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Revised

Strategies to cope with evaporation from liquid walls
APEX FY2000 work

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The liquid as it passes into the fusion chamber and along the wall is exposed to a power flux from the burning plasma, which cause the surface temperature to rise with time as the liquid moves from the inlet to the outlet. The temperature of the surface determines the evaporation rate. We have found from past work that the evaporation is high and strategies for reducing the evaporation rate and coping with high rates are needed. The temperature of Flibe versus time for a surface heat flux is plotted below for 0.35 and 1 MW/m^2 using the transient conduction solution for Flibe. A typical transit time from entrance to exit is about 0.8 s (8 m, 10 m/s). The temperature just a fraction of a millimeter below the surface is also plotted. If there is the slightest turbulence, eddy motion will convect the hot surface layer into the interior and mix with colder liquid. This is what was attempted to be estimated by calculations by Sergei and Ralph in the APEX Interim report. **Notice from Fig. 1 & 2 below how effective mixing would be if it was just 0.3 mm!** There must be lots of ways of getting this amount of convection.

As a check we note the thermal diffusion distance, x, $x=(\alpha\tau)^{0.5} = (2.227\times10^{-7}\times 1)^{0.5}=0.47$ mm for 1 s time, where α is the thermal diffusivity for Flibe. Bremsstrahlung photons above about 5 keV and visible optical radiation should penetrate deeper than this.

The temperature from the transient heat conduction equation[1] is given below:

$$\Delta T = 2q\frac{\sqrt{\alpha\tau}}{k}\left[\frac{1}{\sqrt{\pi}}e^{-F_{0x}^{*\,2}} - F_{0x}^{*}erfc(F_{0x}^{*})\right] \qquad (1)$$

$$\alpha = \frac{k}{\rho c} \qquad (2)$$

$$F_{0x}^{*} = \frac{x}{2\sqrt{\alpha\tau}} \qquad (3)$$

*F** is the normalized distance variable. The temperature as a function of time and space from these equations is plotted in Fig. 1 & 2. The surface temperature (x=0) simplifies to:

$$\Delta T = \frac{2q}{k}\sqrt{\frac{\alpha\tau}{\pi}} \qquad (4)$$

$$\Delta T \propto 1/k^{0.5} \tag{5}$$

If the effective thermal conductivity due to heat transport by convection by eddy motion can be a factor of 10 over the laminar case then ΔT would drop by a factor of 3!

Examples relevant to the divertor are being worked out.

1. M. Jakob, Heat Transfer, Vol I (Wiley, New York, 1949), p258.

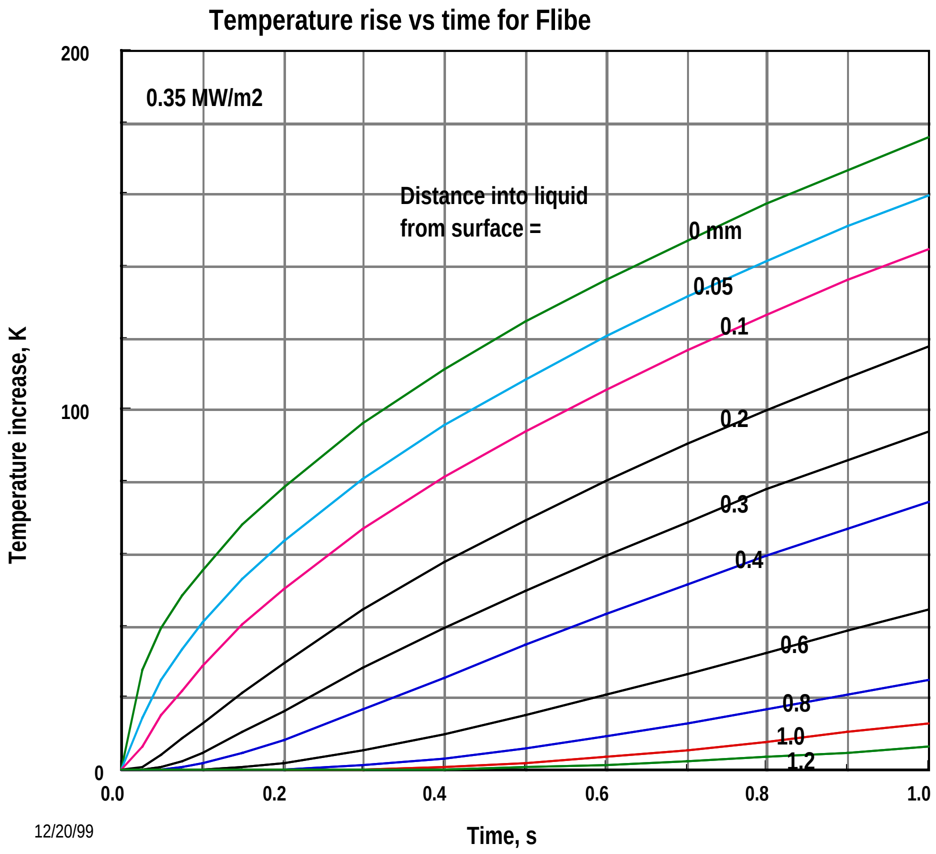

Fig. 1. The temperature of the Flibe at and near the surface is plotted versus time traveling along the flow direction for 0.35 $\mathrm{MW/m^2}$ surface heat load.

