HEAT TRANSFER COEFFICIENTS
FOR
CONDENSING VAPORS ON A HORIZONTAL TUBE

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ABSTRACT

Film coefficients of heat transfer for vapors condensing on a smooth horizontal tube have been experimentally determined by many investigators. The so-called Thermocouple Method and the Wilson Method, have been used and generally accepted as the two methods for determining these film coefficients. A number of different organic vapors have been studied on various condensing surfaces. Nusselt has also developed a theoretical equation,

$$h_N = 0.725\sqrt[4]{\frac{k_f^3 \rho_f^2 \lambda g}{D_o \mu_f \Delta t_{cf}}}$$

for evaluating the film coefficients of vapors condensing on horizontal tubes.

The earlier investigators have shown that theoretical values, h_N, do not check with experimentally determined values, h_e, and that many discrepancies exist among different experimentally determined values. Advocates of the Wilson Method have discredited the accuracy of the Thermocouple Method and vice versa.

With these points in mind, the experimental work in this thesis was undertaken. Film coefficients of heat transfer were experimentally determined for single vapor systems of each of four alcohols condensing on a smooth horizontal tube. Both methods of evaluating the heat transfer coefficients were used. Methyl Alcohol, Isopropyl Alcohol, n-Propyl Alcohol, and n-Butyl Alcohol were studied. A single piece of equipment designed to eliminate problems noted by earlier authors of similar work was used for the entire investigation. Data was

taken for both of the methods simultaneously and under identical operational conditions.

The experimental results of this investigation showed film coefficients of heat transfer by both accepted methods to be of the same order of magnitude for each particular compound. It can be concluded, therefore, that the discrepancies in earlier data are probably due to other factors and not the use of either the Wilson Method or the Thermocouple Method. The results also showed definite evidence that h_e for vapors condensing on a horizontal tube decreases for increasing molecular weight within the homologous alcohol series.

PREFACE

The research described in this thesis was undertaken for the purpose of showing a correlation between the Thermocouple Method and the Wilson Method both of which are generally accepted for experimentally determining heat transfer coefficients for vapors condensing on a smooth horizontal tube. It was the aim of the authors to eliminate the difference in methods of experimentally determining heat transfer coefficients as one of the possibilities for the discrepancies in earlier data.

The experimental work of this thesis was carried out in the Chemical Engineering Laboratories of the Newark College of Engineering, Newark, New Jersey, under the guidance of Professor George C. Keeffe.

The co-authors wish to make grateful acknowledgment of the invaluable aid and advice offered by Professor George C. Keeffe. Appreciation is also due Mr. William Furmadge for his assistance in the construction of the equipment used for this research.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Many investigators have determined heat transfer coefficients for a vapor which is condensing filmwise on a single horizontal tube. Among these are Baker and Mueller (1), McAdam and Frost (2), Othmer (3), Othmer and Berman (4), Othmer and White (5), Reddie (6), Rhodes and Younger (7), Peck and Reddie (15), and Chu (16). Coefficients have been experimentally determined for both single and mixed vapors of many chemical types on various condensing surface areas.

Two methods of calculating experimental coefficients have generally been used by the above group of investigators. The first method which was used by Baker and Mueller (1), Othmer (3), Othmer and Berman (4), and Reddie (6), involves the use of thermocouples to determine the condensing surface temperatures from which the film coefficients may be calculated. The second method used by Rhodes and Younger (7), and Chu (16) is an indirect method for determining film coefficients which was originally suggested by Wilson (8), and is based on the over-all heat transfer coefficients.

Up to this time, there have been differences of opinion as to whether or not heat transfer coefficients for condensing vapors could be accurately determined by the use of the so called, "Thermocouple Method". It was with this discrepancy in mind that the research described in this thesis was undertaken. The purpose of this work was to show a correlation, if any, that might exist between the aforementioned methods. This was accomplished by determining heat transfer coefficients for the condensing vapors of a homologous series of organic compounds on a single horizontal tube under identical conditions.

It was also the purpose of this investigation to show experimentally a decrease in film coefficients with increase in molecular weight for compounds of a homologous series.

THEORY

When condensing a single pure saturated vapor on a horizontal tube the condensate wets the tube and film-type condensation is obtained. The rate of heat transfer is given by the equation,

$$q = h_N A_o \quad (t_v - t_{os}) = h_N A_o \Delta t_{cf} \qquad (1)$$

The terms of this expression and those following are defined under the nomenclature section. As long as the condensate flows in streamline motion, $\left(\frac{4W}{L_t \mu_f} < 4200,\right)$ the following dimensionless equation of Nusselt may be used.

$$h_N = 0.725 \sqrt[4]{\frac{k_f^3 \rho_f^2 \lambda g}{D_o \mu_f \Delta t_{cf}}} \qquad (2)$$

The values of k_f, ρ_f and μ_f of the condensate are taken at a special film temperature t_f

$$t_f = t_v - .75\Delta t_{cf} \qquad (3)$$

In the Nusselt equation Δt_{cf} is ordinarily unknown. However, the two methods which were used in this investigation permitted Δt_{cf} to be determined directly. These are:

1. Thermocouple Method
2. Wilson Method

Thermocouple Method

This method arrives at a satisfactory over-all average value for Δt_{cf} by measuring with thermocouples the tube surface for several points along its length. The over-all average temperature drop across the condensate film, Δt_{cf} may be obtained from the resistance on the vapor side depends on the temperature difference and the temperature of the condensate film, thus R_v varies somewhat as water velocity is changed. However, changes in tube wall temperature brought about by changes in water velocity, would cause only negligible variation in thermal conductivity of the tube wall. Except in cases of extremely high water velocities, the water-side resistance is usually the major resistance. Since the water-side resistance is an inverse function of the water velocity through the tube V_o and neglecting the effects of changes in water temperature due to changes in water velocity, the water-side resistance R_L can be taken as a function of the water velocity, V_o. It has been previously determined for turbulent flow that

$$R_L = 1/\alpha_o V_o^{0.8} \qquad (9)$$

therefore

$$1/U_o = R_v + R_t + 1/\alpha_o V_o^{0.8} \qquad (10)$$

α_o is an empirical constant and may be considered as the apparent individual coefficient of heat transfer from tube to water based on the outside surface for water velocity of 1 ft/sec.

Since R_w is constant and known along with V_o and U_o, R_v the reciprocal of the vapor film coefficient may be determined.

Therefore, the film coefficient or h_w may be determined directly from the relation

$$R_v = \frac{1}{h_w}\,. \qquad (11)$$

equation

$$\Delta t_{cf} = t_v - t_{os}. \tag{4}$$

The experimental value for the condensate film heat transfer coefficient can be found from the relation

$$h_e = \frac{q}{\pi D_o L_t \ \Delta t_{cf}}. \tag{5}$$

The quantity, q, is readily obtained by calculating the amount of heat absorbed by the cooling water per hour.

Wilson Method

In 1915, E. E. Wilson (8) proposed a graphical method of interpreting heat transfer in surface condensers. In this method tube temperatures are not measured but over-all coefficients U_o are available from the relation

$$q = U_o A_o \Delta T = U_o A_o \left[t_v - \left(\frac{T_i + T_o}{2} \right) \right] \tag{6}$$

In correlating these over-all coefficients, Wilson took advantage of the fact that the over-all resistance to heat flow ($\Sigma R = 1/U_o$) is numerically equal to the sum of the individual series resistances, namely, the resistance on the vapor side, R_v; the resistance of the wall, R_w; the resistance of the dirt film, R_d; and that of the water side, R_L. From this concept of resistances in series, it is clear that

$$1/U_o = R_v + R_w + R_d + R_L \tag{7}$$

or in the case of a clean tube as used in this work

$$1/U_o = R_v + R_w + R_L. \tag{8}$$

According to the theoretical equation of Nusselt, the

APPARATUS

The apparatus used for this investigation is shown in Figures 1, 2, and 3. It was essentially a single horizontal No. 316 stainless steel $1\frac{1}{2}$ I.P.S. steel pipe, within which was centered a one inch brass pipe. The purpose of the brass pipe was to decrease the internal area, thus allowing for greater cooling water velocities at specific flow rates. The outer jacket, made of borosilicate glass was twenty-two inches long with a four inch inside diameter. It was reduced at both ends to two inches and assured a condenser surface area of 0.818 square feet. This jacket was made up of two sections and contained three 3/4 inch vapor inlets, one 3/4 inch condensate outlet and one 3/4 inch excess vapor outlet. The vapor inlets were equally spaced and at an angle of thirty degrees from the vertical. The vapor and condensate outlets were placed equidistant from the ends, and at the top and bottom of the jacket respectively. Detailed equipment specifications are given in Table I.

The vapors studies were generated in a five gallon stainless steel boiler which used steam as the heating medium. Cooling water was supplied from the tap and the flow was measured by means of a rotameter. The condenser section was heavily insulated. A small bulb type reflux condenser, vented to the atmosphere, was used as an auxiliary condenser to insure against having the vapor space only partially filled and also to remove any non-condensibles. An arrangement was made to return all condensate directly to the boiler.

The temperature of the tube surface was measured by means of four thermocouples. All were of the chromel-alumel Type No. 22 gage. The

