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SHORTER COMMUNICATION

TETRAFLUOROETHYLENE PROMOTED DROPWISE CONDENSATION

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THE USE of promoters to obtain dropwise condensation, and thus increase the rate of heat transfer, has been the subject of many investigations. Usually the promoters employed in these investigations had a limited promoter life in that they had to be replenished periodically to maintain dropwise condensation, or to assure constant condensation rates. The results reported in this communication were obtained by using a promoter which has an exceedingly long life; namely, a thin Teflon‡ film fused to the steamside surface of a copper tube. The ability of Teflon to promote dropwise condensation was first reported by Topper and Baer [1] who found it to be effective for condensing water, ethylene glycol, nitrobenzene, and aniline. Unfortunately, no heat-transfer data was reported by these authors. Fox and Zisman [2, 3] determined the wetting characteristics for a large number of organic and inorganic liquids using Teflon and several other modified tetrafluoroethylene polymers. Their results indicated that Teflon was the most effective non-wetting agent of the materials investigated. The high heat stability of Teflon (up to 500°F for indefinite periods of time), in addition to its resistance against many chemical exposures, makes it attractive as a promoter for commercial application. Teflon should also be useful as a promoter for basic condensation studies since its promoting characteristics do not change with time. The purpose of this communication is to report some preliminary results which verify the dropwise condensation characteristics of Teflon, and to make available data of over-all and steamside coefficients.

Four 35 in long heat-transfer tubes were used. Two of the tubes (0·84 in O.D., 0·15 in wall thickness) were instrumented with thermocouples to measure their steamside surface temperature. In addition, one of these tubes had a Teflon film (nominal thickness of 0·001 in) fused to its outer surface. The other two tubes (0·625 in O.D., 0·0625 wall thickness) were not instrumented with thermocouples and were only used for the determination of over-all coefficients. As with the thick wall tubes, one of the thin wall tubes had a Teflon film fused to its outer surface. The heat-transfer tube to be tested was inserted in a vertical position in a glass-jacketed single tube condenser. Water was used as the secondary fluid.

Prior to commencing a test run, the condenser was purged of air by allowing a large quantity of steam to flow through the apparatus. With the thin wall tube, the following data were recorded after thermal equilibrium was established: cooling water inlet and outlet temperature, steam temperature in the condenser, condensate temperature, condenser pressure, weight of cooling water used during a test run, and duration of the run. From this data it was possible to calculate the over-all heat-transfer coefficient based on the outside area of the tube and the log-mean temperature difference. With the thick wall tubes, the above-mentioned items were also recorded in addition to the condensing side surface temperature. With the aid of the additional measurements made with the heavy wall tube, it was possible to determine the magnitude of the condensing side heat-transfer coefficient. A weighted average temperature was used to calculate the steamside heat-transfer coefficient since there was a temperature gradient along the length of the tube. However, the tube temperature was constant within 5 per cent for film-type condensation and was constant within 3 per cent for dropwise condensation over the entire length of the tube. All of the test results were obtained with filtered steam which had been passed through a separator to reduce its moisture content. The condenser was operated at a pressure of approximately 15 psia and the inlet steam temperature was 214·8°F.

Figure 1 shows the over-all heat-transfer coefficient as a function of the average cooling water velocity, V, for the four tubes. Curve A represents the coefficient for film-type condensation, and Curve B for dropwise condensation (Teflon-coated tube). The over-all heat-transfer coefficient for dropwise condensation increased from approximately 16 to 30 per cent over that obtained with film-type condensation. The curve for $h_0 = \infty$ was obtained by letting the outside film resistance equal zero and using the experimentally determined inside film resistance and tube resistance in the calculation of U_0.

Figure 2 shows the magnitude of the condensing side heat-transfer coefficient as a function of cooling water velocity for the two modes of condensation. The coefficient obtained for film-type condensation varied from 782 to 1200 Btu/h ft degF, and that for dropwise condensation varied from 3270 to 3710 Btu/h ft degF. The

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‡ Teflon is E. I. Du Pont Company's trade name for its tetrafluoroethylene resin.

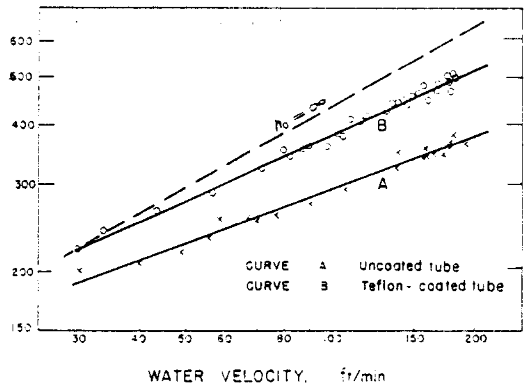

FIG. 1. Over-all heat-transfer coefficient vs. cooling water velocity.

