Free Falling Film Flow in a Rectangular Channel

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Free Falling Water Film Flow in a Rectangular Channel

—— Introduction

➩ Flourish in the research on liquid film flow up to the present

- ✧ Film velocity and its distribution
- ✧ Film thickness
- ✧ Film interfacial structure
- ✧ Stochastic characteristics of film flow
- ✧ Effect of interfacial gas flow on film
- ✧ Effect of wall shear stress on film flow
- ✧ Film flow with a countercurrent gas flow
- ✧ Wavy film flow instability analysis
- ✧ etc.

➩ Rectangular Channel to be used in the research program of magnetohydrodynamic film flow

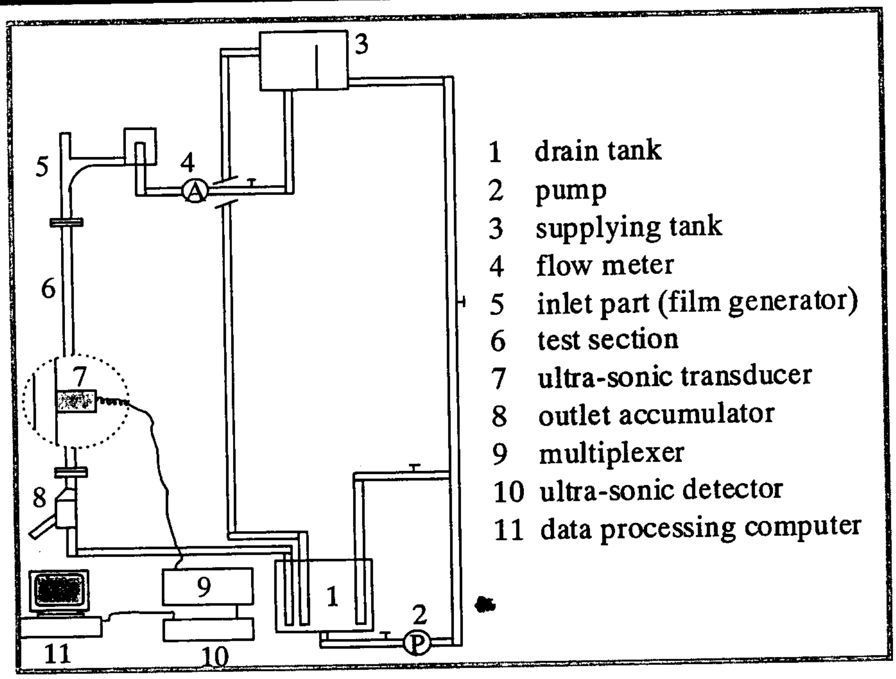
- ✧ There must appear some special characteristics in the film flow of such rectangular channel

➩ Experiment on the rectangular channel with water & Glycerol solution as working liquids

- ✧ To clarify some different phenomena from the conventional understanding
- ✧ To clarify the special characteristics on the free falling film flow of high viscosity Liquid, e.g. Glycerol
- ✧ As a prelude of the research program of MHD channel film flow

Free Falling Film Flow in a Rectangular Channel

—— Experimental equipment and technique



- ✧ Multiplexer has 8 channels with frequency of 24kHz.
- ✧ The maximum sampling rate of AD converter is 10MSps (Mega-Samples per second), and memory limitation of it is 16M words.
- ✧ Pump and the two tanks were cooled so that an approximately constant temperature condition was maintained.

Fig.1 Schematic diagram of experimental setup

Free Falling Film Flow in a Rectangular Channel

—— Experimental equipment and technique

➩ Ultra-Sonic Transmission Technique

——— a Non-Intrusive Measuring Approach

$\delta = t \times v/2$

where δ is thickness

t, to and from ultra-sonic flight time,

v, propagation velocity of the ultra-sonic in the certain material

- Ultrasonic transducers are served as both the wave emitter and the reflected wave receiver
- In this test, frequency of ultrasonic wave is 10MHz, and emission frequency is 10kHz. Transducers used are 1 mm in diameter of sensitive region, and 2 mm in total diameter including the metal shell.

