Overview of Membrane Exchangers

Executive Summary

Membrane exchangers, also called enthalpy cores, are used to recover sensible and latent energy between exhaust air and outside air. The most common air flow arrangement is a cross-flow exchanger where exhaust air and outside air flow cross each other as shown in Figure 1.

Figure 1. Airflow arrangement

 Layers of alternating cross-flow channels in a membrane
Alternating layers of membrane are arranged similar to metal fixed-plate heat exchangers. Smaller exchangers utilize corrugated membrane substrate (Figure 2) or fluted polymer (Figure 3) to add rigidity and space between the alternating membrane layers.

Larger exchangers utilize a metal substrate for rigidity and as a spacer between layers of membrane (Figure 4 and Figure 5).

Traditionally, membrane exchangers have been very limited in commercial applications due to maximum airflow available.

Membrane materials are selected to transfer water vapor and sensible heat. In addition, the material must be air tight to minimize leakage, biostatic (inhibit the growth or multiplication of organisms), and fire resistant (compliance with required UL flame and smoke tests).

Performance Characteristics of Membranes

Latent Performance

Membranes are designed to have high permeance - or a high ability to transmit water vapor. Membranes are air tight, and transmission of water vapor through the membrane is not accomplished through holes - it occurs at the molecular level. Membranes are either a film with a high affinity for water vapor, a media impregnated with a desiccant that has a high affinity for water vapor, or a combination of both. The transmission of water vapor through the membrane is driven by vapor pressure differential from one side of the membrane to the other. The materials used have a selectivity preference for water vapor over other gases. The use of these membranes result in water vapor being transmitted from the more humid air stream to the drier air stream, thus dehumidifying ventilation air in the summer.

The most common membrane materials used are polymers; these are used as both a film and a desiccant. These polymers will not deliquesce (dissolve and melt off) in the presence of liquid water. There are some membranes that use salts, such as Lithium Chloride. These salts will deliquesce in the presence of liquid water. This may require periodic recharging of the exchanger to replace the salts.
Membrane heat exchangers vary in their ability to transfer water vapor. Closer spacing of plates results in more membrane surface area and improved performance. Tight spacing is more practical for smaller exchangers; using tight spacing on large exchangers creates a large air pressure loss. For this reason smaller exchangers for residential applications (< 500CFM) often have higher latent effectiveness than larger exchangers.

- Small exchangers (20 in. x 20 in. and smaller) = 45 to 65 percent latent effectiveness
- Large exchangers (30 in. x 30 in. and larger) = 35 to 55 percent latent effectiveness

**Sensible Heat Transfer**

Membranes are thin, which enables sensible heat transfer to occur easily. The sensible heat exchanged can often match or exceed the performance of metal plate exchangers. Typical sensible heat exchangers have 55 to 70 percent effectiveness.

**Frost**

One of the benefits of membrane exchangers over plate exchangers is their ability to transfer water vapor while minimizing frosting concerns. Below 10°F, frosting may occur from over cooling the exhaust air stream. Frost avoidance methods include outside air face-and-bypass damper control or preheat. Exchangers with metal substrates are designed to withstand formation and thawing of frost. For these exchangers, the minimal amount of frosting time and performance may be acceptable. Frost prevention should be installed in regions that experience prolonged outside air temperatures below 10°F or in applications with elevated return air humidity levels, such as those where humidity is added in the winter.

**Pressure Limitations**

One of the possible disadvantages of membranes versus metal plates is the limitation on air pressure differential. Small membrane designs (Figure 2 and Figure 3) have a 2-in. - 4-in. w.g. maximum pressure differential, while the larger membranes (Figure 4 and Figure 5) can withstand up to 10 in. w.g., although recommended maximum operating pressures are limited to 5 in. w.g. The pressure differential across the exchangers will vary greatly based on size and manufacturer. Typical loss is 0.6 - 1.2 in. w.g. per pass.

**Packaging of Commercial Exchangers**

Membrane exchangers are nominally sized to meet a target face velocity of 300 fpm. To create large exchangers, the spacing on the membranes and flow channels needs to increase, resulting in an acceptable pressure loss. However, this increase in spacing quickly diminishes the latent and sensible recovery. Creating wider spacing between membrane layers also requires spacers to structurally hold the plates. This limits the construction of most membrane exchangers to 20 - 30 square inches. These small exchangers are packaged several ways to overcome the size limits.

**Packaging of Small Exchangers**

Some exchanger designs do not support wider plate spacing (Figure 2 and Figure 3). In order to overcome the inability to scale exchangers to be used at greater airflows, multiple 200 to 400 cfm-sized exchangers are arranged in banks. Numerous block-offs and transitions are required. These transitions and block-offs result in pressure losses of 1 - 1.5 in. w.g. per pass. This loss is in addition to the loss associated with actual exchangers. Using block-offs requires transitional space to allow for full airflow through the exchanger. This transitional space results in an increase in overall equipment footprint.

**Packaging of Larger Exchangers**

Exchangers with metal substrate are scalable in two ways:
- Size (height and width)
- Plate spacing

The overall exchanger size is limited to 30 inches or less, however the plate spacing can be widened - four-wide space exchangers can be assembled as one, i.e., four 20-inch wide space exchangers can be assembled to create one 40-inch exchanger.

