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# BOILING HEAT TRANSFER BETWEEN IMMISCIBLE LIQUIDS

**KENNETH F. GORDON, T. SINGH* and E. Y. WEISSMAN**

Department of Chemical and Metallurgical Engineering,
University of Michigan, Ann Arbor, Michigan, U.S.A.

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**Abstract**—An investigation, apparently the first, was made of boiling heat transfer coefficients between immiscible liquids. Mercury with one of water, methanol or ethanol was used. The apparatus was a 2·5 in diameter glass tube with mercury heated by an external heating wire and the pool boiling liquid above. The data covered the range $\Delta T = 7°–103°F$, $q = 1500–110\,000$ Btu/ft² h with $h = 200–1800$ Btu/ft² h °F. Neither a peak flux nor a decline in $h$ were reached.

**Résumé**—Une recherche, apparemment la première, a été effectuée sur le coefficient de transmission de chaleur par ébullition entre des liquides non miscibles. Le mercure avec de l'eau, de l'alcool éthylique ou de l'alcool méthylique a été utilisé. L'appareil est un tube de verre de 2,5 in. de diamètre contenant du mercure chauffé par une résistance extérieure; la nappe de liquide en ébullition se trouve à la surface du mercure. Les données couvrent le domaine $\Delta T = 7–103°F$, $q = 1500–110\,000$ Btu/ft² h avec $h = 200–1800$ Btu/ft² h °F. Aucune décroissance n'a été observée, ni pour le flux de chaleur, ni pour $h$.

**Zusammenfassung**—Offensichtlich zum ersten Male wurden Wärmeübergangszahlen beim Sieden zwischen nichtvermischbaren Flüssigkeiten ermittelt. In der Versuchsapparatur, einem Glasrohr von 6,35 cm Durchmesser wurde Quecksilber durch einem um das Rohr gewickelten Heizdraht erwärmt. Über das Quecksilber war die siedende Flüssigkeit Wasser, Methanol oder Äthanol geschichtet. Die untersuchten Werte erstreckten sich von $\Delta T = 4–57$ grd und $q = 4000–300\,000$ kcal/m² h mit $h = 980–8800$ kcal/m² hgrd, wobei kein Abfall des Wärmeflusses und der Wärmeübergangszahl zu beobachten war.

**Аннотация**—В статье, возможно впервые, даны результаты исследования по определению коэффициентов теплопереноса между несмешивающимися жидкостями при кипении. Для этой цели брали смеси ртути с водой, метиловым или этиловым спиртом. Установка состояла из стеклянной трубки диаметром 2,5 дюйма, заполненной ртутью, которая снаружи подогревалась электрическим нагревателем. Над трубкой находился резервуар с кипящей жидкостью. Экспериментальные данные соответствуют значениям: $\Delta T = 7–103°F$, $q = 1500–110.000$ Бте/кв. фут час и $h = 200–1800$ Бте/кв. фут час °F. Однако не было замечено уменьшение коэффициента теплообмена от потока тепла -

## NOMENCLATURE

- $h$, boiling heat transfer coefficient, Btu/ft² h °F;
- $k$, thermal conductivity, Btu/ft h °F;
- $q$, heat flux, Btu/ft² h;
- $\Delta T$, temperature difference, °F;
- $\Delta x$, distance, ft.

THE scarcity of published data on boiling from a liquid–liquid interface prompted a preliminary investigation using mercury with one of water, methanol and ethanol. This topic is of interest from both the fundamental and applied viewpoints. A liquid such as mercury would appear to have an unusual type of nucleation because a nucleation site at the interface might become displaced by the agitation from boiling, unlike that on a solid heat transfer interface. Nucleation with highly purified mercury, and another non-reactive liquid, might reasonably be expected to be closer to homogeneous rather than the usual heterogeneous nucleation. The required purity may be difficult to achieve and maintain. Because the mercury–boiling liquid surface might be greatly increased in area and constantly renewed by natural or mechanical agitation, by fluidization or by allowing the hot mercury to flow through the boiling liquid, there is the possibility of technological improvements in boiling equipment where increased capacity is desired, or where fouling presents a problem.