Free Falling Film Flow in a Rectangular Channel

—— Experimental equipment and technique

➪ Data Collection and Process

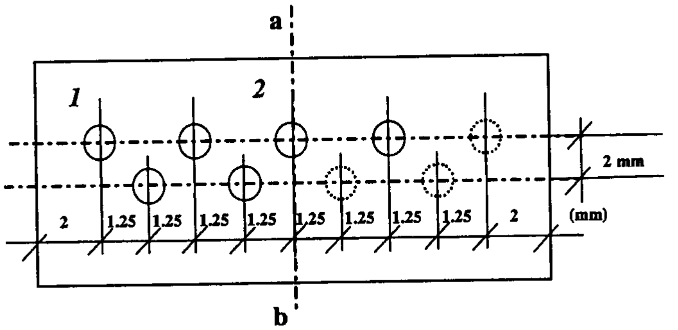


Fig.2 Diagram of ultra-sonic wave transducers arrangement in the carrier

- ✧ **Six transducers were used**
- ✧ **Seven of eight multiplexer channels were set on, one of which was empty**
  for the purpose of distinguishing the correspondence between transducers' signals and their positions
- ✧ **Three postulated points correspond symmetrical points about line a-b**
  the three postulated points were used when calculating the mean film thickness of the whole channel and depicting an whole surface image of the falling film
- ✧ **The mean film thickness of the whole channel is calculated in a weighted value using the data of nine points (including the three postulated points).**

Free Falling Film Flow in a Rectangular Channel

—— Experimental equipment and technique

➪ Data Collection and Process

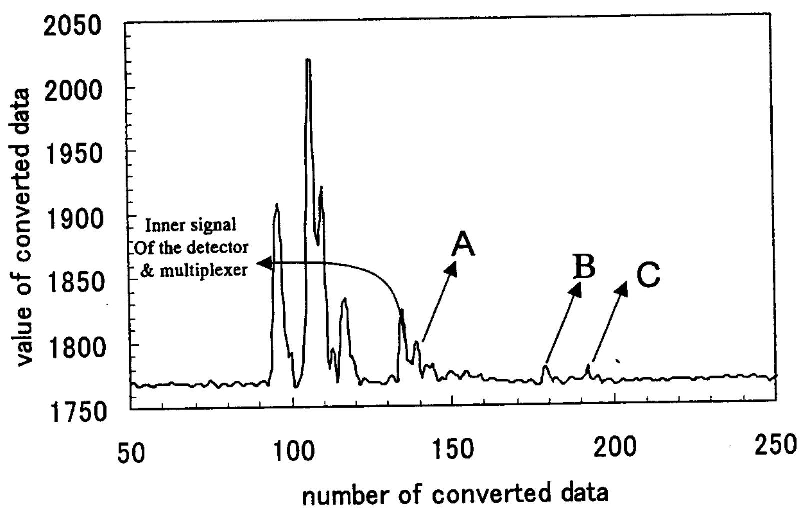


Fig. 3 An example of raw signal obtained by ultra-sonic wave echo and data processing system

- ✧ **Peak A is the reflection at transducer surface (interface between transducer and outer wall surface)**
- ✧ **Peak B represents reflection at interface of inner wall and liquid**
- ✧ **Peak C is reflection at liquid free surface**
- ✧ **The forward peaks are the inner signal of the detector & multiplexer**
- ✧ **Distance between peak A and B corresponds with to & fro ultra-sonic wave flight time in the wall, and so does which between B & C in the liquid film**

Free Falling Film Flow in a Rectangular Channel

—— Experimental conditions

- Both experiments of water and Glycerol-water solution (with Glycerol mass concentration of 45%) were carried out on the same loop
- In the case of water, temperature ranged from 13-17℃, of which the density equals to about 1000 (Kg/m^3), and kinematic viscosity 1.216-1.096 (10^{-6} m^2/s). The variation of ultra sonic expansion velocity in water with changes of temperature were also considered.
- In the case of Glycerol, liquid temperature was maintained from 11.0 to 12.6 ℃, by cooling pump and the two tanks. In this range of temperature, the density is about 1117 (Kg/m^3), and kinematic viscosity 6.94 to 6.37 (10^{-6} m^2/s). The sonic velocity in Glycerol was testified to be around a constant, 1693 (m/s).
- The maximum liquid flow rate was limited by the height difference between positions of upper supplying tank and inlet of test section (i.e., Head).
- Reynolds number is defined as, $Re=4\Gamma/\nu$,where Γ is the volumetric flow rate of liquid per unit wetted perimeter (for the rectangular channel, wetted perimeter D was chosen as, $D=L+2\delta_{mean1}$,where L is the width of channel, δ_{mean1} average local thickness at corner region, i.e., position 1 in Fig.2.) and ν the kinematic viscosity. For case of water, Re varied from 1241 to 7525, and that for the case of Glycerol, 617 to 982.

