Investigation of Rotary Compressor Heat Dissipation Model

Da SHI, Hong TAO, Min YANG
Shanghai Hitachi Electrical Application Co., Ltd
Email: yangm1@shec.com.cn
OUTLINE

1. BACKGROUND
2. COMPRESSOR MODEL
3. UNCERTAINTY ANALYSIS
4. HEAT DISSIPATION MODEL
5. COMPARISON RESULT
6. CONCLUSION
Traditional method

Adiabatic model $\rightarrow$ Discharge temperature $T_d$

Test $\rightarrow$ measured temperature $T_{dm}$

$T_d > T_{dm}$
COMPRESSOR MODEL

Conservation of Mass:
\[ m_{out} = m_{in} (= m_{comp}) \]

Conservation of Energy:
\[ m_{in} h_{in} + P_{comp} - m_{out} h_{out} - \Phi_{comp} = 0 \]

\[ h = f(p, T) \]
OUTLINE

1. BACKGROUND
2. COMPRESSOR MODEL
3. UNCERTAINTY ANALYSIS
4. HEAT DISSIPATION MODEL
5. COMPARISON RESULT
6. CONCLUSION
**UNCERTAINTY ANALYSIS**

1HP constant speed rotary compressor

**Condition:** $T_e=7.2^\circ C$, $T_c=54.4^\circ C$, $T_s=18.3^\circ C$, $T_d=97.2^\circ C$

**Mass Flow:** $m=63.4$ kg/h, **Input Power:** $P=936$ W

<table>
<thead>
<tr>
<th>Variable</th>
<th>± Uncertainty</th>
<th>% of uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>heat dissipation/W</td>
<td>$\Phi=163.5 \pm 4.56$</td>
<td></td>
</tr>
<tr>
<td>input power/W</td>
<td>$P=936 \pm 0.936$</td>
<td>4.21%</td>
</tr>
<tr>
<td>discharge pressure/KPa</td>
<td>$P_d=2147 \pm 5.368$</td>
<td>5.56%</td>
</tr>
<tr>
<td>suction pressure/KPa</td>
<td>$P_s=625 \pm 1.563$</td>
<td>1.29%</td>
</tr>
<tr>
<td>discharge temp./°C</td>
<td>$T_d=97.2 \pm 0.2$</td>
<td>48.49%</td>
</tr>
<tr>
<td>suction temp./°C</td>
<td>$T_s=18.3 \pm 0.2$</td>
<td>33.99%</td>
</tr>
<tr>
<td>mass flow kg/h</td>
<td>$m=63.4 \pm 0.095$</td>
<td>6.46%</td>
</tr>
</tbody>
</table>

There is 4.56 W uncertainty of heat dissipation, about 2.8% of the whole dissipation. The discharge temperature makes the biggest contribution.
UNCERTAINTY ANALYSIS

1.5HP variable speed rotary compressor

**Condition:**  
Te=17.8°C,  
Tc=40.6 °C,  
Ts=19.7 °C,  
Td=53.5 °C

**Mass Flow:** m=56kg/h,  
**Input Power:** P=318.5W

<table>
<thead>
<tr>
<th>Variable</th>
<th>± Uncertainty</th>
<th>% of Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>heat dissipation/W</td>
<td>Φ=28.52 ± 6.66</td>
<td></td>
</tr>
<tr>
<td>input power/W</td>
<td>P=318.55 ± 0.3185</td>
<td>0.23%</td>
</tr>
<tr>
<td>discharge pressure/KPa</td>
<td>Pd=2445 ± 6.113</td>
<td>10.37%</td>
</tr>
<tr>
<td>suction pressure/KPa</td>
<td>Ps=1352 ± 3.38</td>
<td>5.53%</td>
</tr>
<tr>
<td>discharge temp./°C</td>
<td>Td=53.5 ± 0.2</td>
<td>46.35%</td>
</tr>
<tr>
<td>suction temp./°C</td>
<td>Ts=19.7 ± 0.2</td>
<td>37.10%</td>
</tr>
<tr>
<td>mass flow kg/h</td>
<td>m=56 ± 0.084</td>
<td>0.43%</td>
</tr>
</tbody>
</table>

There is 6.66W uncertainty of heat dissipation, about 23% of the whole dissipation. The discharge temperature makes the biggest contribution.
HEAT DISSIPATION MODEL

① heat transfer from the refrigerant to shell wall inside;

② heat transfer from shell wall inside to shell wall outside;

③ heat transfer from shell wall outside to ambient air.

