Institute for Neutron Physics and Reactor Technology (INR)
Karlsruhe Institute of Technology (KIT), Campus Nord
Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldschafen, Germany
http://www.inr.kit.edu/

Karlsruhe Institute of Technology

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Experimental investigation of operating limits of a porous evaporator for a Heat Pipe-based DEMO Divertor Target concept

Wen Wen[a], Bradut-Eugen Ghidersa[a], Hering Wolfgang[a], Jörg Starflinger[b], Robert Stieglitz[a]

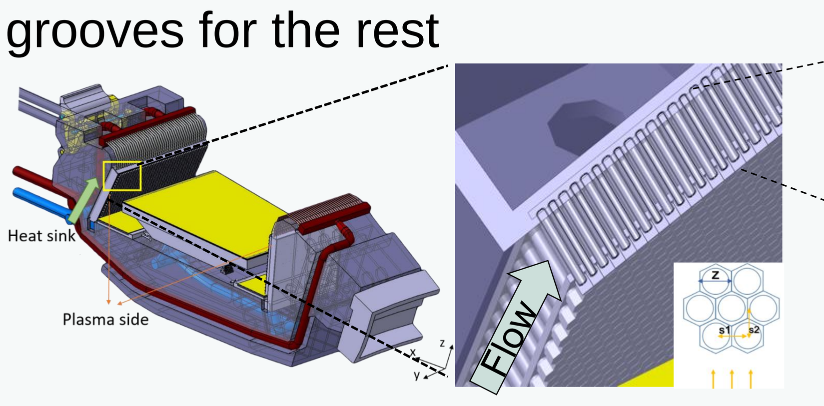
a: Institute for Neutron Physics and Reactor Technology, Karlsruhe Institute of Technology , Karlsruhe, Germany
b: Institute of Nuclear Technology and Energy Systems , University of Stuttgart, Stuttgart, Germany

Objectives

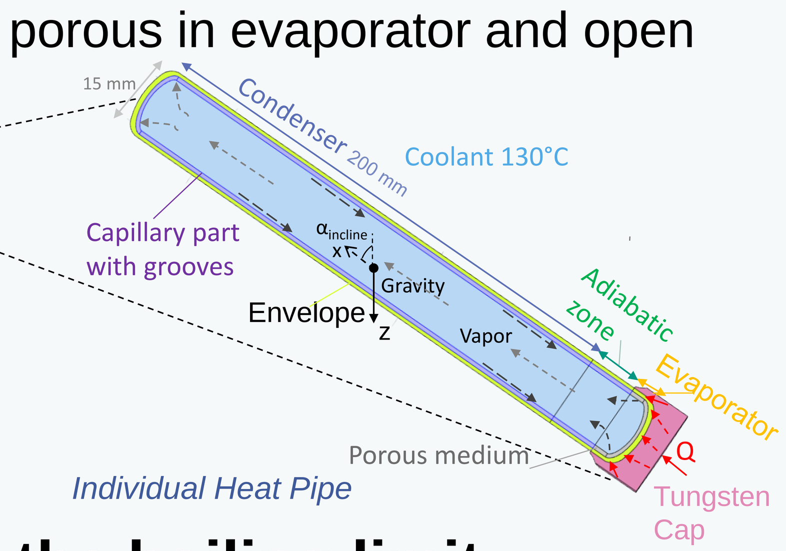
- To evaluate the capability of a water-based Divertor Heat Pipe designed for heat fluxes as high as 20MW/m², the first experiment focused on the boiling limit of its evaporator with different sintered porous structures, (water) filling situations and heat sink conditions.

DEMO-Divertor Heat Pipe Concept (DIV-HP)

- Divertor Heat Pipe target is made out of 230mm long cylindrical Heat Pipes (HPs) forming a staggered arrangement through which the target coolant flows.
- HP capillary structure uses sintered porous in evaporator and open grooves for the rest



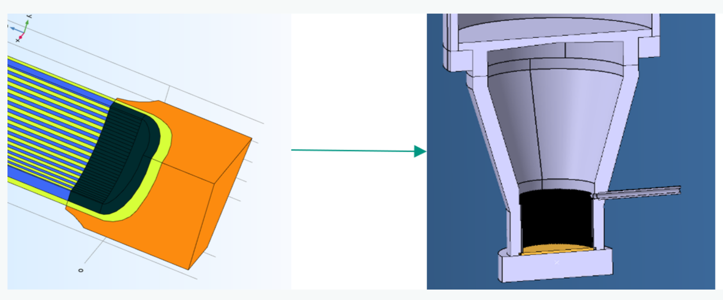
Divertor cassette assembly with a Heat Pipe-based target