This assembly will have a higher pressure loss versus a single, smaller exchanger, but overall has a much lower pressure loss than other designs that use block-offs and transitions. This design eliminates the need for transition space as there is no block-off of the face area.
Executive Summary

- Single exchanger design without need of block-off and transitions.
- Multiple exchanger array increases pressure loss 50 percent vs. single exchanger.
- Latent and sensible heat exchange is reduced by wider plate spacing.

Trane Patent-Pending Sensible Assisted Membrane Option

Trane Sensible Assisted Membrane (SAM™) option is a method of applying membrane exchangers. It allows for larger air flows needed for commercial applications, and at the same time, provides improved performance versus traditional designs. Optimal-spaced membrane layers are used versus wide-spaced membrane layers required for alternative designs. In lieu of using block-offs and transitions to direct air into the membrane exchangers, sensible plate exchangers are used with SAM.

Sensible plate exchangers assist the membrane exchangers and provide multiple benefits versus using block-offs and transitions. Plate exchangers direct air into the membrane exchangers, act like flow straighteners, and do not block face area or drastically increase air pressure loss.

Sensible plates add 0.1 - 0.15 in. w.g. air pressure loss versus 1.0 - 1.5 in. w.g. that transitions and block-offs typically add.

An additional benefit of eliminating transitions and block-offs is a reduction in equipment footprint. Incorporating SAM into an air handler requires no additional up-and-downstream distance.

Pre-cooling Benefits of SAM

Using sensible plates increases the overall sensible effectiveness; a five percent increase over membranes alone is typical. Sensible plates also increase the latent performance of the membrane exchangers.

- Five percent increase of sensible effectiveness
- One to five percent increase of latent effectiveness

Figure 7. Commercial packaging for larger exchangers

Figure 8. No additional distance needed for SAM

Figure 9. Pre-cooling

The sensible exchanger pre-cools the outside air during the summer which raises the relative humidity of the outside air prior to it passing through the membrane exchanger. This boosts the performance of the membrane exchanger as it holds more water vapor at a higher relative humidity.

The vapor pressure differential between airstreams drives the moisture transfer between airstreams. However, the more saturated the membrane is with water vapor, the more the transfer rate (permeability) of the exchanger increases. The pre-cooling effect enables sensible heat exchangers not only to increase the sensible energy exchange, but to also increase latent effectiveness one to six percent, depending on conditions.

The configuration of exchangers allows for pre-cooling when the sensible plates are upstream of the membrane exchanger. The sensible plates downstream of the
membrane exchanger simply provide additional sensible energy recovery. Notice, the alternating sensible plate and membrane exchangers is required for equalization of air pressure loss on the exhaust air path.

The SAM configuration of exchangers also increases the scale at which membranes can be used. The SAM exchanger can be used at airflows higher than 10,000 cfm, (see Figure 9) where most other methods of are not practical above 10,000 cfm. For the medium airflow ranges 2500 to 10,000 cfm, SAM will have higher sensible effectiveness and lower air pressure loss than a single membrane exchanger configuration.

**Example of SAM Application**

In the example, a dedicated outside air handler was evaluated with a membrane exchanger and also with SAM.

- Airflow: 3700 cfm nominal
- Exchanger size: 40-in. x 40-in.
- Face velocity: 300 fpm nominal

**Table 1. Membrane comparisons**

<table>
<thead>
<tr>
<th></th>
<th>Sensible Effectiveness</th>
<th>Latent Effectiveness</th>
<th>Pressure loss - in. w.g. (per path)</th>
</tr>
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<tbody>
<tr>
<td>Membrane only</td>
<td>69.4</td>
<td>37-51</td>
<td>0.62</td>
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<tr>
<td>SAM</td>
<td>74.9</td>
<td>38-58</td>
<td>0.77</td>
</tr>
</tbody>
</table>

**Figure 10. SAM can be used with higher air flows**

![Diagram showing different exchanger configurations](image)

**Figure 11. Exchanger with unit walls removed**

![Exchanger with unit walls removed](image)

**Figure 12. Rooftop unit in place**

![Rooftop unit in place](image)
Executive Summary

Sensible Assistance: Increase in Sensible Effectiveness

The results of the study are summarized below.

- Membrane exchanger sensible effectiveness matches the supplier-stated sensible effectiveness
- SAM predicted sensible effectiveness correlates with model predictions
- SAM enhanced sensible performance is four to five points higher than membrane exchanger without sensible assistance
- SAM sensible effectiveness is 70 to 75 percent

Figure 13. Increase in sensible effectiveness
Sensible Assistance: Increase in Latent Effectiveness

The results of the study are summarized below.

- Membrane exchanger only latent effectiveness two points higher than stated in supplier data.
- SAM increased latent effectiveness one to six points (a three to 10 percent increase in water vapor transfer rate)

**Pressure Drop:** At nominal air flow, pressure loss was recorded at 0.77 in. w.g., which correlates with model predictions.

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**Conclusion**

Membrane exchangers can greatly reduce the amount of energy (mechanical cooling and heating) required. There are multiple drawbacks to traditional designs that have inhibited their use in commercial applications. Trane SAM eliminates the disadvantages of traditional designs.

**Figure 15** shows a data log of July 21-28, 2016 for the example air handler with SAM™ in operation.

Temperatures exceeded 100°F and humidity levels were as high as 148 gr/lb (78°F dpt). As shown, the ventilation air prior to mechanical cooling was reduced below 77°F, and humidity levels below 98 gr/lbm (67°F dpt). The total cooling energy recovered (enthalpy difference recovered) exceeded 60 percent.
Figure 15. Summer cooling log