Heat flow $\Phi$ of each stage should be the same due to the steady state process.
The heat transfer coefficient $k$ can be expressed:

$$\frac{1}{k} = \frac{1}{h_{ref}} + \frac{\delta}{\lambda} + \frac{1}{h_{amb}}$$

In the heat dispersion model, the air-side heat transfer includes convective heat transfer and heat radiation:

$$\Phi = \Phi_c + \Phi_r$$
Convective heat transfer

Convective heat transfer can be described as following:

\[ \Phi_c = h \cdot A \cdot (T_d - T_{amb}) \]

Heat transfer coefficient can be calculated as following:

\[ h = Nu \times \frac{\lambda}{d} \]
Forced convective heat transfer

The forced convection is described:

\[ Nu = C \, Re^n \, Pr^{1/3} \]

Pr is the Prandtl number, Renault number is listed:

\[ Re = \frac{ud}{\nu} \]

Re is about 10,000 \quad C=0.193, \quad n=0.618
Natural convective heat transfer

The empirical correlation of natural convection is shown as following:

\[ Nu_m = C(GrPr)_m^n \]

Here, Gr is the Grashof number. \( C = 0.59 \), \( n = 0.25 \).
Heat radiation

Environment is assumed as the black body, and the compressor is a gray body emissivity $\varepsilon$ and absorptivity $\alpha$ ratio of paint is 0.95. The actual heat radiation is shown:

$$\Phi_r = A(E_1 - E_2)$$

$E_1$ is heat radiation from compressor to environment:

$$E_1 = \varepsilon \cdot \sigma T_d^4$$

$E_2$ is heat radiation from environment to compressor:

$$E_2 = \alpha \cdot \sigma T_{amb}^4$$

$\sigma = 5.67 \times 10^{-8}$
\( m_{\text{comp}} = f_m(T_e, T) \)

\( P_{\text{comp}} = f_p(T_e, T) \)

\( P_{\text{comp}} \) is the pressure of the \( \text{comp} \) component.

\( \Phi = f_{\Phi}(T_d, T_{\text{amb}}) \)

\( h = f(p, T) \)

\( m_{\text{in}} h_{\text{in}} + P_{\text{comp}} - m_{\text{out}} h_{\text{out}} - \Phi_{\text{comp}} = 0 \)
### COMPARISON RESULT

**1.5HP constant speed rotary compressor data in forced-convection**

<table>
<thead>
<tr>
<th>Te(°C)</th>
<th>Tc(°C)</th>
<th>Measured discharge temp (°C)</th>
<th>Model discharge temp (°C)</th>
<th>Adiabatic discharge temp (°C)</th>
<th>Radiation (W)</th>
<th>Forced-convection heat transfer(W)</th>
<th>Model heat dissipati on(W)</th>
<th>Measured heat dissipati on(W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.4</td>
<td>65</td>
<td>113</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>201</td>
</tr>
<tr>
<td>7.2</td>
<td>54.4</td>
<td>97</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>163</td>
</tr>
<tr>
<td>-0.4</td>
<td>40</td>
<td>83</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>110</td>
</tr>
<tr>
<td>-4</td>
<td>30</td>
<td>73</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>84</td>
</tr>
<tr>
<td>1.5</td>
<td>40</td>
<td>81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>106</td>
</tr>
<tr>
<td>7.2</td>
<td>45</td>
<td>83</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>112</td>
</tr>
<tr>
<td>10</td>
<td>45</td>
<td>81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>106</td>
</tr>
<tr>
<td>1.5</td>
<td>30</td>
<td>68</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>10</td>
<td>40</td>
<td>74</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>87</td>
</tr>
<tr>
<td>10</td>
<td>30</td>
<td>60.8</td>
<td>60.8</td>
<td>64.2</td>
<td>20</td>
<td>38</td>
<td>58</td>
<td>58</td>
</tr>
</tbody>
</table>
COMPARISON RESULT

- Comparison in discharge temperature and heat dissipation of 1.5HP constant speed compressor in forced-convection.
Comparison in discharge temperature and heat dissipation of 1.5HP variable speed compressor in forced-convection.
## COMPARISON RESULT

1.5HP constant speed rotary compressor data in natural-convection

<table>
<thead>
<tr>
<th>Te(°C)</th>
<th>Tc(°C)</th>
<th>Measured discharge temp (°C)</th>
<th>Model discharge temp (°C)</th>
<th>Adiabatic discharge temp (°C)</th>
<th>Radiation (W)</th>
<th>Natural-convection heat transfer (W)</th>
<th>Model heat dissipation (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.4</td>
<td>65</td>
<td>113.1</td>
<td>116.7</td>
<td>124.9</td>
<td>83</td>
<td>56</td>
<td>139</td>
</tr>
<tr>
<td>7.2</td>
<td>54.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.4</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-4</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.2</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>30</td>
<td>68.4</td>
<td>70.2</td>
<td>74</td>
<td>29</td>
<td>19</td>
<td>48</td>
</tr>
<tr>
<td>10</td>
<td>40</td>
<td>74.4</td>
<td>76.1</td>
<td>79.5</td>
<td>35</td>
<td>23</td>
<td>58</td>
</tr>
<tr>
<td>10</td>
<td>30</td>
<td>60.8</td>
<td>62.2</td>
<td>64.2</td>
<td>21</td>
<td>13</td>
<td>35</td>
</tr>
</tbody>
</table>
OUTLINE

1. BACKGROUND
2. COMPRESSOR MODEL
3. UNCERTAINTY ANALYSIS
4. HEAT DISSIPATION MODEL
5. COMPARISON RESULT
6. CONCLUSION
CONCLUSION

• Heat dissipation model
  
  forced-convection
  natural-convection
  heat radiation

• The discharge temperature model deflection is less than 4 °C, the average heat dissipating error is below 15%,

• Calculate an accurate value for discharge temperature
THE END

THANKS!