COEFFICIENTS OF HEAT TRANSFER BETWEEN CONDENSING ORGANIC VAPORS AND A VERTICAL COPPER TUBE

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INTRODUCTION

Investigators as early as 1844 conceived resistance of heat flow as a resistance of films, but it has been within the last twenty years that this concept has been developed in this country. In 1922 investigators (27) first elaborated on the film concept, breaking up the resistance of heat flow into the individual resistances of the films and metal wall. In the condensation of vapors on a metal tube the resistances encountered are those of the cooling liquid film, the tube wall and the condensing vapor film. There has been intensive investigation (10,24, 30, 33) on the calculation of water film coefficients and tube wall resistances. Very little investigation has been reported on film coefficients in condensing vapors other than with steam. Thus it may be seen that only the film coefficient of the condensing vapor remains to be known in order to calculate the heat flow. This fact shows the importance of determining film coefficients of condensing vapors.

Recent investigations show two definite types of condensation film and dropwise. By using a pyrex pipe around the condenser tube in this investigation it is possible to observe the type of condensation of each material studied.

Steam was studied as a calibration of the equipment since there has been more work done and more data available in which steam was used than any other material.

The purpose of this investigation is threefold, first to correlate the actual experimental results obtained for the organic vapors with the theoretical results obtained by use of the Nusselt equation. Second, to attempt to correlate the coefficients of heat transfer with the physical properties of organic liquids and third, to attempt to correlate the coefficients of heat transfer with the relative position of the organic liquid in series.

REVIEW OF LITERATURE

Resistance to heat flow as a resistance of films. In the transfer of heat from a liquid or gas on one side of a metal surface to a liquid or gas on the other side of the metal surface there exists a resistance through which the heat must flow. As we know it today this resistance may be broken down into individual resistances. The first resistance encountered is that of the film of the gas or liquid on the high temperature side of the tube. Next the metal wall offers a resistance to the flow of heat. Third the film of the liquid or gas on the low temperature side of the tube acts as a barrier to the flow of heat, this is the film concept of heat transfer. The film concept was first conceived by Peclet in 1844 but was thought to hold only for a liquid film. In 1912, Langmair extended the concept to include also the gas film. Gurney, (13), was probably the first American scientist to follow up this concept. He had noted that data taken on the same apparatus with different velocities gave varying rates of heat transfer. In an article published in 1911 he used the concept that there is a stagnant layer of the heating or cooling medium at the tube wall which varies in thickness with the velocity of the medium. He also noted the resistance of the metal wall was so small as to be neglegable. In this article Gurney refers to several articles by European authors cheifly Hausbrand (14). Kenny's article, (22) in 1913 giving the results of varying velocity of flow past a tube wall was the only work of this kind until 1922 when McAdams and Frost (27) presented their article reviewing interest in the film concept.

<u>Film Temperature Measurements</u>. After this revival of interest, there immediately appeared the problem of measuring the film temperature. McAdams and Frost (29) later in 1922 advanced an answer to this problem. They measured the temperature of the surface of the tube wall on the vapor side by imbedding and soldering base metal thermocouples into the tube. They then called the true temperature drop from the vapor to the cooling liquid the difference in temperature between the tube wall measured in the above manner and the cooling liquid. Since this time almost all investigations have used this method of obtaining the true temperature drop, the only variation being in the method of measuring the temperature of the tube wall. This explains the variation in the results obtained by different investigators. Othmer and Coats (38) give a review of the methods employed past and present, for measuring the true tube wall temperature. The methods used since McAdams and Frost's article (29) vary considerably. Callander and Nicolson (7) drilled wells in a cast iron cylinder at various distances from the surface and measured the temperature with mercury thermometers. While Stanton(43) measured the temperature by the linear expansion of the tube.

<u>Difficulty in film temperature Measurement. with Thermocouples.</u> By far the most common method of measuring the tube wall temperatures is by imbedding thermocouples into the tube wall. Orthmer and Coats (38) attacked the common method of imbeding thermocouples stating that if the thermocouples were not insulated that heat would be conducted to the junction by condensation of the vapor and the thermocouple wires and that if it

were insulated that the insulation would cause unnatural flow. They recommended that a deposit of the same metal as the thermocouple be placed on the tube wall over a rather large surface and the thermocouple attached to the deposit. Colburn and Hougan (8) immediately attacked this method stating that it would have the same effect as not insulating the thermocouples. They then advanced a method which was to cut angular slots in the tube wall and seal the junction with glycerol-litharge cement. This lead to the use of various other sealing materials such as Japan varnish used by Nagle (35, 36).

