PRELIMINARY THERMAL/HYDRAULICS ASSESSMENT OF THE MOLTEN SALT BLANKET CONCEPT

By S. Smolentsev

- The ultimate goal of the analysis is to address and resolve the most critical thermal/hydraulics issues for three MS blankets:
  - FLiNaBe-Self-Cooled;
  - DC-Be, He and FliBe;
  - DC-Pb, He and FliBe.

- Assessment was performed using the same reactor configuration and power loading used for the APEX Task IV re-circulating blanket.

  Average neutron wall load  = 4.61 MW/m$^2$;
  Peak neutron wall load     = 5.45 MW/m$^2$;
  Average surface heat flux  = 0.95 MW/m$^2$. 
IMPORTANT ISSUES

- Is it possible to keep the maximum FW temperature < 550°C?
- How high are the interface temperatures (FS-multiplier, FS-coolant, FS-breeder)?
- Is it possible to achieve the breeder bulk temperature at the exit 100-200°C higher than 550°C and to keep the structure temperatures < 550°C at the same time?
- How large is the heat flux escaping from the breeder into coolant (DC blanket)?
- How much heat is deposited in the breeder and how much is in the coolant?
- How to improve heat transfer (if present conditions are not sufficient)?
- What penalty (in terms of the pressure drop) do we pay for the heat transfer improvement?
- What adjustments are needed to achieve the specified blanket parameters (high bulk temperature, low interface temperatures, low pressure drop)?
- Is there any solid FLiBe at the walls? How thick is the solid FLiBe layer?
### ASSESSMENT STATUS

<table>
<thead>
<tr>
<th>Blanket</th>
<th>Thermal Analysis</th>
<th>Hydraulics</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLiNaBe-Self-Cooled</td>
<td>In progress</td>
<td>In progress</td>
<td>Thermal/Hydraulics analysis for a similar blanket design (FliBe re-circulating blanket) had been performed in the APEX Task IV studies.</td>
</tr>
<tr>
<td>DC-Be, He and FLiBe</td>
<td>In progress</td>
<td>In progress</td>
<td>The results are expected to be similar to those for the DC-Pb, He and FliBe blanket. Calculations of the pressure drop in the Be pebble bed have been done.</td>
</tr>
<tr>
<td>DC-Pb, He and FLiBe</td>
<td>Done</td>
<td>Done</td>
<td>The results are shown below.</td>
</tr>
</tbody>
</table>
SUMMARY OF THE APPROACHES USED

HEAT TRANSFER: Numerical calculations

\[
\rho C_p \left( \frac{\partial T}{\partial t} + U \frac{\partial T}{\partial x} + V \frac{\partial T}{\partial y} + W \frac{\partial T}{\partial z} \right) = \frac{\partial}{\partial x} \left( k \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left( k \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left( k \frac{\partial T}{\partial z} \right) + q'''
\]

PRESSURE DROP IN He: Summation of friction and local pressure losses


\( Re \sim 10^5 \rightarrow \) turbulent flow

PRESSURE DROP IN FLiBe (FLiNaBe): MHD codes

Breeder: \( Ha/Re \sim 0.06 >> (Ha/Re)_{cr} = 0.005 \rightarrow \) laminar flow model
Coolant: \( Re \sim 10^3 \rightarrow \) turbulent flow, k-epsilon MHD model
DC-Pb, He and FliBe BLANKET

The blanket parameters have been adjusted to have:
- Minimum FliBe T \( \sim 40 \) K above the melting point (459°C);
- Maximum temperature of the FS structure < 550°C;
- All interface temperatures < 550°C;
- He \( \Delta T = 450-300 = 150 \) K;
- Flibe \( \Delta T = 700-500 = 200 \) K.

The adjustments are the following:
- He velocity in the FW channels = 75 m/s;
- He velocity in the Sec. Wall channels = 104 m/s;
- FliBe velocity = 0.11 m/s;
- Artificial wall roughening: a) FW He channels (only second and third passes, only one wall), b) Sec. Wall He channels (only one wall).

