Chapter 3

Application to creeping flow around moving cylinder

3.1 Introductory remarks

A lot of research related to the study of liquid flow behavior has been conducted in the past. In order to enhance the operating performance of machine such as the heat exchanger in largest equipment of energy facilities to the smallest device of micro-reactor, the study of liquid flow behavior has been extensively applied in various industrial fields. Until now, numerous measurement techniques have been developed in order to investigate the flow characteristics in those equipments.

Through our survey, quite quantitative works [1], [2], [3], [4], [5], [6] have been dedicated to clarify the liquid flow behavior in micro-channel. For example, Ngoma and Erchiqui [7] through their mathematical calculation investigated the effects of slip coefficient and heat flux on the liquid flow in between two plates of micro-channel. They confirmed that the liquid flow behavior in the micro-channel significantly affected by the slip coefficient, pressure difference, heat flux, electro-kinetic separation imposed to the liquid but in various ways of affection.

On the other hand, Kawahara et al. [8] conducted their experimental work to investigate the effects of various liquid properties on adiabatic two-phase flows in a micro-channel. Among their findings, bubble in the micro-channel with contraction flow was found to elongate and rapidly flow and thus causing the reduction in the void fraction. Another experiment of bubble in micro-channel was done by Luo and Wang [9] through their 3D-PIV system. Through their experimental test, the measurement accuracy was slightly affected since the seeding particles stuck around the walls of the micro-channel.

The measurement method of PIV has been developed time to time to enhance its application in various liquid flow fields not only in relatively large scale of flow, but also in the thin micro-channel and thin liquid film flow. However, the limitations that usually caused by the seeding particles is inevitable. As an alternative technique to clarify the flow behavior of liquid film in various flow fields, laser tagging method using photochromic dye tracer is developed.
In this study, we applied the laser tagging method to study the creeping flow of moving cylinder in a rectangular channel with the aim to evaluate its applicability in the flow field measurement.

3.2 Objective of this experiment

The purpose of this experiment is to assess the applicability of laser tagging method by photochromic dye tracer to the measurement of fluid flow. The experiment is carried out to visualize the creeping flow around a moving cylinder. From the movement of the dye traces, the velocity profiles of the creeping flow in the rectangular cavity are measured. The dye traces are formed in a dot matrix shape to allow vorticity and divergence characteristics of flow field.

3.3 Methodology

3.3.1 Experimental setup and procedure

Figure 3-1 shows the schematic view of the experimental setup for the creeping flow experiment. We generated the flow test by using a circular cylinder with diameter, \( d_c = 10 \text{ mm} \) placed in a channel (length=190mm, width=50mm, depth=20mm) and connected to a movable stand. The circular cylinder was moved by the movable stand with a constant velocity, \( V_c = 18.8 \text{ mm/s} \). The depth of the liquid was approximately 15mm.

Above the channel, UV laser light (\( \lambda = 248 \text{ nm} \)) sourced from a KrF Excimer laser was irradiated to the liquid film surface to activate the photochromic dye traces. The laser light was possible to be irradiated around the moving cylinder by using the laser tagging method. However, the irradiation timing must be controlled accurately. In order to achieve the closest visualization of wake flow around the cylinder, we irradiated the laser light around 4mm from the cylinder edge. The laser pulse was 17ns in duration and 450mJ/pulse in energy.

Furthermore, a 20mm×20mm screen plate composed of arrayed holes (diameter=0.5mm, pitch=2mm) was placed on the laser light path to form a set of dot matrix dye traces. A cylindrical lens was placed before the screen on the light path to expand the irradiation range of the UV light. Moreover, a halogen lamp was used as the lighting source to assist the visualization of the dye traces movement.
The traces images were then captured by CCD camera and recorded by a video camera recorder (SONY's DCR-TRV20) with 30fps at 3008×2000 pixel resolution. Thus, the spatial resolution of actual space and temporal resolution were respectively, 17μm and 0.03s. The motion pictures were then transferred to a still image data for analysis. The images were changed to the binary images in order to enhance the contrast between liquid and dye traces. The position of the each dye trace was determined by digitizing their coordinates.

![Fig. 3-1 Schematic view of experimental setup for creeping flow experiment](image_url)

3.3.2 Experimental condition

The Reynolds number, $Re$ is defined by the following equation:

$$Re = \frac{\rho V_c d_c}{\eta}$$  \hspace{1cm} (3-1)

where, $\rho$ is the density, $V_c$ is the cylinder velocity, $\eta$ is the dynamic viscosity of the working fluid and $d_c$ is the cylinder diameter. The experiment was conducted at three positions in $x$-axis around the cylinder, i.e. $-15\text{mm}<x<10\text{mm}$, $10\text{mm}<x<15\text{mm}$ and $25\text{mm}<x<30\text{mm}$. The cylinder was moved in negative direction of $x$-axis. The Reynolds number, $Re$ was fixed at 61 (cylinder velocity, $V_c=18.8\text{mm/s}$). The experiment was done at room temperature, $T_e = 20\text{--}22 ^\circ\text{C}$.  

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