NATURAL CIRCULATION TEST CAMPAIGN
ON HERO-2 BAYONET TUBES TEST SECTION

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Objectives

- The innovative nuclear systems (SMR, Gen-IV reactors) require relatively new approaches to accomplish at the fundamental function of heat removal both in operative and accidental conditions, in order to achieve the goal of safety and economics.

- ENEA in collaboration with POLIMI and SIET is leading some studies on innovative heat exchangers within the framework of a National Research Program funded by the Italian Minister of Economic Development.

- SIET laboratories in Piacenza is hosting a series of experimental campaign with HERO-2 test section:
  - In 2015: to support the heat exchange characterization and instability detection of bayonet tubes.
  - In 2016: to characterize the behavior in natural circulation conditions typical of a DHR system for SMR

- The experimental databases obtained are useful to qualify T/H system codes supporting the design and safety analysis of innovative nuclear reactors. It also allows the performance comparison against alternative solutions, e.g. helical tubes steam generators for SMR reactors.
**HERO-2 facility**

**HERO-2** (Heavy liquid mEtal pRessurized water cOoled tube #2)

- Two parallel tubes built with commercial elements (AISI304)
- Three concentric tubes
- Interchangeable inlet orifice for flow stabilization
- HERO Design Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>180 bar</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>300-400 °C</td>
</tr>
<tr>
<td>Test Section height</td>
<td>7.3 m</td>
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</tbody>
</table>

- Hot/cold leg 3/4“
- Condenser tube 2” (AISI316) inclined 3°
- Pool at atmosphere conditions
- System to maintain the pool level
- System to control the Filling Ratio (FR)

\[
FR = \frac{(M_{\text{max}} - M_{\text{extracted}})}{M_{\text{max}}} (19.5 \text{ kg})
\]
HERO-2 facility

105 electrical resistors 
each tube 
(240 W @ 100 V)

Present Test Campaign Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Power each tube</td>
<td>25.2 kW</td>
</tr>
<tr>
<td>Max heaters temperature</td>
<td>350 °C</td>
</tr>
<tr>
<td>Max pressure</td>
<td>70 bar</td>
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</tbody>
</table>

The power generation could be considered linear even though the heaters leads to a certain discontinuity in the stream of power supplied (hot/cold spots)
Commissioning

- Fluid TCs calibration

- Orifice calibration (Kv=0.122)
  \[ \dot{m} = \dot{m}_{\text{tube1}} + \dot{m}_{\text{tube2}} = K_v \rho \left[ \sqrt{\frac{\Delta p_{DP11}}{\rho}} + \sqrt{\frac{\Delta p_{DP21}}{\rho_0}} \right] \]

- Heat losses characterization
  \[ \dot{Q}_{\text{loss}} = \dot{Q}_{\text{el}} - \dot{m}_{\text{refill}} \cdot (h_v(T_{\text{pool}}) - h_w) \]

- Vapor quality at the exit of the test section
  \[ x = \frac{\dot{Q}_{\text{el}} - \dot{m}(h_{ls}(P_{\text{out}}) - h(T_{\text{in}}, P_{\text{in}}))}{\dot{m}(h_{vs}(P_{\text{out}}) - h_{ls}(P_{\text{out}}))} \]
The power and FR completely define every steady-state conditions.

- **21 double-tube tests (DTs)**
  - FR 0.69, 0.64, 0.5, 0.43, 0.32
  - power from 5.0 to 50.0 kW

- **19 single-tube tests (STs)**
  - FR 0.72, 0.65, 0.56, 0.45, 0.35
  - power from 5.5 to 22.5 kW

- **8 double tube tests with non-condensable gas (N₂) at FR 0.50**
  - non-condensable mass 4 and 7 g
  - power from 11 to 50 kW.
Data analysis

The facility tends to pressurize increasing the power at constant FR, and the increase in pressure becomes more evident increasing the FR due to lower amount of compressible volume. The ST tests are characterized by lower power than the DT ones and relative greater hydraulic resistance (exclusion of a heated bayonet tube) → higher $P_{sat}$ for the same total power.
Data analysis

The mass flowrate increases when the FR increases, except for the higher FR where trend stops. At constant FR, the flowrate is characterized by a local minimum value due to two conflicting phenomena:

- the increase of the vapor quality → increases the pressure losses
- the pressurization → reduces the pressure losses.
Increasing the FR, the quality in the vapor chamber decreases due to the higher pressurization levels.
The global exchange coefficient decreases due to the increase of the liquid fraction in the condenser.
Data analysis – tests with non-condensable (FR=0.5)

Higher pressurization at increased nitrogen concentration, meaning a deterioration of the heat removal.
Flowrate tends to increase as effect of the pressurization and the lower vapor quality that reduce the pressure losses.
Conclusions

- In the frame of a national project and in collaboration with POLIMI and SIET, the bayonet tubes steam generator solution has been investigated in view of future application on SMR reactors and Gen-IV systems.

- The results of the post-test analysis conducted with RELAP5 mod 3.3 of the first test campaign (2015) conducted to characterize the heat exchange, and detect and quantify thermalhydraulic instabilities of the parallel tubes, is the object of the paper “Post-test analysis for the characterization of the bayonet tubes HERO-2 component” under review at NURETH-17 Conference.

- The present experimental campaign to characterize the operability of the bayonet tubes as DHR system working in natural circulation for PWR SMR in passive accidental conditions have shown a consistent behavior of the facility.

- The database is useful for the qualification of computer codes supporting the design and safety analysis of innovative reactors. The test campaign will be used for the assessment of RELAP5 system code.
Thank You for the attention