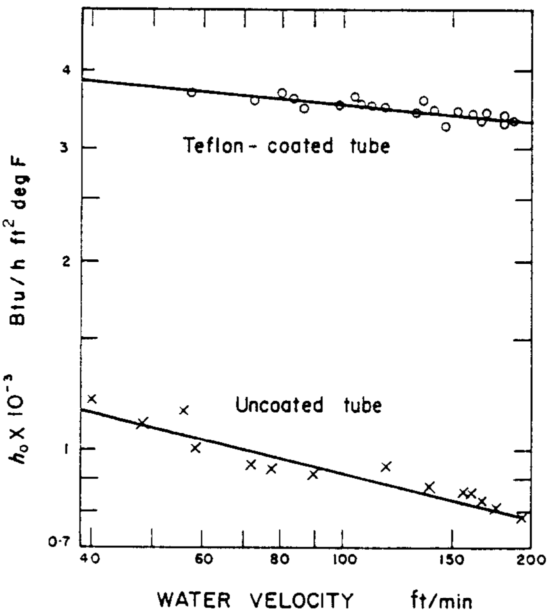

FIG. 2. Steam-side heat-transfer coefficient vs. cooling water velocity.

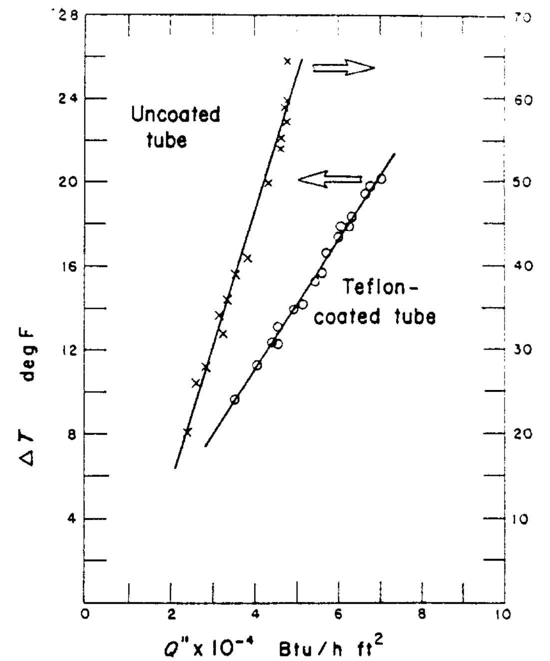

FIG. 3. Steam-to-surface temperature drop vs. heat flux.

coefficients for dropwise condensation ranged from 240 to 330 per cent larger than the film-type coefficients.

Figure 3 shows the variation of the steam-to-surface temperature difference with heat flux. It is observed that an approximate linear function exists between these two variables.

Table 1 summarizes the results obtained by several investigators who reported heat-transfer coefficients and heat flux data for the dropwise condensation of steam. An examination of these results shows that the coefficients measured for the Teflon promoted surface are smaller than those obtained with the other promoters cited in Table 1. These results seem to indicate that the chemical nature of the promoter has a large influence on the magnitude of the condensing coefficient and, consequently, the heat flux.

A thirty-day durability test was conducted with the thin wall Teflon-coated tube. During the test, the over-all heat-transfer coefficient was measured daily. The results showed that there was no detectable change in the over-all coefficient during this period. Visual observation also confirmed that the mode of condensation remained dropwise during the test. The ability of Teflon to maintain its effectiveness as a promoter over extended periods, as opposed to the relatively short life of many of the other promoting agents used in previous investigations, should make it attractive for commercial applications.

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Table 1. Comparison of film coefficients for dropwise condensation of steam

Investigator	Promoted surface	Height of surface (ft)	Range of h_0 (Btu/h ft² degF)	Range of ΔT (degF)	Range of Q'' (Btu/h ft²)	Promoter life
Shea *et al.* [4]	Benzyl mercaptan on copper	1·92	7000–75 000	1·36–28·8	74 000–276 000	8–10 h
Nagle *et al.* [5]	Oleic acid on chrome plate	2·0	11 000–17 000	5·2 –13·9	77 000–170 000	40–60 h
Fitzpatrick *et al.* [6]	Benzyl mercaptan on copper	6·08	7000–16 000	—	68 000–252 000	8–10 h
Le Fevre *et al.* [7]	Dioctadecyl disulphide on copper	0·203 and 0·416	—	2·9 –12·1*	11 000– 56 000*	—
	Dodecanetris silane	0·203 and 0·416	—	3·9 –15·5*	10 000– 53 000*	—
Edwards *et al.*	Teflon on copper	2·92	3270– 3710	9·6– 21·2	35 600– 70 500	> 30 days

* Estimated from Fig. 1 of Reference 7.

liquids on low energy surfaces I. Polytetrafluoroethylene, *J. Colloid Sci.* **5**, 514–531 (1950).
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