Types of Condensation. It has been known for many years that when steam condenses that it may condense on a surface in two ways, either in small droplets which run together but not entirely covering the surface, or in a film which completely covers the surface. These types of condensation are known respectivly as dropwise and film condensation. Other vapors condense in the same manner, although most organic vapors condense in film type condensation. Nagle and Drew (35) found that the type of condensation has a great influence on the film coefficient. Dropwise condensation gives a much higher film coefficient than film condensation. The Nusselt equation approximates the film coefficient for film type condensation but gives results much to low for dropwise condensation. Nagle, Bays, Bonderman and Drew (36) presented an article on the effect of tube surface on the type of condensation and gave conditions under which each type would be favored. Such as dropwise condensation being favored by a polished tube.

Film Coefficients for Condensing Steam. There has been intensive investigations of film coefficients for steam since 1920. McAdams and Frost carried out several investigations (27, 28) and Basil Heastie (15) derived formulae from these results for the metric system. Some of the more recent investigators include Fitzpatrick, Baum, and McAdams (12) in 1939 and Baker Raymark, and Stroebe (13) also in 1939. Both of these articles deal with the condensation of steam on vertical tubes. In all of these investigations the method of calculating the steam film coefficient was to measure the velocity of cooling water, calculate the water film coefficient and from the temperature drop to calculate the steam film coefficient.

Heat Transfer Studies on Materials Other than Steam. An investigation by Morris and Whitman (33) using oil and water in pipes derived a basic equation for heating and cooling and showed that previous results could be duplicated. Kirkbride and McCabe, (23), Smith (42), Rhodes and Younger (40), Sherwood and Patrie (41), Heindel (17), and others followed with investigations of condensing various organic compounds. The condensation of mixed vapors was investigated by Baker and Mueller (4, 5) using a horizontal tube. They used systems such as benezene and water, and toluene and water. From this work an investigation by Kirkbride (23) an emperical equation was formulated in which the film coefficient was independent of temperature drop. Another investigation along this same line was carried out by Wallace and Davidson (47) using the system ethanolwater. The type of condensation was described as "Film - dropwise". Around 1936 a series of investigations on the condensation of Dowtherm vapors was carried out by Holser

Ullock, Goffert, Kony and Brown (45) and Badger (2).

Methods Used in Heat transfer Calculations. Heat may flow in three distinct mechanisms, conduction, convection and radiation.

Conduction, as defined by McAdams, (26) is the transfer of heat from one part of a body to another part of the same body, or from one body to another in physical contact with it, without appreciable displacement of the particles of the body. The basic equation in conduction is Fourier's law which expressed mathematically is:

$$\frac{dQ}{d\theta} = -K A \frac{dt}{dL} \qquad (1)$$

Since for conduction in steady state, the temperature gradient and the rate of flow are independent of time the above equation may be written:

$$q = \frac{K A \Delta t}{L} \qquad (2)$$

In the case of unsteady heat flow, Fourier's law becomes:

$$\frac{\partial t}{\partial \theta} = \frac{K}{\rho C}\left[\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2}\right] \qquad (3)$$

Radiation is the transfer of heat from one body to another body by means of Radiqnt energy. The basic equation for radiation is a form of the Stephan-Botzmann (44) equation, which is as given by McAdams (26):

$$q = 0.172\,(A)\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right](FA)\,(FE) \qquad (4)$$

Convection, as defined by McAdams (26) is the transfer of heat from one point to another withing a fluid gas or liquid by mixing of one portion of the fluid with another. The basic equation in connection is an expression for the overall performance:

$$q = UA\Delta t \qquad (5)$$

In breaking up the overall performance into the individual resistances, there is as a general rule in condensing vapors, three resistances, that of the vapor film, of the tube wall, and of the cooling solution film. The sum of these resistances must equal the overall resistance or:

$$U_w = \frac{1}{\frac{1}{h_w} + \frac{LD_1}{KD_{av}}} + \frac{D_1}{D_2\, hv} \qquad (6)$$

The water film resistance is equal to the reciprocal of the water film coefficient. This coefficient has been proven experimentally, in the case of turbulent flow through circular pipes, to follow the Dittus and Bolter equation (10):

$$\frac{h_w D}{K} = 0.0225 \left(\frac{DG}{z}\right)^{0.8} \left(\frac{C\,z}{K}\right)^{0.4} \qquad (7)$$

In condensing vapors on a horizontal tube the only equation available is the Nusselt equation (37)

$$h_v = 0.725 \left(\frac{K^3 \rho^2 g \lambda}{D\, z\, \Delta t}\right)^{0.25} \qquad (8)$$

where h is the average film coefficient around the perrimeter of the tube.

