Augmentation of Film Condensation on the Outside of Horizontal Tubes

LEON R. GLICKSMAN, B. B. MIKIC, and DONALD F. SNOW

Department of Mechanical Engineering
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

For ordinary pressure ranges in the absence of noncondensable gases, the controlling resistance in film condensation is the conduction resistance through liquid film. For condensation on the outside of a horizontal tube, the liquid film thickness (Figure 1a) increases along the tube periphery, and consequently the condensation heat transfer coefficient decreases from the top of the tube, where it is highest, to the bottom, where it reaches its lowest value (Sparrow and Greg, 1959). In fact, the contribution of the area near the bottom of the tube to the overall performance is rather small. It is clear that a reduction of the film thickness in this area should augment the heat transfer performance.

This investigation considered augmentation of film condensation by breaking the condensate layer with a nonwetting strip. A Teflon strip was used, with water as the condensing fluid. The concept is schematically shown in Figure 1b. The flow of condensate from the upper part of the tube is interrupted by a slightly inclined tape. Below the tape, new condensate with a thinner film will be formed. Several mechanisms could contribute to the augmentation of heat transfer for this configuration. The most obvious is the formation of a new thinner layer on the lower half of the tube. Secondary flows caused by thermocapillary forces at the film break could also augment the heat transfer.

In this investigation a variety of tape arrangements were used to demonstrate experimentally the augmentation of condensation heat transfer achieved by breaking the film and to attempt to determine the most favorable tape geometry.

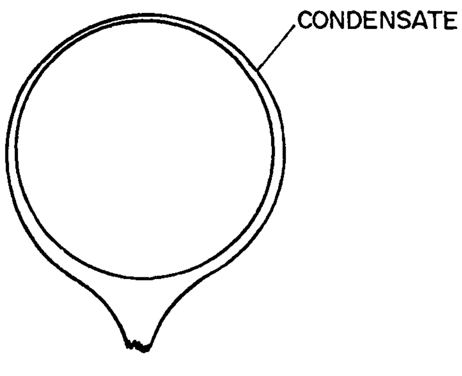

Fig. 1a. Normal condensing film.

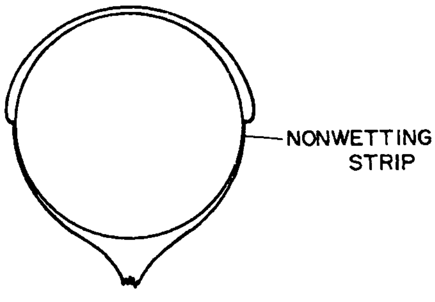

Fig. 1b. Film with nonwetting strips.

EXPERIMENTAL PROGRAM

Description of Apparatus

The apparatus is schematically shown in Figure 2. The test sections were made from 1.27 cm copper tubing. The condenser was 30.48 cm long and the shell diameter was 10.16 cm. The coolant was water.

The Teflon used in these tests was in the form of a tape with an adhesive backing, 3.2 mm wide and 0.16 mm thick.

The same two copper tubes were used for five different types of tape geometries and an additional test was made with bare tubes. All tape geometries are shown in Figure 3.

The total condenser heat flux was evaluated from the coolant flow rate and temperature rise. The temperature was measured with copper-constantan thermocouples before and after

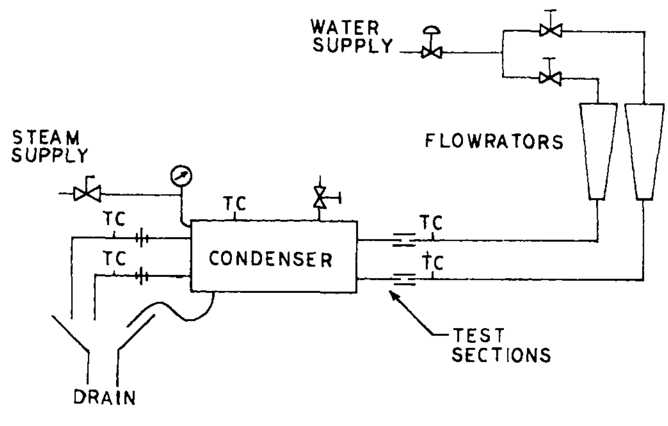

Fig. 2. Schematic of the apparatus.

the test section respectively. The steam temperature was also measured by a thermocouple.

A complete description of the apparatus and procedure is given in Snow (1969).

RESULTS

Noncondensables

It is important to eliminate noncondensable gas effects from the experiments. In the initial test series the steam supply pressure was increased to raise the steam velocity through the test chamber until the overall heat transfer coefficient reached a constant value corresponding to negligible noncondensable gas effects.

The lower tube gave erratic results because of its proximity to the condensate drain where splashing and some blowback occurred. Also the two tubes were widely spaced and condensate from the top tube splashed intermittently on the lower tube. Therefore, all of the results presented in this paper are for the upper tube.

Heat Transfer Coefficient

The rate of heat transfer to the top tube was found from an energy balance on the water flowing inside the tube. The condensation heat transfer coefficient on the outside of the tube was calculated from the overall coefficient, allowing for the radial conduction through the tube wall and predicted heat transfer coefficient for flow inside the tube. The latter value was found from the modified McAdams correlation (Rohsenow and Choi, 1961) with a correction for entrance effects based on the work of Hartnett (1955).