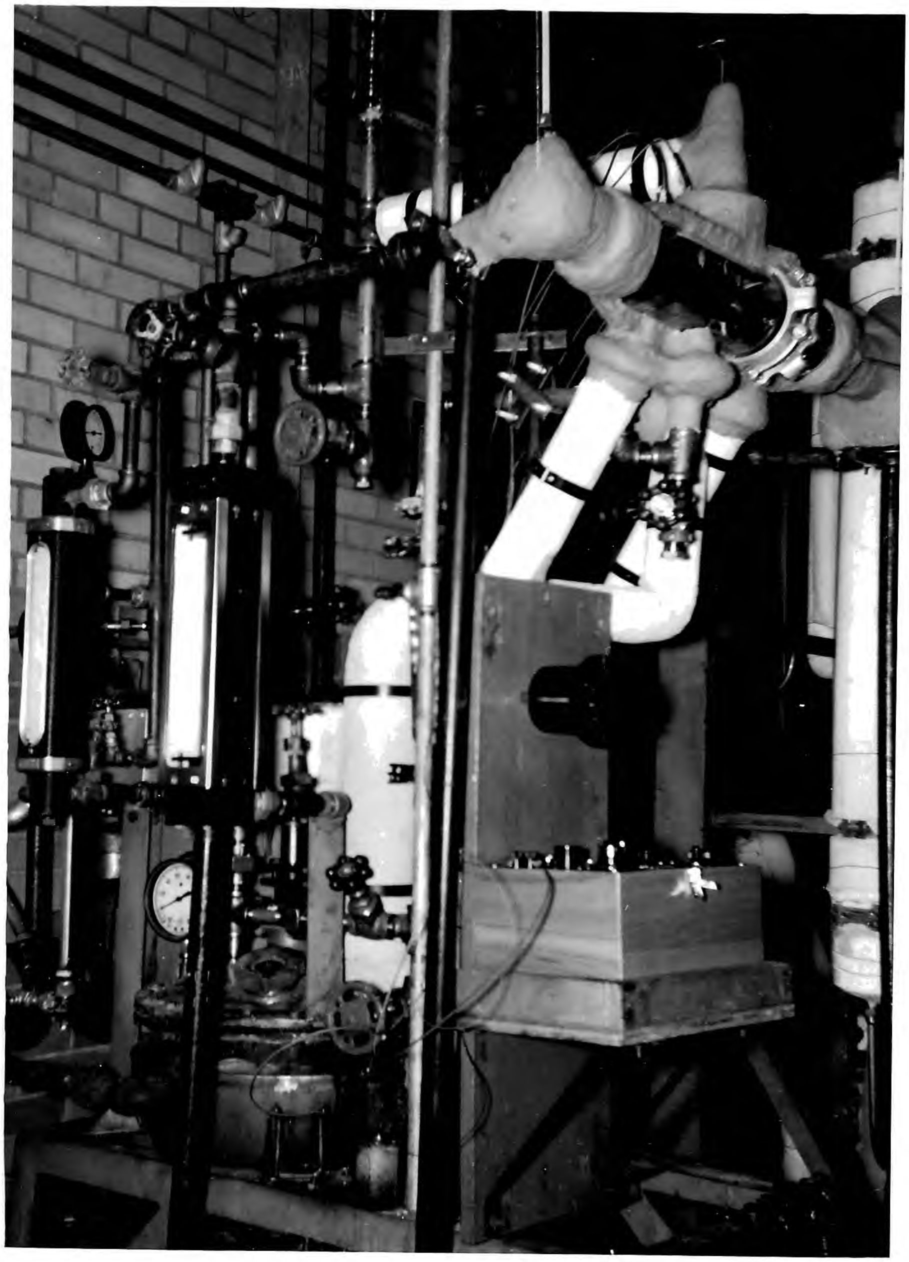


Fig. 1 Photograph of Experimental Apparatus

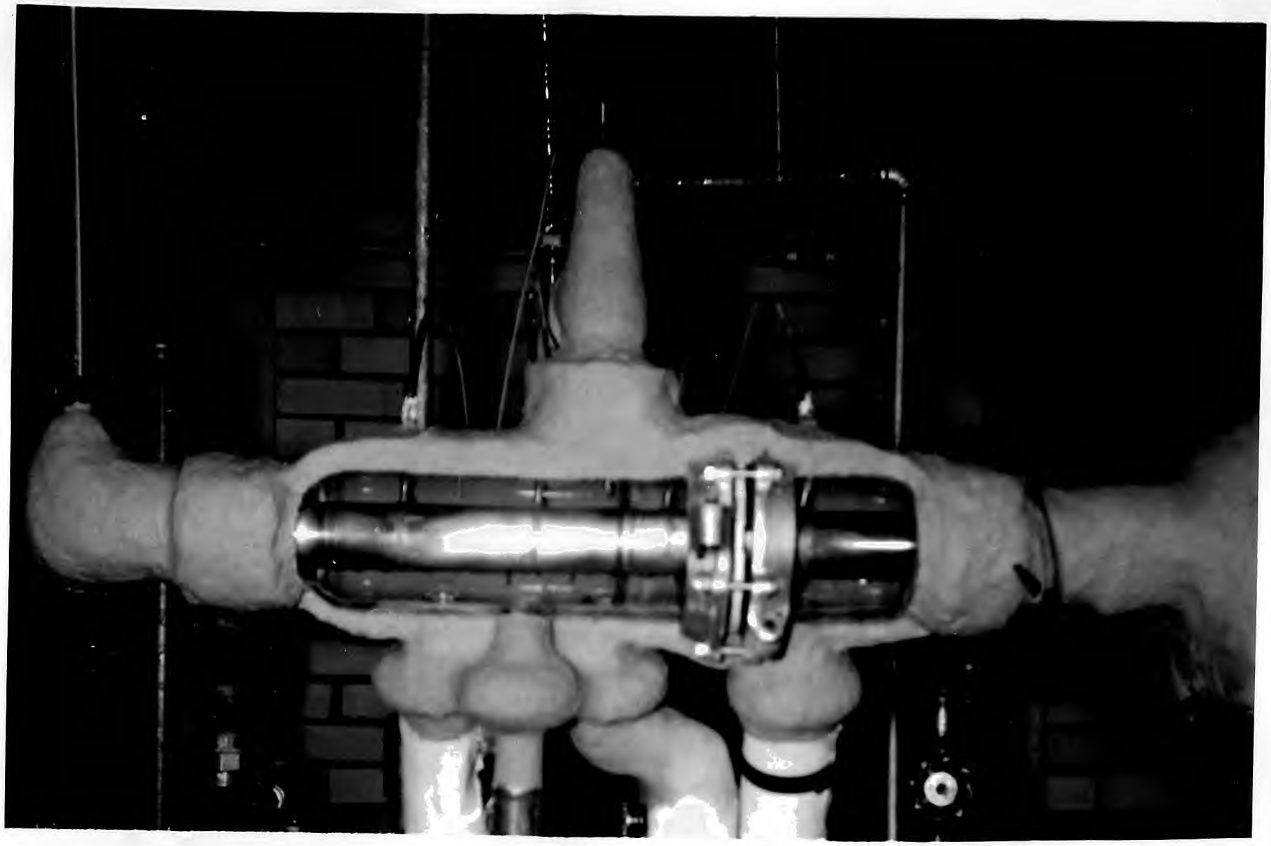
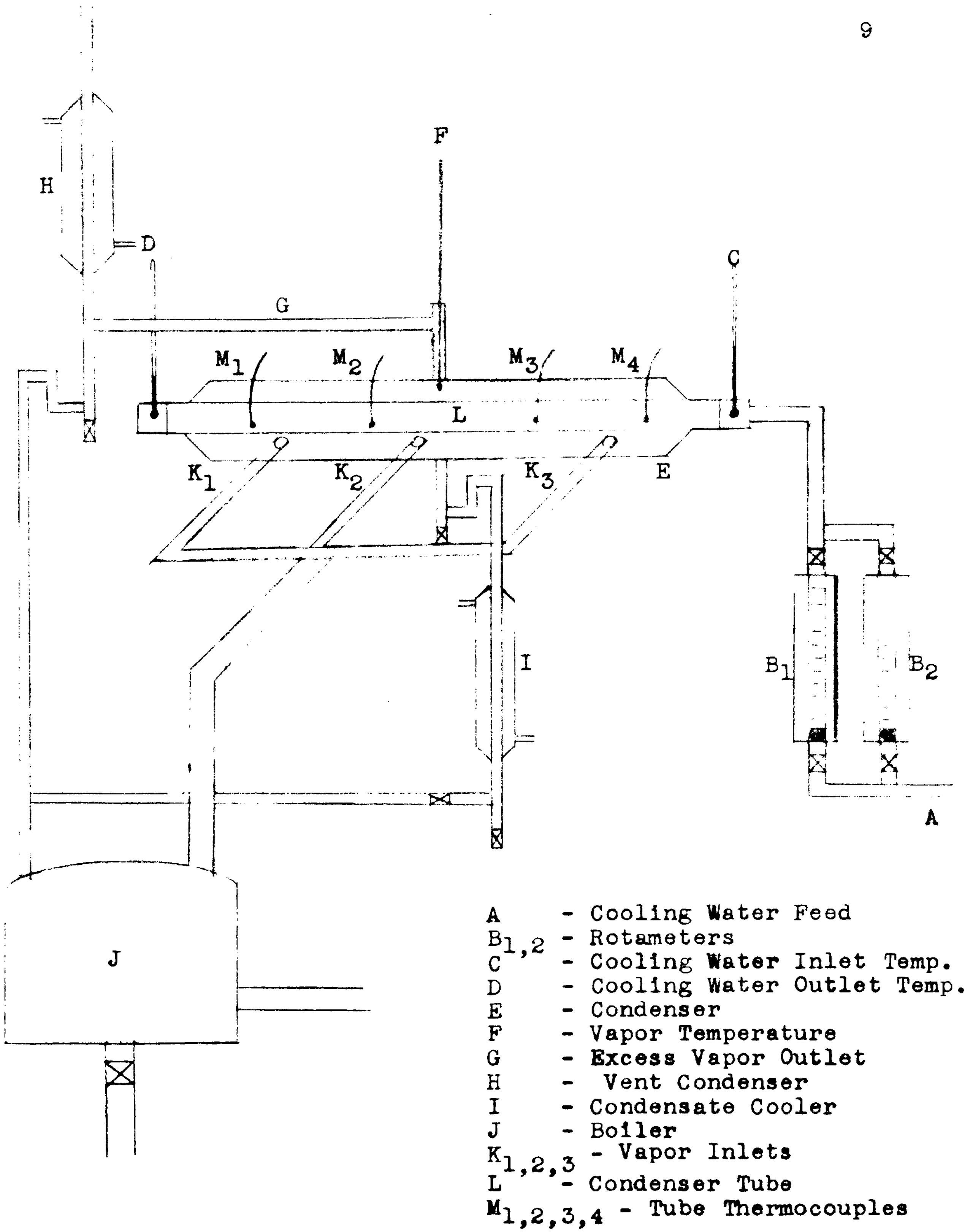


Fig. 2 Photograph of Horizontal Condenser Tube and Jacket



A - Cooling Water Feed
$B_{1,2}$ - Rotameters
C - Cooling Water Inlet Temp.
D - Cooling Water Outlet Temp.
E - Condenser
F - Vapor Temperature
G - Excess Vapor Outlet
H - Vent Condenser
I - Condensate Cooler
J - Boiler
$K_{1,2,3}$ - Vapor Inlets
L - Condenser Tube
$M_{1,2,3,4}$ - Tube Thermocouples

FIGURE 3

DIAGRAMMATIC SKETCH OF EXPERIMENTAL APPARATUS

TABLE I

Experimental Equipment Specifications

Condenser tube-316 stainless steel	
Effective length of a condenser tube	1.667 ft.
Outside diameter of condenser tube	0.1565 ft.
Inside diameter of condenser tube	0.1341 ft.
Condenser tube wall thickness	0.0112 ft.
Condensing surface area	0.818 ft.^2
Thermal conductivity of condenser tube	9.4 $\frac{\text{Btu ft}}{\text{hr ft}^2\ {}^\circ\text{F}}$
Outside diameter of internal pipe	0.1095 ft.
Inside diameter of jacket	0.333 ft.
Thermocouples-Chromel Alumel No. 22 gage	
Potetiometer-Leeds and Northrup Portable type Model No. 8667	

installation of the thermocouples was performed similar to the method described by Baker and Mueller (1). The method of installing the tube thermocouples is shown in Figure 4. A groove 1/8 inches wide by 3/32 inches deep was cut around the tube and at an angle of 30° for 1/2 inch. At the end of this angular groove, a 1/16 inch hole, 1/4 inch long was drilled. By this method of installation the thermocouple junctions were beneath the surface and, regardless of the position of the junction on the perimeter of the tube, no condensate flowing over the junction could be affected by the groove. The lead wires came out of the groove at the top and approximately 1/3 of the circumference of the tube away from the junction.

Many methods of sealing the lead wires into the groove were tried. The method that was finally adopted and that proved successful was to remove the top insulation from the wires in order to bring one lead around each side of the tube. The junction was then placed in the well and the leads soldered into the groove. The solder was polished until flush with the tube surface.

The thermocouples were brought to the outside of the jacket through 3/16 inch stainless steel tubing.

Thermocouples were positioned in the lower quadrant as previous investigators, (1) and (6), determined points located here gave temperatures with little appreciable deviation from the average tube surface temperature. All thermocouples were brought to a selector switch box, and the electromotive force was measured by a Leeds and Northrup portable potentiometer, Model 8667. The cold junction was maintained

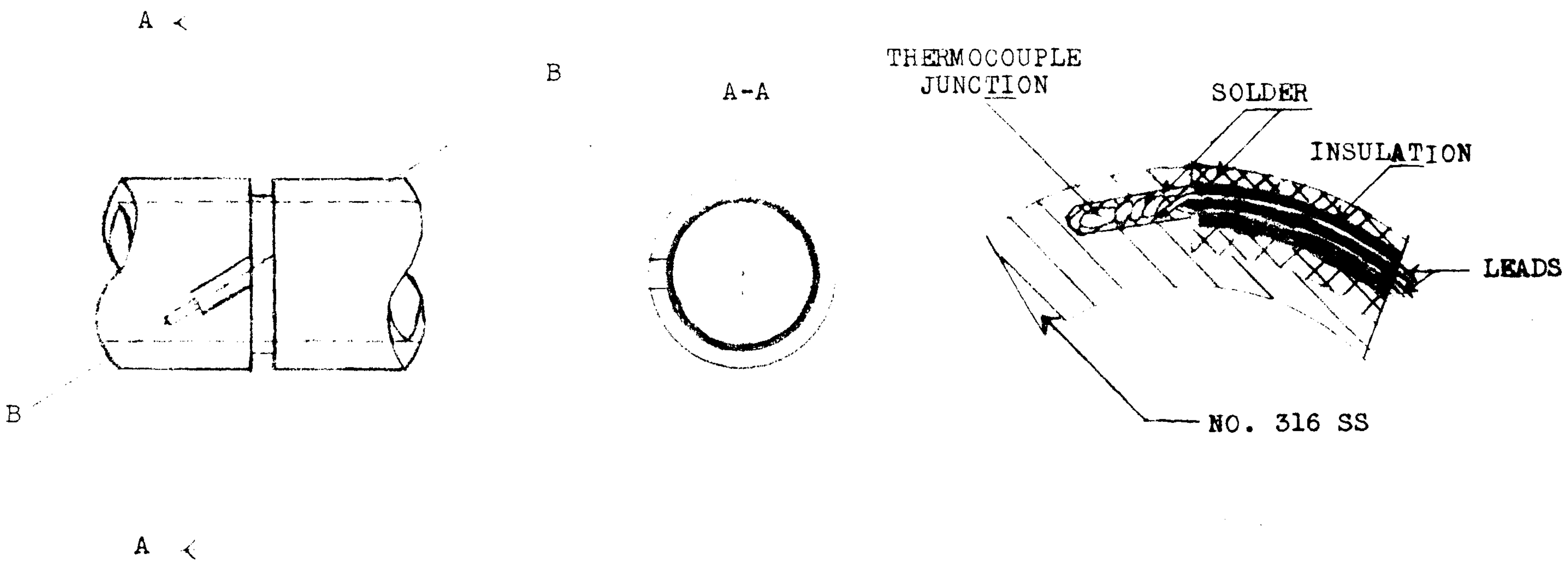


Fig. 4 SKETCH OF THERMOCOUPLE INSTALLATION

at 32°F by insertion in a thermos flask containing ice. Thermocouples were read to the nearest 0.01 millivolt.

Thermometers reading 0.1°C were provided to measure vapor, and inlet and outlet cooling water temperatures.

EXPERIMENTAL PROCEDURE

Thermocouples for the measurement of tube surface temperatures were calibrated at several points against an accurate thermometer of the mercury expansion type before installation. An accuracy of 0.1 °C was obtained. After installation all thermocouples were checked at several temperatures.

The rotameters for measuring cooling water flow rate were calibrated over the operational range.

Vapors to be studied were generated in the stainless steel boiler and a steady stream was allowed to flow to the horizontal tube condenser. The excess vapors were removed in the small auxiliary condenser with the vapor velocity being maintained at a minimum to prevent flooding the reflux condenser.

Cooling water was passed through the annular space of the condenser tube, perpendicular to the vapor stream.

The first step in making a run was to set the desired rates. This accomplished, the apparatus was left undisturbed until steady state conditions were reached. The condition of equilibrium was assumed when a sequence of check readings showed no appreciable change in the tube surface temperatures. A portion of the lagging was then removed from the condenser in order to make certain that the condensation was of the true filmwise type.

An experimental run was then started. E.M.F. readings were taken for each of the thermocouples along with readings of inlet and outlet cooling water, and vapor temperatures. A run consisted of taking a series of readings at five minute intervals over a period of twenty to thirty minutes.

EXPERIMENTAL RESULTS

EXPERIMENTAL RESULTS BY THERMOCOUPLE METHOD FOR METHYL ALCOHOL

Run No.	q Btu/hr	$\frac{W}{L_t}$ #/ft hr	$\frac{4W}{L_t \mu_f}$	t_v °F	t_{os} °F	Δt_{cf} °F	t_f °F	h_e	h_N	$\frac{h_e}{h_N}$	$\left(\frac{\lambda \mu_f}{k_f \Delta t_{cf}}\right)^{\frac{1}{2}}$
1	12,000	15.25	62.4	147.5	109.7	37.8	119.2	388	428	.907	10.0
2	11,300	14.32	59.0	147.5	113.0	34.2	121.9	405	457	.887	10.5
3	10,420	13.25	55.5	147.5	117.2	30.3	124.8	422	462	.913	11.1
4	8,960	11.40	49.0	147.5	121.0	26.5	127.6	415	488	.853	11.7
5	7,530	9.55	41.4	147.5	123.9	23.6	129.8	391	502	.779	12.4
6	5,090	6.47	28.1	147.5	126.4	21.1	131.7	295	515	.573	13.1
7	4,240	5.38	23.7	147.5	129.5	18.0	134.0	288	537	.536	14.0
8	4,030	5.10	22.9	147.5	131.4	16.3	135.5	302	493	.613	15.3
9	3,455	4.36	20.0	147.5	132.2	14.5	136.8	292	572	.510	15.4
10	3,080	3.90	17.9	147.5	133.3	14.2	136.8	264	542	.487	17.6

EXPERIMENTAL RESULTS BY WILSON METHOD FOR METHYL ALCOHOL

Run No.	q Btu/hr	$\frac{W}{Lt}$ #/ft hr	U_o	$1/U_o$	$1/V^{0.8}$	h_w	t_v °F	Δt_{cf} °F	t_{os} °F	t_f °F	h_N	$\frac{h_w}{h_N}$	$\left(\frac{\lambda \mu_f}{k_f \Delta t_{cf}}\right)^{\frac{1}{2}}$
1	12,000	15.25	161.5	.00618	.191	424	147.5	34.6	112.9	121.6	433	0.980	10.90
2	11,300	14.32	153.0	.00654	.235	463	147.5	29.8	117.7	125.1	442	1.048	11.84
3	10,420	13.25	141.5	.00707	.268	435	147.5	29.3	118.2	125.5	444	0.980	11.92
4	8,960	11.40	123.2	.00812	.349	439	147.5	24.9	122.6	128.8	455	0.965	12.98
5	7,530	9.55	104.5	.00957	.457	422	147.5	21.8	125.7	131.2	464	0.930	13.88

