High heat flux cooling for accelerator targets

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Accelerator targets, both for radioisotope production and for high neutron flux sources generate very high thermal power in the target material which absorbs the particles beam. Generally, the geometric size of the targets is very small and the power density is high. The design of these targets requires dealing with very high heat fluxes and very efficient heat removal techniques in order to preserve the integrity of the target. Normal heat fluxes from these targets are in the order of 1 kW/cm^2 and may reach levels of an order of magnitude higher.

Few techniques exist to deal with such high heat fluxes. One of the techniques uses a jet-impingement that has been shown to be able to deal with heat fluxes up to 40 kW/cm^2 using water as coolant [1]. A second technique is a micro-channel cooling that can deal with a heat flux of up to about 1 kW/cm^2, but has the advantage that it can be integrated into the target [2]. The cooling ability of each technique depends also on the cooling agent used. Jet-impingement requires very high jet velocities of more then 100 m/s to cool 40 kW/cm^2 if water is used as the cooling agent. A possible improvement might be achieved by using a liquid metal such as gallium instead of water. A few theoretical and experimental studies have indicated that liquid gallium can improve significantly the heat transfer efficiency for both flow configurations [3,4,5].

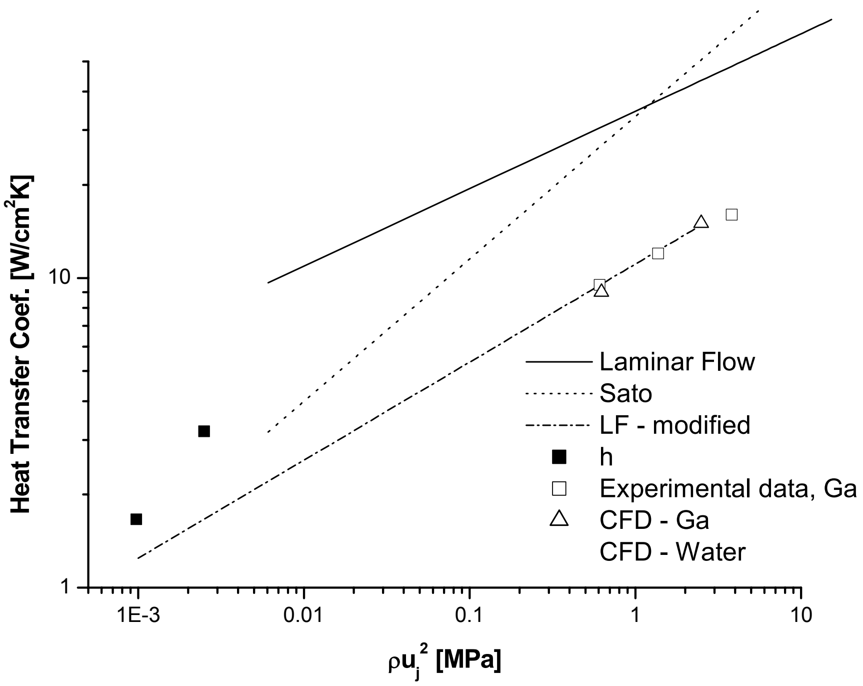

Figure 1: Heat transfer coefficient from hot wall to coolant for water and Gallium as a function of the coolant dynamic energy ρu_j^2 (jet diameter 8 mm)

Figure 1 presents the heat transfer coefficient due to jet impingement cooling for water and gallium as a function of the coolant dynamic energy, which is the relevant value for the evaluation of the cooling system efficiency. The heat transfer coefficient for water has been calculated by the Lienhard correlation [1], which is based on fitting extensive experimental data. For Gallium, values are given using two correlations for liquid metals. One is a theoretical correlation for laminar flow conditions developed by Lienhard [1]. He claim that due to the low Prandtl numbers of liquid metals this correlation should hold also for turbulent conditions. The other is by Sato et. al. [5] based on data from a reverse case where hot liquid metal jet impinges on a cold plate and partially melts the surface. Both liquid metal correlations demonstrate the high potential of using Gallium instead of water. For Gallium we have some experimental data by Blackburn and Yanch [2] which fits quite well with the Sato correlation. In addition, CFD calculations, with the commercial code STAR-CD, have been preformed and are presented in this figure. Excellent agreement was found when we calculated the heat transfer coefficient for water jets, but the results for gallium deviate significantly from the values calculated with the liquid metal correlations. This is probably since the code is tuned for water and air (high and medium value Prandtl number fluids) and not for liquid metals. We started collaborating with Prof. A. Yarin from the Technion in order to test and improve the accuracy of the CFD calculations for liquid metal flows.

