Conceptual Design of Advanced Blanket Using Liquid Li-Pb

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Li-Pb blanket studies at Kyoto Univ.

Topics include in this talk

• Li-Pb loop and its operation
• SiC-LiPb blanket concept development
• Deuterium permeability evaluation of SiC materials at high temperature
• Solid electrolyte cell studies for LiPb purity control
LiPb Loop in Kyoto University

Test section operated above 600 °C

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>temperature [°C]</td>
<td>350 ~ 450</td>
</tr>
<tr>
<td>inventory [liter]</td>
<td>6</td>
</tr>
<tr>
<td>Flow rate [l/min]</td>
<td>0 ~ 5</td>
</tr>
<tr>
<td>fluid</td>
<td>Li-Pb</td>
</tr>
<tr>
<td>material</td>
<td>SUS316</td>
</tr>
</tbody>
</table>
LiPb Loop in Kyoto University
High Temperature Operation

700°C Operation velocity: 0.7~1.0 cm/s

- 16 hours operation above 650°C, maximum temperature is 710 °C
- Temperature fluctuated due to flowing rate fluctuations

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MHD pressure drop measurement

\[ P_{\text{loss}} = \sigma B^2 v L \]

\( \sigma \): resistance  \( B \): Magnetic field  
\( v \): velocity  \( L \): diameter

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MHD pressure drop measurement

Temperature: 350°C
Magnetic Field: 0.11 T
Flow rate: 1.75~4.5 [l/min]
velocity: 18.27~47.25 [cm/s]
Compatibility tests

SiC/SiC composite tube was installed in the LiPb loop. Tube section was heated above 600 degree C with LiPb flow. Possible corrosion is observed with microscopes.

SiC/SiC tube

Inner surface of SiC after exposure

Test section: heated and cooled

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Compatibility test 2

Same compatibility test being performed with stainless steel, Ferritic steel and other candidate materials.

Stainless steel tube

Electron-microscope image

Microscope image

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1) LiPb-RAFM blanket with SiC insert
   • compatibility issue
   • thermal insulation
   • MHD pressure drop
   • tritium solubility

2) SiC Heat Exchanger program
   • Dual coolant for high temperature heat
     → heat extraction with He from LiPb using SiC components.
     → high temperature He as secondary heat transfer medium.
SiC-LiPb Blanket Concept

- Module box temperature made of the RAFS must keep under 500 °C.
- Li-Pb outlet temperature target 900 °C.
- We propose the new model of active cooling in Li-Pb blanket.
- This concept is equipped He coolant channels in SiC/SiC composite and provides more efficient isolation between the RAFS and high temperature Li-Pb.
- We evaluate the feasibility of high temperature blanket in this model.

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Model of Calculation (ANISN)

One Dimensional Neutron Transport Code (ANISN)

- TBR
- Neutron Shield
- Nuclear Heating

Neutron Flux

Plasma Region 100 [cm]

Li$_{17}$-Pb$_{83}$

SiC/SiC: 1.5 [cm]

0.5x0.5cm He Channel

FW(F82H): 1.5 [cm]

0.5x0.5 He Channel (8MPa)

<table>
<thead>
<tr>
<th>Li-Pb [cm] (Net thickness [cm])</th>
<th>40.5<del>55 (45</del>59.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^6$Li [%]</td>
<td>7.4 ~ 90</td>
</tr>
</tbody>
</table>
Neutron Shielding

Distribution of Neutron Flux

Relation with Thickness (Li-Pb) and Neutron Flux on end of blanket.

With thickness of 43 cm can be obtained:

- All Neutron Flux: $10^2$ decrease
- 0.1 MeV: $10^2$ decrease
- 14 MeV: $10^3$ decrease

50cm Li-Pb (6Li 90%) provides these parameters.
Tritium Breeding

Tritium Breeding Rate

Relation with Thickness (Li-Pb) and TBR

• Contribution to $^7$Li for TBR is less than 5% of all.

• $^6$Li concentration is needed.

TBR $\geq 1.2$

$^6$Li 70%  55cm

$^6$Li 90%  50cm
Evaluation of Nuclear Heating

- Distribution of nuclear heating was calculated.
- Intense nuclear heating by neutron was observed at the front of Li-Pb.
- Heat removal corresponds to this distribution must be designed.
Heat Transfer Analysis

Temperature of RAFS side must keep under 500°C. Temperature of Li-Pb is determined by active cooling of SiC/SiC composite panel with He channels.

1. High Temperature Li-Pb
2. Large Nuclear Heating

For example: $T_{He}=350 \, ^\circ C$, $V_{He} = 8 \, [m/s]$
Results of Heat Transfer Analysis

- Max Li-Pb temperature is obtained as a function of He coolant flow speed.

He Coolant Temp. = 350 °C

He flow speed

<table>
<thead>
<tr>
<th>Max LiPb temp.</th>
<th>He flow speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>600°C</td>
<td>11.6 m/s</td>
</tr>
<tr>
<td>700°C</td>
<td>16.5 m/s</td>
</tr>
<tr>
<td>800°C</td>
<td>21.0 m/s</td>
</tr>
<tr>
<td>900°C</td>
<td>25.5 m/s</td>
</tr>
</tbody>
</table>

• 900 °C Li-Pb is possible with moderate He velocity.

Relation with Li-Pb side temperature and He velocity ($P_{He} = 8$ [MPa])

SiC/SiC 1.5 cm, He channel 0.5x0.5cm
Outlet Temp. and Velocity of Li-Pb

• Required Li-Pb velocity is calculated.

<table>
<thead>
<tr>
<th>Outlet temp.</th>
<th>LiPb flow speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>600°C</td>
<td>1.01 cm/s</td>
</tr>
<tr>
<td>700°C</td>
<td>0.78 cm/s</td>
</tr>
<tr>
<td>800°C</td>
<td>0.68 cm/s</td>
</tr>
<tr>
<td>900°C</td>
<td>0.51 cm/s</td>
</tr>
</tbody>
</table>

The MHD pressure drop is considered to be negligible in this condition (~1 cm/s).

**Relation with outlet temperature and Li-Pb flow velocity**

- Net thickness 54.5 cm, Li-Pb thickness 50 cm
- $^6\text{Li} = 90\%$, TBR = 1.2
- Li-Pb inlet : 300°C
- Mean Flow Path 100 cm, Flow path height 10cm
Conclusion

- LiPb-SiC blanket concept is now actively studied in Japan at Kyoto University.
- Experimental study is performed to confirm the and design.
- Some of the experiments are unique and valuable for international efforts for liquid blanket development, particularly DCLL or similar.
Ultimate goal of this program in Kyoto is to develop a concept of high temperature blanket. Small scale blanket module will be demonstrated in 4 years. System and component design will be made. Small neutron source will be used for tritium transfer experiment. DCLL and further SiC-LiPb configuration will be possible to be tested under TBM. Feasibility of high temperature blanket is of extreme importance for efficient generation and hydrogen production process. (We also study socio-economics of fusion in future market.)