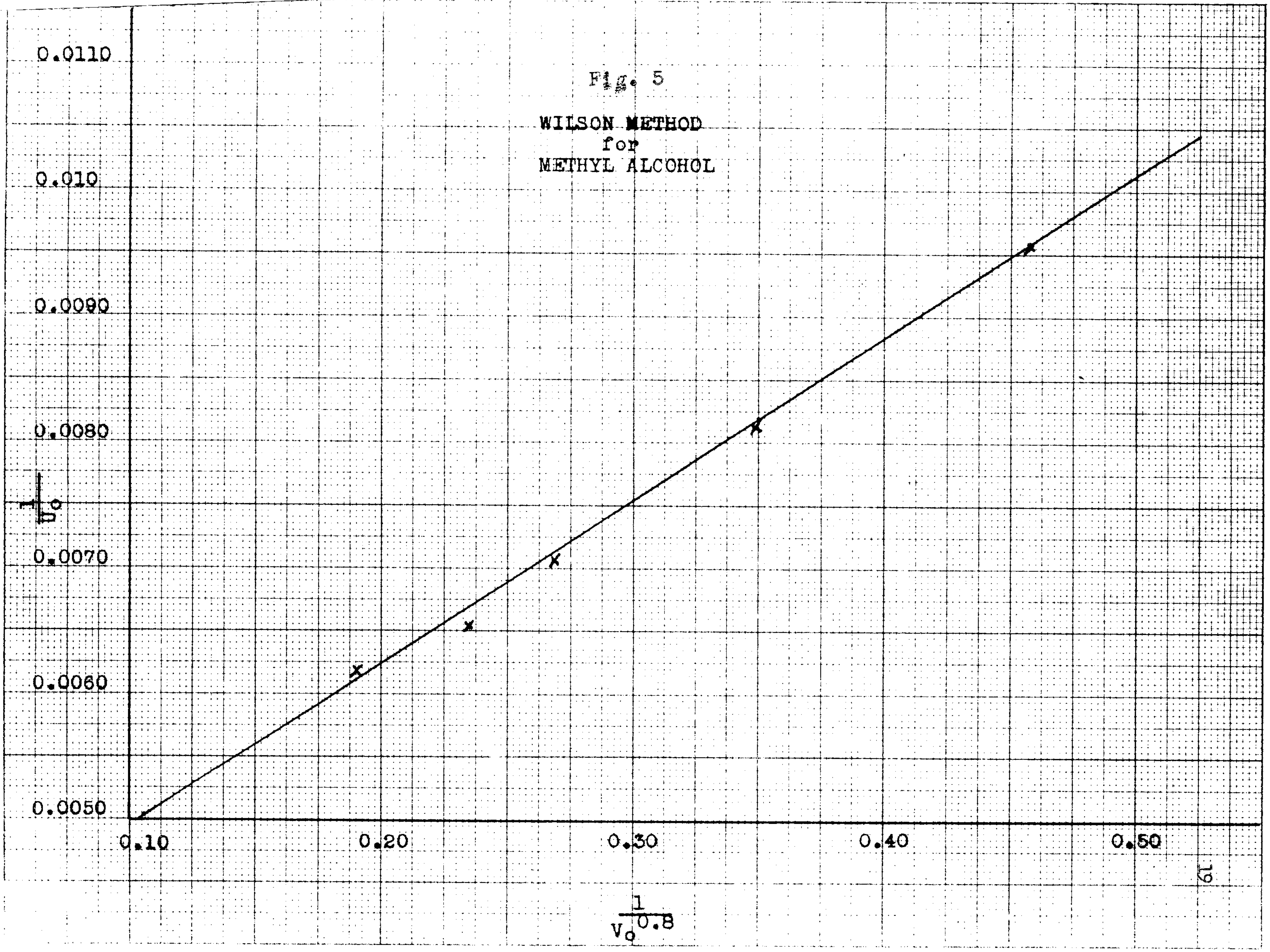


Fig. 5

WILSON METHOD
for
METHYL ALCOHOL

Fig. 6

Heat Transfer vs.
Tube Surface Temperature
for
METHYL ALCOHOL

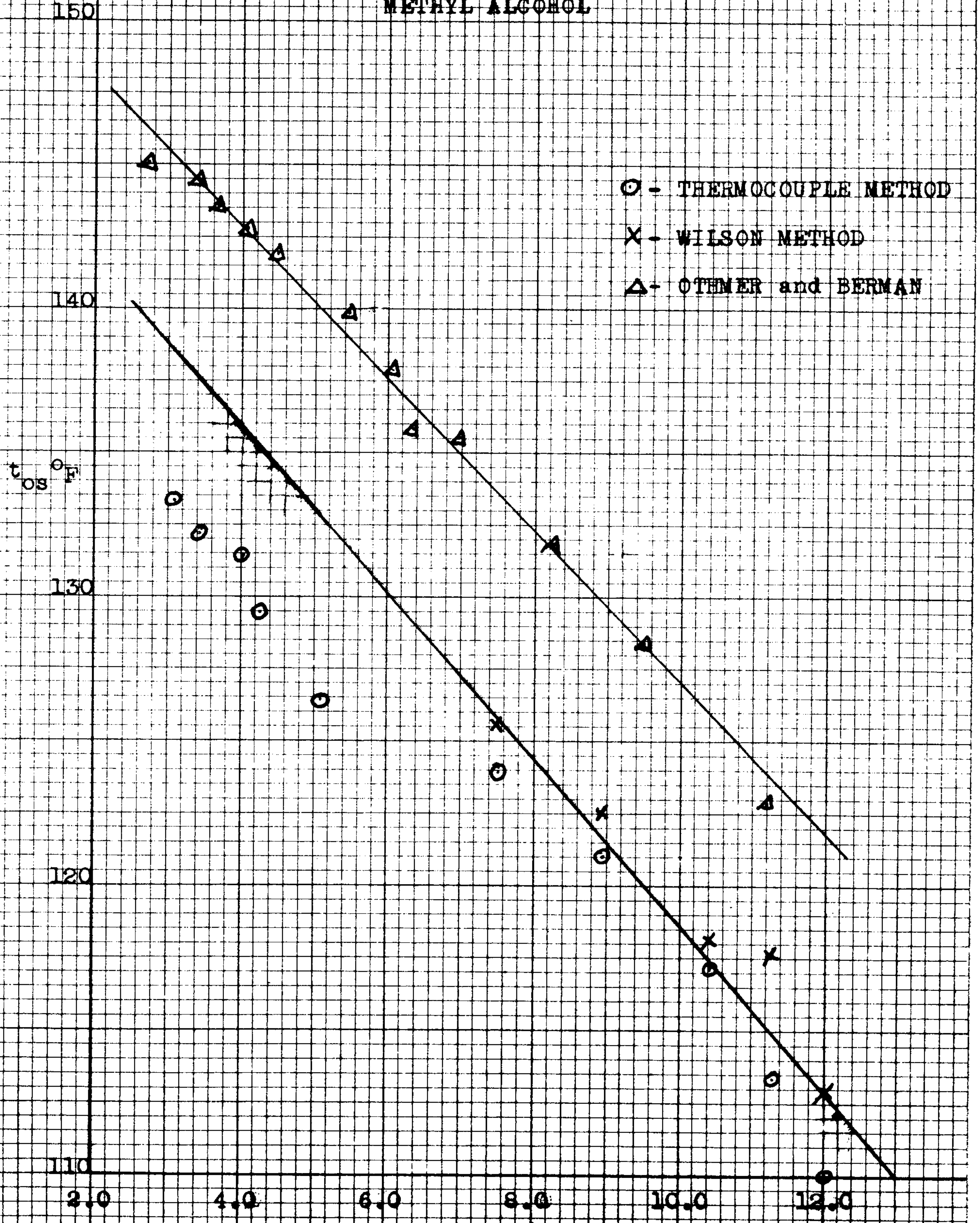
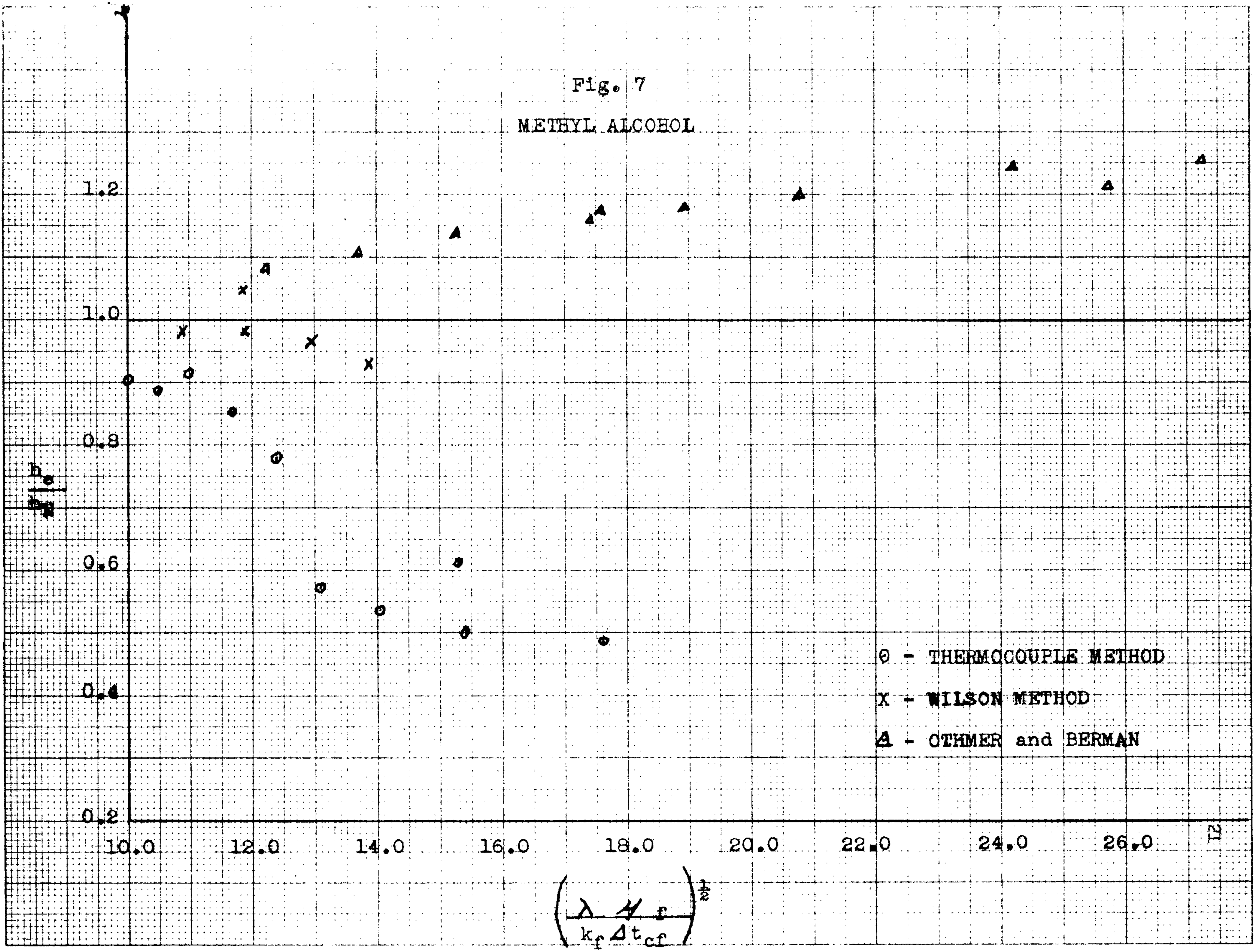


Fig. 7

METHYL ALCOHOL



EXPERIMENTAL RESULTS BY THERMOCOUPLE METHOD FOR ISOPROPYL ALCOHOL

Run No.	q Btu/hr	$\frac{W}{L_t}$ #/ft hr	$\frac{4W}{L_t \mu_f}$	t_v °F	t_{os} °F	Δt_{cf} °F	t_f °F	h_e	h_N	$\frac{h_e}{h_N}$	$\left(\frac{\lambda \mu_f}{k_f \Delta t_{cf}}\right)^{\frac{1}{3}}$
1	11,740	24.6	35.4	179.2	106.7	72.5	124.8	198.5	204	.948	11.08
2	10,780	22.6	35.5	179.2	113.0	67.2	129.8	196.5	212	.927	10.96
3	10,290	21.6	34.7	179.2	118.2	61.0	133.4	206.5	217	.952	11.40
4	9,320	19.6	34.1	179.2	125.2	54.0	138.7	211.0	228	.956	11.80
5	8,400	17.6	31.3	179.2	129.3	49.9	141.8	206.0	233	.885	11.98
6	7,180	15.0	28.3	179.2	135.2	44.0	146.2	200.0	245	.816	12.42
7	6,170	12.9	25.2	179.2	140.2	40.0	150.2	191.0	252	.758	12.80

EXPERIMENTAL RESULTS BY WILSON METHOD FOR ISOPROPYL ALCOHOL

Run No.	q	$\frac{W}{L_t}$ #/ft hr	U_o	$1/U_o$	$1/V^{0.8}$	h_w	t_v °F	Δt_{cf} °F	t_{os} °F	t_f °F	h_N	$\frac{h_w}{h_N}$	$\left(\frac{\lambda \mu_f}{k_f \Delta t_{cf}}\right)^{\frac{1}{2}}$
1	11,740	24.6	116.8	.00856	.191	198.0	179.2	72.5	105.7	124.7	209	.948	10.42
2	10,780	22.6	107.3	.00931	.235	188.5	179.2	70.0	109.2	126.7	211	.895	10.55
3	10,290	21.6	103.0	.00972	.268	187.5	179.2	67.0	112.2	128.2	214	.877	10.72
4	9,320	19.6	93.7	.01068	.349	185.2	179.2	61.5	117.7	133.0	222	.835	10.82
5	8,400	17.6	87.0	.01150	.457	199.5	179.2	51.4	127.8	140.6	238	.838	11.28

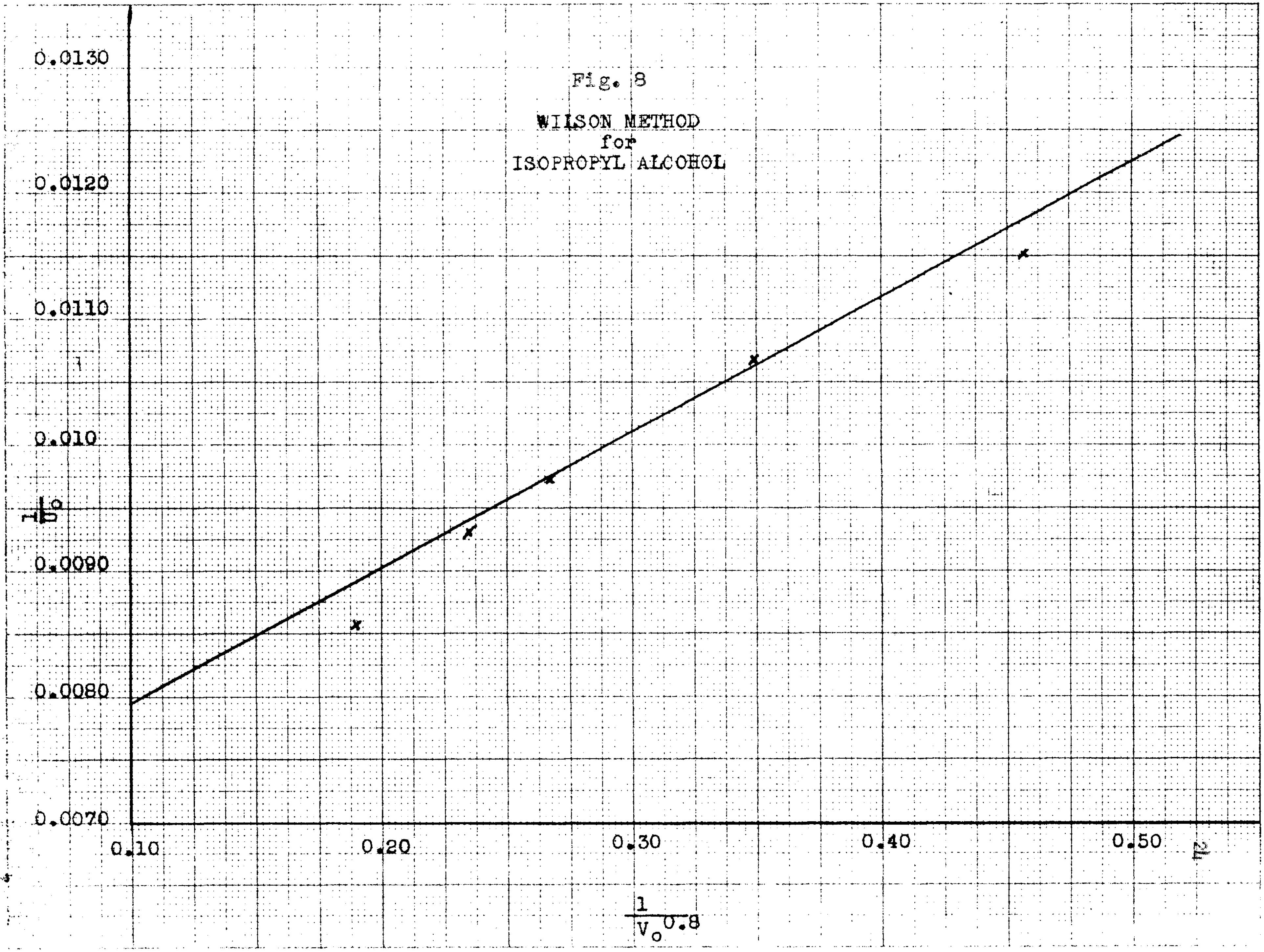
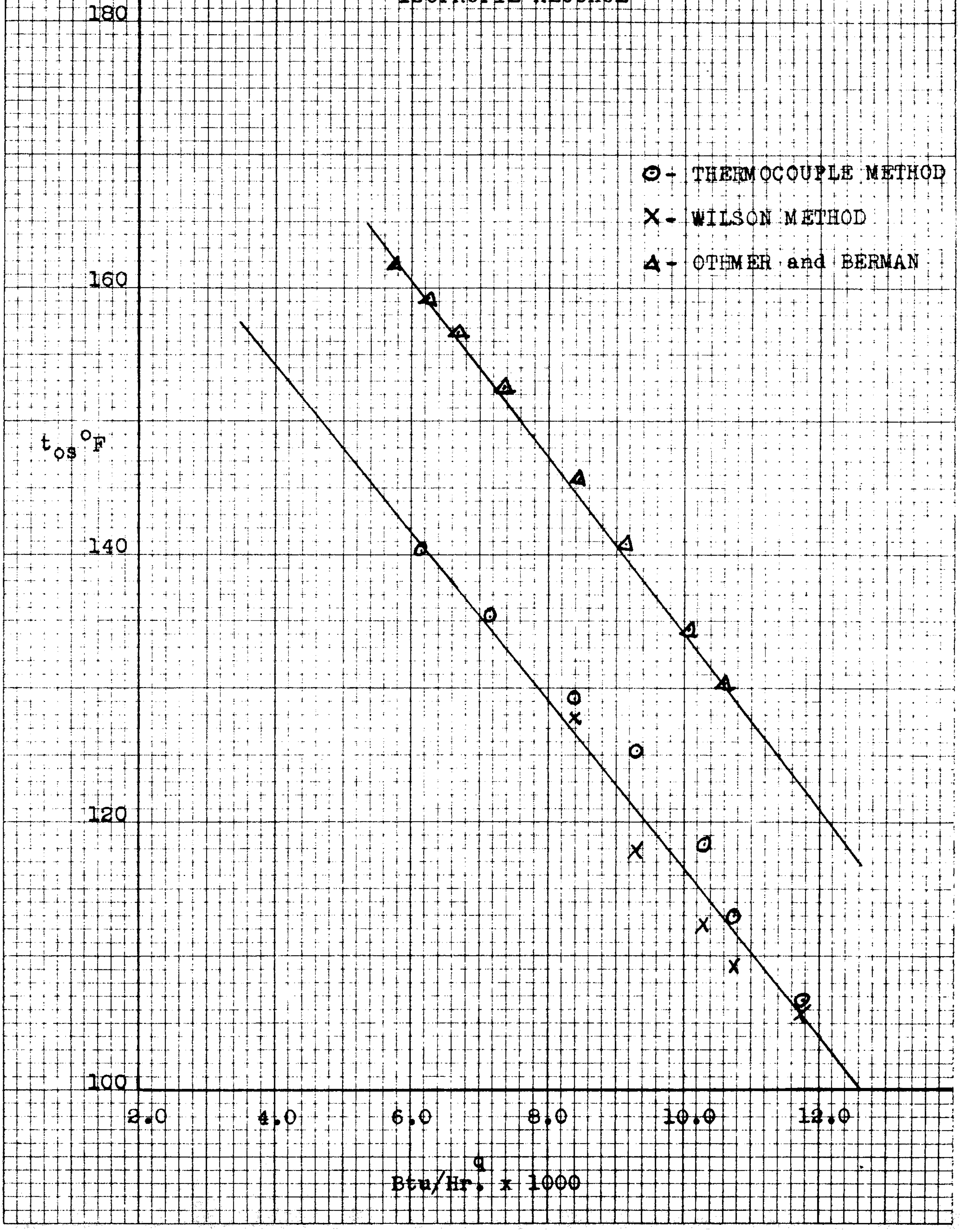