The Nusselt equation for condensing vapors on a vertical tube is:

$$h_v = 0.943 \left(\frac{K^3 \rho^2 g \lambda}{N\, z\, \Delta t}\right)^{0.25} \qquad (9)$$

where h is the average film coefficient over the length of the tube.

Monrad and Badger (32) found that when using long tubes there is a deviation from the Nusselt equation due to the increase in velocity of the condensing film down the tube wall until it is in turbulent motion.

The Nusselt equation was derived on the following assumption:

(1) Steamline motion exists throughout the continuous film of condensate.

(2) The force of gravity alone causes the flow of condensate over the surface.

(3) The effect of the vapor velocity upon the thickness of condensate film may be neglected.

III EXPERIMENTAL

Purpose of Study

The purpose of this investigation is

1. To correlate the experimentally determined condensing vapor film coefficients with the theoretical results obtained by use of the Nusselt equation.

2. To attempt to correlate the vapor film coefficients with the physical properties of organic liquids.

3. To attempt to correlate the vapor film coefficients with the position of the organic liquid in a series.

Plan of Investigation

The plan of investigation is to investigate steam and two organic series, the alcohols and acetates, through the amyl group. Steam is to be first investigated in order to check the apparatus against that of other investigations, since more work has been done condensing steam than any other material. It is planned to make six 15 minute runs on each material using a constant rate of flow of cooling water and varying the steam pressure and (or) the steam condensate rate. It is planned to sum up this data and the data of Morrison (34), carried out on the same apparatus in 1939. This should cover the two organic series very thoroughly over as wide a range as is possible using the apparatus as constructed.

Materials

__Methyl Alcohol__. The methyl alcohol used was purchased from Phipps and Byrd, Richmond, Virginia. This solvent was 99 per cent pure.

__Ethyl Alcohol__. The ethyl alcohol used was secured from the laboratory and was tested to be 90 per cent pure.

This material was "Solox" (see page 47) made by United States Industrial Alcohol, Inc.

Methyl Acetate. The methyl acetate used was purchased from Carbide and Carbon Chemical Corporation, Charleston, West Virginia. This solvent was 97 per cent pure.

Ethyl Acetate. Carbide and carbon Chemicals Corporation. 99 per cent pure.

iso Propyl Alcohol. Carbide and Carbon Chemicals Corporation. 99 per cent pure.

iso Propyl Acetate. Carbide and Carbon Chemicals Corporation. 99 per cent pure.

n Butyl Alcohol. Carbide and Carbon Chemicals Corporation. 99 per cent pure.

n. Butyl Acetate. Carbide and Carbon Chemicals Corporation. 91 per cent pure.

Amyl Alcohol. The amyl alcohol used was purchased from the Sharples Solvents Corporation, Wyandotte, Michigan and specified as 99 per cent pure.

Amyl Acetate. Sharples Solvents Corporation. 99 per cent pure.

Apparatus

Still (Fig. 1) The still B was made from a 3 foot section of 10 inch cast iron pipe with 1½ inch solid flanges bolted on at bottom and top. A steam coil, 19 feet of standard half inch copper tubing in the shape of a spiral, was inserted by tapping the side of the still at bottom and top. The steam line A was connected to the coil and the condensate escaped through the steam trap C.

Condenser (Fig. 1) The vapors then travel through a well lagged 18 gage copper pipe D and enter the condenser E which was made from a 3 foot section of a 4 inch pyrex glass pipe. The vapors then condense on the vertical 38 inch section of 18 gage ¾ inch copper condenser tube which is kept cool by water flowing upward through it. The water is fed from the constant head barrell J, through standard ¾ inch galvanized pipe. This pipe is connected to the condenser tube by means of a 3 inch section of rubber tubing. An electric light bulb F is connected to the condenser in order to observe the type of condensation. Both the still and condenser are well lagged, the still with asbestus plaster, and the condenser with Carey air cell insulation.

Secondary Condenser (Fig. 1) The vapors condense on the condenser tube and flow down it, through a liquid seal and into a secondary condenser, which is a two foot glass condenser. Its purpose is to further cool the condensate and prevent loss by vaporization.

