Diffuser performance of centrifugal compressor in supercritical CO$_2$ power systems

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Layout

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• Literature review
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Background

• energy and industry-related emissions are predicted to be more than double by 2050 compared to 1990 levels [1],
• CO₂ is a high density working fluid and is CO₂ is a low-cost, non-flammable and non-toxic [2],
• sCO₂ systems were originally conceived for nuclear and concentrated solar power generation applications [3, 4]
Review (experiment)

Tokyo Institute of Technology, 2012 [5]

Review (modelling)

Baltadjiev, Lettieri and Spakovszky, 2015 [7]  
Behafarid, Podowski, 2016 [8]  
Pecnik, Rinaldi and Colonna, 2012 [9]
Real gas effect on one-dimensional flow

\[
\frac{d}{dx} (\rho u A) = 0 \quad \text{and} \quad u du + \frac{1}{\rho} dp = -dw_{shaft}
\]

\[
\frac{dM^2}{M^2} = -2 \left[ \frac{1 + (\Gamma - 1)M^2}{(1 - M^2)} \right] \frac{dA}{A} + \left[ \frac{1}{(1 - M^2)} \frac{1}{u} \left( \frac{\partial v}{\partial T} \right)_p \frac{\Gamma}{(\Gamma - 1)} \right] \frac{dw_{shaft}}{C_p}
\]

\[
\frac{1}{A} \frac{dA}{dx} \rightarrow \frac{1}{2(\Gamma - 1)} \frac{1}{v} \left( \frac{dv}{dT} \right)_p \frac{dw_{shaft}}{C_p dx}, \quad M \rightarrow 1
\]

\[
\Gamma = 1 + \frac{\rho}{C} \left( \frac{\partial C}{\partial \rho} \right) = \frac{1}{2} \rho^3 C^4 \left( \frac{\partial^2 v}{\partial P^2} \right) = \frac{v}{2C^2} \left( \frac{\partial^2 P}{\partial v^2} \right) \quad \text{and} \quad C^2 = \left( \frac{\partial P}{\partial \rho} \right)_s = -v^2 \left( \frac{\partial P}{\partial v} \right)_s > 0
\]
Modelling setup

<table>
<thead>
<tr>
<th>$\Gamma$</th>
<th>Behaviour (Thompson, 1971 [10])</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Gamma &gt; 1$</td>
<td>Sound speed increases with $P$; behaviour of usual substances</td>
</tr>
<tr>
<td>$\Gamma = 1$</td>
<td>Constant sound speed; $P$ a linear function of $\rho$</td>
</tr>
<tr>
<td>$0 &lt; \Gamma &lt; 1$</td>
<td>Sound speed decreases with $P$</td>
</tr>
<tr>
<td>$\Gamma = 0$</td>
<td>$P$ a linear function of $V$</td>
</tr>
<tr>
<td>$\Gamma &lt; 0$</td>
<td>Negative curvature of isoentrope; behaviour of unusual substances</td>
</tr>
</tbody>
</table>
Results

![Graph showing pressure vs. S/C ratio with markers VN13 and VN17.]

![3D model showing Mach Number distribution.]
Results (density and sound speed)

(VN13: - - , VN17: —)
Conclusions

• explicit representation and characterisation of the real gas effects of the fluid on the one-dimensional internal flow behaviour and related mechanisms
• The changes in the flow properties have been examined by changing the cross-sectional area in a selected vaned diffuser
• modelling is performed with ANSYS CFX 17.1, including a generated lookup table from REFPROP for CO₂ real gas properties
• the results show that the model with 17 vanes has higher pressure drop in throat and can lead to flow instability
• it confirms the fact that the higher number of vanes leads to smaller operation range for this specific diffuser design
• further investigation is needed to confirm this outcome for higher and lower incidence angle in leading edge
Thank you

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References