Energy balance:
- Flibe: 56%
- He FW flows: 31%
- He poloidal flows: 13%
# DC-Pb, He and FliBe: He cooled FIRST WALL

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>He inlet temperature</td>
<td>300°C</td>
<td></td>
</tr>
<tr>
<td>He velocity</td>
<td>75.2 m/s</td>
<td></td>
</tr>
<tr>
<td>He exit temperature (1st pass)</td>
<td>333°C</td>
<td></td>
</tr>
<tr>
<td>He exit temperature (2d pass)</td>
<td>366°C</td>
<td></td>
</tr>
<tr>
<td>He exit temperature (3d pass)</td>
<td>400°C</td>
<td></td>
</tr>
<tr>
<td>Maximum FW temperature (1&lt;sup&gt;st&lt;/sup&gt; pass)</td>
<td>540°C</td>
<td></td>
</tr>
<tr>
<td>Maximum FW temperature (2d pass)</td>
<td>535°C</td>
<td></td>
</tr>
<tr>
<td>Maximum FW temperature (3d pass)</td>
<td>565°C</td>
<td>More reduction in the FW temperature can be achieved by reducing the poloidal length of the third pass.</td>
</tr>
<tr>
<td>FW pressure drop</td>
<td>0.28 MPA</td>
<td>Includes viscous friction, local pressure losses in the bends and poloidal manifolds</td>
</tr>
</tbody>
</table>
DC-Pb, He and FLiBe: MULTIPLIER+He+BREEDER

2-D temperature field

1st FLiBe pass

Interface and bulk temperatures

Heat escaped from FLiBe into He

Radial temperature distributions at three poloidal locations
## DC-Pb, He and FLiBe: MULTIPLIER+He+BREEDER

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet FLiBe temperature</td>
<td>500 °C</td>
<td></td>
</tr>
<tr>
<td>FLiBe velocity</td>
<td>10.8 cm/s</td>
<td>Slug velocity profile, laminar flow</td>
</tr>
<tr>
<td>Exit FLiBe temperature (1st pass)</td>
<td>600 °C</td>
<td>Countercurrent flow (He flows from top to bottom, FLiBe flows from bottom to top)</td>
</tr>
<tr>
<td>Exit FLiBe temperature (2d pass)</td>
<td>700 °C</td>
<td>Concurrent flow (both He and FLiBe flow from top to bottom)</td>
</tr>
<tr>
<td>He inlet temperature in the Sec.Wall poloidal flows</td>
<td>400° C</td>
<td></td>
</tr>
<tr>
<td>He velocity</td>
<td>104 m/s</td>
<td></td>
</tr>
<tr>
<td>He outlet temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frozen FLiBe layer at the Sec.Wall</td>
<td>1-2 mm thick, 2-3 m long</td>
<td>Based on T&lt;T_{melt}. Formed at the top.</td>
</tr>
<tr>
<td>Heat flux from FLiBe into He</td>
<td>~0.2 MW/m²</td>
<td>7% of heat generated in FLiBe</td>
</tr>
<tr>
<td>Maximum FLiBe temperature</td>
<td>1000° C</td>
<td></td>
</tr>
<tr>
<td>Maximum Pb temperature</td>
<td>850° C</td>
<td></td>
</tr>
<tr>
<td>Maximum interface temperature</td>
<td>555° C</td>
<td>Without taking into account natural convection</td>
</tr>
<tr>
<td>Pressure drop in poloidal He flow</td>
<td>0.25 MPa</td>
<td></td>
</tr>
<tr>
<td>Pressure drop in the FLiBe flow</td>
<td>0.02 MPA</td>
<td></td>
</tr>
</tbody>
</table>
PRESSURE DROP ACROSS THE Be PEBBLE BED

Viscous component
(Ergun S., 1952)
\[
\left( \frac{\Delta P}{l} \right)_v = 150 \frac{(1-F)^2}{F^3} \frac{\mu U}{d^2} + 1.75 \frac{1-F}{F^3} \frac{\rho U^2}{d}
\]

Electromagnetic component
(Wong C., 1983)
\[
\left( \frac{\Delta P}{l} \right)_{em} = \sigma UB^2 / F
\]

Total pressure drop
\[
\Delta P = l \left( \left( \frac{\Delta P}{l} \right)_v + \left( \frac{\Delta P}{l} \right)_{em} \right)
\]

- Calculations have been conducted for 5 cm Be pebble bed with \( F=0.4 \)
- Contribution of the electromagnetic component is almost negligible
- The decision on the pebble dimension and Flibe velocity will be made based on the heat transfer considerations
CONCLUSIONS AND FUTURE STUDIES

- The most important thermal/hydraulics issues for three blanket concepts have been formulated.

- Many calculations have been performed for the DC-Pb, He and Flibe blanket. It has been shown that the design has a lot of flexibility and the blanket parameters can be adjusted to meet the basic design requirements.

- In the next R&D studies more detailed considerations should be given to 3-D effects, countercurrent flows in the FW, Flibe flows (shape of the velocity profile, natural convection, effect of temperature on the physical properties), natural convection in Pb, solidifying/melting process in Flibe near the walls.

- The thermal/hydraulics analysis for two other concepts has been initiated and the results will be presented soon.