Experimental Investigation on Power Generation with Low Grade CO$_2$ Transcritical Power Cycle

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Background

• As a natural working fluid, CO$_2$ has been widely used in refrigeration and heat pump systems due to its zero ODP, negligible GWP and good thermophysical properties etc.;
• It can also be employed for power generation from low temperature heat resources;
• However, the comprehensive experimental analyses for a low temperature CO$_2$ power generation system operations and controls need to be further investigated and developed;
• Experimental analysis on the low temperature power generation system with T- CO$_2$ Rankine cycle have therefore been carried out and some meaningful results are presented.
Test rigs of CO$_2$ Transcritical Rankine Cycle (T-CO$_2$)

- The system consisted of a number of essential components including a CO$_2$ turbine/expander with generator, finned-tube air cooled condenser, liquid receiver, liquid pump and thermal oil-heated CO$_2$ gas generator.

- In addition, the test rig was fully instrumented with calibrated sensors, flow and power meters, as shown in Figure.
Test rigs of CO$_2$ Transcritical Rankine Cycle (T-CO$_2$)

- The plate gas generator was heated indirectly by exhaust flue gases of an 80kWe CHP unit through a thermal oil circuit and a thermal oil boiler installed inside the CHP exhaust.

- The CO$_2$ turbine was integrated with a high speed and permanent magnet synchronous generator with rated rotation speed up to 18,000 rpm.

Photographs of the system components.
Test results of CO₂ Transcritical Rankine Cycle (T-CO₂)

Variation of operating parameters for the system test.

<table>
<thead>
<tr>
<th>Thermal oil inlet temperature (°C)</th>
<th>Thermal oil flow rate (kg/s)</th>
<th>Condenser inlet air flow temperature (°C)</th>
<th>Condenser inlet air flow rate (m³/s)</th>
<th>CO₂ mass flow rate (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>142.4~144.4</td>
<td>0.25~0.5</td>
<td>22.5~23.5</td>
<td>4.267</td>
<td>0.2~0.3</td>
</tr>
</tbody>
</table>

Variations of CO₂ turbine pressures with different CO₂ pump speeds and heat source flow rates

Variations of CO₂ pump pressures with different CO₂ pump speeds and heat source flow rates
Test results of T-CO$_2$ (Cont.)

Variations of CO$_2$ turbine and pump temperatures with different CO$_2$ pump speeds and heat source flow rates
Test results of T-CO$_2$ (Cont.)

Variations of CO$_2$ turbine powers with different CO$_2$ pump speeds and heat source flow rates

Variations of turbine efficiencies with different CO$_2$ pump speeds and heat source flow rates
Performance of oil-heated CO$_2$ gas generator

Temperature vs. heat transfer rate diagrams of lower thermal oil flow rate and higher CO$_2$ flow rate

Temperature vs. heat transfer rate diagrams of lower thermal oil flow rate and lower CO$_2$ flow rate

Temperature vs. heat transfer rate diagrams of higher thermal oil flow rate and higher CO$_2$ flow rate
Control Strategies

Relations between thermal oil mass flow rates and CO₂ turbine inlet temperatures

Relations between CO₂ mass flow rates and CO₂ turbine inlet temperatures
Control Strategies (Cont.)

Relations between thermal oil mass flow rates and CO₂ turbine inlet pressures

\[ y = 0.0324x - 2.4953 \]
\[ R^2 = 0.9521 \]

Relations between CO₂ mass flow rates and CO₂ turbine inlet pressures

\[ y = 0.0041x - 0.1202 \]
\[ R^2 = 0.9098 \]
Conclusions

• A small-scale T-CO₂ test rig was developed and tested to investigate the effects of two important operating parameters including heat source mass flow rate and CO₂ mass flow rate on the system performance.

• The measured and calculated turbine power generations and overall turbine efficiency all decreased with higher CO₂ mass flow rate.

• At higher thermal oil mass flow rate, the measured and calculated power generations, turbine isentropic and overall efficiencies and gas generator heat capacity were all increased.

• The CO₂ temperature and pressure at the turbine inlet are two important parameters which can be efficiently controlled by both thermal oil flow rate and CO₂ mass flow rate based on measurements.
Thank you...

Questions?