Thermocouples (Fig. 1) The temperature of the condenser tube wall was measured by six copper constantan thermocouples G, spaced 6 inches apart along the length of the tube, the six couples covering the perimeter of the tube once. These couples were made by slotting the tube, covering the constantan wire with solder at the junction, and filing smooth. The constantan wire was insulated with cappilary glass tubing to prevent the flow of heat by conduction from the hot vapor to the junction. These wires were led out through the upper copper disk by means of a packed joint. These thermocouples were calibrated in place with steam.

Resistance Thermometers (Figs. 1 and 2) The other temperatures taken were measured with resistance thermometers made by the Brown Instrument Company of Philadelphia. They were placed as shown in Fig. 1, numbered 1 to 7. The auxilary equipment used, as shown in Fig. 2, consisted of an air cell battery 1, a standardizing panel 2, a type 9001 indicator 3, a connection block 4, and a 12 point switch 6.

Millivoltmeter (Fig. 2) The millivoltmeter 9 was a type 8757-B potentiometer, manufactured by the Leeds and Northrup Company of Philadelphia.

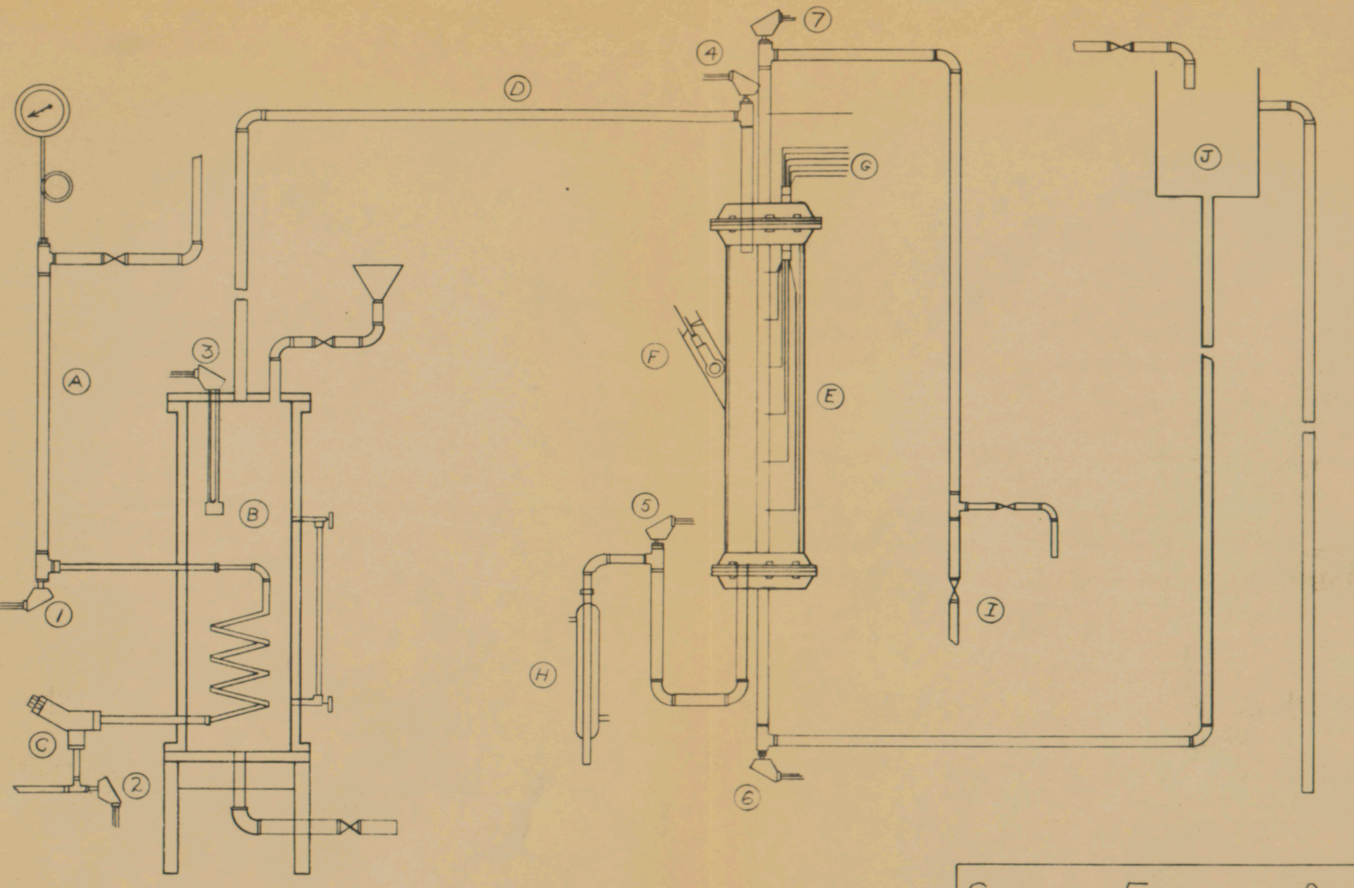
Wiring (Fig. 2) The constantan wire used was No. 28 BWG and was purchased from the Central Scientific Company, Chicago. The copper wire used throughout was No. 18 BWG copper bell wire and was purchased locally. It will be noticed that two circuits go through the twelve point switch 6; one circuit is composed of all thermometer bulbs, the other, all of the thermocouples. It was possible then by means of the double throw switch to read every thermometer and thermocouple by turning the pointer of the selector switch to the desired number.

