Turbulent Velocity Measurement of Rectangular Sub-channel Mixing Using Laser Doppler Velocimetry

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Abstract

The methodology used to measure water velocity across compound rectangular channels connected by a thin gap under balanced flow conditions is presented. The objective of this research is to generate sub-channel flow maps, which can be used to assess models used in nuclear safety analysis sub-channel codes. Laser Doppler Velocimetry (LDV) is used in order to obtain 2-dimensional (axial and transverse) flow velocity measurements of water in the sub-channels. The resulting flow distribution in the sub-channels shows bilateral symmetry with respect to the center of the gap, whereas the transverse maps are more irregular. Velocity measurements are taken at different heights above the mixing inlet in order to find the full development of the flow.

1. Background

The study of turbulent mixing is an important research area in thermalhydraulics which helps investigate different phenomena such as the presence of large-scale flow oscillations that occur during turbulent mixing in sub-channels [1]. Additionally, nuclear fuel burn-up and heat transfer are affected by the flow distribution of the coolant around fuel bundles. Thus, velocity and turbulence information can be used to analyze these parameters. For sub-channel thermalhydraulics codes, the mixing of coolant around nuclear fuel bundles can be approximated by the study of mixing around compound channels connected by thin gaps (H-shaped cross-sections). Therefore, the geometry tested in this experiment is two-interconnected rectangular sub-channels.

There are several efforts being made at McMaster University to investigate phenomena associated with turbulent mixing. Laser Doppler Velocimetry (LDV) is a valuable tool utilized for gathering experimental data which can be analyzed and compared with Computational Fluid Dynamics (CFD) models. The objective of this experiment is to investigate flow distributions in the sub-channels using the LDV system as an initial step towards the study of turbulent mixing phenomena.

1.1 LDV System

Velocity and turbulence intensity measurements in this experiment are acquired using a 2-component LDV system. An Argon laser beam is used to measure the velocity of small particles in water that flow in the sub-channels and gap. In order to assume that the velocity of the fluid is the same as the velocity of the particles, it is assumed that the particles measured are very small relative to the fringes' size [2]. Velocities are measured by two laser beams that intersect and generate fringe patterns. For each velocity direction (axial and transverse) there is a set of two beams: 514.5nm in wavelength for axial; and 488.0 nm for transverse direction. When particles move across the volume of interest, light is scattered as bright fringes are crossed. Consequently, a different fringe pattern with fluctuating intensities is created. The frequencies of the new pattern are proportional to the particles' velocities [2]. The system uses a specialized program, FlowSizer, to analyze and convert the frequencies obtained by the laser receiver into actual velocities.

1.2 Test Section

The test section analyzed consists of two identical sub-channels milled in acrylic. Each sub-channel has a rectangular base of 6.00mm by 14.42mm and is connected along their entire length by a 15.50mm by 3.82mm gap. The vertical length of both is 1524.0mm which represents a L/D_h of 172.66mm. The mixing section is at the inlet of the test section, which is located at the bottom. Figure 1 shows a schematic representation of the test section and its dimensions.

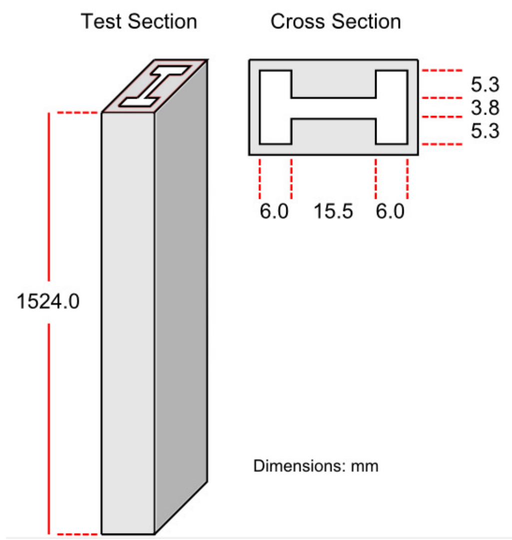


Figure 1: Test section dimensions

2. Experiment

Transverse and axial velocities are acquired and analyzed at different heights along the cross section in order to generate velocity flow maps that show the full development of the flow and the symmetry of the flow patterns with respect to the gap.

2.1 Experimental Loop

The loop consists of the acrylic test section previously described connected to two separate flow loops that are mixed at the inlet of the test section. The bulk water flow into and out of each of the sub-channels, is measured by Rosemount 8711 Magnetic flow meters which are logged by a LabView acquisition program. Water is pumped from a water tank through the loops by a 3 horsepower pump which is controlled by a variable frequency drive. Figure 2 shows a schematic representation of the experimental loop.

