# THERMAL CONDUCTIVITY OF CONDENSING VAPOR FILMS.

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An investigation of the transfer of heat through a series of resistances shows that often a large proportion of the total temperature drop occurs at the boundaries of a conductor and not through its mass proper. For example, if we investigate the temperature gradient in an air preheater heated by flue gas, we will find that no appreciable temperature drop occurs through the metal wall of the heater and that temperature changes throughout the air or flue gas are nearly equalized by convection currents. In this apparatus nearly the entire temperature drop occurs at the inner and outer surface of the metal. The cause for the large temperature referred to is the presence of a stationary film of the fluid, flue gas or air on the surface of the solid and through which heat must be transferred by the process of conduction. Convection does not take place in this adsorbed layer owing to the lack of freedom of motion, and since gases are very poor conductors of heat the film has a high thermal resistance.

It is the purpose of this paper to report the results of some investigations conducted on the thermal conductivity of one particular fluid film. The film studied was a condensing vapor film such as exists in any condenser tube. The particular substance investigated was carbon tetrachloride. The sketch of the apparatus is shown in figure 1 and consists of a boiler connected to a copper tube water jacketed condenser and accessories. The two Liebig glass condensers condensed the excess vapor not condensed in the copper tube, as it was desirable to have the entire length of the copper tube active in condensing vapors. The experimental procedure consisted, briefly, in distilling a quantity of carbon tetrachloride in a measured length of time and determining the temperature drop through the film and tube by means of thermocouple measurements of the temperature of the outside of the copper tube. For this purpose three pairs of chromel and copel wires were soldered to the outside of the copper condenser tube. A Leeds and Northrup potentiometer, range 0 to 16 millivolts, was used to read the potentials set up at the thermocouples.

During the runs, which lasted from 30 to 80 minutes, the potential at each thermocouple was read every three minutes. Table I shows the recorded values of Run No. 4. The figures show that fairly constant readings were obtained.

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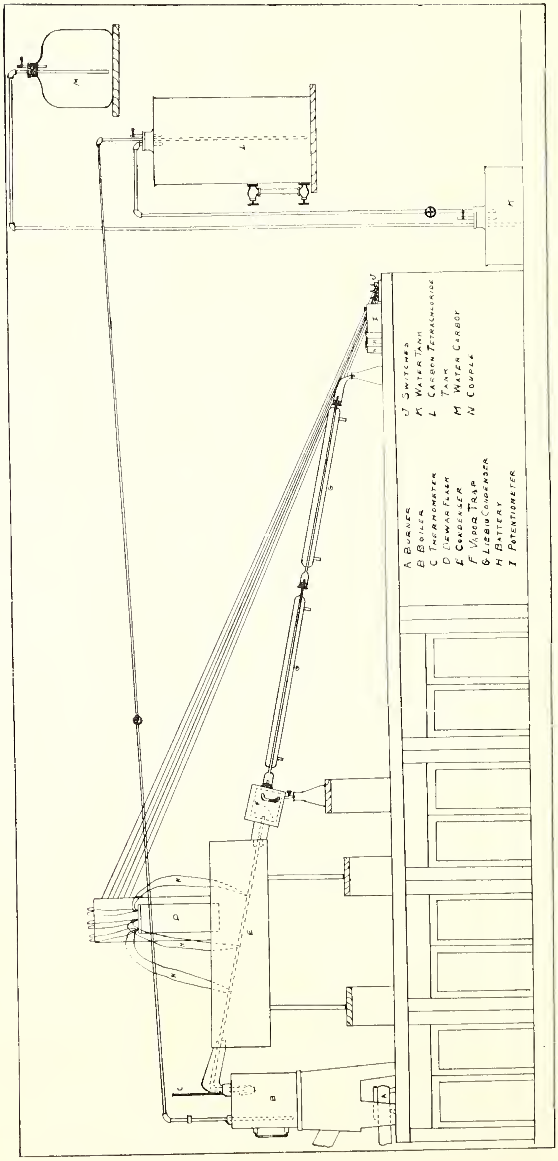


Fig. 1—Diagram of apparatus used in studying thermal conductivity of condensing vapor films.

TABLE I.—Recorded values of Run No. 4.

| | Couple 2 | Couple 2 | Couple 2 |
|---|---|---|---|
| | 3.12 | 3.08 | 2.87 |
| | 3.12 | 3.08 | 2.87 |
| | 3.11 | 3.07 | 2.87 |
| | 3.11 | 3.06 | 2.84 |
| | 3.11 | 3.08 | 2.83 |
| | 3.11 | 3.07 | 2.81 |
| | 3.11 | 3.07 | 2.79 |
| | 3.10 | 3.07 | 2.75 |
| | 3.09 | 3.05 | 2.75 |
| | 3.09 | 3.04 | 2.73 |
| | 3.09 | 3.03 | 2.72 |
| | 3.08 | 3.03 | 2.71 |
| | 3.07 | 3.03 | 2.71 |
| | 3.07 | 3.03 | 2.71 |
| | 3.07 | 3.03 | 2.70 |
| | 3.05 | 3.03 | 2.69 |
| | 3.07 | 3.03 | 2.69 |
| | 3.07 | 3.03 | 2.69 |
| | 3.04 | 3.00 | 2.64 |
| | 3.07 | 3.03 | 2.66 |
| | 3.04 | 3.00 | 2.63 |
| | 3.03 | 2.99 | 2.63 |
| Average | | | |
| | 3.085 | 3.042 | 2.742 |
| Corresponding Temperature from Calibration Curves in degrees Centigrade | | | |
| | 68.65 | 67.3 | 60.62 |

Average Temperature in degrees Fahrenheit, 149.94.
Weight condensed in copper condenser, 10485.8 grams.
Weight condensed in Liebig condenser, 17891.8 grams.
Length of run, 63 minutes.