Cold Junction (Fig. 2) A one gallon jar, 12 inches high, insulated with a layer of asbestus and covered with a piece of insulation board made up the cold junction 8, a resistance thermometer was imersed in the ice and water bath to measure the temperature. All thermocouple leads were immersed in the jar as shown.

Balances. A set of O. Hans balances, accurate to within one gram, sold by the Central Scientific Company, was used in measuring water rates and condensate rates.

Timer. A Luxor Photographic Timer, manufactured by the Burke and James Company, Chicago, was used for timing.

Tarred Pails. Various tarred pails were used to measure condensate and water rates.



LEGEND

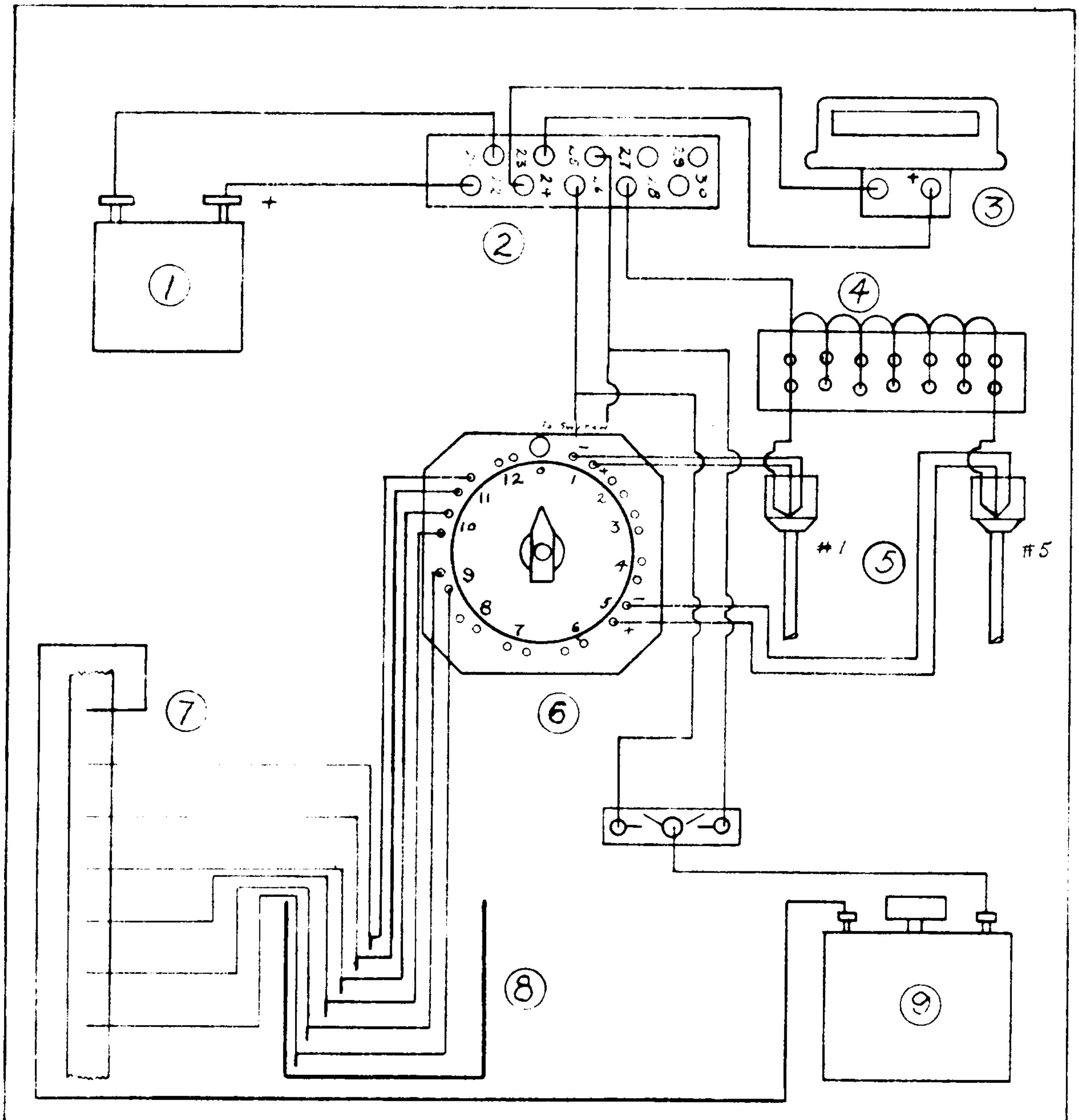
A. INLET STEAM LINE
B. KETTLE
C. STEAM TRAP
D. VAPOR LINE
E. PRINCIPAL CONDENSER
F. ELECTRIC LIGHT BULB
G. THERMOCOUPLE LEADS
H. SECONDARY CONDENSER
I. COOLING WATER RETURN
J. CONSTANT LEVEL TANK
2. Etc. THERMOMETERS