* Present address; Nylonge Corp., 1294 W. 70th St., Cleveland 2, Ohio, U.S.A.

Only one study of the topic has been found. As a portion of an investigation of two-phase boiling, Bonilla and Eisenberg [1] measured fluxes to butadiene boiling off water under pressure. The only temperature given is that of the metal surface heating the lower water phase which, with the boiling temperature of butadiene, gave a heat transfer coefficient. As most of the temperature drop occurred across the water the coefficients do not approximate the boiling heat transfer coefficients at the liquid–liquid interface.

There are several studies of related phenomena, the vaporization of liquid superheated drops in a second liquid [2] or at the interface of two other liquid phases [3, 4]. Fluxes are not measured for such discontinuous behavior. In these works it appears that homogeneous rather than heterogeneous nucleation is important.

## EXPERIMENTAL

The apparatus (Fig. 1), consisted of a hard glass test-tube (2·5 in diameter and 21 in long) with the lower 6 in wrapped with nichrome heating wire plastered with asbestos cement. The top of the test tube was connected to two glass condensers in series to condense the boiled liquid and a separating funnel for filling the test-tube which was enclosed in a glass wool filled box. Reagent grade triple distilled mercury was used without purification between runs. Distilled water and reagent grade alcohols were employed.

After steady-state had been reached the boil-over was measured by timing the collection of condensate in a graduated cylinder. At high fluxes the batch hold-up of boiling liquid was relatively small compared with the rate so that the runs were from 1 to 30 min. The heat flow from condensation measurements ranged from 70 per cent of the electrical input at low fluxes to 100 per cent at high fluxes, fifty-fold greater, where the heat leak becomes of much less relative importance. The condensate rate yielded the heat flux while thermocouples in each phase gave the temperatures and differences. The mercury thermocouple was 0·5 in below the level interface, that in the boiling liquid was 2 in above the boiling interface as one 0·5 in above oscillated violently at high fluxes due to contact with the bouncing mercury.

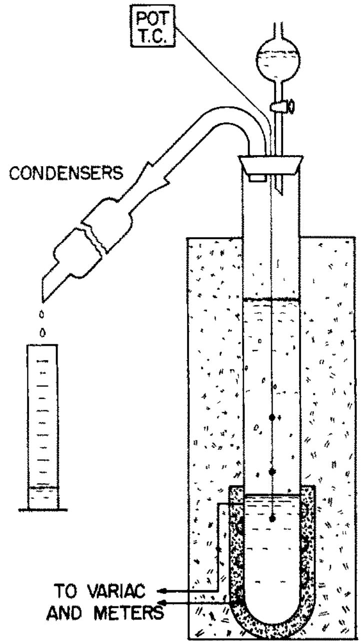


FIG. 1. Apparatus.

The temperature difference used employs the temperature of mercury 0·04 ft beneath the oscillating surface. The resistance of the mercury to heat transfer is unknown. If it were stagnant it would correspond to a $k/\Delta x$ of about 115 Btu/ft$^2$ h °F but as it is mixed due to convection currents and oscillation of the surface the effective value of $k/\Delta x$ may be more than an order of magnitude greater than this as indicated by heat transfer coefficients up to 1800 Btu/ft$^2$ h.

Despite great care a clean liquid–liquid interface could never be achieved during a run. Under a strong light a superficially clean surface would show many very small particles like white dust, most probably glass from the tube. Presumably these served as the nucleation sites. At low fluxes streams of bubbles rose from the center of the interface with no preference for bubbling at the wall. Droplets of the liquid being boiled would often form on the glass wall an inch or more below the interface remaining for tens of seconds before disappearing.