The thermocouples had previously been calibrated by filling the jacket with water, the temperature of which was measured by mercury thermometers. Calibration readings were made every five degrees. The results of nine runs are shown in Table II.

TABLE II. Results of nine runs of calibration readings.

| Run | θ | Cu. Condensate in grams | Liebig Condensate in grams | $W_1$ | $W_2$ |
|---|---|---|---|---|---|
| 2 | 80/60 | 28,491.6 | 8,992.1 | 47.2 | 14.85 |
| 3 | 80/60 | 19,207.3 | 18,193.8 | 31.75 | 30.1 |
| 4 | 63/60 | 10,485.8 | 17,891.8 | 22.05 | 37.55 |
| 5 | 58/60 | 10,054.1 | 18,208.1 | 22.95 | 41.5 |
| 6 | 30/60 | 6,571.4 | 5,373 | 28.95 | 23.7 |
| 7 | 60/60 | 13,488.4 | 6,747.9 | 29.7 | 14.85 |
| 8 | 56/60 | 13,021.6 | 14,486.2 | 30.7 | 34.2 |
| 9 | 36/60 | 7,692.3 | 9,952.2 | 28.25 | 36.6 |
| 10 | 45/60 | 9,785.7 | 11,907.1 | 28.7 | 35.0 |

The quantity of liquid condensing in the copper condenser and also that condensing in the Liebig condenser was weighed. The heat transferred through the copper tube was calculated from the known heat of condensation of carbon tetrachloride. The area of the tube was of course calculated from careful measurements of its length and diameter. (Table III.)

TABLE III. Calculated results of experiments.

| Run | $\frac{Q}{\theta}$ | $\Delta t$ | V | H | $h_v$ |
|---|---|---|---|---|---|
| 2 | 3,935 | 53.5 | 10.23 | 263.5 | 264.5 |
| 3 | 2,655 | 33.8 | 12.25 | 280.5 | 281.5 |
| 4 | 1,839 | 19.76 | 12.92 | 333.3 | 335.0 |
| 5 | 1,918 | 18.18 | 14.12 | 377.9 | 380.0 |
| 6 | 2,420 | 31.62 | 10.15 | 274.0 | 275.2 |
| 7 | 2,482 | 33.9 | 7.91 | 262.2 | 263.2 |
| 8 | 2,572 | 31.1 | 13.34 | 296.2 | 297.5 |
| 9 | 2,360 | 30.82 | 13.50 | 274.5 | 275.8 |
| 10 | 2,403 | 32.9 | 13.14 | 261.7 | 262.7 |

The values of the conductivity of the condensing vapor film vary from 262.7 to 380. Table IV gives the numerical values of the constants of the apparatus and of carbon tetrachloride.

TABLE IV.—Numerical values of the constants of the apparatus and of carbon tetrachloride

CALCULATED CONSTANTS

| | |
|---|---|
| a | 0.001043 |
| $A_1$ | 0.2792 |
| $A_2$ | 0.3291 |
| A | 0.3042 |
| $d_1$ | 0.03643 |
| $d_2$ | 0.0429 |
| $k_{Cu}$ | 220 |
| L | 0.003255 |
| N | 2.44 |
| Boiling point of carbon tetrachloride | 169.7° F. |
| Heat of Vaporization | 83.52 B. t. u./lb. |

The nomenclature used in this article conforms with common usage and is explained by Table V.

TABLE V.—Nomenclature Used.

| *Symbol* | *Meaning* | *Units* |
|---|---|---|
| $a$ | Cross-sectional area of copper tube | Sq. ft. |
| $A_1$ | Inside area of copper tube | Sq. ft. |
| $A_2$ | Outside area of copper tube | Sq. ft. |
| $A$ | Arithmetic mean area of copper tube | Sq. ft. |
| $d_1$ | Inside diameter of copper tube | ft. |
| $d_2$ | Outside diameter of copper tube | ft. |
| $H$ | Overall coefficient of conductivity | B.t.u./hr./sq. ft./° F. |
| $h_V$ | Condensing film coefficient of conductivity | B.t.u./hr./sq. ft./° F. |
| $k_{Cu}$ | Coefficient of conductivity of copper | B.t.u./hr./sq. ft./°F./ft. |
| $L$ | Thickness of copper tube wall | ft. |
| $N$ | Length of effective condensing surface of copper tube | ft. |
| $Q$ | Quantity of heat transferred through copper tube | B.t.u. |
| $\triangle t$ | Temperature difference (vapor to outside of copper tube) | °F. |
| $V$ | Mass velocity (average) | lbs./sec./sq. ft. |
| $W_1$ | Weight of condensate from copper tube | lbs./hr. |
| $W_2$ | Weight of condensate from Liebig Condenser | lbs./hr. |
| $\theta$ | Time | hrs. |