Liquid Velocity Distribution in a Flat Channel with Sudden Expansion

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Abstract. The experimental study of the flow structure behind the sudden expansion of the flat channel is performed. The cross section of the channel is 20x200 mm and the step height is 12 mm. Visualization of the flow structure and measurements by means of particle image velocimetry (PIV) is performed using high power green laser sheet and CCD camera. Liquid velocity profiles are measured by means of laser Doppler anemometry (LDA). Automatic position system is used. The structure of liquid flow distribution evolution behind the sudden channel expansion is shown. The data about pressure drop is presented for different liquid flow rates.

1. Introduction
An important problem in the creation of energy-efficient equipment is the study of passive heat transfer intensifiers. Often, for this purpose, devices with flow separation are used. Such devices are simple and reliable, therefore they are often used in various technical devices, including high-energy equipment and burner chambers.

One of the simplest examples of such equipment is channel or pipe with a sudden expansion. Due to intensive vortex formation after expansion, a significant intensification of heat exchange processes occurs. Despite numerous research works on the matter, a number of questions are still open even for single-phase flows.

The effect of sudden expansion of the channel on the flow structure and on the coordinate of boundary layer reattachment was studied in [1]. The influence of periodic disturbances directed into the main flow or near-wall region was considered in [2]. Impacts were created using electromechanical or aerodynamic (jet) generators. The velocity profiles in a channel with a backward-facing step obtained using the PIV method were shown. Data on turbulent fluctuations in a given flow was presented.

The purpose of this study is to measure the velocity distributions by means of PIV and LDA in order to obtain information about fluctuation characteristics of the flow. The pressure drop behind the sudden expansion of the flat channel is studied as well.

2. Experimental setup
The scheme of the test section is presented in Figure 1. Experiments were carried out at liquid flow rate of 2.6 m³/h (Re = 6600). The experimental setup was a closed loop. The test liquid, distilled water, was pumped from the main tank through the flow measurement system and pressure water supply. For flow measurement, an ultrasonic flow meter was used. Uncertainty of flow measurement
was 2 percent of the measured value. The work area was a flat channel with dimensions of 1000x200x20 mm. To create a sudden expansion, a flat insert made of 600 mm long and 12 mm high plexiglass was mounted into it. The step height $H$ was 12 mm. In the experiments the liquid temperature in the loop was controlled in the range of 25.9-25.1 °C by the automatic system of thermal stabilization. At the inlet of the test section, the honeycomb grid was installed.

To measure the velocity profile in the channel, PIV and LDA were used. Polyamide particles with sizes of 20÷50 microns were added to the liquid. LDA system LAD-05 was used. The laser measurement volume was moved automatically using the control-moving device at the given coordinates. To build the grid the appropriate software was used. The coordinate grid represented a set of points with a certain step, spanning the channel from the near to the far wall. The pitch was 0.5 mm across the main channel width. Near the walls, the pitch was reduced to 0.1 mm due to the required increase in measurement accuracy. After obtaining the velocity profile at a certain distance from the step, the coordinate device was moved to collect data at the next distance from the step, where the velocity measurement started again. After the measurements were completed, the obtained data was exported to the program for post-processing. High power green laser sheet and CCD camera was utilized both for the flow visualization and organization of PIV measurements.

![Experimental setup](image)

Figure 1. Experimental setup: (a) – the scheme of measurements; (b) – the test section geometry; (c) – the photograph of the test section.

3. Experimental results

3.1. Liquid velocity distributions

In our first test we performed the flow visualization in the channel (Figure 2). It was conducted at a distance of 0-10 $H$ from the point of the sudden expansion of the channel. Positions of limits ($H = 0$ and $H = 10$) are shown as orange lines in the figure. Laser sheet and CCD camera were utilized in order to obtain the visualization data. Green laser with a maximum power of 1 W was used in our experiments. The power was set at 500 mW. Typical points of the flow can be clearly seen in the figure. At the top of the channel there is the zone of the high speed. The flow recirculation zone was
found just after the expansion point. It was found that for a single-phase flow, the location of the flow separation point is approximately 7–9 H from the ledge. After the reattachment point the organization of the flow in the channel starts. The zone with a high level of vorticity ends approximately at this point.

Liquid velocity distributions at different distances from the point of the sudden channel expansion obtained using LDA system are presented in Figure 3. Here $y$ is the distance from the bottom wall of the channel and $Y$ is the channel height (20 mm). Distances from the sudden expansion are marked in the right bottom parts of figures. The position $-2H$ is before the sudden expansion. A near parabolic velocity profile is found in this region. Just after the step ($H=0.6$) the recirculation zone with negative values of the liquid velocities is found. The maximum amplitude of the negative velocity is shifted to the bottom wall of the channel with increasing distance from the step. Similar data can be found in the literature. After the reattachment point the velocity profiles begin re-establishing. At the distance of $8H$ negative values of the mean velocities are not found. This is in a good agreement with our visualization data (see Figure 2). A good agreement between the velocity profiles obtained using LDA and PIV has been obtained.

![Figure 2. Flow structure visualisation behind the sudden expansion of the channel.](image)

![Figure 3. Liquid velocity distributions behind the sudden channel expansion.](image)

### 3.2. Pressure drop

Measurements of pressure drop were carried out. Two pressure taps were situated at -60 and 160 mm from the step position. The distance between taps was 220 mm. The U-type pressure drop manometer was utilized. Experiments were performed for different liquid flow rates ($Q_l = 2.6-5.6 \text{ m}^3/\text{h}$). Results are presented in Figure 4. The maximum pressure drop in our experiments was 20 mm (H2O). A good linear dependence for the root square of the pressure drop for various liquid flow rates was found.
Conclusions
Experimental investigations of the flow characteristics in a flat channel with a sudden expansion have been performed. Laser sheet visualization, LDA, PIV and pressure drop monitoring were used as test methods. The data on the liquid velocity distributions and pressure drop is presented. The presented data base may be used for verification and validation of modern numerical codes based on RANS and LES approaches at IT SB RAS.

In our further investigations, the structure of two-phase gas liquid flow in this geometry will be studied both experimentally and theoretically. PIV/LIF system will be used. Numerical simulation will be carried out using LES approach.

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References
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