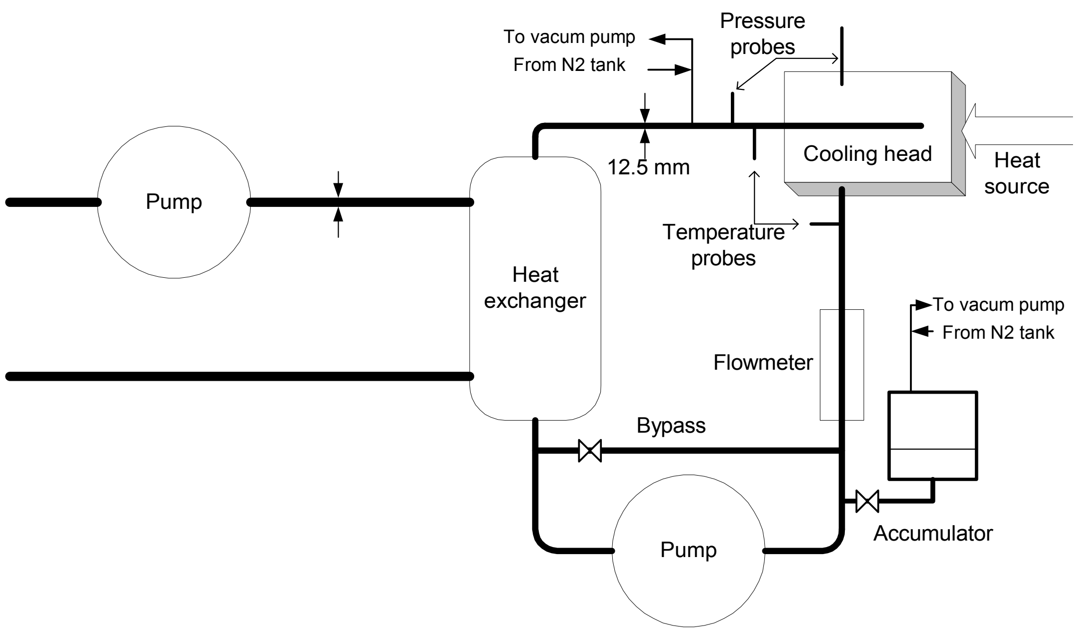

Figure 2: A schematic diagram of the cooling loop

In order to evaluate the actual potential of jet impingement for high heat flux cooling, experimental cooling loops based on water and liquid gallium jet impingement are being designed and built. Figure 2 presents a schematic of the Gallium experimental cooling loop and table 1 presents the design and working parameters of both systems.

Table 1: Nominal, minimal and maximal values for water and Gallium experimental cooling loops

Parameter		Water system			Gallium system		
		Minimum value	Nominal value	Maximum value	Minimum value	Nominal value	Maximum value
Power	[kW]	0	15	20	0	15	20
Heat flux	[kW/cm^2]	0	1	5	0	1	5
Flow rate	[l/s]	0	0.5	1	0	2.5	5
Jet velocity	[m/s]	0	10	20	0	50	50
Jet diameter	[mm]	5	8	12	5	5	12
Jet distance	[mm]	4	4	20	4	4	20
Coolant temperature	[C]	20	30	50	40	50	75
Wall temperature	[C]	20	200	200	40	200	200
Coolant pressure	[Pa]	1	5	5	1	1	1.5
Inlet pressure	[Pa]	1	25	32	1	11	11

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