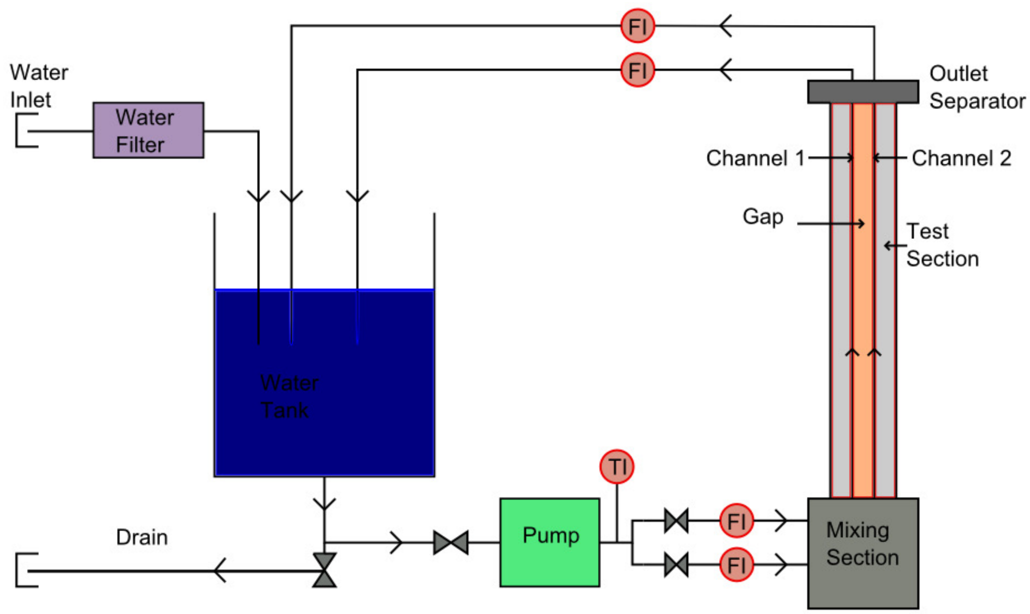


Figure 2: Experimental loop

2.2 Laser Setup

The laser is set up on a table adjacent to the experimental loop and is connected to a beam splitter for axial and transverse velocity measurements. It is then connected to the transmitter and receiver probes which are placed at opposite sides of the test section with the receiver positioned 30° off axis. Figure 3 illustrates this set up.

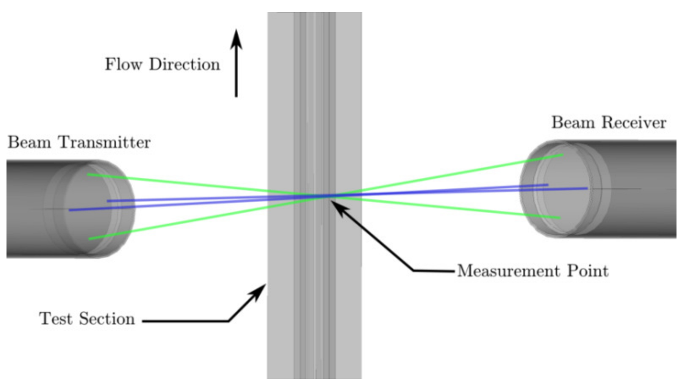
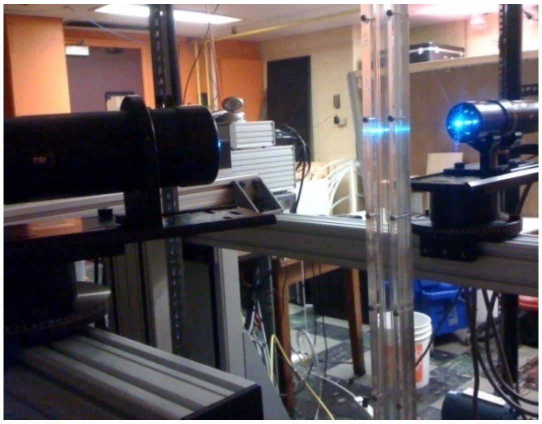


Figure 3: Receiver and transmitter probes positioning

The transmitter and receiver are bolted to a transverse arm which allows for remote control of the apparatus' displacement in the x, y and z directions. Thus, data can be acquired at different locations of interest within the test section. In order to acquire data, the receiver must be carefully positioned so that its focal length (30cm) coincides with the beams' intersection (coming from the transmitter). Both components are connected to a frequency and phase signal processor which is connected to a computer. FlowSizer is used to analyze the gathered data and calculate flow velocities. Figure 4 shows a picture of the TSI transmitter, receiver and transverse arm; as well as the laser beams intersecting the test section.



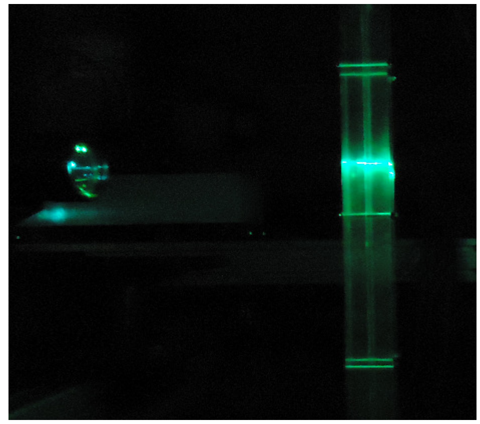


Figure 4: Receiver, transmitter and traverse arm (left); and laser intersecting test section (right)

2.3 Experimental Procedure

The LDV system is used to gather data of the axial and transverse velocity across the test section. The laser is powered at 2W (optical) and the pump is regulated to provide 1kg/s to each of the sub-channels and thus achieve an almost balanced flow. The electrical arm is used to move the transmitter and receiver probes as needed.