CHEMICAL ENGINEERING DEPT.
VIRGINIA POLYTECHNIC INSTITUTE
BLACKSBURG, VIRGINIA

HEAT TRANSFER APPARATUS

DRAWN BY - R.H.M.
CHECKED BY - DR. A.H.G.
TRACED BY - H.E.H.

FIG. No. 1

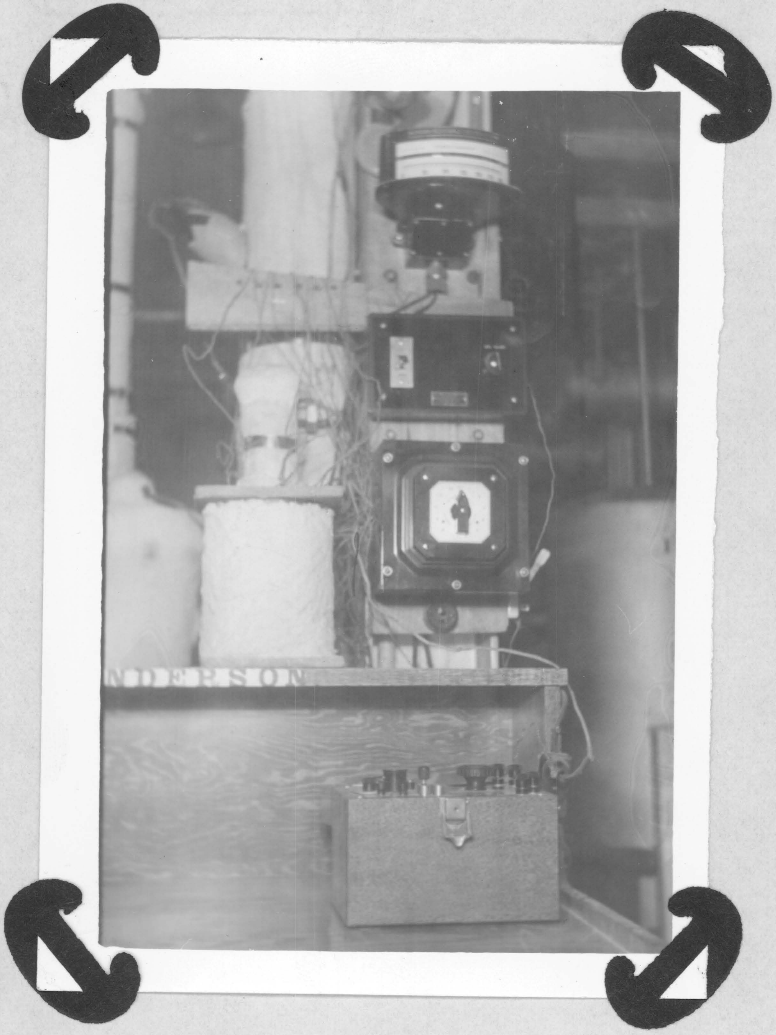


LEGEND

1 AIR CELL BATTERY
STANDARDIZING PANEL
3 TYPE 9001 INDICATOR
4 CONNECTION BLOCK
5. THERMOMETER BULBS
6. 12-POINT SWITCH
7. HOT JUNCTION THERMOCOUPLE
8 COLD JUNCTION THERMOCOUPLE
9 L AND N MILLIVOLTMETER