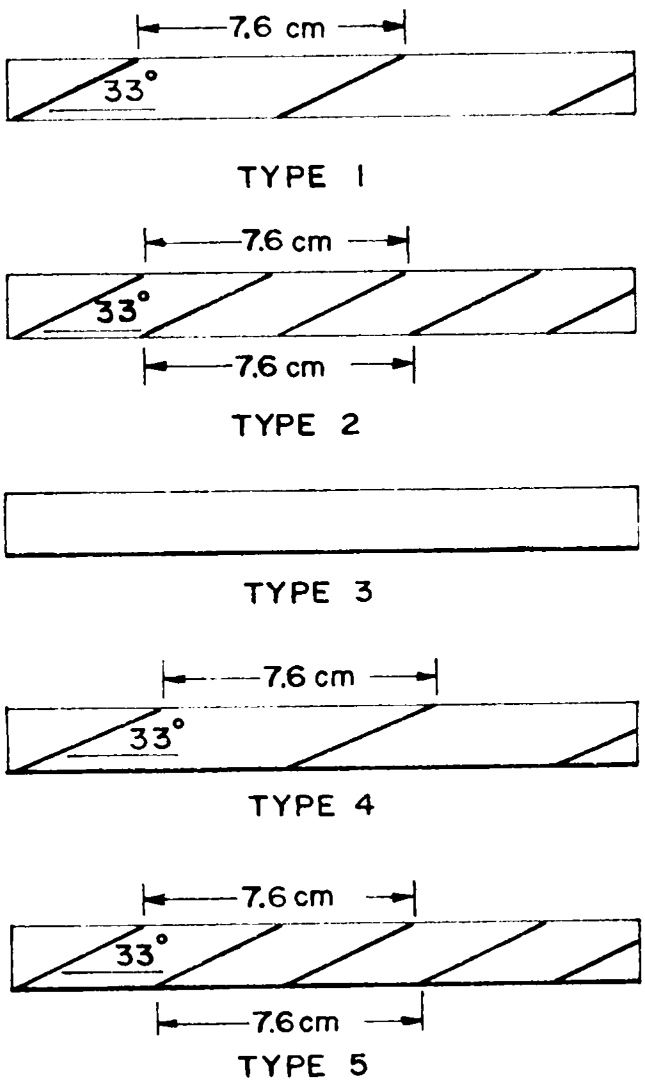

Fig. 3. Nonwetting strip configurations on the outside of the tube.

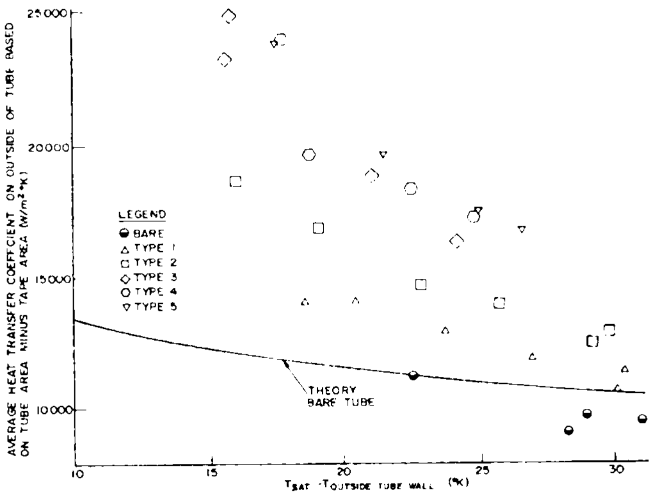

Fig. 4. Heat transfer coefficient for nonwetting strips and for bare tubes.

The heat transfer coefficient based on the tube surface area less the tape area is presented on Figure 4. Since the tape has a very poor thermal conductivity, the area covered by tape is essentially insulated. All of the taped configurations show an improvement over the bare tube. Types 3, 4, and 5 give approximately the same results: all have tape on the bottom. There is only a modest improvement in the heat transfer when the film is also interrupted along the sides of the tube. Therefore, the bottom tape configuration is most important for heat transfer improvement.

The heat transfer improvement due to nonwetting strips is less noticeable at high temperature differences, that is, at high condensation rates. At high condensation rates, the thick condensation film may be able to bridge the barrier of the thin nonwetting strip. Thicker nonwetting strips should be investigated in the future.

CONCLUSIONS

Experimental results showed that heat transfer in film condensation outside a horizontal tube can be substantially augmented (up to a factor of 2) by breaking the film with nonwetting horizontal strips. Of all the geometries tested, it appears that the most effective one is the tape positioned at the bottom of the tube.

The observed augmentation is caused mainly by reduction of the condensate layer thickness.

LITERATURE CITED

Cary, J. D., and B. B. Mikic, "The Influence of Thermocapillary on Heat Transfer in Film Condensation," *Trans. ASME, J. Heat Transfer*, in press.

Hartnett, J. P., "Experimental Determination of the Thermal-Entrance Length for the Flow of Water and Oil in Circular Pipes," *Trans. ASME*, 77, 1211 (1955).

Rohsenow, W. M., and H. Choi, *Heat, Mass and Momentum Transfer*, p. 192, Prentice-Hall, New Jersey (1961).

Snow, F. D., "Augmentation of Film Condensation of the Outside of Horizontal Tubes," M.S. thesis, Mass. Inst. Technol., Cambridge (1969).

Sparrow, E. M., and J. L. Greg, "Laminar Condensation Heat Transfer on a Horizontal Cylinder," *Trans. ASME, J. Heat Transfer*, 81C 291, (1959).

Manuscript received November 15, 1972; revision received February 28 and accepted March 5, 1973.