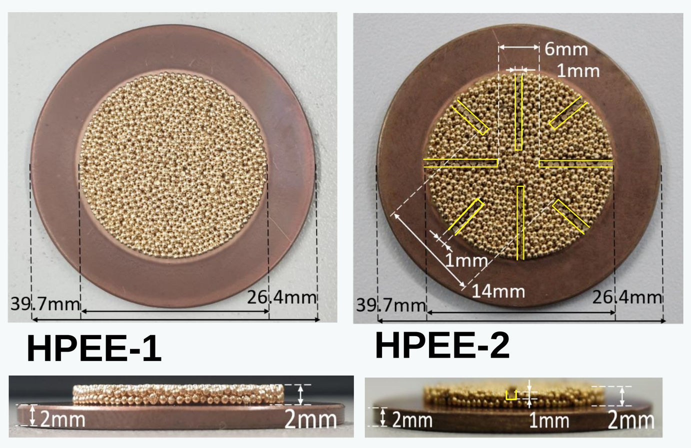


Individual Heat Pipe

Experiment for evaluation of the boiling limit

- The experiment aims to evaluate the boiling limit;
- Specific Heat Pipe mock-ups focus on the evaporator performance (HPEE) under similar operating conditions as for DIV-HP.
- Due to the manufacturing issues, the original porous structure (Cu with grain radius 118µm and 0.42 porosity) is replaced by one made out of bronze (CuSn10 with grain radius 400µm and 0.47 porosity).