Free Falling Film Flow in a Rectangular Channel

—— Results

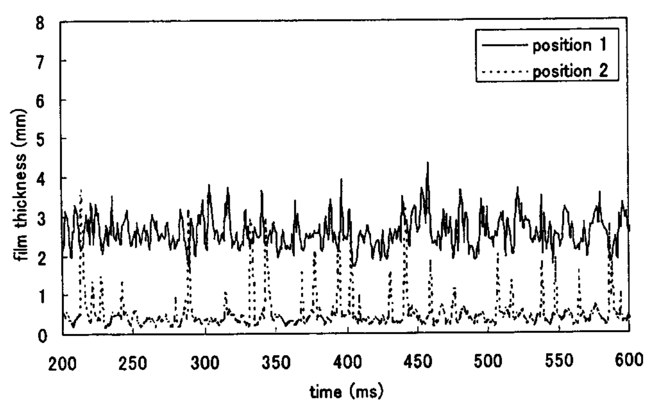


Fig.4 Time traces of liquid film thickness, at longitudinal position of 1000 mm and horizontal position of 1 and 2 (in Fig.2) with Re=6056, Q=1.66 liter/min (for case of water)

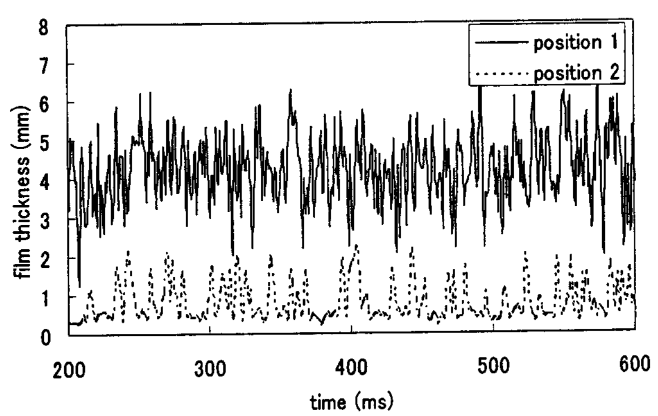


Fig.5 Time traces of liquid film thickness, at longitudinal position of 945 mm and horizontal position of 1 and 2 (in Fig.2) with Re=799, Q=1.65 liter/min (for case of Glycerol)

- Common wave phenomena large waves and small waves coexist on the surface of film
- different characteristics at point 1 and 2 (see figure 2)
  - thickness amplitude
  - frequency of large wave
- Non-uniform mass distribution in the rectangular channel (see next page, surface image)

