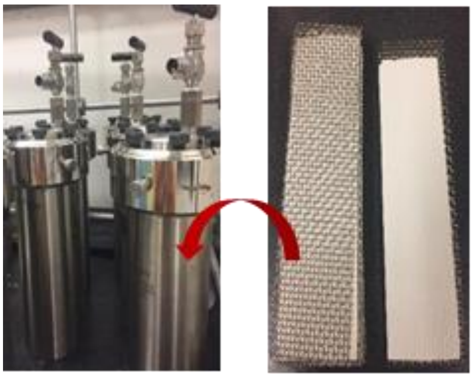

Fig. 1: Pressure vessels and membrane samples.

2. Experiments

The membrane tested in this study, Mx4, is a hydrophilic film coated on a hydrophobic PE-based substrate supplied by CORE Energy Solutions Inc. [4]. Two series of experiments were designed and performed with the purpose of estimating ERV membrane core life time. A set of 15 samples (5 cm x 18 cm, each), separated by stainless steel meshes, were placed inside a pressurized vessel at different conditions for up to 3,500 hours, see Fig. 1. The samples and test conditions are listed in Table 1.

Table 1: Membrane accelerated degradation test conditions.

Sample Series	Temperature (°C)	Pressure (psi)	Atmosphere	RH%
Series 1	115	150	air	0, 25, 50, 75, 100
Series 2	80, 105, 115	150	oxygen	100

2.2. Results and discussion

Figure 2 shows the trend in elongation at break (%) and degradation time (OIT) for samples heat treated in air with RH% from 0 to 100 (series 1). As shown in Fig. 2, the elongation % and initiation of oxidative degradation time decreases over testing time for all of the samples. Moreover, higher RH causes faster degradation for membranes at the same conditions.

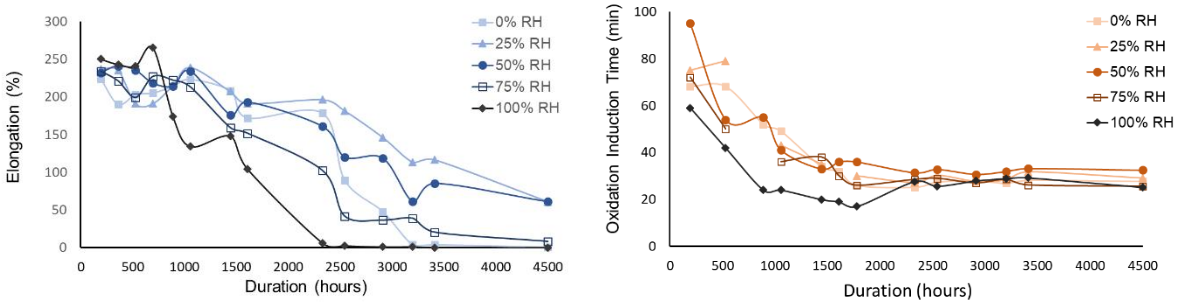

Fig. 2. Elongation at break (%) decrease for degrading membranes series 1 over time (left). Oxidative degradation time for membranes series 1 over time (right).

The effect of oxygen content on lifetime of the membranes series 1 and 2 at 115℃ and 100% RH is shown in Figure 3. From the elongation at break and OIT results we can conclude that the lifetime for the membranes in air is almost 10 times longer than the same membranes in oxygen.

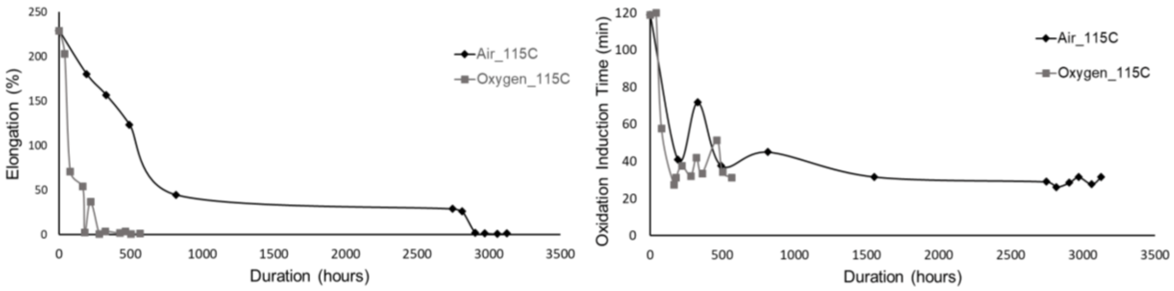

Fig. 3. Elongation at break (%) decrease for degrading membranes series 1 and 2 at 115℃ and 10% RH over time (left). Oxidative degradation time for membranes series 1 and 2 at 115℃ and 100% RH over time (right).

In another comparison, the effect of temperature on failure time of membranes series 2 is evaluated. Results are plotted as the failure times versus $1/Temperature$ (Figure 4). In summary, the failure time for both tensile test and oxidative degradation decreases at higher temperatures. As demonstrated in Fig. 4, failure time is almost a linear function of $1/T$.

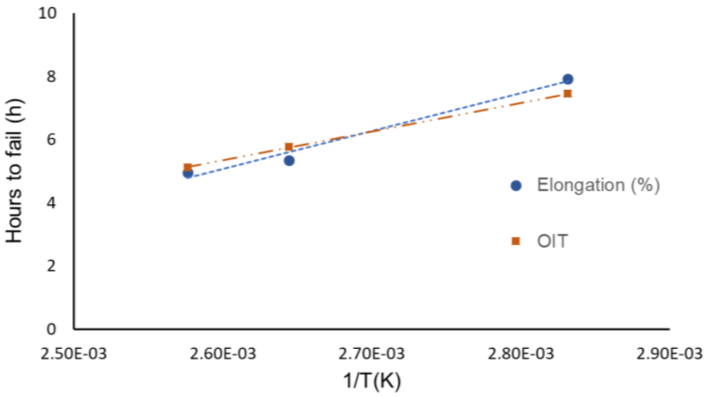

Fig. 4. Failure time for membranes series 2 versus $1/Temperature$

Conclusion

Calculating membrane lifetime under different conditions, we determined the effect of environmental conditions such as temperature, RH, and oxygen content on longevity of a membrane. The results of lifetime studies at accelerated conditions can be correlated to operational conditions to predict expected lifetime of the membrane and the ERV core performance in usage conditions according to ASHRAE standard 84 [5]. Lifetime results for both series 1 and 2 samples will be discussed in the full paper.

References

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