Flow Field Visualization of Vapor Condensation in the Enclosure

By

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1. Introduction

A study of thermo-fluid dynamics including phase-changes of fluid in enclosures has been paid a wider attention recently in connection with the practical requirement of developing effective heat transfer systems and devices, such as thermosyphons or heat pipes. Although the subject has long been one of the central themes in heat transfer problems, the incompleteness in understanding the vaporization and condensation mechanisms of fluid makes it difficult to formulate a sound modeling of the flow field for obtaining an optimum design of safety equipments for power plant, cooling systems for building, and various heat exchangers for industrial applications. A detailed flow field survey and heat transfer in enclosures shall be most appreciated as a fundamental and necessary step to investigate these problems.

In this report, a fundamental investigation is conducted for flow field undergoing vapor condensation onto the flat plate in a simple thermosyphon. Flow visualization by means of laser holographic interferometry is implemented along with supplimentary temperature and pressure measurements of vapor in the vessel.

2. Experimental Setup and Method

2.1. Laser Holographic Interferometer

A 5 mW He-Ne laser holographic interferometer was used to take flow visualization pictures in this experiment, the layout of which is schematically illustrated in Fig. 1. After the optical system be properly aligned and the ratio of object beam intensity to that of reference beam correctly adjusted by the optical filter, pictures are taken

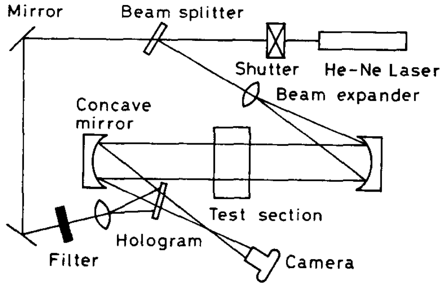

Fig. 1. Schematic Illustration of Laser Holographic Interferomater.

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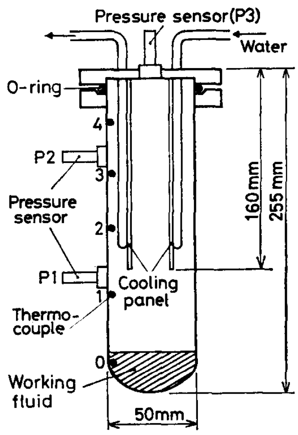
under various thermal conditions by means of real-time exposure technique.

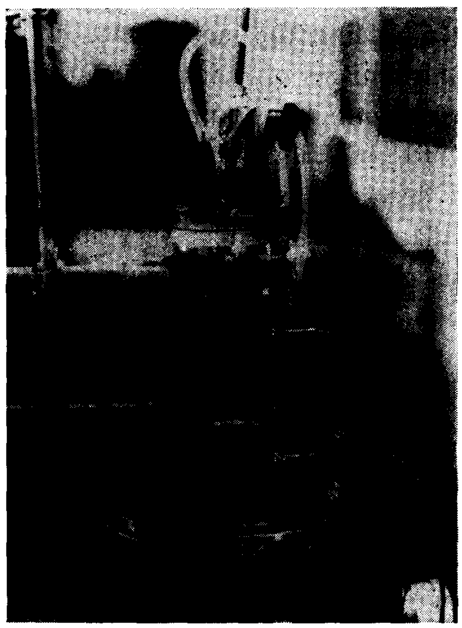
2.2 Thermosyphon Model

Figure 2 shows a schematic illustration of thermosyphon model and its picture settled in the water bath. It is a specially designed Pyrex glass tube with square cross-sectional area of about 50-by 50-mm with 200 mm in length, which is connected to the circular tube of 50 mm long to be capped by the sealing flange. On the bottom side of the flange, a pair of rectangular cooling panels of 37-by 160-mm in size and 1 mm in thickness backed with a *U*-shaped coolingwater pipe are set in parallel about 22 mm apart each other to realize a two dimensional condensation test section in the model.

Three pressure transducers and four copper-constantan thermocouples are installed on the model. Pressure sensors are set flash with the glass surface to measure surface pressure, and thermocouples are protruded into the vessel about 2 mm to measure vapor temperatures.



(a) Schematic View and Sensor Location



(b) Picture of Model in Water Bath

Fig. 2. Thermosyphon Model used in Experiment.