Free Falling Film Flow in a Rectangular Channel

—— Results

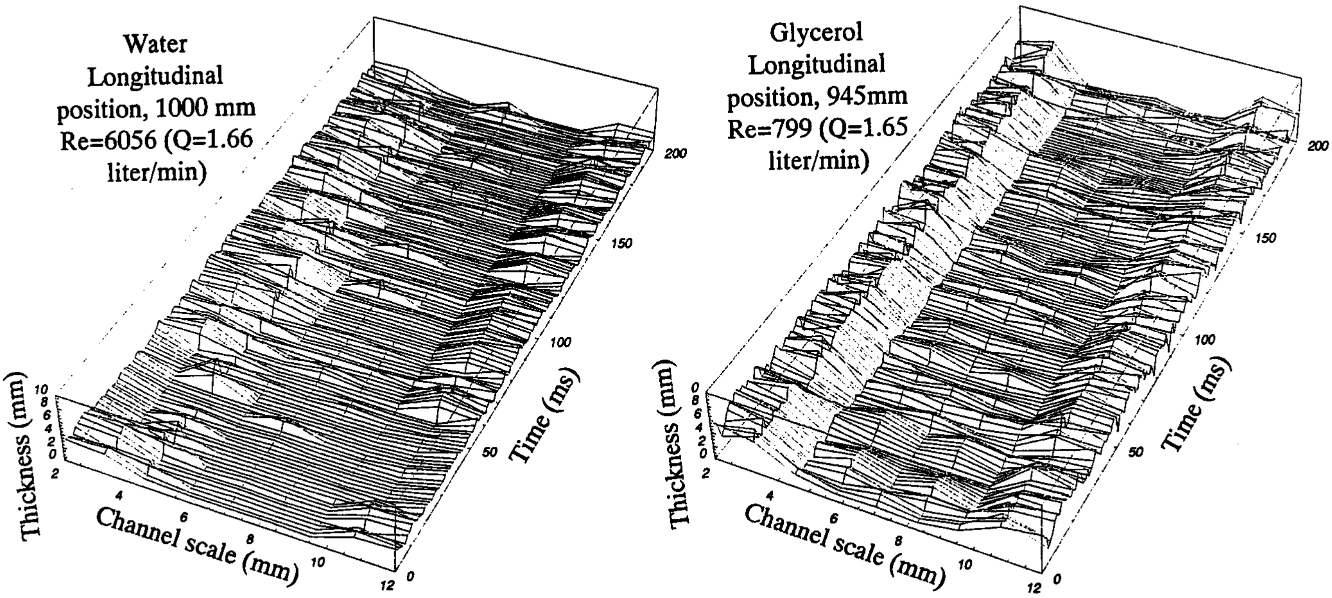
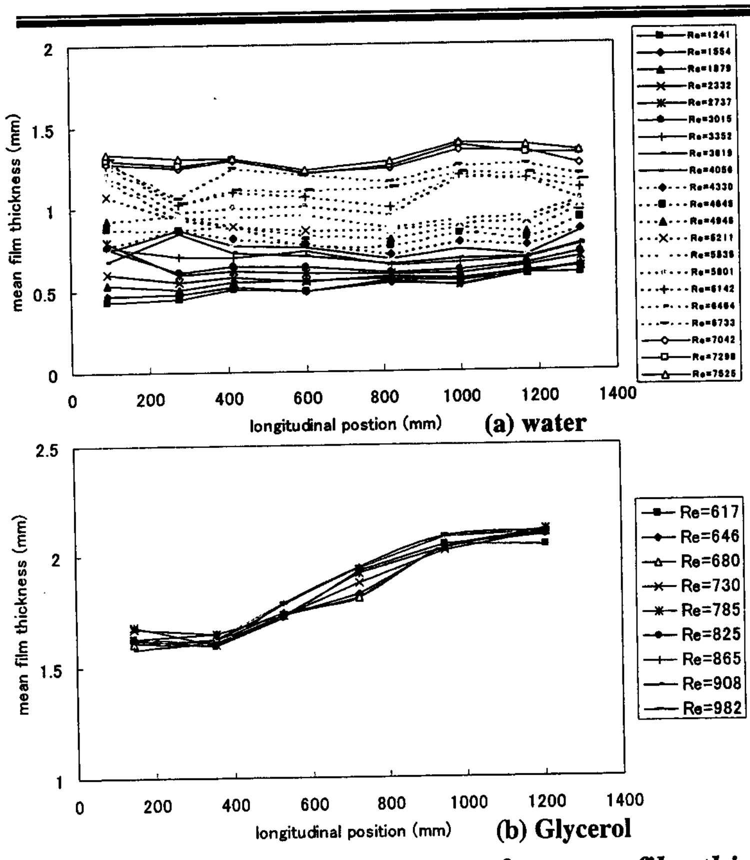


Fig.6 Time dependent surface image of free falling liquid film flow in a rectangular channel

✧ Shape of the wavy free surface & Mass distribution in the rectangular channel

Free Falling Film Flow in a Rectangular Channel

—— Results



✧ The fact that film thickness increase with Reynolds number at each position, although there are several exceptions.