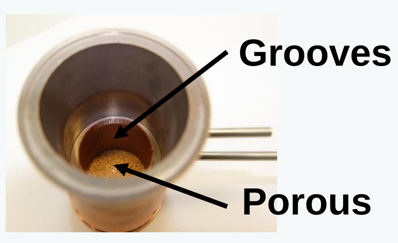

Divertor Heat Pipe evaporator and Experiment mock-up model



Diameter: 26mm
Thickness: 2mm

Grooves width: 1mm
Grooves depth:1mm

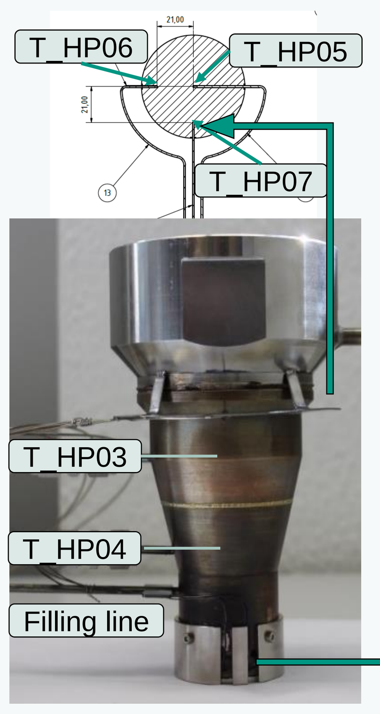

Condenser view inside



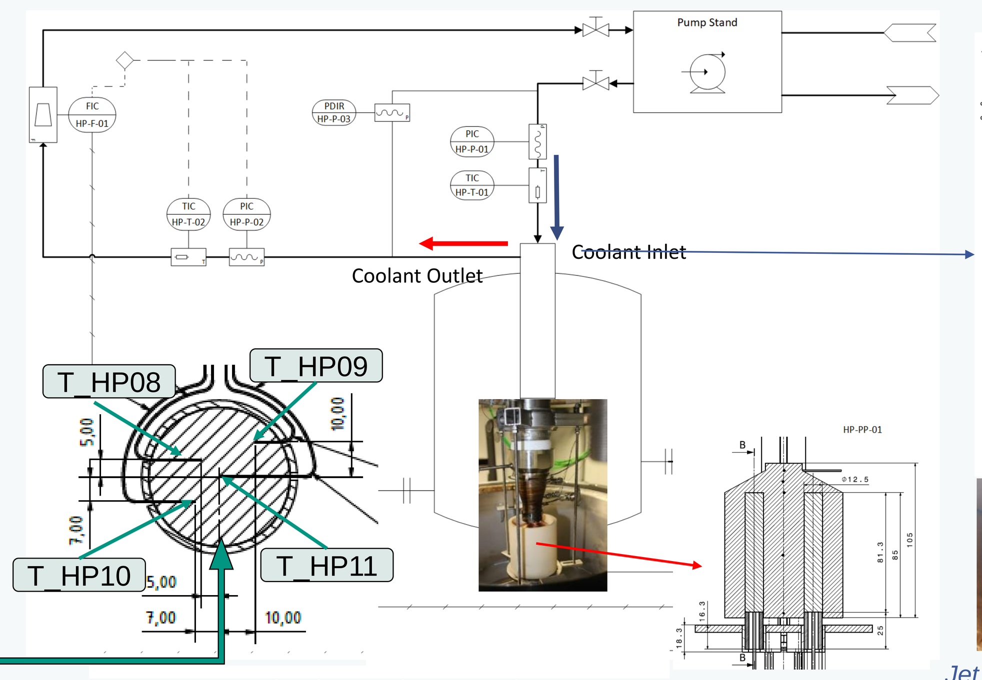
Evaporator view inside

Sintered porous evaporator: with plain shape; with grooves

- 2 sintered porous evaporator designs:
  - HPEE-1: a 2mm thick plain sintered porous structure
  - HPEE-2: a 2mm thick porous structure with 1mm depth grooves

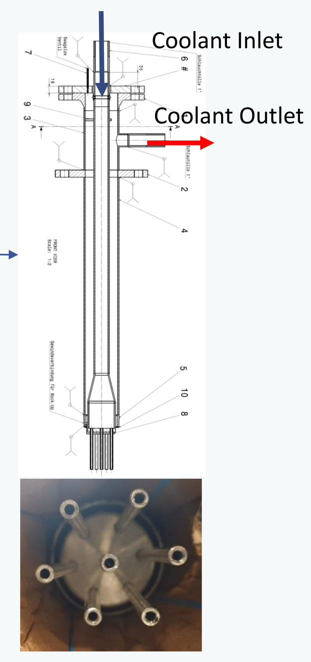


Mock-up with 9 thermal sensors



- 3 TEs : 5mm under the condenser surface
- 2 TEs : in HPEE body for vapor temperature
- 4 TEs : evaporator surface

Electric copper heater with inserted 6 heater rods



Jet impingement cooling at the condenser side

- Heat loading was applied using an electric cooper heater;
- HPEE's temperature variation was monitored by 9 thermocouples;
- Power evaluated calorimetrically on the heat sink coolant side.

Experimental heat transfer performance evaluation

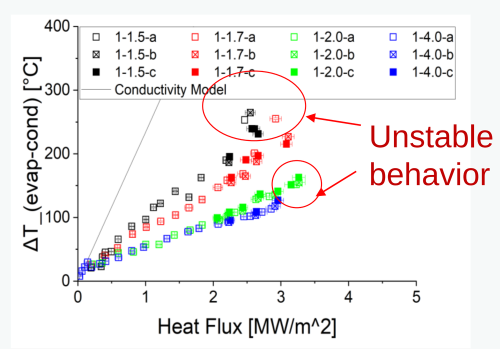
Method

- Water content is evaluated for three heat load ranges:

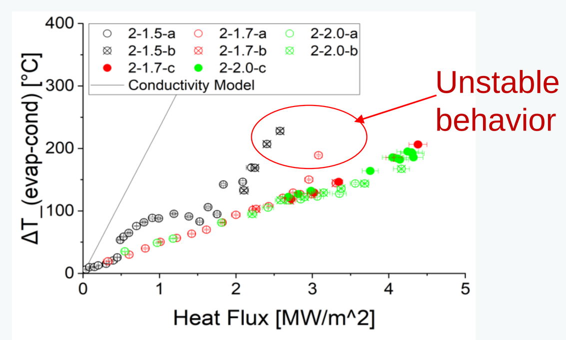
Heat load range	Liquid inventory
0-1MW/m²	1.5ml
1-5MW/m²	1.7ml
5-20MW/m²	2.0ml

- The heat sink's coolant flow rate was set in 3 different ways :
  - **(a)** fixed flow rate (90l/h) maintained during different heating steps,
  - **(b)** flow rate adjusted to keep the coolant temperature increase constant (8°C),
  - **(c)** flow rate adjusted to keep the condenser temperature constant at 80°C.
- Each HPEE was filled initially with 1.5ml and had its performance evaluated by increasing the heat flux from 0.2 MW/m^2 stepwise with typical jump of 0.2MW/m^2, until there were signs of dry-out, the flow rate increased to next level. Then, the water content was increased to the next quantity and the investigation repeated.