Fig. 8

WILSON METHOD
for
ISOPROPYL ALCOHOL

Fig. 9
Heat Transfer vs.
Tube Surface Temperature
for
ISOPROPYL ALCOHOL



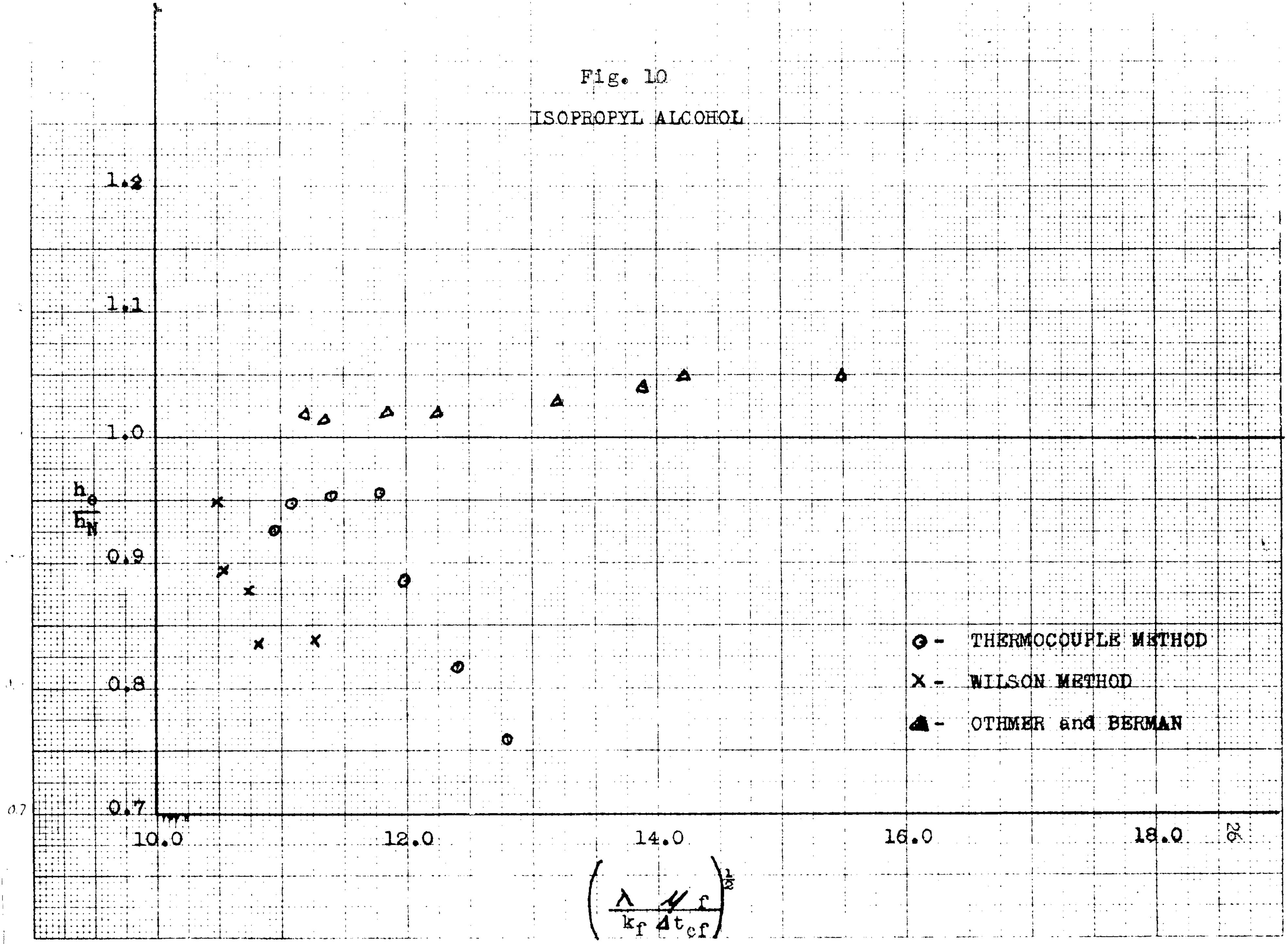


Fig. 10

ISOPROPYL ALCOHOL

EXPERIMENTAL RESULTS BY THERMOCOUPLE METHOD FOR n-PROPYL ALCOHOL

Run No.	q Btu/hr	$\frac{W}{L_t}$ #/ft hr	$\frac{4W}{L_t \quad f}$	t_v °F	t_{os} °F	Δt_{cf} °F	t_f °F	h_e	h_N	$\frac{h_e}{h_N}$	$\left(\frac{\lambda \mu_f}{k_f \Delta t_{cf}}\right)^{\frac{1}{2}}$
1	14,900	30.3	47.7	204.2	119.2	85.0	140.4	214	214	1.042	9.60
2	13,950	28.3	46.3	204.2	125.4	78.8	145.1	216	215	1.005	9.78
3	13,370	27.9	48.0	204.2	132.3	71.9	150.3	227	228	.995	9.94
4	12,120	24.6	46.1	204.2	138.2	66.0	154.7	225	236	.954	10.00
5	11,400	23.0	43.2	204.2	139.1	65.1	155.3	216	237	.937	10.14
6	10,900	22.0	41.7	204.3	146.0	58.2	160.5	229	247	.926	10.40
7	9,850	19.9	39.4	204.2	151.8	52.4	164.9	230	256	.898	10.65

EXPERIMENTAL RESULTS BY WILSON METHOD FOR n-PROPYL ALCOHOL

Run No.	q Btu/hr	$\frac{W}{L_t}$ #/ft hr	U_o	$1/U_o$	$1/V^{0.8}$	h_w	t_v °F	Δt_{cf} °F	t_{os} °F	t_f °F	h_N	$\frac{h_w}{h_N}$	$\left(\frac{\lambda \mu_f}{k_f \Delta t_{cf}}\right)^{\frac{1}{2}}$
1	14,900	30.2	124.0	.00805	.191	217	204.2	84.0	120.2	145.4	218	.993	9.30
2	13,950	28.3	116.0	.00863	.235	212	204.2	80.5	123.7	147.8	221	.959	9.44
3	13,370	27.9	111.3	.00898	.268	213	204.2	76.8	127.4	150.5	224	.949	9.63
4	12,120	24.6	102.2	.00978	.349	216	204.2	68.6	135.6	156.0	233	.927	9.88
5	11,400	23.0	96.5	.01037	.418	224	204.2	62.2	142.0	160.7	241	.930	10.20