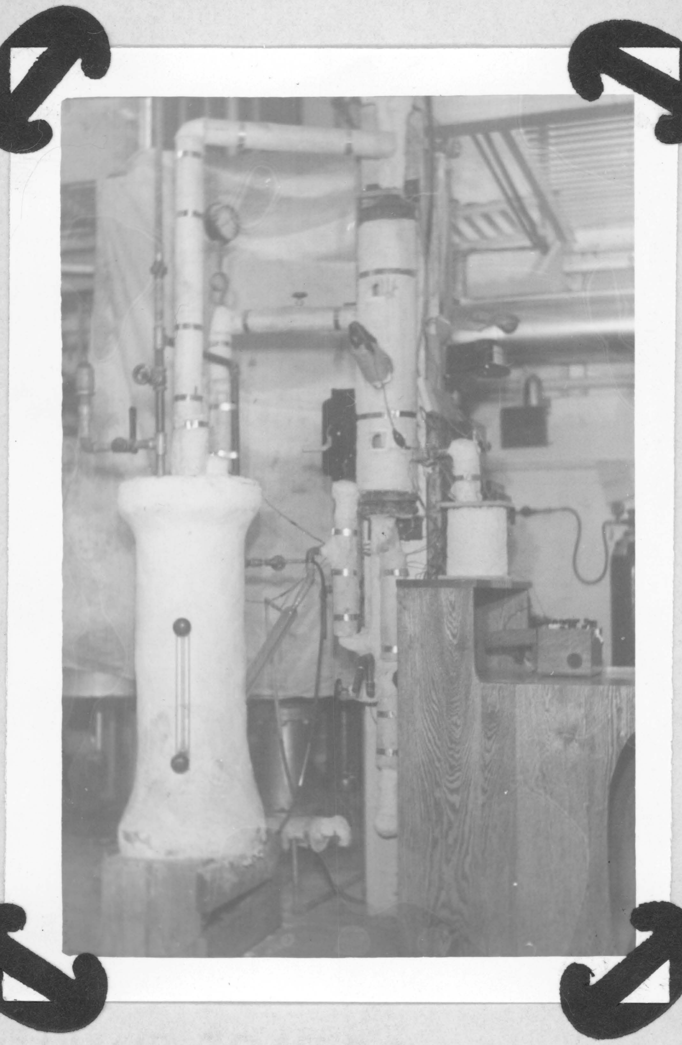
CHEM. ENG. DEPT.
VIRGINIA POLYTECHNIC INST.
BLACKSBURG, VIRGINIA
WIRING DIAGRAM
FOR HT TRANSFER EQPT.
DRAWN BY H.E.H.
CHECKED BY A.H.C
TRACED BY H.E.H.

FIG. NO. 2



Front View of Apparatus

Showing instrument panel and cold junction jar.



Left Side View of Apparatus

Showing still and condenser

Methods of Procedure

The procedure followed in making a run was to first set the constant water velocity of 8 pounds per minute. This valve was chosen so as to have definite turbulent flow through the condenser tube. A definite steam pressure and steam condensate rate was set and after the vapor into the condenser reached the same temperature as the vapor in the top of the still a run was started. Readings of the resistance thermometers and thermocouples were taken at 0, 5, 10 and 15 minutes and at the end of 15 minutes the steam condensate and vapor condensate weighed.

Methods of Calculation

The actual vapor film coefficients were calculated in the usual way. That is, the overall coefficient calculated from the basic equation and then solving for the individual resistances.

The Nusselt equation was used to calculate a valve of vapor film coefficient, which will be spoken of as the Nusselt valve.

DATA

The data is presented in sequence, with the complete data on each material included in one place. The runs are numbered in the order Steam; methyl, ethyl, propyl, butyl, and amyl alcohols; methyl, ethyl, propyl, butyl and amyl acetates. Figures represent 5 minute readings, and letters represent a 15 minute average.

