Development of Operating Envelope Limits for Equipment Tested in a Wind Tunnel

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Background

- Test heat exchangers over a wide range of conditions.
- Specific heat exchanger testing.
- Plan to construct a wind tunnel in ATRC @ OSU.
- Extension to our existing psychrometric rooms facility.
- Design specification of wind tunnel facility:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>-40°C to 60°C</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>20-90%</td>
</tr>
<tr>
<td>Maximum cooling capacity of the tested equipment</td>
<td>35 kW (10 tons @ -40°C)</td>
</tr>
<tr>
<td>Maximum air flow rate</td>
<td>425 m³/min (15,000 CFM)</td>
</tr>
<tr>
<td>Dimensions</td>
<td>14.6 m × 2.3 m × 4.9 m high</td>
</tr>
</tbody>
</table>
Wind Tunnel Schematic
Conditioning Bay Configurations

A direct expansion evaporator and a condensing unit

A secondary loop system with cooling coil and chiller
Wind Tunnel Description

- Conditioning bay consists of:
  - Cooling coil or evaporator,
  - Heating elements,
  - Steam injection system.

- Equipment capacity tested is limited by conditioning bay capacity.

- Capacities of different conditioning bay components are:

<table>
<thead>
<tr>
<th>Component</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporator (or cooling coil)</td>
<td>35 kW (10 tons) @ -40°C</td>
</tr>
<tr>
<td>@ air outlet</td>
<td></td>
</tr>
<tr>
<td>Heating element</td>
<td>80 kW</td>
</tr>
<tr>
<td>Steam injection system</td>
<td>40 kg/hr of saturated steam @ 620 kPa</td>
</tr>
</tbody>
</table>
Conditioning Bay Chiller Model:

- (ACHP) model developed by Bell (2010) is used.
- Main components of conditioning bay chiller are:
  - Evaporator,
  - Condenser,
  - Compressor,
  - Expansion valve.
- Evaporator and condenser modeled as fin and tube heat exchangers.
- AHRI 540 standard for the compressor map (Bitzer-4TES9y).
Compressor Operating Envelope

- Saturated suction temperature, $T_e$ of $-50$ to $-55^\circ C$ is desired.
- Typically compressors don’t operate at $T_e=-55^\circ C$ & $T_c=60^\circ C$.
- Cascade system can overcome the issue.
Capacity Control

- Higher compressor power consumption with increase in Te.
- Limited cooling water and electricity supply.
- A system with multiple compressor in parallel can be used or
- Systems with different capacities can be used in parallel.

35 kW cooling capacity at -38 °C $T_e$
Testing in Wind Tunnel

- Heat transfer with the surroundings:
  - Air in tunnel exchanges heat with the surroundings through walls.
  - Wind tunnel as a rectangular box.
  - Simple thermodynamic and heat transfer laws mentioned by Holman (1997) are used.
  - Surroundings temperature ~25°C.
  - Nusselt number computed using fundamental heat transfer correlations.

Simplified wind tunnel geometry

Heat transfer as a function of wind tunnel temperature @15,000 CFM
Testing in Wind Tunnel

- Procedure to test capacity limit of equipment tested inside the tunnel.
- Compare required versus available capacity for each component.
Evaporator (or Cooling Coil) Testing

- Maximum capacity of cooling coil is a function of:
  - Air inlet temperature
  - Inlet relative humidity
  - Sensible heat ratio (SHR).

- Heat balance is used in tunnel to calculate air conditions.
- For 0°C temperature line, there is a cut off at SHR<0.6.
- There is cut off of both temperature lines at SHR>0.8

Heat addition by heaters and humidifier for air with an RH of 60%

Cooling coil with a SHR of 0.5
Evaporator (or Cooling Coil) Testing

- The maximum capacity is limited by capacity of heating elements and humidifier.
- For a cooling coil of capacity 10 tons, the bay capacity limit is reached.
- Heaters have excess capacity, the humidifier capacity becomes the actual limitation.

Impossible process with SHR=0.5

Undesirable cooling process with SHR=0.9
Condenser (or Heating Coil) Testing

- Analysis remains the same as for cooling coil test section.
- SHR of the test section is always 1.
- Cooling equipment is required.
- Heating coil of 10 tons capacity can be tested.
Conclusion:

- A procedure to investigate the operating envelope limits for tested components inside the wind tunnel is explained.
- Cooling coil and heating coil with a capacity of 10 tons or lower can be tested.
- Steam humidification limits the minimum possible SHR for cooling coil.
References:


Thank you for your attention!

Questions?