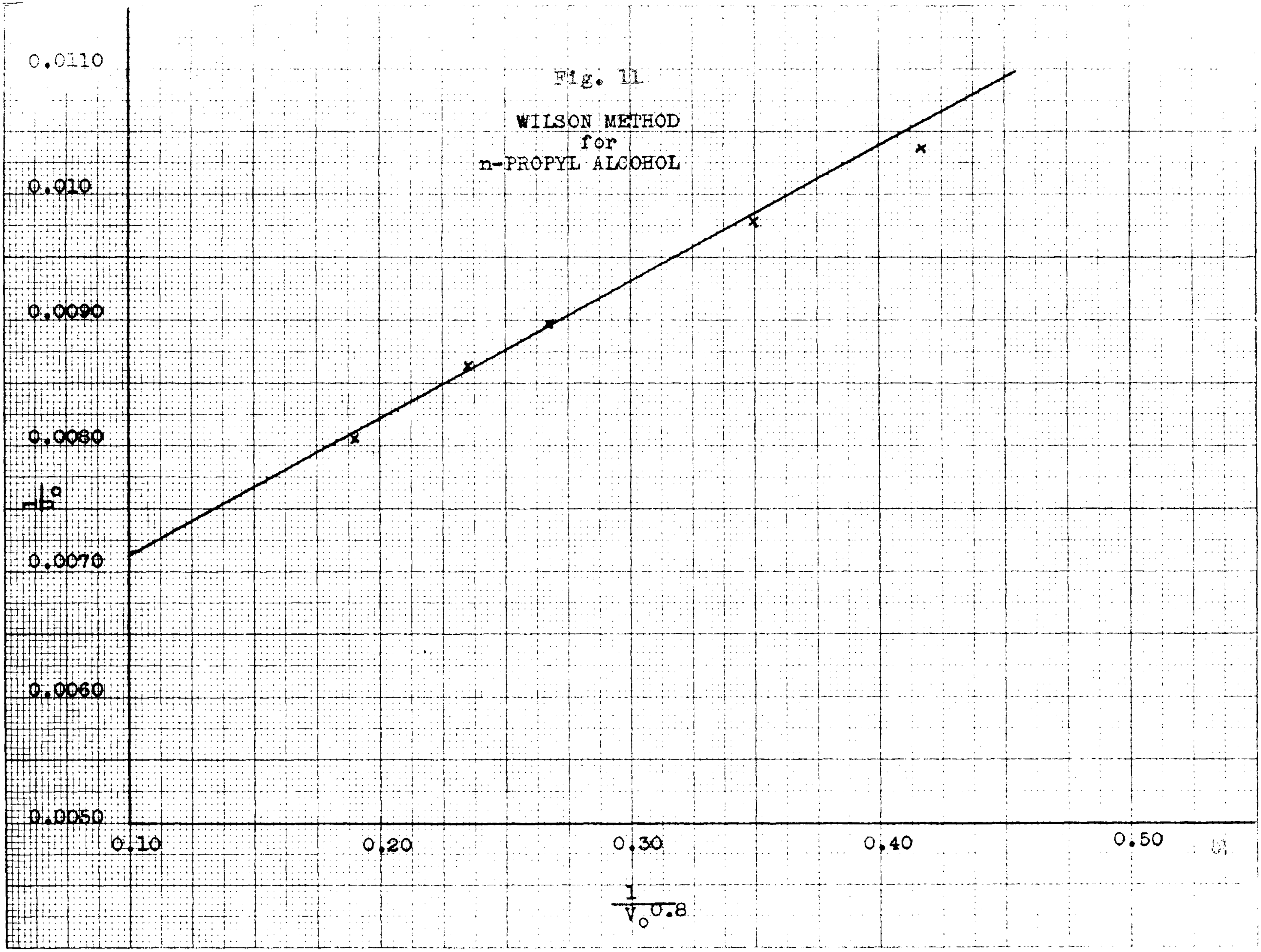


Fig. 11

WILSON METHOD
for
n-PROPYL ALCOHOL

Fig. 12
Heat Transfer vs.
Tube Surface Temperature
for
n-PROPYL ALCOHOL

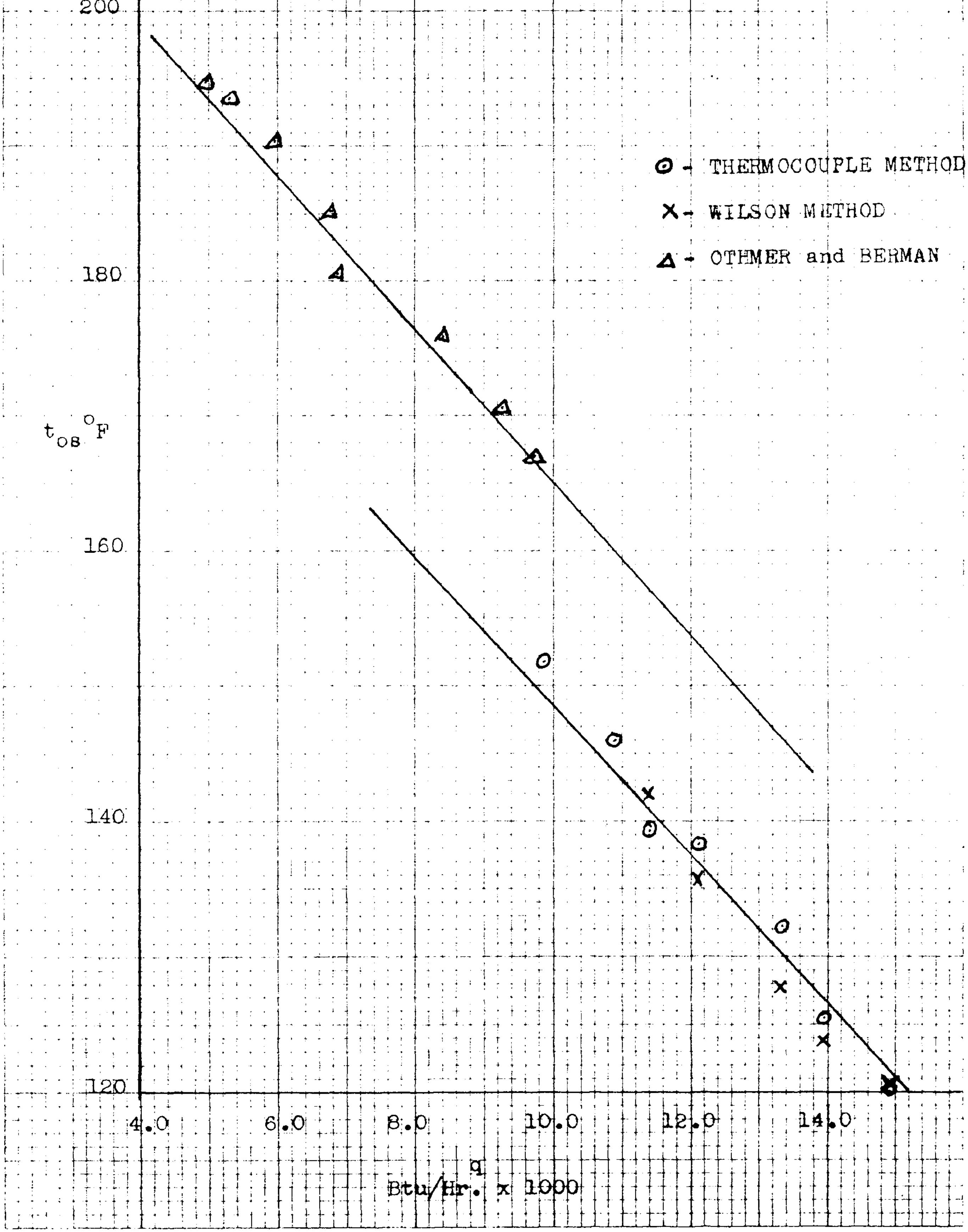
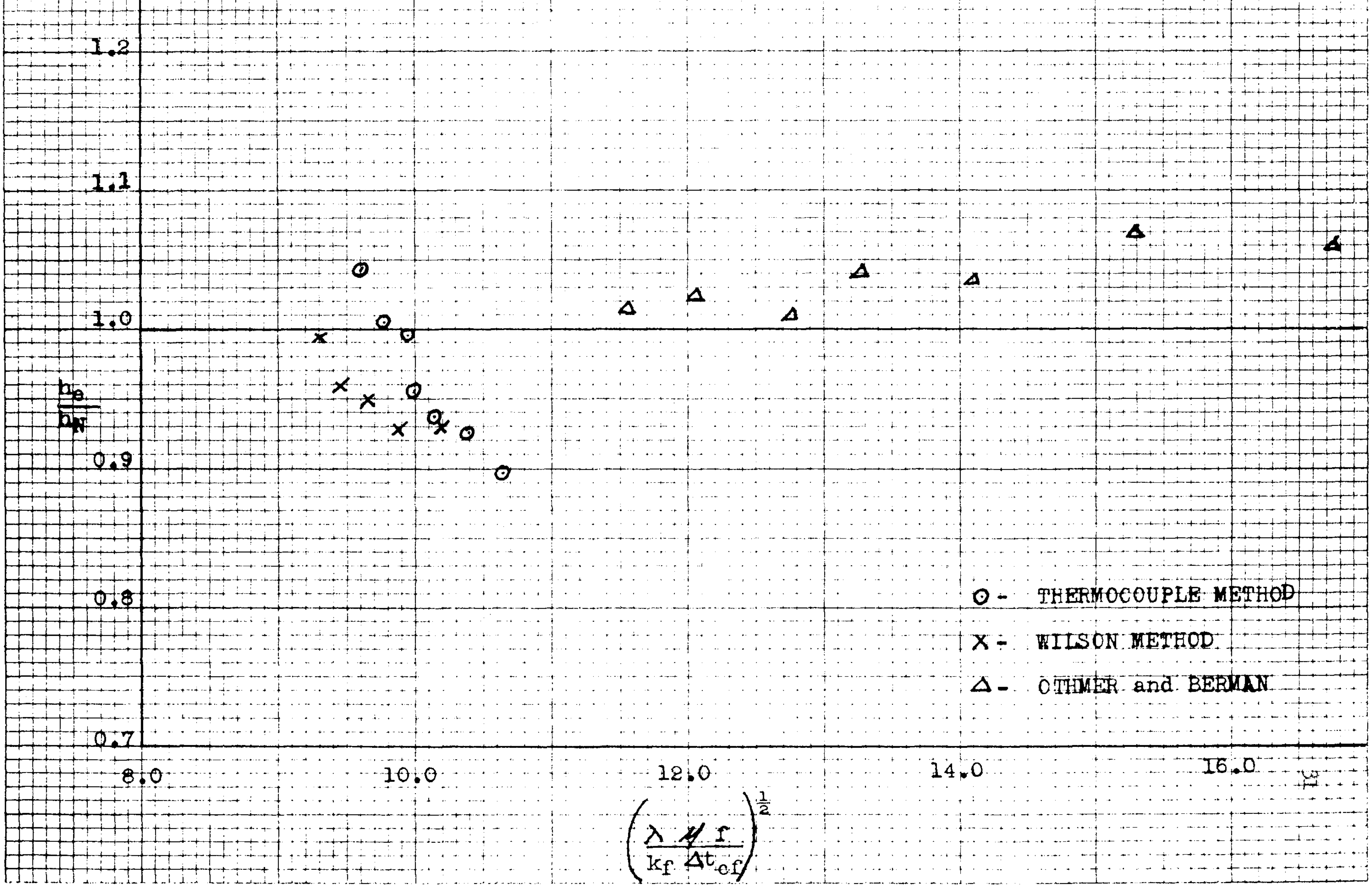


Fig. 13

n-PROPYL ALCOHOL



EXPERIMENTAL RESULTS BY THERMOCOUPLE METHOD FOR n-BUTYL ALCOHOL

Run No.	q Btu/hr	$\frac{W}{L_t}$ #/ft hr	$\frac{4W}{L_t \mu_f}$	t_v °F	t_{os} °F	Δt_{cf} °F	t_f °F	h_e	h_N	$\frac{h_e}{h_N}$	$\left(\frac{\lambda \mu_f}{k_f \Delta t_{cf}}\right)^{\frac{1}{2}}$
1	17,440	41.3	71.0	244	133.9	110.1	161.3	192.5	194	.993	7.51
2	16,980	40.2	71.8	244	136.0	108.0	163.0	192.0	196	.980	7.44
3	16,440	39.1	74.3	244	141.2	102.8	167.0	195.5	202	.967	7.83
4	15,450	36.6	70.0	244	144.0	100.0	169.0	189.0	203	.932	7.48
5	15,300	36.3	72.2	244	146.5	97.5	171.0	192.0	207	.927	7.45
6	14,800	35.1	70.8	244	149.5	94.5	173.0	191.5	209	.915	7.45
7	14,250	33.7	69.8	244	151.3	92.7	174.5	188.0	206	.912	7.46
8	14,020	33.3	70.6	244	152.9	91.1	175.7	188.5	212	.890	7.46
9	13,900	32.8	70.1	244	155.2	88.8	177.4	191.5	214	.895	7.53
10	13,730	32.6	71.1	244	157.5	86.5	179.0	194.0	216	.897	7.55
11	13,480	31.8	69.9	244	159.8	84.2	180.8	196.0	218	.897	7.60
12	13,350	31.6	69.8	244	159.0	85.0	180.3	192.5	218	.880	7.60

EXPERIMENTAL RESULTS BY WILSON METHOD FOR n-BUTYL ALCOHOL

Run No.	q Btu/hr	$\frac{W}{L_t}$ #/ft hr	U_o	$1/U_o$	$1/V^{0.8}$	h_w	t_v °F	Δt_{cf} °F	t_{os} °F	t_f °F	h_N	$\frac{h_w}{h_N}$	$\left(\frac{\lambda \mu_f}{k_f \Delta t_{cf}}\right)^{\frac{1}{3}}$
1	17,440	41.3	114.3	.00874	.191	187	244	114.0	130.0	158.5	197	.950	7.41
2	16,980	40.2	111.5	.00897	.203	184	244	113.0	131.0	159.0	197	.932	7.43
3	16,440	39.1	108.2	.00923	.235	186	244	108.0	136.0	163.0	198	.937	7.46
4	15,450	36.6	102.0	.00982	.244	170	244	111.0	133.0	160.6	197	.855	7.41
5	15,300	36.3	101.1	.00988	.268	175	244	106.5	137.5	164.0	199	.884	7.41
6	14,800	35.1	98.0	.01020	.303	177	244	102.0	142.0	167.5	200	.887	7.52
7	14,250	33.7	94.5	.01058	.303	166	244	104.5	139.5	165.5	200	.833	7.46
8	14,020	33.5	93.4	.01071	.346	176	244	97.7	146.3	170.7	205	.858	7.54
9	13,900	32.8	93.0	.01077	.349	175	244	97.3	146.7	171.0	205	.853	7.52
10	13,930	32.5	92.2	.01085	.417	197	244	85.4	158.6	180.0	216	.912	7.65
11	13,480	31.8	91.2	.01099	.457	209	244	78.9	165.1	184.8	224	.933	7.74
12	13,350	31.6	87.7	.01141	.417	177	244	92.4	151.6	174.4	211	.838	7.46

