Investigation on hydrodynamic parameters of regenerator of a miniature Stirling cryocooler

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Abstract

The performance of a Stirling cooler depends on the optimization of its regenerator. The regenerator can be modelled using CFD to study their performance under steady and steady-periodic flow conditions. But the results depend on the accuracy of the hydrodynamic and heat transfer parameters given as the closure relations. In this study, a CFD assisted methodology was used to obtain the directional permeability and Forchheimer coefficient for 325 and 400 mesh SS wire screen regenerators from the published experimental data. The permeability and Forchheimer coefficient obtained from experimental data are correlated to a dimensionless friction factor and compared with the friction factor obtained from the correlations proposed by Gedeon et al., Tong et al., Blass, Miyabe, and Tanaka. The correlation given by Blass is very much in agreement with the experimental data and using this correlation, friction factor was calculated for #200, #250, #300, and #450 wire matrix and the viscous resistance term D and the inertial resistance term C are iteratively adjusted to get the same friction factor. These are used as the closure relations in the CFD analysis using FLUENT to get the pressure drop across commonly used regenerator filler materials for a given set of mass flow rate and pressure at outlet.

Analysis

The friction factor of a porous media can be correlated in terms of Reynolds number as [1],

\[ f = \frac{2 \kappa}{\kappa_{Re}} + 2 \kappa_{Re} \]

where the Reynolds number is defined as,

\[ Re = \frac{\rho u D}{\mu} \]

The Forchheimer inertial coefficient is given by,

\[ \kappa_{Re} = \frac{C_{Re}}{2} \]

The pressure drop in the matrix is caused by form drag and skin friction. Their effects on the equation for friction factor can be shown as [2],

\[ f = C_{s} + C_{i} \frac{Re}{Re_{c}} \]

The different correlation constants available in literature are summarized in Table 1.

<table>
<thead>
<tr>
<th>Correlation</th>
<th>C_{s}</th>
<th>C_{i}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gedeon/Wood</td>
<td>68.556</td>
<td>0.5274</td>
</tr>
<tr>
<td>Tong/London</td>
<td>44.71</td>
<td>0.3243</td>
</tr>
<tr>
<td>Blass</td>
<td>47.245</td>
<td>0.4892</td>
</tr>
<tr>
<td>Miyabe</td>
<td>33.603</td>
<td>0.337</td>
</tr>
<tr>
<td>Tanaka</td>
<td>40.7413</td>
<td>0.5315</td>
</tr>
</tbody>
</table>

Table 1. Correlation constants in the friction factor correlation [2]

From the experimental pressure drop, the inertial resistance coefficient C and the Viscous resistance coefficient D are obtained using a CFD assisted methodology [1] for 325 mesh and 400 mesh SS wire screen regenerators and the friction factor is expressed in terms of C and D. Friction factor was evaluated for different standard correlations and the correlation which is in best agreement with the correlation obtained from the experimental pressure drop was selected. The closure parameters C and D required for FLUENT analysis were obtained for #200, #250, #300 and #450 wire mesh SS regenerators for a given set of mass flow rate and pressure at outlet.

Materials and properties

<table>
<thead>
<tr>
<th>Matrix Type</th>
<th>Length [mm]</th>
<th>Diameter [mm]</th>
<th>Wire diameter [µm]</th>
<th>Porosity, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>325 mesh SS screen</td>
<td>38.1/7.94</td>
<td>42.0</td>
<td>69.69</td>
<td></td>
</tr>
<tr>
<td>400 mesh SS screen</td>
<td>38.1/7.94</td>
<td>36.96</td>
<td>69.69</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Characteristics of porous structures used for experimental study [1]

Results

Figure 1. Friction factor for 325 mesh SS screen regenerator.

Figure 2. Friction factor for 400 mesh SS screen regenerator.

Figure 3. Static pressure contours in a 300 mesh regenerator (m = 1.44 g/s)

Figure 4. Pressure drop across 325 mesh SS regenerator.

Figure 5. Pressure drop across 450 mesh SS regenerator.

Figure 6. Pressure drop obtained by simulation for selected regenerator matrix.

Conclusions

- Among the various correlations considered, correlation by Blass is in good agreement with the friction factor obtained from CFD assisted methodology [1].
- From the friction factor obtained from Blass correlation, the viscous resistance D and inertial resistance C were calculated for 325 and 400 meshes.
- The pressure drop obtained from CFD simulation using the above hydrodynamic parameters were in good agreement with the experimental data.
- From the Blass correlation, the hydrodynamic closure relations were calculated for other standard meshes and pressure drop across the regenerator was obtained using FLUENT.
- From this friction factor, the inertial and viscous resistance can be obtained iteratively and can be used as input parameters in FLUENT analysis.
- The proposed method is helpful to predict the hydrodynamic parameters of filler materials used in the cryogenic regenerator.

References