First, the z position (distance above the inlet) is chosen to define the cross-sectional area at which the transverse and axial velocities will be taken. The first measurements are acquired at a height of 100.0mm above the mixing section, where the flow is not fully developed. The subsequent step is to take measurements across the x and y direction every 0.5mm. Thus, a grid of points with two-dimensional data is acquired as presented in figure 5. With this data, it is possible to generate 3D and contour flow maps of both axial and transverse velocities.

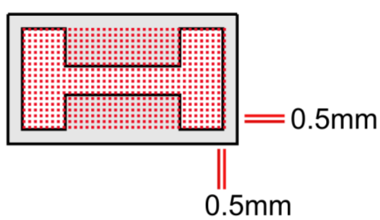


Figure 5: Measurement points' distribution

The parameters measured at each mesh point are: average axial velocity, average transverse velocity, Reynolds number and bulk velocity. At each point, 10000 measurements are taken. The average velocities are then calculated; and the uncertainties can be statistically found as the standard deviation of the samples gathered. The frequency at which data is acquired ranges between 500 and 1000 Hz. The experimental procedure is repeated at a height of 750mm, where it is fully developed.

3. Results

Figure 6 shows a sample plot of average axial velocity along the centre of one of the sub-channels across the y direction at a height of 750mm above the inlet section. Figure 7 shows a sample contour map of average axial velocity for the entire cross-section at the same height.

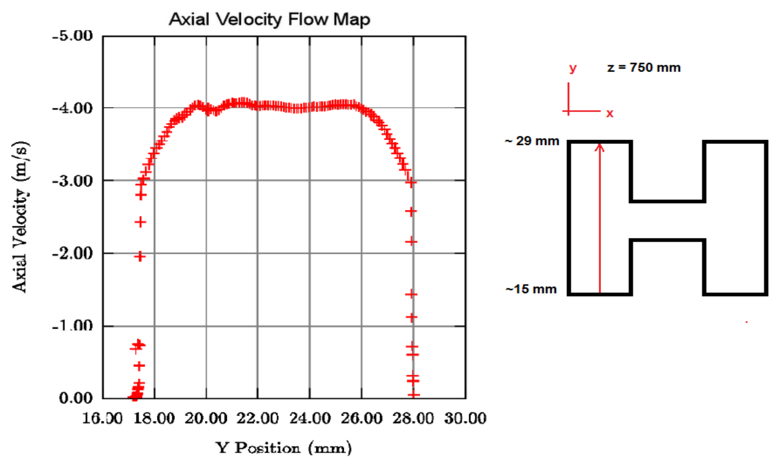


Figure 6: Average axial velocity across a sub-channel at a 750mm height

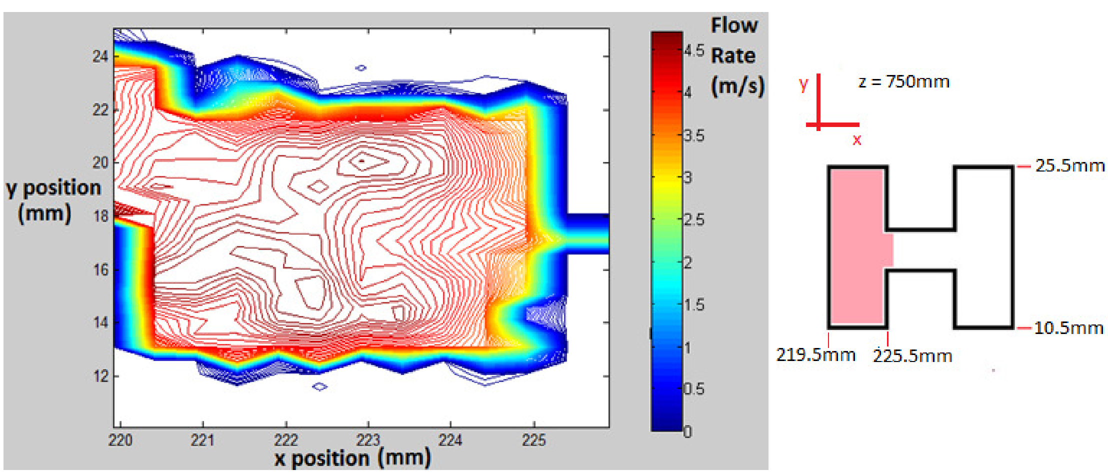


Figure 7: Contour map of average axial velocity across a sub-channel at a 750mm height

4. References

[1] L. Meyer and K. Rehme, "Large-Scale Turbulence Phenomena in Compound Rectangular Channels", Experimental Thermal and Fluid Science, Vol. 8, Iss. 4, 1994, pp. 286-304.

[2] H. –E. Albrecht, *Laser Doppler and phase Doppler measurement techniques,* Berlin, Springer: 2003, pp. 79-162.