§23. Simulation Experiment of Confinement Improvement of Plasmas for Super Science Highschool (SSH) Program (Fluid Dynamics Experiment in Kitchen)

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Super Science Highschool (SSH) program is physics education program for highschool students. An experiment simulating the improved confinement of plasma magnetically confined is invented using simple instruments one can prepare in the kitchen[1]. Figure 1 shows very simple experimental setup for the understanding of the Ekman flow using an electric hot plate (1400W), an aluminum pot (30cm diameter, 10cm depth, 7000cc), a spoon and water (with 6cm height) that are usually available in the kitchen. The temperature of the water is measured at the center and edge of the pot near the bottom (10mm above the bottom of pot) with thermometers. The region of the pot bottom heated by the electric hot plate is localized near the center with a diameter half of the pot diameter (15cm diameter). To have better localization of the heated region, an aluminum pot is recommended rather than a steel pot, because the smaller heat capacity results in a larger difference between the temperatures at the center and at the edge.

Figure 2(a) shows the time evolution of the water temperatures measured at the center and edge of the pot. The hot plate is turned on at 60 seconds and the water is stirred by a spoon only during the period from 360 to 420 seconds with a rotation speed of 90 rpm. Both the temperatures in the edge and center increase linearly after the hot plate is turned on. Because of the convective flow of water in the pot, there is no difference in the temperatures at the center and edge of the pot. While stirring the water (t = 360 - 420 second) there is a small difference in the temperatures because the convective flow maintaining the uniformity of the temperature is distorted by the rotation of the water. After stopping the stirring, the water keeps rotating inertially for several minutes. Just after stopping stirring, the central temperature increases rapidly with a rate of increase of 30 degree per minute, which is more than ten times faster than the rate of increase before stirring (2.5 degree per minute). This sharp increase stops after 20 second and the difference in temperature between the edge and center reaches 10 degrees. The differences in temperature are kept for one and a half minutes, then the difference becomes small with the decrease of the central temperature.

The mechanism of sharp increase of central temperature can be explained as follows. The centrifugal force produces higher pressure near the edge then a downstream flow along the barrier and a flow toward the center along the base of the pot is driven by the non-uniformity of the pressure. Because the flow toward the center along the base is localized in a thin layer, the water in this flow continues to be heated when it travels from the edge to the center without rising up. As seen in Fig.3(a), the central temperature near the bottom of the pot is higher than that near the water surface. In general, the reversal of the temperature gradient (higher temperature at lower part of the water) is unstable, however, it can be sustained with rotation of the water. This phenomena contradicts common sense that hotter water rises to the top. During the steady state phase after the rapid increase of the central temperature, the flow in the thin layer along the bottom is damped and the upper temperature becomes identical to the lower temperature, which indicates that normal convective flow appears central region (r < 6 cm) as seen in Fig.3(b). The rotational flow still exists in the outer region (r > 6cm) and the upper part of the water is at a higher temperature than normally predicted. In this phase, the central region is governed by convective flow, while the outer region is governed by the rigid rotation.

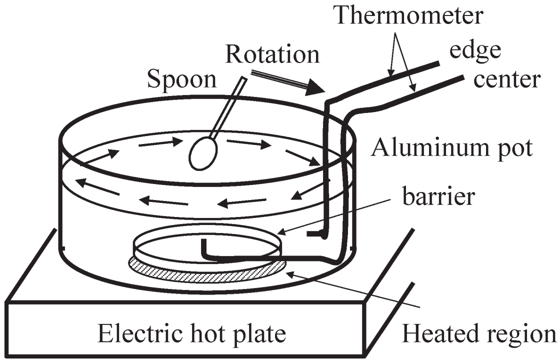

Fig. 1. Experimetal setup in the kitchen.

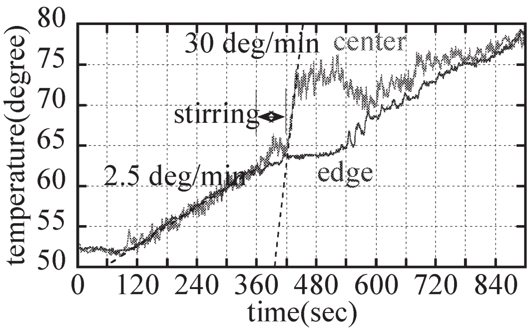

Fig. 2. Time evolution of water temperature measured at the edge and center in the pot near the bottom (10mm from the bottom of pot), when there is no barrier.

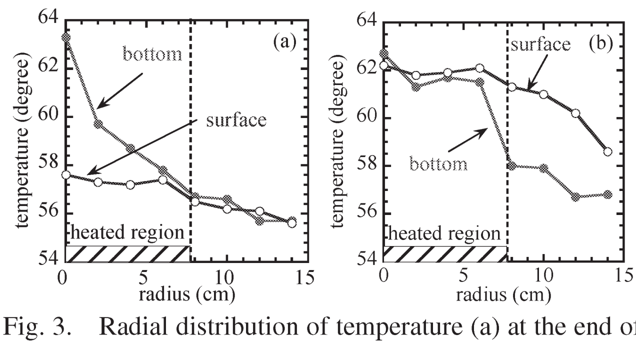

Fig. 3. Radial distribution of temperature (a) at the end of the rapid increase of temperature and (b) during the steady state phase after the rapid increase of temperature when there is no barrier.

Reference

1) Ida, K., et.al., American J. Phys. 73 (2005) 635