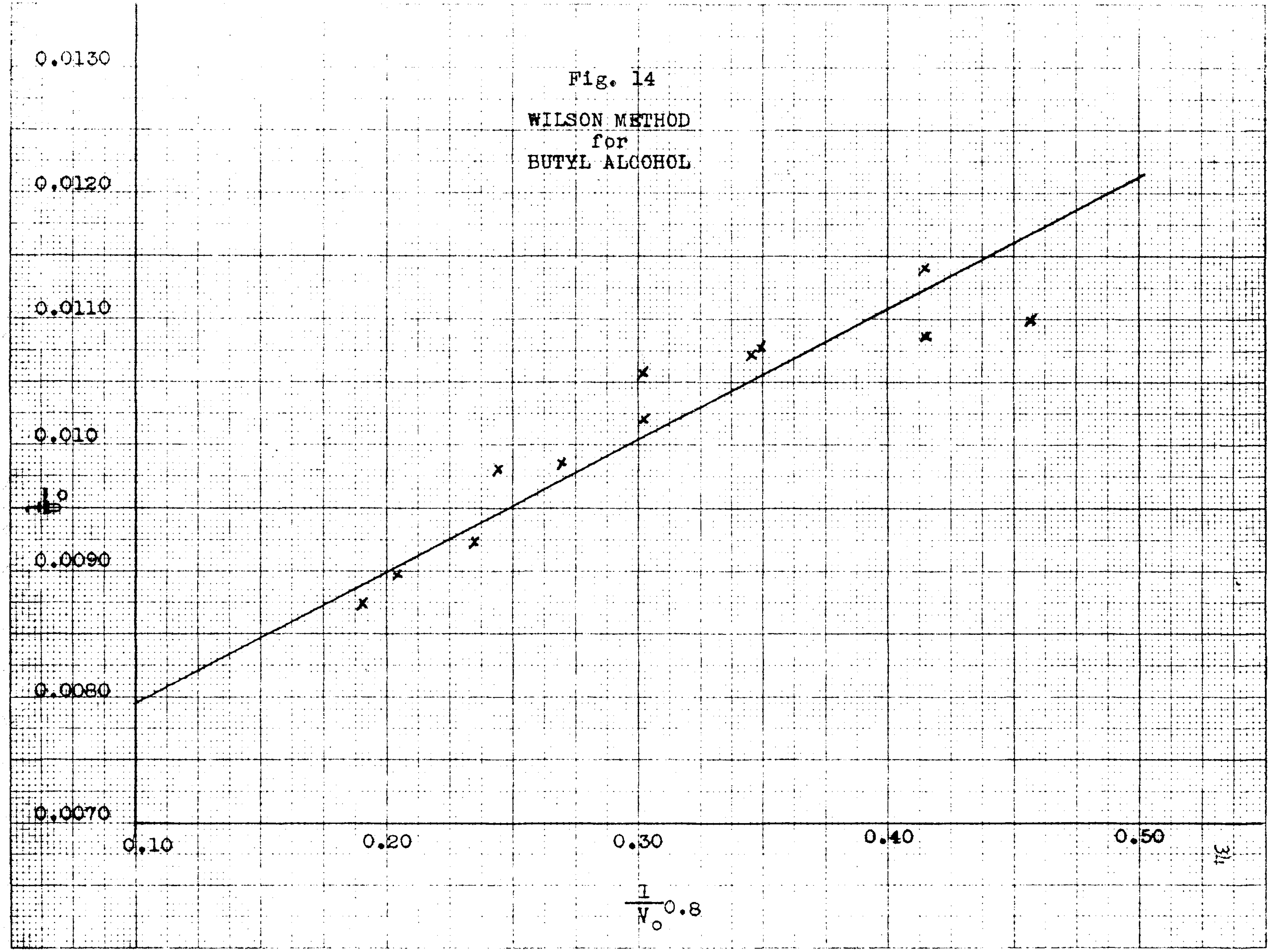


Fig. 14

WILSON METHOD
for
BUTYL ALCOHOL

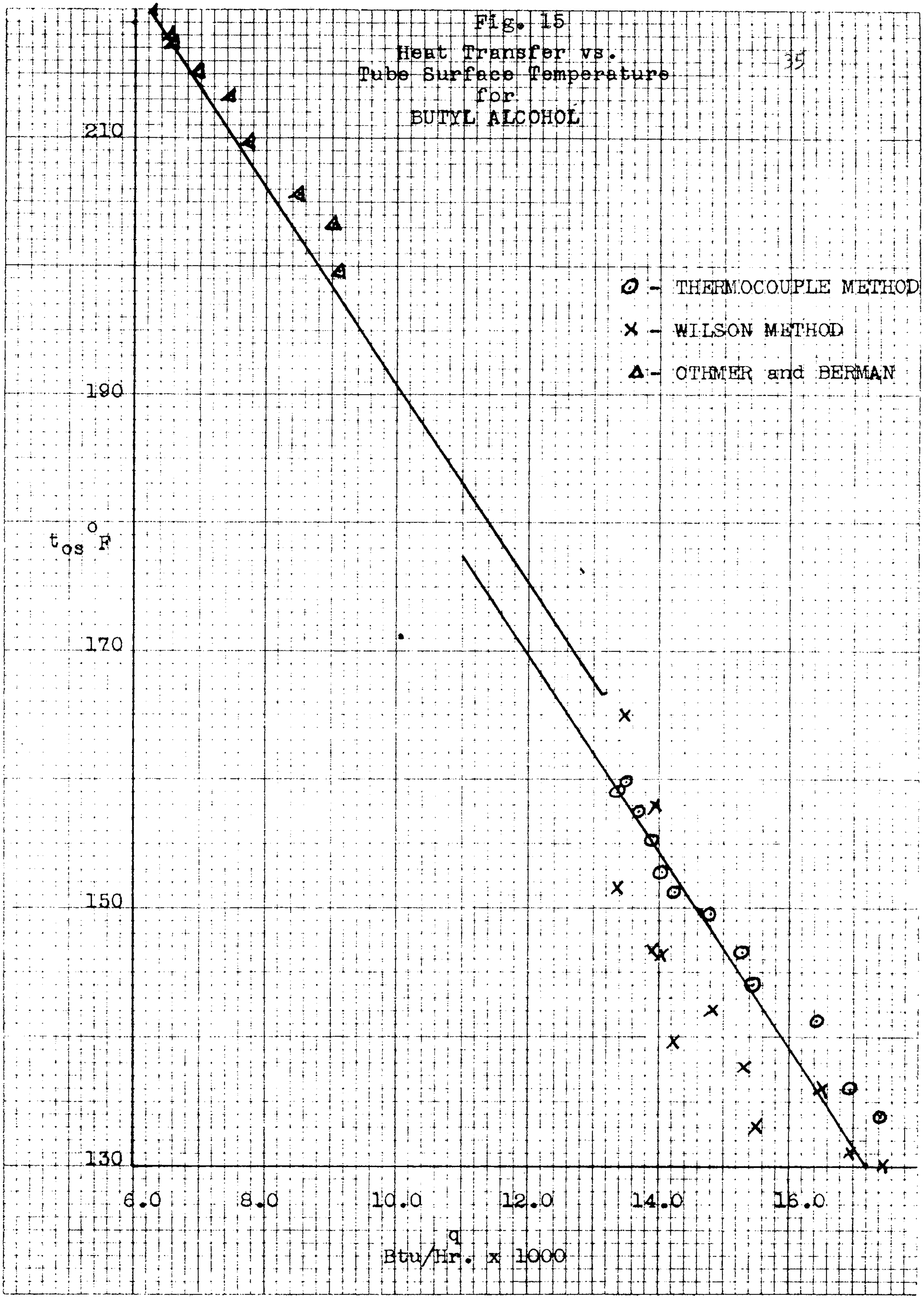


Fig. 15
Heat Transfer vs. Tube Surface Temperature for BUTYL ALCOHOL

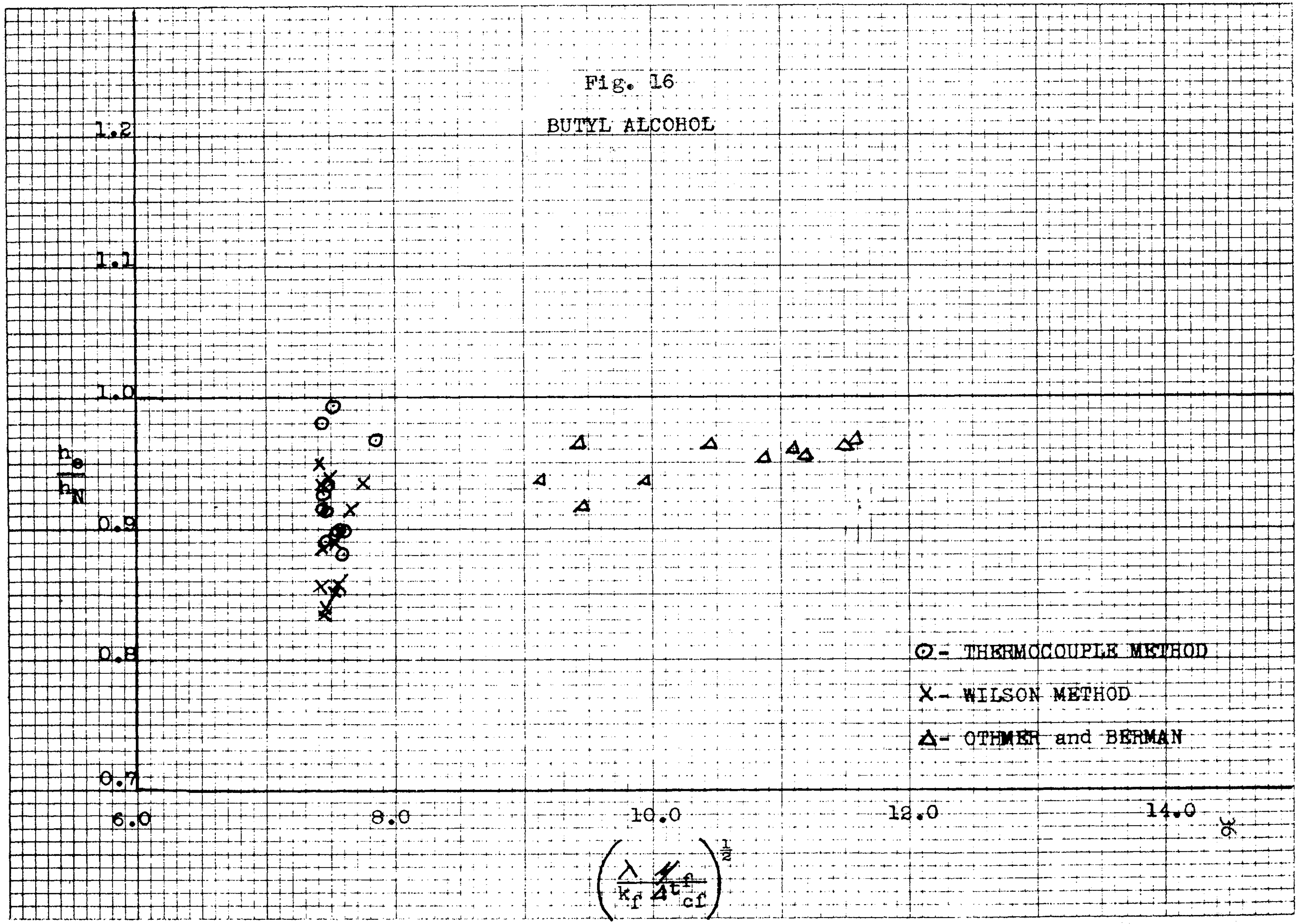


Fig. 16

BUTYL ALCOHOL

TABLE NUMBER 10

Correlation of Experimental Heat Transfer Coefficients for Vapors Condensing on a Horizontal Tube vs Heat Load

	Heat Load q Btu/hr	Condensate $\frac{W}{L_t}$ #/ft.hr	Film Coefficient h_e Btu/hr ft^2 $^\circ$F
Methyl Alcohol	6,000	7.7	438
	8,000	10.2	434
	10,000	12.7	430
	12,000	15.2	426
Isopropyl Alcohol	6,000	12.6	195
	8,000	16.8	194
	10,000	21.0	194
	12,000	25.2	195
n-Propyl Alcohol	8,000	16.3	232
	10,000	20.3	226
	12,000	24.4	221
	14,000	28.4	214
n-Butyl Alcohol	10,000	23.8	203
	12,000	28.5	196
	14,000	33.2	192
	16,000	37.9	188

Fig. 17

Heat Transfer Coefficients
vs
Heat Load

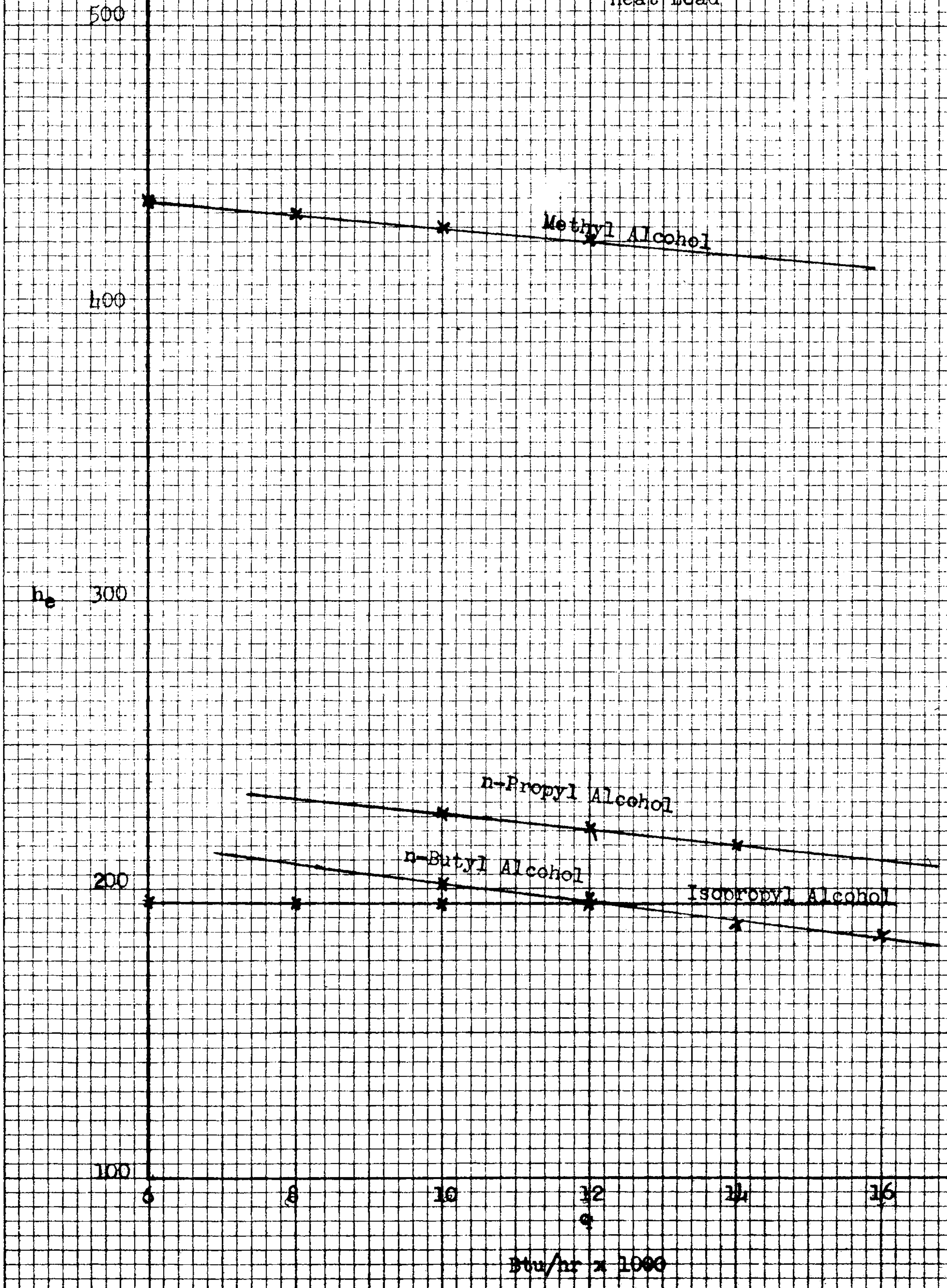
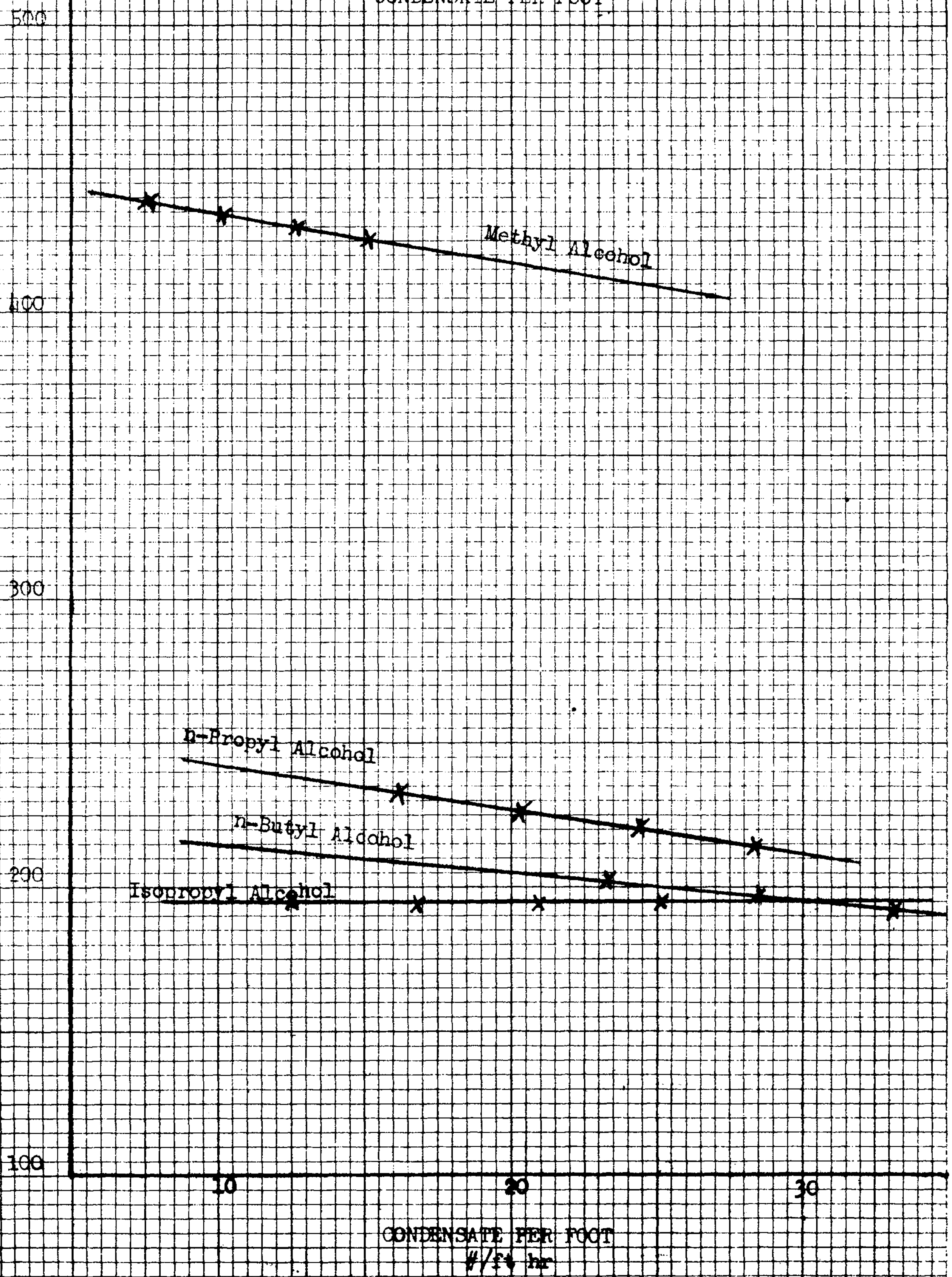


Fig. 18

HEAT TRANSFER COEFFICIRNTS
VS
CONDENSATE PER FOOT



DISCUSSION OF RESULTS

The experimental results of this investigation are illustrated in tables 2 thru 9. These tables show the condensate film coefficients for Methyl Alcohol, Isopropyl Alcohol, n-Propyl Alcohol and n-Butyl Alcohol and the operating conditions for each. Two tables are given for each compound, a Wilson Method and a Thermocouple Method tabulation. To further clarify the data the following notes are offered:

The heat load, q, is the heat absorbed by the cooling water in B.t.u. per hour. The pounds condensate per foot of tube is a calculated value based on the measured heat load. The vapor temperatures are measured values. The outside surface temperatures are an average measured value in the Thermocouple Method and a calculated value in the Wilson Method. The values of the over-all temperature drop across the film are calculated in both methods as described in the theoretical development section. The over-all coefficient of heat transfer, U_o, is calculated as described in the theoretical section and is based on the outside surface area. The value for cooling water velocity, V, is calculated for the annular space within the condenser tube and based on measured water rates.

All of the data in this thesis was taken on one piece of equipment as shown in Figures 1, 2, and 3 and is described in the apparatus section. Data was taken only after equilibrium conditions were reached for each run and sufficient time for all non-condensable vapors to be removed was allowed. Data used for both methods of calculations were taken at the same time under identical operational conditions. Figures

6, 9, 12, and 15 show a graphical summarization of the outside tube surface temperatures as determined by both methods versus the experimental heat load, q. Also shown in these figures are the experimental results previously obtained by Othmer and Berman(4). The data of this work shows a good correlation of the outside tube surface temperatures as determined for both methods at a given heat load. Thus experimental heat transfer coefficients also show a good correlation. Outside surface temperatures and experimental heat transfer coefficients are, however, definitely lower than those previously obtained by Othmer and Berman. It should be noted though that Othmer and Bermans' (4) work also gave higher values for outside surface temperatures and heat transfer coefficients than earlier work by Othmer and White (5).

Since the outside surface temperatures and heat transfer coefficients obtained in this investigation by both the Thermocouple Method and the Wilson Method were of the same order of magnitude and showed a good correlation of the two methods, we the authors believe that the higher results obtained by Othmer and Berman were possibly due to unrecognized pressure build up and thus the use of low values of ΔT_{cf} for calculations. To further substantiate this conviction two points should be noted. First, if the curves plotted in Figures 6, 9, 12, and 15 of q vs outside tube surface temperature for Othmer and Bermans' data are extrapolated to infinitely small values of q, the predicted outside tube surface temperatures for a particular compound becomes higher than the boiling point for that liquid under normal atmospheric pressure. Secondly, Othmer and White (5) obtained lower values for h_e and tube surface temperatures than those subsequently found by Othmer and Berman. Othmer and Berman then evaluated the earlier results to be erroneous due to the supposed presence of non condensable vapors produced by the decomposition of the alcohols into aldehydes and hydrogen.

In this investigation non condensable vapors are ruled out because the apparatus was made solely of glass, 316 stainless steel, and teflon. Also, the equipment was well vented and runs made over long periods of time showed no deviation in experimental data. Extrapolation of curves of q vs outside tube surface temperature obtained from data in this investigation predict values of tube surface temperatures lower than normal boiling points at all values for q.

The calculated values of $\frac{h_e}{h_N}$ and the demensionless constant $\left(\frac{\lambda \mu_f}{k_f \Delta t_{cf}}\right)^{\frac{1}{3}}$ for the experiments performed in this investigation together with those based upon data obtained by Othmer and Berman for the same compounds are shown in Figures 7, 10, 13, and 16. Table number 10 gives a summary of the experimental heat transfer coefficients found in this investigation with respect to heat load. Values of all coefficients in this table are calculated from outside tube surface temperatures vs heat load plots for each compound. It should be noted that h_e varies inversely with q for Methyl Alcohol, n-Propyl Alcohol and n-Butyl Alcohol but remains almost constant for Isopropyl Alcohol.

Although we have found h_e to vary inversely with q it was noted that slight variations in slope of the heat load vs tube surface temperature plots could cause h_e to become constant or even to vary directly with q. It was also noted that Chu (16), contrary to normally expected or predicted results, found h_e to vary directly with q for toluene. Also the experimental results of this investigation as shown in Table 10 and Figures 17 and 18 give definite evidence that the trend is for h_e to decrease for each succeeding member of the primary alcohol series.

RECOMMENDATIONS

The following recommendations are suggested:

1. Investigation of the range at low heat load, q, where tube surface temperature approaches that of the saturated vapor under normal atmospheric conditions.

2. Investigate the cause for the differences of heat transfer coefficients between a homologous series of organic compounds as a function of their diffusivity.