Runs were made on a roof with operators on the up-wind side with a mercury meter between

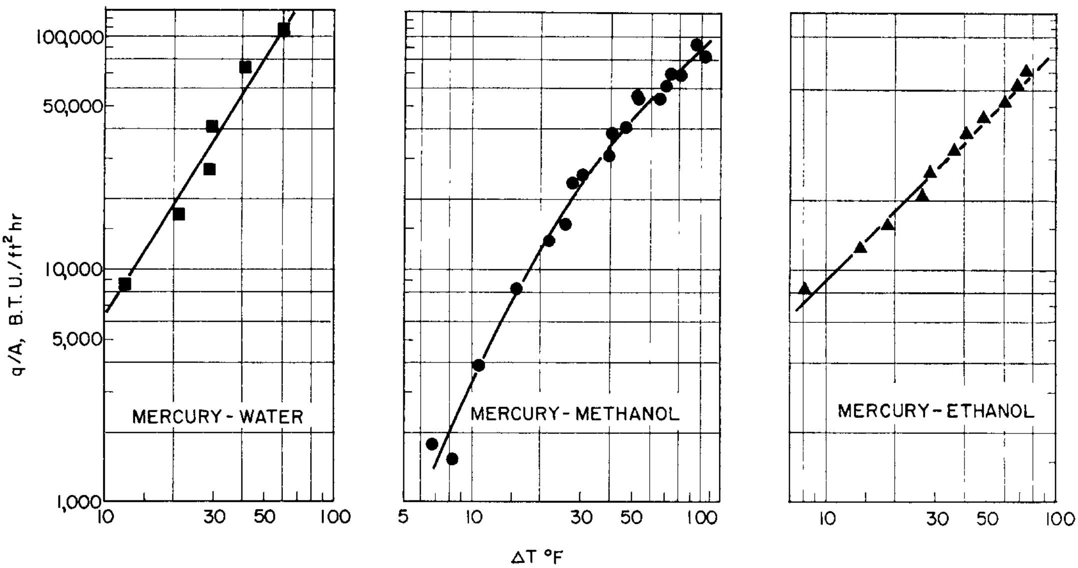


FIG. 2. Heat flux as a function of temperature difference.

themselves and the apparatus. There was an open metal box at the bottom of the wooden box to catch mercury in case of a break or leak. No trouble with mercury vapors was encountered.

Future investigations might employ guard heaters, continuous addition of the boiling phase, several thermocouples in the mercury, and a larger tube to reduce the possibility of appreciable entrainment at high boil-up rates. The effect of dirt should be examined.

## RESULTS

In Figs. 2 and 3 the heat fluxes and transfer coefficients, based on the constant, level, superficial area, are shown as a function of the temperature difference between the two phases, $\Delta T$.

Even up to a $\Delta T$ of 100°F neither the heat flux nor the transfer coefficient have started to decrease. This is possibly due to the violent oscillations of the interface increasing the actual interfacial area for heat transfer as $\Delta T$ is increased until at high fluxes there is violent churning with mercury droplets passing into the lighter liquid then falling back.

For submerged tubes in atmospheric pressure pool boiling, previous investigators [5] have

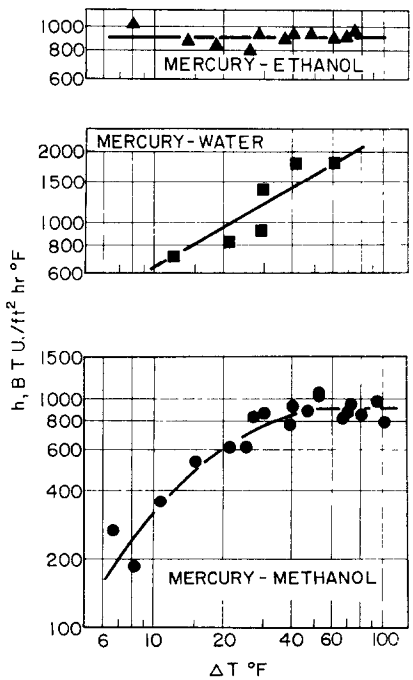


FIG. 3. Heat transfer coefficient as a function of temperature difference.

found peak fluxes of about 400 000 Btu/ft$^2$ h, at $\Delta T$ of about 50°F for water; about 126 000 Btu/ft$^2$ h at about 55–90°F for ethanol and about 124 000 Btu/ft$^2$ h at about 100°F for methanol. In the present work, no evidence of a heat flux peak or for a decrease in $h$ may be seen up to a $\Delta T$ of 100°F leading to a belief that the use of a liquid pool rather than a solid surface for pool boiling might lead to record fluxes based on the horizontal area. Because boiling is such a strong function of surface condition, it is dangerous to generalize.

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