2.3. Real-Time Interference Hologram[1)]

Pictures of fringe pattern for vapor flow field in condensation region are taken in the following processes; firstly, a thermally equilibrium initial condition of the test section (i.e. condensation region before heat energy is applied) is stored on the AGFA-GEVAERT film plate, and secondly, after processed, this plate (hologram), is placed back to the same position as a reference, then finally, the fringe patterns which appears as a result of interference of current object beam with that of initial conditions stored in this reference hologram corresponding to the density change of vapor generated by heating in the thermosyphon is taken on a regular 35 mm (ASA 400) film by camera.

Two kinds of interference fringe pattern are possible to be taken in the picture; one is a displacement fringe pattern and the other, a density contour fringe pattern. The former is obtained as a result of relative movement of the initially arranged reference fringes caused by a vapor density change. This fringe pattern, therefore, is useful for detecting a small deviation of density distrubution from the reference condition, but requires a delicate adjustment of optical equipments at the time of initial fringe pattern setting as well as a careful data processing of fringe movement. On the other hand, the latter is obtained means on the initially non-fringe (or infinitely focused fringe) condition on the film. Data processing for the latter is rather straightforward, since the fringe pattern realized corresponds directly to a density distribution of the vapor.

2.4. Measurement

Most of the pictures were taken by means of density contour fringe method, although those by displacement fringe method were also obtained to compare the relative advantages of both methods.

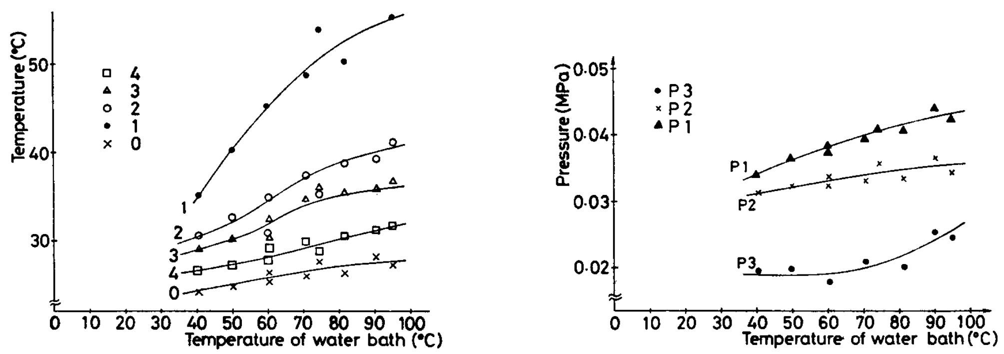
All the data were taken after thermal equilibrium had established in the thermosyphon model settled in the water bath, with cooling panels always kept at uniform temperatures of about 20°C by a water circulation. Four kinds of pure liquids, viz. distilled water, benzene, acetone and Freon 11 were used as working fluid for the purpose of examining the effect of difference in latent heat on the vapor condensation flow field.

Typical Reynolds numbers based on the estimated vapor speed from the measured heat transfer rate and on the gap distance between two cooling panels were about in the order from 50 for distilled water to 200 for Freon 11.

3. Results and Discussions

Followings are a part of typical results obtained in the experiment.

Figure 3 shows temperature and pressure distributions for acetone in the steady state operation of thermosyphon, with temperature changes of water bath as a parameter. These distributions indicate that the vapor in the vesel is not thermally uniform, but has a fairly large temperature (and, therefore, dinsity) gradient. Mea-



(a) Temperature Distributions (b) Pressure Distributions

Fig. 3. Temperature and Pressure Distributions in Thermosyphon for Acetone as Working Fluid