3. Examine to see if there might be some parameter causing the deviation of experimental heat transfer coefficients from those theoretically calculated using the Nusselt equation.

4. Determine the validity of the Wilson Method over a wider range by attaining higher Reynold's numbers.

NOMENCLATURE

A_o — Outside surface area of condenser, square feet.

C_p — Specific heat at constant pressure, B.t.u. per (pound) (^oF).

D_o — Outside diameter of condenser tube, feet.

g — Acceleration of gravity (feet per hour)^2 - 4.18×10^8.

h_e — Average condensate film heat transfer coefficient, B.t.u. per (hour) (square foot) (^oF).

h_N — Average condensate film heat transfer coefficient, B.t.u. per (hour) (square foot) (^oF).

h_w — Average condensate film heat transfer coefficient, B.t.u. per (hour) (square foot) (^oF), as calculated by the Wilson Method.

k_f — Thermal conductivity of condensate at t_f, (B.t.u.) (foot) per (hour) (square foot) (^oF).

k_w — Thermal conductivity of tube wall, (B.t.u.) (foot) per (hour) (square foot) (^oF).

L_t — Length of condenser tube, feet.

q — Rate of heat transfer through condenser tube, B.t.u. per hour.

T_i — Temperature of cooling water at entrance of condenser tube, ^oF.

T_o — Temperature of cooling water at exit of condenser tube, ^oF.

t_f — Average value of condensate film temperature, ^oF.

t_{os} — Average value of outside surface temperature, ^oF.

t_v — Average value of saturated vapor temperature, ^oF.

R_d — Resistance to heat transfer, dirt film.

R_L — Resistance to heat transfer, water side.

R_v — Resistance to heat transfer, vapor side.

R_w — Resistance to heat transfer, tube wall.

U_o — Over-all heat transfer coefficients based on outside surface area of condenser tube, B.t.u. per (hour) (square foot) (^oF).

NOMENCLATURE

V_o — Velocity of cooling water through inside of condenser tube, feet per second.

W — Weight of condensate, pounds.

α_o — Empirical constant.

ΔT — Temperature drop, °F.

Δt_{ce} — Over-all average temperature drop across film, °F.

λ — Enthalpy change, latent heat of condensation at saturation temperature, B.t.u. per pound.

μ_f — Absolute viscosity of condensate film at t_f, pounds per (hour) (foot).

ρ_f — Density of condensate film at t_f, pounds per cubic foot.

APPENDIX

APPENDIX CONTENTS

ORIGINAL DATA METHYL ALCOHOL

Run No.	T_i °C	T_o °C	Water Rate #/hr	Vapor Temp °C	Thermocouples			
					1	2	3	4
					– Millivolts –			
1	12.6	15.0	2775	64.2	1.94	1.72	1.67	1.61
	12.6	15.0		64.2	1.94	1.74	1.67	1.63
	12.6	15.0		64.2	1.97	1.74	1.68	1.62
	12.6	15.0		64.2	1.95	1.73	1.67	1.62
2	12.6	15.3	2284	64.2	2.03	1.80	1.76	1.68
	12.6	15.4		64.2	2.06	1.83	1.78	1.66
	12.65	15.4		64.2	2.04	1.83	1.79	1.69
	12.65	15.4		64.2	2.04	1.82	1.78	1.68
3	12.7	15.9	1810	64.2	2.14	1.94	1.85	1.77
	12.7	15.8		64.2	2.12	1.94	1.87	1.77
	12.7	15.9		64.2	2.14	1.94	1.87	1.77
	12.7	15.9		64.2	2.13	1.94	1.86	1.77
4	12.9	16.7	1295	64.2	2.18	2.03	1.98	1.85
	12.9	16.7		64.2	2.19	2.04	1.97	1.85
	12.9	16.7		64.2	2.19	2.02	1.96	1.85
	12.9	16.7		64.2	2.19	2.03	1.97	1.85
5	12.95	17.7	880	64.2	2.26	2.11	2.04	1.94
	12.95	17.7		64.2	2.26	2.11	2.06	1.97
	12.95	17.7		64.2	2.25	2.10	2.07	1.95
	12.95	17.7		64.2	2.26	2.11	2.06	1.95
6	13.15	20.7	880	64.2	2.32	2.14	2.07	2.01
	13.15	20.5		64.2	2.32	2.12	2.07	2.02
	13.15	20.6		64.2	2.33	2.13	2.06	2.01
	13.15	20.6		64.2	2.32	2.13	2.07	2.01
7	13.4	24.1	220	64.3	2.45	2.29	2.22	2.14
	13.4	24.1		64.3	2.46	2.28	2.26	2.14
	13.5	24.2		64.3	2.44	2.27	2.24	2.14
	13.4	24.1		64.3	2.45	2.28	2.24	2.14
8	8.3	23.3	152	64.5	2.31	2.17	2.26	2.23
	8.2	23.3		64.5	2.32	2.18	2.25	2.23
	8.2	22.8		64.5	2.32	2.17	2.24	2.24
	8.3	23.0		64.5	2.31	2.17	2.24	2.23

ORIGINAL DATA METHYL ALCOHOL

Run No.	T_i °C	T_o °C	Water Rate #/hr	Vapor Temp °C	Thermocouples 1	2	3	4
					- Millivolts -			
9	13.8	28.5	130	64.3	2.45	2.29	2.22	2.14
	13.8	28.6		64.3	2.46	2.28	2.26	2.14
	13.8	28.6		64.3	2.44	2.27	2.24	2.14
	13.8	28.6		64.3	2.45	2.28	2.24	2.14
10	8.6	29.0	84	65.0	2.36	2.24	2.27	2.26
	8.6	29.1		65.0	2.37	2.23	2.27	2.27
	8.6	29.0		65.0	2.37	2.23	2.31	2.27
	8.6	29.0		65.0	2.36	2.23	2.27	2.27

ORIGINAL DATA ISOPROPYL ALCOHOL

Run No.	T_i °C	T_o °C	Water Rate #/hr	Vapor Temp °C	Thermocouples - Millivolts -			
					1	2	3	4
1	12.35	14.6	2775	81.8	1.93	1.64	1.59	1.47
	12.3	14.65		81.8	1.96	1.65	1.58	1.48
	12.35	14.7		81.8	1.92	1.64	1.58	1.50
	12.35	14.7		81.8	1.94	1.64	1.58	1.49
2	12.4	15.0	2285	81.8	2.07	1.77	1.72	1.57
	12.4	15.0		81.8	2.07	1.79	1.74	1.57
	12.4	15.0		81.7	2.09	1.81	1.72	1.57
	12.4	15.0		81.8	2.08	1.79	1.73	1.57
3	12.45	15.6	1810	81.7	2.21	1.95	1.88	1.67
	12.4	15.55		81.7	2.21	1.96	1.86	1.67
	12.4	15.55		81.6	2.22	1.94	1.86	1.66
	12.4	15.55		81.7	2.21	1.95	1.87	1.67
4	12.4	16.5	1295	81.7	2.33	2.09	2.03	1.85
	12.4	16.4		81.7	2.33	2.09	2.02	1.84
	12.4	16.4		81.7	2.34	2.10	2.01	1.86
	12.4	16.4		81.7	2.33	2.09	2.02	1.85
5	12.5	17.8	880	81.7	2.45	2.22	2.11	1.96
	12.5	17.8		81.7	2.46	2.23	2.14	1.97
	12.5	17.8		81.7	2.45	2.21	2.13	1.97
	12.5	17.8		81.7	2.45	2.22	2.13	1.97
6	12.8	23.3	380	81.7	2.57	2.33	2.24	2.14
	12.8	23.3		81.8	2.57	2.34	2.24	2.13
	12.8	23.2		81.7	2.56	2.33	2.23	2.13
	12.8	23.3		81.7	2.57	2.33	2.24	2.13
7	13.0	28.7	220	82.3	2.70	2.44	2.37	2.30
	13.0	28.5		82.2	2.69	2.46	2.36	2.29
	13.0	28.6		82.3	2.71	2.46	2.38	2.28
	13.0	28.6		82.3	2.70	2.45	2.37	2.29

ORIGINAL DATA n-PROPYL ALCOHOL

Run No.	T_i °C	T_o °C	Water Rate #/hr	Vapor Temp °C	Thermocouples			
					1	2	3	4
					- Millivolts -			
1	12.5	15.5	2775	95.7	2.30	1.95	1.84	1.73
	12.5	15.5		95.7	2.28	1.96	1.84	1.73
	12.5	15.5		96.0	2.29	1.94	1.87	1.74
	12.5	15.5		95.7	2.29	1.95	1.85	1.73
2	12.5	15.9	2285	95.8	2.47	2.13	2.01	1.85
	12.5	15.9		95.8	2.45	2.11	2.01	1.83
	12.5	16.0		95.7	2.44	2.10	1.99	1.85
	12.5	15.9		95.8	2.45	2.11	2.01	1.85
3	12.5	16.6	1810	96.0	2.62	2.29	2.18	1.97
	12.5	16.6		96.0	2.60	2.27	2.16	1.99
	12.5	16.6		95.8	2.60	2.27	2.15	1.98
	12.5	16.6		95.8	2.61	2.28	2.17	1.98
4	12.7	17.9	1295	96.0	2.68	2.41	2.35	2.14
	12.7	17.9		95.8	2.70	2.44	2.35	2.15
	12.7	17.9		95.8	2.66	2.40	2.34	2.14
	12.7	17.9		95.9	2.68	2.42	2.35	2.14
5	12.7	18.8	1045	95.8	2.69	2.46	2.43	2.24
	12.7	18.7		95.8	2.65	2.44	2.42	2.24
	12.7	18.75		95.8	2.62	2.44	2.40	2.24
	12.7	18.75		95.8	2.65	2.45	2.42	2.24
6	12.8	28.7	380	95.8	2.68	2.57	2.52	2.50
	12.8	28.7		95.8	2.70	2.58	2.53	2.49
	12.8	28.7		95.8	2.69	2.58	2.54	2.49
	12.8	28.7		95.8	2.69	2.58	2.53	2.49
7	13.0	37.8	220	95.8	2.84	2.74	2.68	2.65
	13.0	37.8		95.8	2.84	2.73	2.70	2.66
	13.0	37.8		95.8	2.84	2.72	2.69	2.66
	13.0	37.8		95.8	2.84	2.73	2.69	2.66

ORIGINAL DATA n-BUTYL ALCOHOL

Run No.	T_i °C	T_o °C	Water Rate #/hr	Vapor Temp °C	Thermocouples - Millivolts -			
					1	2	3	4
1	12.5	16.0	2775	117.7	2.67	2.24	2.25	1.92
	12.5	16.0		117.7	2.66	2.24	2.24	1.95
	12.5	16.0		117.7	2.67	2.24	2.25	1.95
	12.5	16.0		117.7	2.67	2.24	2.25	1.95
2	12.6	16.3	2550	117.7	2.74	2.33	2.29	2.05
	12.6	16.3		117.7	2.76	2.33	2.29	2.02
	12.6	16.3		117.7	2.75	2.33	2.29	2.04
	12.6	16.3		117.7	2.75	2.33	2.29	2.03
3	12.6	16.6	2225	117.7	2.82	2.40	2.34	2.06
	12.6	16.65		117.7	2.84	2.39	2.32	2.06
	12.6	16.6		117.7	2.83	2.40	2.33	2.06
	12.6	16.6		117.7	2.83	2.40	2.33	2.06
4	12.7	16.95	2020	117.7	2.94	2.53	2.43	2.10
	12.7	16.95		117.7	2.93	2.54	2.40	2.10
	12.7	16.95		117.7	2.92	2.52	2.45	2.10
	12.7	16.95		117.7	2.93	2.53	2.43	2.10
5	12.7	17.4	1810	117.7	3.02	2.62	2.50	2.20
	12.7	17.4		117.7	3.03	2.63	2.50	2.16
	12.7	17.4		117.7	3.02	2.63	2.50	2.18
	12.7	17.4		117.7	3.02	2.63	2.50	2.18
6	12.8	18.1	1550	117.7	3.03	2.68	2.57	2.29
	12.8	18.1		117.7	3.04	2.66	2.58	2.28
	12.8	18.1		117.7	3.04	2.67	2.58	2.29
	12.8	18.1		117.7	3.04	2.67	2.58	2.29
7	13.1	18.2	1550	117.7	3.12	2.76	2.59	2.36
	13.1	18.2		117.7	3.13	2.75	2.57	2.31
	13.1	18.2		117.7	3.12	2.76	2.62	2.33
	13.1	18.2		117.7	3.12	2.76	2.59	2.33
8	12.8	18.7	1320	117.7	3.09	2.75	2.71	2.38
	12.8	18.7		117.7	3.06	2.76	2.68	2.38
	12.8	18.7		117.7	3.08	2.76	2.70	2.38
	12.8	18.7		117.7	3.08	2.76	2.70	2.38

ORIGINAL DATA n-BUTYL ALCOHOL

Run No.	T_i °C	T_o °C	Water Rate #/hr	Vapor Temp °C	Thermocouples			
					1	2	3	4
					- Millivolts -			
9	13.15	19.2	1295	117.7	3.18	2.84	2.69	2.44
	13.1	19.1		117.7	3.19	2.86	2.72	2.44
	13.1	19.2		117.7	3.18	2.82	2.71	2.45
	13.15	19.1		117.7	3.18	2.84	2.71	2.44
10	13.0	20.3	1045	117.7	3.13	2.87	2.81	2.52
	13.0	20.3		117.7	3.11	2.87	2.83	2.55
	13.0	20.3		117.7	3.12	2.87	2.82	2.54
	13.0	20.3		117.7	3.12	2.87	2.82	2.54
11	13.0	21.5	880	117.7	3.17	2.95	2.89	2.61
	13.0	21.5		117.7	3.14	2.94	2.88	2.62
	13.0	21.5		117.7	3.16	2.93	2.90	2.60
	13.0	21.5		117.7	3.16	2.94	2.89	2.61
12	13.2	20.4	1045	117.7	3.28	2.96	2.84	2.57
	13.2	20.3		117.7	3.27	2.94	2.84	2.59
	13.2	20.3		117.7	3.29	2.95	2.84	2.58
	13.2	20.3		117.7	3.28	2.95	2.84	2.58

OTHMER'S DATA METHYL ALCOHOL

Run No.	q Btu/hr	$\frac{W}{L_t}$ #/ft hr	t_v °F	t_{os} °F	Δt_{cf} °F	t_f °F	h_e	h_N	$\frac{h_e}{h_N}$	$\left(\frac{\lambda \mu_f}{k_f \Delta t_{cf}}\right)^{\frac{1}{2}}$
1	2,700	3.39	148.0	145.30	2.70	145.98	1,180	890	1.325	34.10
2	3,400	4.28	148.0	144.50	3.50	145.38	1,150	827	1.390	30.50
3	3,640	4.77	148.0	143.60	4.40	144.70	980	780	1.255	27.20
4	4,060	5.10	148.0	143.78	5.22	144.08	918	755	1.215	25.75
5	4,450	5.58	147.8	141.90	5.90	143.37	891	715	1.245	24.20
6	5,430	6.82	147.8	139.80	8.00	141.80	800	665	1.200	20.80
7	6,060	7.62	147.5	137.90	9.60	140.65	750	635	1.180	18.95
8	6,350	7.97	147.3	135.89	11.11	139.70	740	628	1.175	17.60
9	6,990	8.75	147.2	135.53	11.67	138.45	707	610	1.162	17.42
10	8,250	10.35	147.1	131.93	15.17	135.70	642	567	1.140	15.27
11	9,500	11.95	147.0	128.30	18.70	133.00	601	540	1.110	13.70
12	11,200	14.05	147.0	122.90	24.10	129.00	549	505	1.085	12.25

OTHMER'S DATA ISOPROPYL ALCOHOL

Run No.	q Btu/hr	$\frac{W}{L_t}$ #/ft hr	t_v °F	t_{os} °F	Δt_{cf} °F	t_f °F	h_e	h_N	$\frac{h_e}{h_N}$	$\left(\frac{\lambda \mu_f}{k_f \Delta t_{cf}}\right)^{\frac{1}{2}}$
1	5,750	11.95	182.05	161.75	20.3	166.85	335	318	1.050	15.48
2	6,240	12.92	182.05	159.15	22.9	164.85	321	308	1.040	13.90
3	6,680	13.84	182.03	156.83	25.2	163.15	313	298	1.050	14.22
4	7,380	15.30	182.00	152.50	29.5	159.90	295	287	1.030	13.20
5	8,450	17.55	182.00	145.60	36.4	154.70	274	269	1.020	12.23
6	9,160	19.00	182.00	140.90	41.1	151.20	263	258	1.020	11.85
7	10,070	20.90	181.90	134.40	47.5	146.20	250	246	1.015	11.35
8	10,600	22.00	181.80	130.30	51.5	143.10	243	238	1.020	11.20

