Evaporation Spray Cooling Concept of the First Wall

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Spray Cooling of the First Wall :

- **Array of liquid metal jets hit the backside of the first wall, assuring that the first wall remains wetted,**

- **Entire FW heat is removed by evaporation,**

- **Required liquid metal velocity so low that probably no insulating coatings required,**

- **Heat transfer by evaporation at the FW and condensation in the HX requires very low ΔT and leads therefore to high efficiency,**

- **Low vapour pressure of candidate liquid metals (K,Na,Li) reduces primary stresses in FW decisively.**

Example of a FW Tube with Spray Cooling

toroidal length of tube	**3 m**
tube inner diameter	**50 mm**
wall thickness front/back	**3 mm/ 2 mm**
pitch of tubes	**60 mm**

tube material : refractory metal

coolant : sodium at 1200K/ 0.15 MPa
lithium at 1400K/ 0.0179 MPa
lithium at 1500K/ 0.0427 MPa

heat of evaporation 3849 kJ/kg
20110 kJ/kg (lithium 1400K)
19757 kJ/kg (lithium 1500K)

vapour density 0.391 kg/m^3
0.0116 kg/m^3 (lithium 1400K)
0.0262 kg/m^3 (lithium 1500K)

LM density 731 kg/m^3
422 kg/m^3 (lithium 1400K)
411 kg/m^3 (lithium 1500K)

velocity of sound 724 m/s
1420 m/s (lithium 1400K)
1464 m/s (lithium 1500K)

For one Tube :

heat input by surface heat flux
$Q' = 2\ MW/m^2 * 3\ m * 0.06\ m = 0.36\ MW$

vapor generation
$M' = 360\ kW : 3849\ kWs/kg = 0.0935\ kg/s$
0.0179 kg/s (lithium 1400K)
0.0182 kg/s (lithium 1500K)

LM volume flow rate
$V'_{lm} = 0.0935\ kg/s : 731\ kg/m^3 = 0.128\ E\text{-}3\ m^3/s$
$= 0.0424\ E\text{-}3\ m^3/s$ (lithium 1400K)
$= 0.0443\ E\text{-}3\ m^3/s$ (lithium 1500K)

vapour flow rate
$V'_{vap} = 0.0935\ kg/s : 0.391\ kg/m^3 = 0.239\ m^3/s$
$= 1.541\ m^3/s$ (lithium 1400K)
$= 0.6947\ m^3/s$ (lithium 1500K)

flow cross section
$A = \pi/4 * (0.05\ m)^2 = 19.4\ E\text{-}4\ m^2$

LM velocity **$v_{lm} = 0.066\ m/s$**
0.022 m/s (lithium 1400K)
0.023 m/s (lithium 1500K)

vapour velocity **$v_{vap} = 123\ m/s$**
794 m/s (lithium 1400K)
358 m/s (lithium 1500K)

Conclusions :

- **Spray cooling with an evaporating alkali metal can remove heat fluxes much higher than 2 MW/m^2.**

- **Heat from the FW can be extracted with alkali metal vapour and transferred to helium of a closed cycle gas turbine power conversion system at a maximum helium temperature up to 900°C (sodium) or 1200° C (lithium).**

- **Temperature difference between the FW and the helium in the power conversion system is minimized by the excellent heat transfer by evaporation(FW) and condensation(HX).**

- **Low coolant pressure (0.15 MPa for sodium, 0.018 to 0.043 MPa for lithium) minimises primary stresses in FW, increasing FW lifetime and decreasing failure rate.**

- **Suitable fluids are K, Na, Li (in the order of increasing operating temperature). (examples : Saturation temperature of sodium 1200K, lithium 1400-1500K)**

- **Experience with heat pipes shows that for example Na works with Stainless steel, Incoloy 800, Hastelloy X and Molybdenum.**
  Li works with Tungsten, Molybdenum, Tantalum, Niobium.