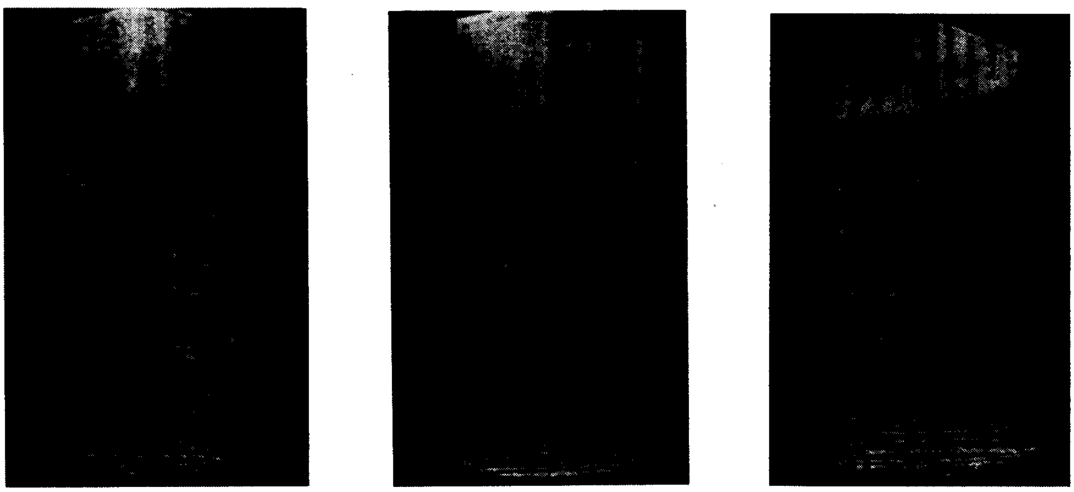
sured pressures are all much lower than the saturated vapor pressures predicted by the corresponding temperature data of Fig. 3 (a). It is probably due to the fact that the pressure sensor does not detect the vapor pressure correctly, since it is covered with a thin liquid film followed by a kind of thermal layer of condensing vapor created near the wall. The reason of lower liquid temperature (at thermocouple #0) than the adjacent vapor temperature (at thermocouple #1) is probably due to the low thermal conductivity of acetone liquid which, again, may cause the thermal layer between the liquid and the vapor. However, more detailed investigation shall be continued to evaluate these data of temperature and pressure distributions in the thermosyphon model.

Some typical steady state flow patterns or density distributions of condensing vapor visualized by the method of density contour fringe pattern technique are shown in Fig. 4. By now, no clear pictures are available for distilled water as working fluid due to shortcoming of experimental setup, so that the inevitable formulation of water drops on the inner wall of the vessel completely cover up the inside view of the flow field and distort fringe patterns. Although the obtained fringe patterns in the figure look similar for all three fluids, the spatial distributions in the vicinity of the cooling panel are apparently different; acetone has a largest spatial density gradient perpendicular to the panel surface, while benzene has a medium and Freon 11 has a smallest.

An existence of fairly large density gradient region which may be called "condensation layer" is quite contrary to what we have initially expected, since we have had the image of very thin, so-called Knudsen layer between the condensing vapor and the liquid film on the cooling panel.

Another feature indicating these pictures is that vapor condensation seems to be taken place quite uniformly on the cooling panel except for a lower region of about one-fifth from the bottom edge where a large density gradient is occurred along the panel surface.

General view of a rate of density change in the flow field for benzene is shown in



(a) Acetone (R_e=73, T_v=36°C) (b) Benzene (R_e=190, T_v=48°C) (c) Freon 11 (R_e=114, T_v=18°)

Fig. 4. Laser Hologram of Flow Field of Vapor Condensation Region.

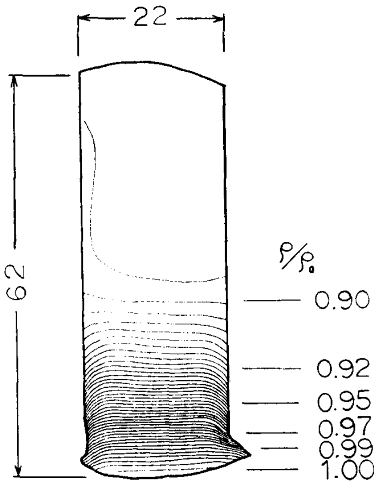


Fig. 5. General View of Rate of Density Change for Benzene.

Fig. 5, which is processed from the date of Fig. 4(b) as the vapor density at the lowest fringe in the picture by a reference.

4. Conclusion

Flow fields of the condensing vapor in the two dimensional thermosyphon were visualized by virtue of a real-time laser holographic interferometry. The measured spatial density distribution is much larger than we have expected, which implys the existence of fairly thick transient layer of condensing vapor. called "condensation layer" where temperature and density changes of vapor are fairly large.

Further investigation shall be continued with the emphasis on the detailed survey on this condensation layer to clarify the mechanism of vapor condensation on the solid surface in enclosures.

References

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