Experimental results



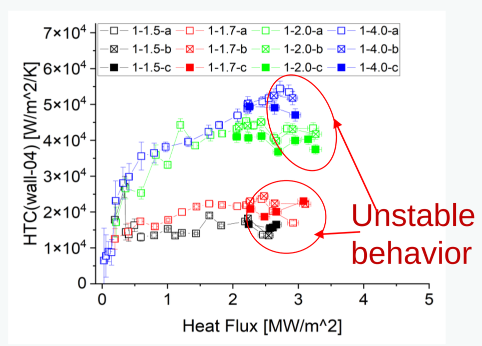
(HPEE-1)



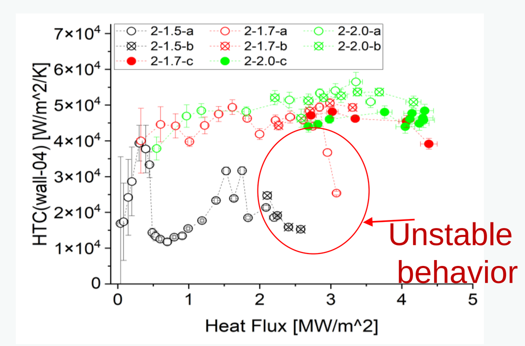
(HPEE-2)

Temperature difference between evaporator and condenser (the solid line indicates a pure conductive heat transfer)

- The $\Delta T_{\mathrm{evaporator-condenser}}$ of both HPEEs were smaller than one from pure conductive heat transfer;
- The difference reduced when liquid inventory increased until 2.0ml;
- HPEE-2 didn't show unstable temperature behavior with 2ml until 4.3MW/m^2



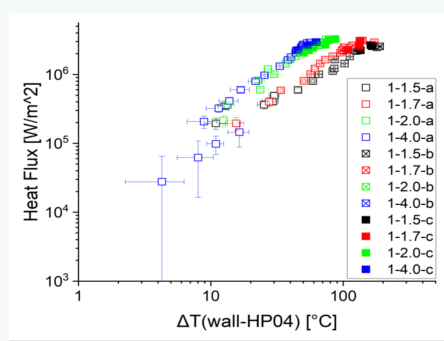
(HPEE-1)

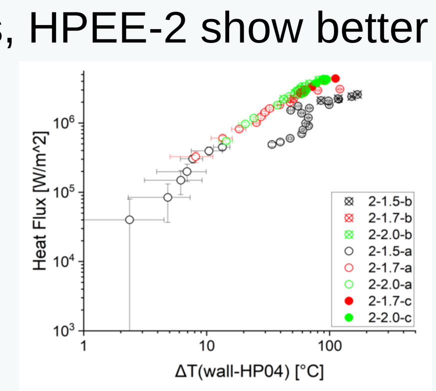


(HPEE-2)

Evaporator Heat Transfer characteristic

- Evaporator Heat Transfer characteristic is a function of the heat flux and $\Delta T_{\mathrm{wall-H04}}$: the temperature difference between the evaporator sintered porous and CuCrZr plate interface and the vapor temperature at HP04.
- The Evaporator Heat Transfer characteristic reduced when the unstable behavior is observed. For the same loading conditions, HPEE-2 show better performance.


(HPEE-1)


(HPEE-2)

Boiling curves

- For HPEE-1, at the same heat flux, the difference between the measured temperature at evaporator wall and vapor was lower with higher water content.
- $\Delta T_{\mathrm{wall-H04}}$ of HPEE-2 was lower than one of HPEE-1, except for the 1.5ml case.
- The flow rate changes show less impact on the boiling curve.

Conclusions

- HPEE-2 with grooves on sintered porous evaporator has better performance than HPEE-1;
- Maximum heat flux 4.3MW/m² was reached with HPEE-2 filled 2ml water, and there was no sign of the localized dry-out. However, the electric copper heater reached its operation limit.

EUROfusion

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