Development of Correlations for Thermophysical Properties of Supercritical Hydrogen in High Temperature Superconducting (HTS) Generators

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Abstract

The storage and generation of power has been a main objective over the past decade. To accomplish such an objective, superconductors are introduced in 1976, which observed a salient growth in power generation systems. However, electrical losses such as AC losses and thermal losses due to conduction, convection and radiation in these superconductors are invariable. In order to overcome and reduce these losses, use of cryogenic fluids above their critical temperature is necessary. One such fluid being studied in this work is supercritical hydrogen (SCH). Various thermophysical properties such as density, viscosity, thermal conductivity and specific heat of SCH were studied. The results reveal that with the rise in temperature and pressure, the change in thermophysical properties of SCH. Besides, few correlations have been developed for the same at various pressures and temperatures. The developed correlations are elaborated such that, the use of supercritical hydrogen (SCH) may be explored in the HTS generator for improving its performance. Due to the dynamic nature of HTS generators, unlike HTS cables, the cooling system should be able to provide and maintain monitoring.

The work reported here uncovers the thermophysical properties of supercritical hydrogen (SCH) to be utilized in HTS generators.

Due to the reduced size, weight and higher power system stability HTS generators were preferred over conventional generators.

Prior developing long life of HTS generators, SCH with desirable properties are being considered and subjected to further scrutiny for replacing conventional coolants.

Though there have been significant research work carried out in the field of supercritical fluids, the concentration on SCH is minimal.

Introduction

The simple single phase correlations such as Ditto-Boelter-Neilson correlation and Greinelli correlation cannot accurately capture the heat transfer behaviour in the near critical temperature region because it is sensitive to the variations of the thermophysical properties.

The four properties which are taken into consideration in this work are: Density, Thermal conductivity, Viscosity, Specific heat.

Figure 1 shows the thermophysical properties of SCH as a function of temperature at varying pressure. At constant pressures, Cp values decrease as temperature increases.

However, as the pressure increases corresponding values of specific heat increases. The Cp lines at different pressures shown in Figure 1 are identical with respect to temperature.

On the contrary, there is a sudden fall in thermal conductivity followed by gradual increase in temperature. Figure 2 draws the conclusion of inferior flow with compact heat absorption with respect to thermal conductivity. An overview of the density graph shows a decrease in the value of density with the increase in temperature. A sudden change in the density value is observed above the critical temperature Tc, in the case of viscosity, the value of viscosity tends to fall at first, however gradually increases with increase in temperature. The paths carried out by viscosity at various pressures are identical with smaller deviations. That slight value in the fitted is errors and are calculated. The plunge in viscosity proves improved flow rate of SCH. Furthermore, the temperature range taken into consideration while plotting the graph is from 33.10K - 33.195K.

Table 1

<table>
<thead>
<tr>
<th>Properties</th>
<th>Temperature Range</th>
<th>Correlation and Correlation Coefficients</th>
<th>Adj. R-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (1/2) (kg/m2)</td>
<td>33.10 K ≤ T ≤ 33.195K</td>
<td>μ = (1/2) (T) exp(1/2)</td>
<td>0.9966</td>
</tr>
<tr>
<td>Viscosity (μm/s)</td>
<td>58.10 K ≤ T ≤ 63.195K</td>
<td>C = 10(μm/s) = (T) exp(10)</td>
<td>0.9786</td>
</tr>
<tr>
<td>Specific heat (Cp)</td>
<td>33.10 K ≤ T ≤ 33.195K</td>
<td>μ = 1.00(μm/s) = (T) exp(1.00)</td>
<td>0.9951</td>
</tr>
<tr>
<td>Thermal conductivity (κ)</td>
<td>33.10 K ≤ T ≤ 33.195K</td>
<td>μ = (μ(μm/s) = (T) exp(μ(μm/s))</td>
<td>0.9905</td>
</tr>
</tbody>
</table>

To establish the accuracy of fitted model, statistical parameters such as Arithmetic Average of the Absolute Values of the Relative Errors (AARE %) and Sum of Absolute of Residual (SAR) have been utilized. Small values of these parameters refer to reliable correlation. The Arithmetic Average of the Absolute Values of the Relative Errors (AARE %) is defined in Eq. (1),

\[ AARE\% = \frac{100}{N} \sum_{i=1}^{N} \frac{|X_{exp} - X_{cal}|}{X_{exp}} \]  

Another such parameter is the Sum of Absolute of Residual (SAR) which is defined in Eq. (2), which put forth the reliability of correlation for more intense data points.

\[ SAR = \sum_{i=1}^{N} |X_{exp} - X_{cal}| \]  

Figure 2 shows Percent Relative Error (RE %) which is defined in Eq. [4] for each thermophysical properties as a function of temperature and pressure.

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Figure 2 shows Percent Relative Error (RE %) which is defined in Eq. [4] for each thermophysical properties as a function of temperature and pressure.

Table 2

<table>
<thead>
<tr>
<th>Property</th>
<th>AARE %</th>
<th>RE %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>0.296</td>
<td>0.75723</td>
</tr>
<tr>
<td>Viscosity</td>
<td>0.296</td>
<td>0.75723</td>
</tr>
<tr>
<td>Specific heat</td>
<td>0.296</td>
<td>0.75723</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>0.296</td>
<td>0.75723</td>
</tr>
</tbody>
</table>

Figure 2: RE% of correlations as function of temperature

The AARE%, ARES and SAR values of the correlation developed for SCH in comparison with the NIST values of every thermophysical properties is revealed in Table 2.

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References

Table 1: Correlations for thermophysical properties of SCH for various temperature range at Pc=1.315MPa.