§21. Study on Thermal Mixing of Liquid-metal Free-surface Flow by Obstacles Installed at the Bottom of a Channel

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The liquid divertor concepts in fusion reactors have been widely investigated for magnetic fusion reactors [1]. Recently, Rhoad[2] investigated the effects of magnetic field on the turbulent wake of a cylinder in free-surface MHD channel flow. He reported that the MHD flow under the vertical magnetic field showed the best performance for heat transfer enhancement in the range of the interaction parameter, N, from 0 to 1. To our knowledge, only a few experimental studies on heat transfer of the free-surface flow have conducted.

In this study, the delta-wing and the cubic obstacle were used as the vortex generators, and their wake effects on thermal mixing in liquid metal ($Ga_{67}In_{20.5}Sn_{12.5}$) free-surface flow were investigated. In order to grasp the thermal mixing of these obstacles, the liquid metal free-surface flow in the channel without magnetic field was partially heated and the temperature distributions on the channel bottom were measured.

An experimental apparatus used in this study is called "LMX (Liquid Metal Experiment)" located at Princeton Plasma Physics Laboratory (PPPL). The LMX consists of 0.80 m length, 0.10 m width acrylic channel as a test channel, a vortex flow meter, an Archimedes-style screw pump, a heat exchanger cooled by a de-ionized water and a storage tank as illustrated in Fig. 1. The working fluid was a gallium-indium-tin (Ga67In20.5Sn12.5) eutectic alloy described in Table 1 that flowed through the channel with a mean depth of 0.01 m at the flow velocities from 0.03 to 0.20 m/s. Argon gas as a pressurized gas was used to prevent the oxidation. 25 K-type thermocouples with the accuracy of ±0.1℃ were installed at the bottom wall of channel with mostly equi-spaced separation of 0.034 m as illustrated in Fig. 2. In order to calculate the heat loss and the mean temperature gradient of the flow for the heat flux evaluation, the K-type thermocouples were installed inside the fluid at the inlet and outlet positions of the channel, respectively. The test obstacle was installed at the center of the flow channel and at the upstream of the heater position installed at the free-surface. The obstacles blockage ratio (β=d/2L; d is the width of obstacle and 2L is the width of the channel) is roughly 0.05. The experiments were performed Reynolds number range of 3000 to 18000, based on the equivalent hydraulic diameter and the mean flow velocity. The fluid circulated using an Archimedes-style screw pump with a constant flow rate with 5% flow fluctuation around the mean as described in Ref. [2]. The heater plate made of Aluminum Nitride ceramic has an area of 0.075 m x 0.025 m is placed on the free-surface. This heater injects a constant heat flux of 0.18 MW·m-2 to the fluid and raised the surface temperature of flow by a few degrees. A heat exchanger installed behind the pump used to cool the heated fluid back to starting temperature. The experiments were conducted for three different configurations: 1) no obstacle, 2) cubic obstacle, and 3) delta-wing obstacle. The size of the cubic obstacle was designed such that the blockage ratio is 0.05. The delta-wing obstacle has 2 characteristic angles: a lift angle of θ=20° from the bottom wall of the channel and an apex angle of ϕ=25°. Both of the obstacles were made of acrylic resin.

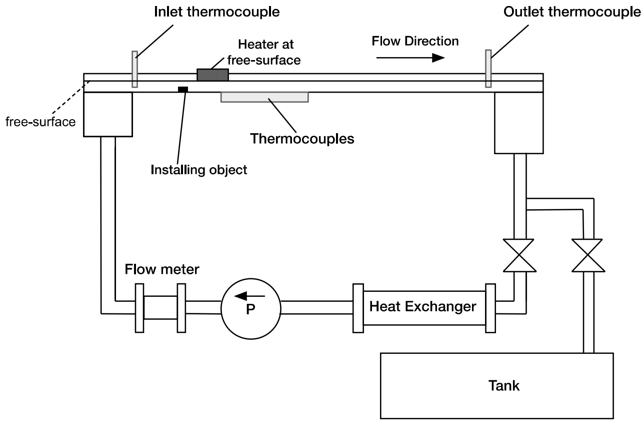

Fig. 1. Experimental apparatus

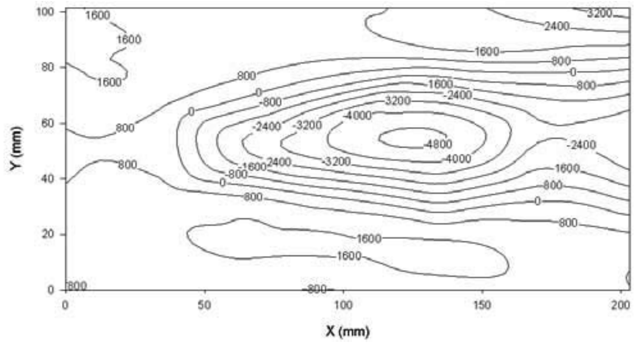

Fig. 2. Heat flux contours on the bottom of the test channel in case of a delta-wing obstacle at Re=18000

The heat flux contours at the bottom of the test channel at Reynolds number of 18000 is shown in Fig. 2. The heat flux increased by a delta-wing obstacle compared to a cubic obstacle and without an obstacle. The results of these experiments can be summarized as follows:

(1) From the comparison of the temperature contours, the delta-wing obstacle transports the high temperature fluid heated at the free-surface to the bottom wall more efficiently than the cubic obstacle and the reference case.

(2) From the comparison of heat flux contours and the maximum heat flux points, it is found that the obstacle enhanced the thermal mixing of the fluid, and the delta-wing obstacle allows the faster mixing of the higher temperature fluid from the free-surface to the wall compared to the cubic obstacle.

This would help removal of the localized high heat flux from the wall of the free-surface flow by using the delta-wing obstacles.

1) Abdou, M. A. et al.: FED **54** (2001) 181.
2) Rhoads J. R. et al.: JFM **742** (2014) 446.