# §13. Design Activity of High Flux Irradiation Test Module of IFMIF

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During irradiation test in IFMIF, accurate temperature control and monitoring of specimens are required since irradiation characteristics of materials have a strong dependency on temperature. In the high flux test module (HFTM) of IFMIF, temperature control using cooling by gas and heating by electric heaters are supposed to be used. A severe restriction is imposed on the temperature control in HFTM because available space for heaters, insulations, cooling channels and so on is very restricted (about 0.5 l for the specimens) while different irradiation temperature must coexist within it. From these reasons, the temperature control for specimens in the HFTM is one of the most challenging issues of the IFMIF design activities.

The authors have proposed an alternative design concept of HFTM with high cooling performance in which specimens are set in cast-like capsules and precise measurement of specimen temperature is possible [1,2]. In Kyushu University, a series of studies on the HFTM has been developed so far based on the assumption of a constant nuclear heating, taking no account into the spatial distribution of nuclear heating. It is, however, envisaged that the produced neutron flux has a spatial distribution in a plane normal to the beam direction and it was reported that it was attenuated by about 1 % as it traveled for 1 mm toward the beam direction [3]. Since nuclear heating is considered to have a similar distribution to that of neutron flux, it is feared that a warp or buckling of capsule, that is the irradiation unit in the HFTM, occurs due to the temperature difference between the front and rear side of the beam direction. For the advanced design, it is indispensable to investigate thermal behaviors with the non-uniform heating. Here, we performed heat transfer experiments taking the non-uniform power density distribution into account. Moreover, thermal-hydraulic analysis was performed numerically to investigate basic heat transfer performances such as a relation between capsule temperature and coolant velocity and to estimate the heater power required to even temperature profile and to achieve a certain temperature level in a capsule.

The spatial distribution of the heat generation in the irradiation volume in the HFTM assumed in this study is an approximate estimation obtained by referring to [4]. In the experiment, mica heaters with power density variations are used in order to simulate the non-uniform nuclear heating while ceramic heaters are used for the temperature control mainly to homogenize the temperature profile in the capsule. The gas loop system and the test section used for the present investigation are the same as those described by previous work [1], gaseous nitrogen is similarly used as imitation gas and Reynolds number is varied with the range from 7000 to 22000. It is found from the experimental results that the temperature difference in the capsule of 37.1 $^{o}$C without heating of ceramic heaters can be mitigated to 28.7 $^{o}$C with the maximum heating of ceramics heater. This is due to relatively small power of the ceramic heaters compared to the mica heaters. Additionally, despite the temperature control of the ceramic heaters, temperature at the end of the capsule does not rise sufficiently. It was concluded that other heaters which compensate the low volumetric heat generation rate at the end of the capsule have to be added in order to realize more uniform temperature distribution in the capsule in addition to the ceramic heaters with higher power.

Following this, simulations were performed taking one typical capsule as the standard configuration and keeling the similarity to the experiment. Based on the experimental results, an additional heater was introduced to the end of the capsule. In the calculations, four kind of fully developed flows with mean flow velocity of 43.7, 78.9, 87.6 and 263 m/s at the inlet are provided as the inlet conditions of coolant flow. The corresponding Reynolds numbers at the inlet, based on the channel width of 1 mm, are 939.3, 1691, 1880 and 5636, respectively. The flow is laminar at Re=939.3 and 1691 while turbulent at Re=1880 and 5636. All calculations are presented for the capsule at the most heavily loaded location. Obtained temperature profile in the beam direction indicates almost symmetric profile against the geometrical center in the beam direction although it is envisaged that the heat production profile in the beam direction may make a large temperature difference between the front and the rear side of the capsule. Temperature profiles in the span-wise direction for both cases, one with nuclear heating only and the other with nuclear as well as heater heating to aim at uniform temperature, show that temperature distributions are well improved by heaters for temperature control. It should be noted that the effect of the end heater is prominent and it remarkably contributes to the realization of the uniform temperature profile in the capsule. From results of the relation between supplied heater power and the maximum temperature in the capsule, it is found that the capsule temperature doesn't rise so much for large Reynolds number cases even if a huge power is supplied. Moreover we derived the conclusion from the relation between the maximum temperature and the temperature difference in the capsule that a high capsule temperature causes a large temperature difference and small Re leads to a small temperature difference in the capsule compared with large Re case at the same temperature level. These results indicate that small Re number is preferable to be used.

**References**

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