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SUBJECT: MEASUREMENT OF THE THERMAL CONDUCTIVITY OF FLINAK

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MEASUREMENT OF THE THERMAL CONDUCTIVITY OF FLINAK

A. METHOD

The thermal conductivity of Flinak (11.5 mol% NaF, 42 mol% KF, 46.5 mol% LiF) has been determined in a Deem type apparatus that was designed by M. Tobias and L. Basel. In the course of calibration and operation of the apparatus certain modifications were introduced by the authors. These consisted of substitution of calibrated Pt - Pt Rh thermocouples for uncalibrated Chromel-Alumel thermocouples and certain construction details in the outer cylinder that were introduced to decrease the possibility of corrosive attack of the welds. A simplified schematic diagram of the apparatus is given in Figure 1.

B. THEORY

From the diagram it can be seen that thermocouples A and B do not come in contact with the corrosive liquid but are located slightly below the metal surfaces on both sides of the sample. Therefore, the temperature drop that is measured includes the drop across part of the metal walls. This metal wall resistance to heat flow may include any contact resistance as well and is assumed to be independent of the sample thickness and will be designated as R_W. The resistance across the sample is equal to $\frac{x}{kA}$ where x is the sample thickness A the area normal to heat flow and k is the thermal conductivity of the sample. If ΔT_s is the total temperature drop we can write:

$$\Delta T_s = Q\left(\frac{x}{kA} + R_W\right) \tag{1}$$

where Q = rate of heat flow.

(1) one can be rewritten as:

$$\frac{\Delta T_s}{\Delta T_M} \frac{L}{K_M}$$

$$\frac{A\,\Delta T_s}{Q} = \frac{1}{k}x + A\,R_W \tag{2}$$

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From (2) it is seen that if the results of runs made at the same average temperature and at several sample thicknesses are plotted as

$$\frac{\Delta T_t A}{Q} \text{ vs } x$$

the slope of the line so obtained is equal to $\frac{1}{k}$.

C. RESULTS

The results of the three independent measurements of thermal conductivity that were made are given in Table I. The first entry was madeon one apparatus and the other two on another apparatus, both of the same design and construction in all essential features.

TABLE I

	k, $\frac{\text{BTU}}{\text{hr-ft}^2\text{-}^\circ\text{F/ft.}}$	Average T, °C.	Temp. Range, °C.
1.	2.9	690	634 - 747
2.	2.6	540	490 - 590
3.	2.5	620	567 - 670

An error analysis of the method of determining the thermal conductivity (see Appendix) indicates that this difference of the valuesobtained is to be expected. The uncertainty in the measurement indicates that the three values might be more properly reported as 2.9 ± .4, 2.5 ± .2, 2.6 ± .2 respectively.

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APPENDIX

ELEMENTARY ERROR ANALYSIS

Equation (2) can be written as:

$$\frac{A \Delta T_s}{Q} = \frac{1}{k} x_s + A R_W \tag{2}$$

We can also write:

$$Q = \frac{k_m A \Delta T_m}{x_m} \tag{3}$$

where k_m = thermal conductivity of Armco iron

ΔT_m = temperature drop across iron

x_m = thickness of iron across which temperatures are measured

From (2) and (3):

$$\frac{\Delta T_s x_m}{k_m \Delta T_m} = \frac{1}{k} x_s + A R_W \tag{4}$$

The plots of the data were actually constructed from equation (4).

It is therefore clear from (4) that:

$$k = \Phi(x_s, x_m, \Delta T_s, \Delta T_m, k_m) \tag{5}$$

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We can write from (5):

$$\Delta k = \frac{\partial \Phi}{\partial x_s} \Delta x_s + \frac{\partial \Phi}{\partial x_m} \Delta x_m + \frac{\partial \Phi}{\partial (\Delta T_s)} \Delta(\Delta T_s) + \frac{\partial \Phi}{\partial (\Delta T_m)} \Delta(\Delta T_m)$$

$$+ \frac{\partial \Phi}{\partial k_m} \Delta k_m \qquad (6)$$

where Δx_s, Δx_m, etc. indicate the errors involved in measuring each of these quantities. From equation (4) the partial derivatives can be evaluated.

When this is done we obtain as a final result:

$$\Delta k = \frac{\Delta x_s}{\alpha} + \frac{x_s \Delta T_s \Delta x_m}{\Delta T_m k_m \alpha^2} \quad \frac{x_m x_s \Delta(\Delta T_s)}{\Delta T_m k_m \alpha^2} \quad \frac{x_m x_s \Delta T_s \Delta(\Delta T_m)}{k_m \Delta T_m^2 \alpha^2}$$

$$+ \frac{x_m x_s \Delta T_s \Delta k_m}{k_m^2 \Delta T_m \alpha^2} \qquad (7)$$

where $\alpha \equiv \frac{\Delta T_s x_m}{\Delta T_m k_m} - A R_W$

Using this notation (4) can be written as:

$$k = \frac{x_s}{\alpha} \qquad (8)$$

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From (7) and (8) we can write:

$$\frac{\Delta k}{k} = \frac{\Delta x_s}{x_s} + \frac{\Delta T_s \, \Delta x_m}{\Delta T_m \, k_m \, \alpha} + \frac{x_m \Delta(\Delta T_s)}{\Delta T_m \, k_m \, \alpha} + \frac{x_m \Delta T_s \, \Delta(\Delta T_m)}{k_m \Delta T_m^{\,2} \, \alpha} + \frac{x_m \Delta T_s \, \Delta k_m}{k_m^2 \Delta T_m \, \alpha} \qquad (9)$$