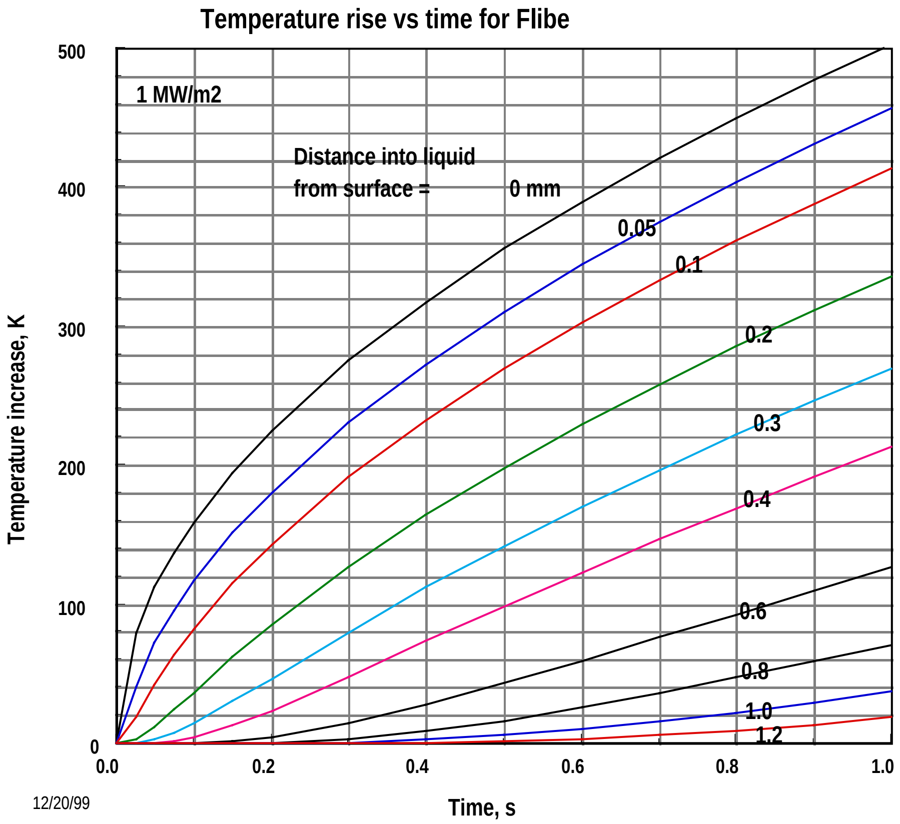

Fig. 2. The temperature of the Flibe at and near the surface is plotted versus time traveling along the flow direction for 1 MW/m^2 surface heat load.

Some strategies to cope with the problem of high evaporation rates of Flibe:

1-Employ turbulence to mix and lower surface temperature. We need computational models and experiments to aid this work. We need methods to enhance turbulence particularly near the surface. There is a strong shear in the flow near the surface which should result in turbulence down stream from the nozzle until this shear layer dissipates. Roughened nozzle interiors should enhance this effect.

2-Reduce the transit or exposure time. Except for the very surface the temperature is almost linear with time so halving the time would halve the temperature rise. In some designs we can flow from each end thus keeping the speed the same but halving the exposure time. Increasing the speed may be possible but since the pumping power goes like speed cubed this strategy will be marginal.

3-Move the liquid wall away from the plasma. This increases the evaporating area and pumping power but decreases the heat load per unit area which should result in a net gain.

4-Use a cooler than the bulk stream at the surface. This stream was assumed to come straight from the heat exchanger. This temperature was assumed to be 500 °C in the interim report. It was a compromise from the 550 °C from the HYLIFE-II design. The inlet to the heat exchangers for HYLIFE-II was assumed to be 650 °C. We are compromising by attempting to use 550 C as the mixed mean outlet from the blanket which is the inlet to the heat exchangers. The bulk liquid from the mixed outlet would be recycled.

5-Lower the inlet temperature from our previously assumed 500 °C. This strategy is difficult because of the high melting point of Flibe but there is some move possible here. The preferred formulation of Flibe ($2LiF+BeF_2$) has a melting point of 460 °C. By reformulating the salt the melting point can be lowered at the expense of increasing evaporation rate at any given temperature and increasing viscosity. The lower melting point of 360 °C is obtained for $LiF+BeF_2$. The inlet temperature might be lowered possibly to 450 °C.

6-Employ a halo plasma between the normal edge plasma and the liquid wall sustained by auxiliary heating to attenuate the evaporating flux even more.