OTHMER'S DATA n-PROPYL ALCOHOL

Run No.	q Btu/hr	$\frac{W}{L_t}$ #/ft hr	t_v °F	t_{os} °F	Δt_{cf} °F	t_f °F	h_e	h_N	$\frac{h_e}{h_N}$	$\left(\frac{\lambda \mu_f}{k_f \Delta t_{cf}}\right)^{\frac{1}{2}}$
1	4,980	9.98	210.0	194.9	15.1	198.68	390	363	1.075	17.55
2	5,300	10.60	210.0	193.5	16.5	197.60	380	358	1.060	16.75
3	5,980	12.00	210.0	190.2	19.8	195.15	357	343	1.070	15.30
4	6,750	13.50	209.5	185.2	23.8	191.60	335	324	1.035	14.10
5	6,850	13.75	209.2	180.4	28.8	187.90	318	306	1.040	13.25
6	8,400	16.83	209.0	175.9	33.1	184.20	300	297	1.010	12.75
7	9,270	18.55	208.5	170.5	38.0	180.00	288	280	1.025	12.05
8	9,730	19.45	208.4	167.0	41.4	177.35	278	274	1.015	11.55

OTHMER'S DATA n-BUTYL ALCOHOL

Run No.	q Btu/hr	$\frac{W}{L_t}$ #/ft hr	t_v °F	t_{os} °F	Δt_{cf} °F	t_f °F	h_e	h_N	$\frac{h_e}{h_N}$	$\left(\frac{\lambda \mu_f}{k_f \Delta t_{cf}}\right)^{\frac{1}{2}}$
1	6,130	14.4	243.5	221.4	22.1	226.90	327	338	.968	11.58
2	6,230	14.6	243.5	220.5	23.0	226.25	319	331	.964	11.50
3	6,490	15.2	243.0	218.7	24.3	224.80	315	328	.960	11.10
4	6,570	15.4	243.1	217.9	25.2	223.20	308	322	.957	11.20
5	6,930	16.2	242.7	215.5	27.2	222.30	301	313	.955	10.88
6	7,440	17.4	242.7	213.2	29.5	220.60	297	308	.963	10.45
7	7,770	18.2	242.3	209.7	32.6	217.80	282	301	.936	9.94
8	8,500	20.0	242.3	205.6	36.7	215.00	273	297	.919	9.45
9	9,010	21.1	242.3	203.2	39.1	213.00	272	282	.964	9.42
10	9,120	21.3	242.3	199.6	42.7	210.30	258	275	.937	9.11

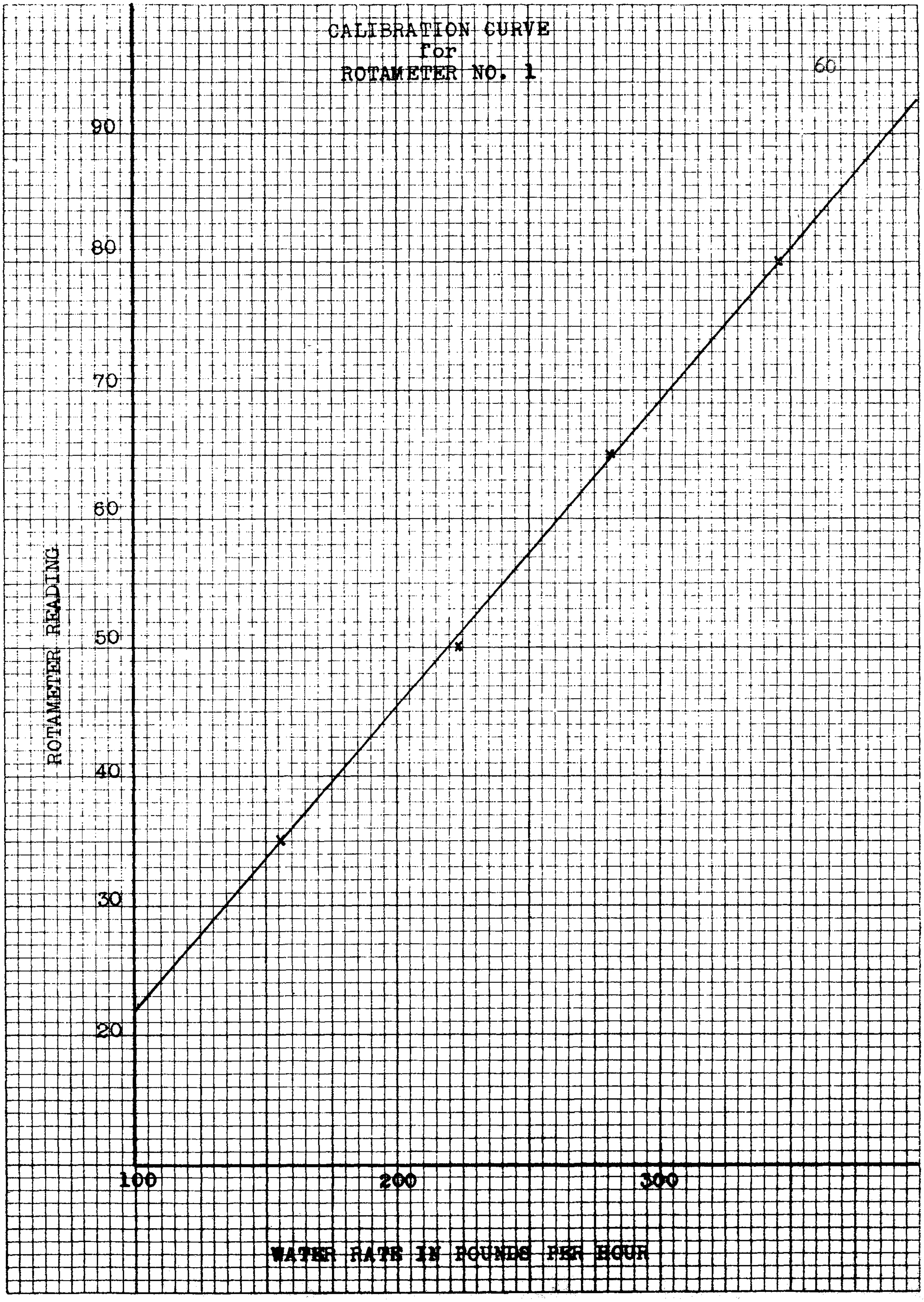
ROTAMETER CALIBRATION

Rotamer No. 1 Factor 0.82 G.P.M. Sp. Gr. 1

Serial No. W 12-4142.1

Read lower disc of bob

Rotameter Reading	Time Seconds	Wt. Water lbs.	Temp °C	# / hr
20	900	20.06	12.5	80.3
35	900	38.87	10.5	155.5
50	600	37.18	9.2	223.0
65	600	47.06	8.0	282.4
80	600	57.62	7.5	346.0
100	480	56.06	7.0	421.0



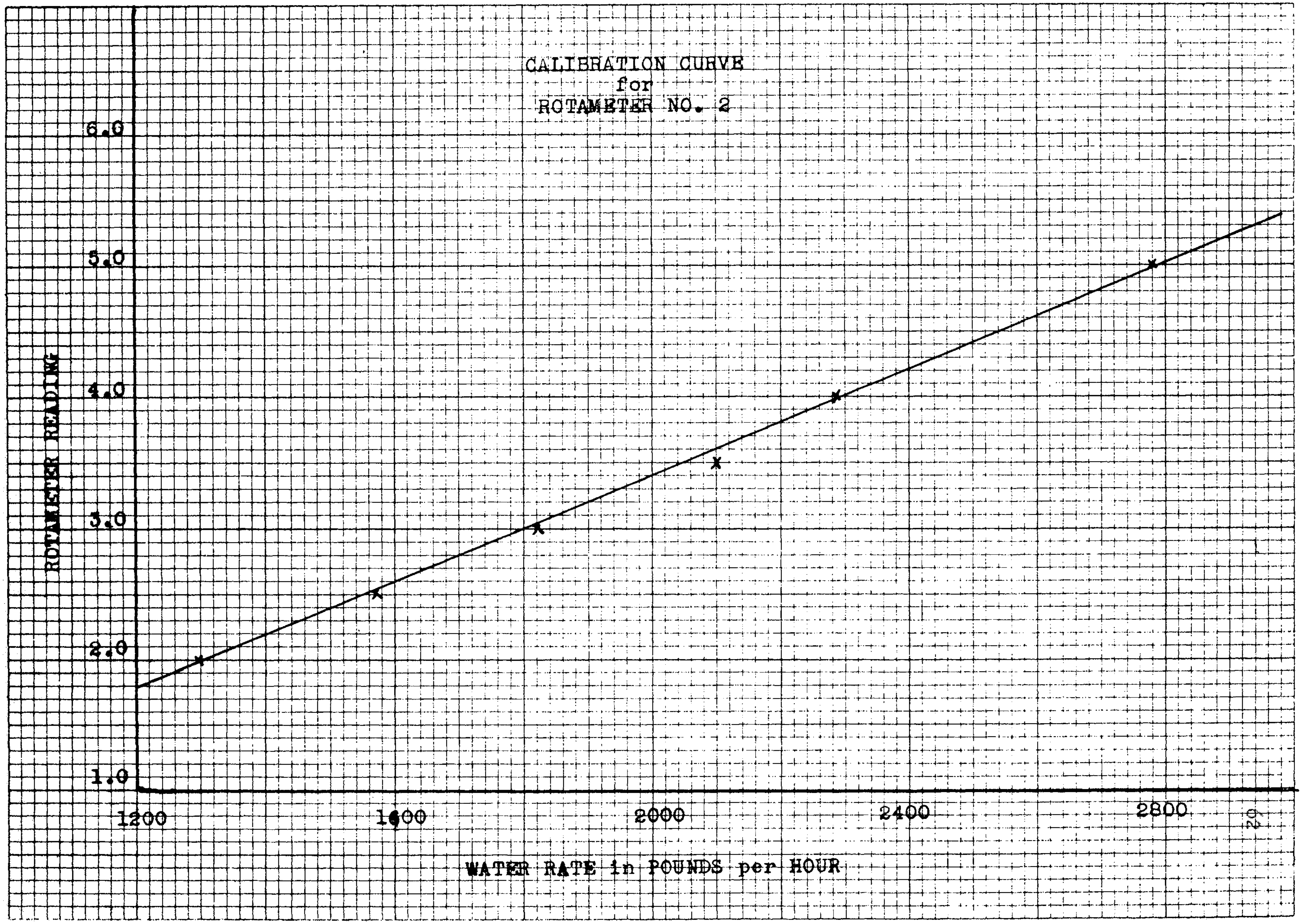
CALIBRATION CURVE
for
ROTAMETER NO. 1

ROTAMETER CALIBRATION

Rotameter # 2

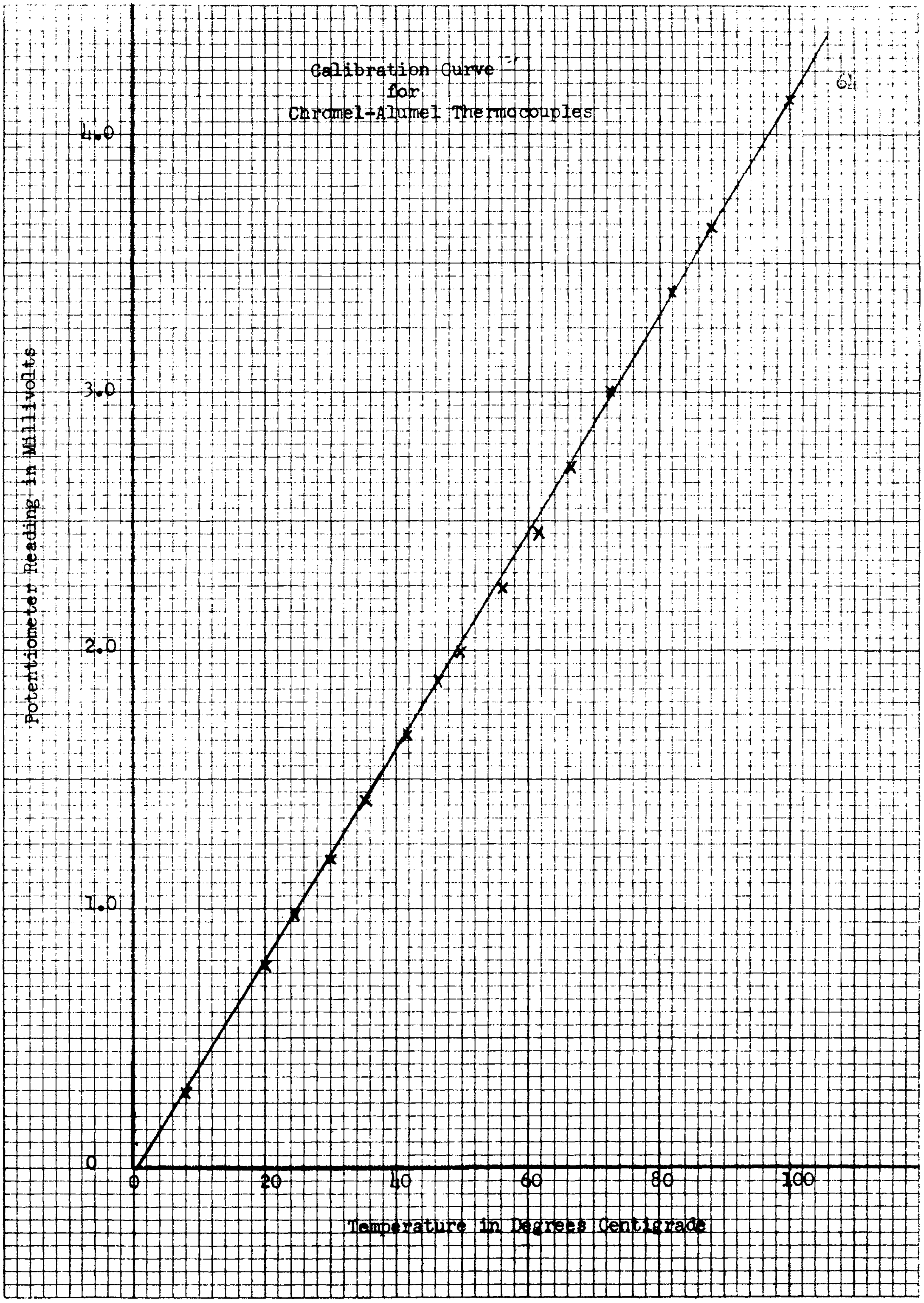
Read lower disc of bob

Rotameter Reading G.P.M.	Time Seconds	Wt. Water lbs.	Temp °C	# / hr
1.0	300	64.80	7.0	778
1.5	150	43.87	6.0	1054
2.0	120	43.12	5.2	1295
2.5	120	52.25	5.0	1569
3.0	100	50.50	5.0	1820
3.5	90	52.44	5.0	2100
4.0	60	38.06	5.0	2285
5.0	60	46.37	5.0	2780
5.5	60	50.50	5.0	3030


CALIBRATION CURVE
for
ROTAMETER NO. 2
ROTAMETER READING
6.0
5.0
4.0
3.0
2.0
1.0
1200
1600
2000
2400
2800
WATER RATE in POUNDS per HOUR

THERMOCOUPLE CALIBRATION

Temperature °C	E.M.F. - Millivolts
8.3	0.28
20.1	0.77
24.7	0.97
25.6	1.01
26.3	1.04
30.2	1.19
35.5	1.42
41.8	1.67
43.9	1.75
46.5	1.88
49.7	1.99
56.2	2.24
61.8	2.45
66.5	2.72
72.6	3.0
75.5	3.07
81.8	3.39
88.0	3.64
99.8	4.13
100.0	4.14
100.0	4.14



Calibration Curve
for
Chromel-Alumel Thermocouples

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