If we let $\beta \equiv AR_W$ then

$$\alpha = \frac{\Delta T_s \, x_m}{\Delta T_m \, k_m} - \beta$$

and equation (9) can be written as

$$\frac{\Delta k}{k} = \frac{\Delta x_s}{x_s} + \frac{\alpha + \beta}{\alpha}\left(\frac{\Delta x_m}{x_m} + \frac{\Delta(\Delta T_s)}{\Delta T_s} + \frac{\Delta(\Delta T_m)}{\Delta T_m} + \frac{\Delta k_m}{k_m}\right) \qquad (10)$$

Equation (10) indicates the fractional error in k as a function of the errors in each of the relevant variables. These can be estimated and so the uncertainty in the measurement can be evaluated.

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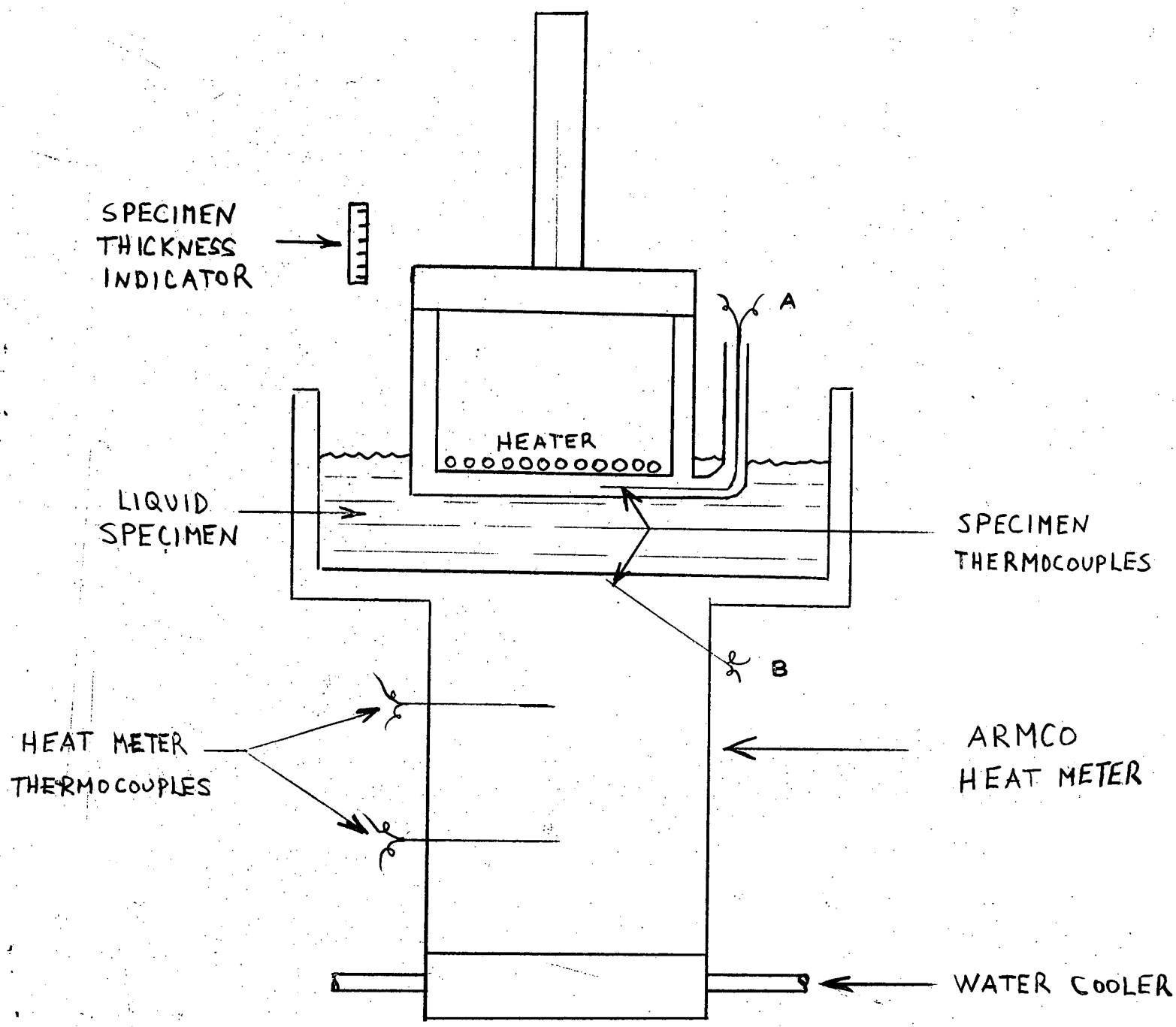
SPECIMEN THICKNESS INDICATOR
A
HEATER
LIQUID SPECIMEN
SPECIMEN THERMOCOUPLES
B
HEAT METER THERMOCOUPLES
ARMCO HEAT METER
WATER COOLER

FIGURE 1