✧ Of the same Reynolds number, mean film thickness keeps approximately constant.

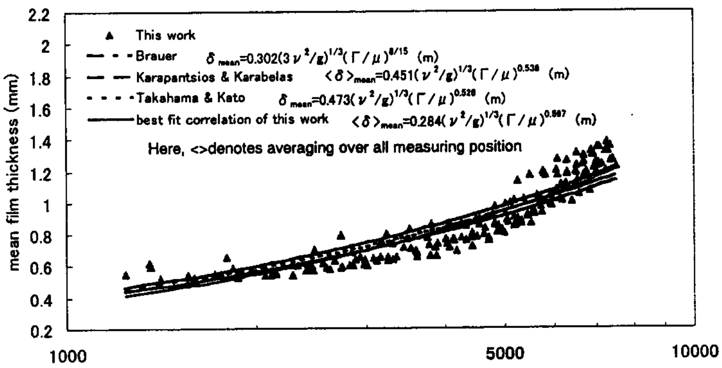
✧ For the case of Glycerol solution, it interestingly shows a completely different variation trend from that of case of water.

✧ mean film thickness changes in a very small range with the change of Reynolds number at any individual longitudinal position

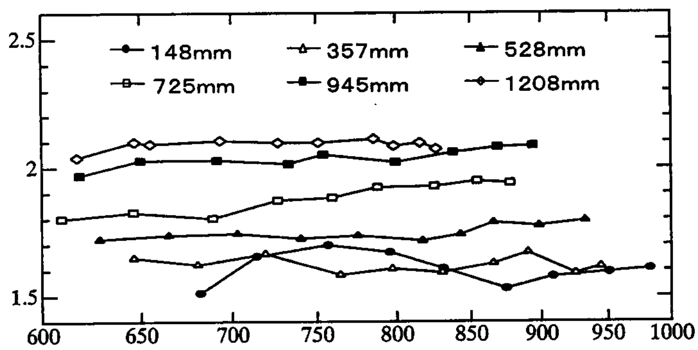
✧ the reason why there appears such a peculiar phenomenon comparing to the conventional understandings about free falling liquid film flows will be investigated further.

Fig.7 Longitudinal distributions of average film thickness

Free Falling Film Flow in a Rectangular Channel
—— Results



Reynolds number **(a) water**



Reynolds number **(b) Glycerol**

Fig.8 Variation of the mean film thickness with Reynolds number

- ✧ the so-called best fit correlation of data was done in the way similar to that of other researchers, however it seems that, in this case, the mean film thickness doesn't exponentially vary with the Reynolds number, as it does in other researches. That may be due to the shape of flow channel, then the non-uniform mass distribution in channel.
- ✧ A turning-point of the variation of mean film thickness can be noticed around Reynolds number of 3700. When Re>3700, mean film thickness increase in a much steeper slope.
- ✧ For the Glycerol case, similar to that Fig.7 shows, the variation of mean film thickness with Re is also quite different from that of the case of water.
- ✧ At any individual location, the mean film thickness of channel keeps approximately constant with the change of Re. However, it surprisingly increases with the increase of longitudinal distance (from the top of test section).

Free Falling Film Flow in a Rectangular Channel
—— Remarks

✧ **Experiments on the rectangular channel** with the same size as that of the research program of MHD film flow and **with water & Glycerol-water solution** as the working liquid have been carried out.

✧ By use of the **ultra-sonic wave transmission technique**, local liquid film thickness on six points was measured at different longitudinal positions and then the time dependent surface image of free falling liquid film flow in a rectangular channel was depicted, a non-uniform trough-like shape of the liquid surface in the channel was observed.

✧ The **average film thickness** of the whole cross-section of liquid film was evaluated by the weighted average value of nine points with different Reynolds numbers at each longitudinal position.

- For case of **water**, although the variation trend of the film thickness with longitudinal position and with Re in this test was similar to the results obtained by other researchers, there were many differences from them due to the different channel shape.
- For the case of **Glycerol**, it showed rather different phenomena with the conventional understandings of free falling liquid film flow. Further investigations on it are needed.

✧ **As a prelude of the research of channel film flows in the presence of magnetic field, Ultra-sonic transmission technique was confirmed to be feasible.**