Thermometer Readings. Under the heading "Resistance Thermometers", the thermometers are given a number. The key to these numbers is:

1. Temperature of steam to still
2. Temperature of steam condensate from still
3. Temperature of vapor in top of still

4. Temperature in top of condenser

5. Temperature of vapor out of condenser

6. Temperature of cooling water into condenser

7. Temperature of cooling water out of condenser

8. Temperature of cold junction bath for thermocouples

Thermocouple Readings. The thermocouples are numbered 1 to 6 from the top of the tube to the bottom.

TABLE NO. 1

Data for steam

Run no.	Steam press p.s.i.	Resistance thermometers - deg. F							
		1	2	3	4	5	6	7	8
1	10	232	226	210	210	76	50	85	35
2	10	230	206	210	210	84	50	66	35
3	10	231	204	210	210	71	50	57	35
4	10	231	203	209	209	70	50	55	35
A	10	231	210	210	210	75	50	66	35
5	15	237	220	210	210	96	50	95	36
6	15	240	211	210	210	97	50	89	36
7	15	242	211	210	210	96	50	96	36
8	15	240	209	210	210	78	50	87	37
B	15	240	213	210	210	92	50	92	36
9	15	240	233	210	210	200	51	88	37
10	15	238	225	210	210	150	51	81	37
11	15	240	224	210	210	202	51	85	37
12	15	240	222	210	210	192	51	76	38
C	15	240	226	210	210	186	51	83	37
13	15	238	235	210	210	162	52	94	39
14	15	240	215	210	210	168	51	58	39
15	15	240	228	210	210	184	52	87	39
16	15	241	207	210	210	108	51	70	39
D	15	240	221	210	210	156	51	77	39

TABLE NO. 2

Data for steam (continued)

Run no.	Time min.	Steam rate lb./hr.	Cond. rate lb./hr.	Thermocouples.- m.v.					
				1	2	3	4	5	6
1	0			4.01	4.01	3.62	3.80	3.12	2.05
2	10			3.11	3.20	2.91	2.40	1.10	0.68
3	20			2.08	1.92	9.98	0.70	0.60	0.60
4	30			2.10	2.01	1.05	0.70	0.66	0.65
A	-	20.7	6.0	2.83	2.79	2.14	1.90	1.37	1.00
5	0			4.20	4.18	3.82	4.00	3.60	2.95
6	10			4.10	4.10	3.78	4.00	3.60	3.40
7	20			3.95	4.05	3.70	3.82	3.00	1.90
8	30			4.00	3.90	3.30	3.10	1.90	0.92
B	-	32.8	16.3	4.06	4.06	3.68	3.73	3.63	2.29
9	0			4.30	4.12	3.82	3.82	2.55	1.20
10	10			4.28	4.20	4.05	4.20	3.80	3.70
11	20			4.28	4.21	4.06	4.14	3.66	2.80
12	30			3.85	4.00	3.50	3.40	1.90	1.00
C	-	26.2	15.3	4.18	4.13	3.86	3.89	2.98	2.18
13	0			4.48	4.40	4.18	4.30	4.04	3.90
14	10			2.08	2.04	1.20	0.90	0.88	9.75
15	20			4.48	4.38	4.15	4.22	3.80	2.60
16	30			3.65	3.61	3.10	2.70	1.20	0.80
D	-	19.2	11.8	3.67	3.61	3.16	3.03	2.48	2.01

TABLE NO.3

Data for methyl alcohol

Run no.	Steam press p.s.i.	Resistance thermometers - deg. F 1	2	3	4	5	6	7	8
17	1.5	211	137	147	147	142	58.0	70.0	34
18	1.5	212	140	148	148	147	58.5	70.5	34
19	1.5	212	142	148	148	147	58.5	70.0	34
20	1.5	212	142	148	148	147	58.0	70.0	34
E	1.5	212	140	148	148	146	58.6	70.0	34
21	1.0	211	140	148	148	143	58.5	68.0	34
22	1.0	210	138	148	148	110	58.0	68.5	34
23	1.0	210	138	147	147	92	58.0	68.0	34
24	1.0	210	138	147	147	86	58.0	67.5	34
F	1.0	210	139	148	148	108	58.0	68.0	34
25	0.75	210	136	147	147	82	58.0	63.5	34
26	0.75	210	135	147	147	78	58.0	63.0	34
27	0.75	210	134	147	147	75	58.0	63.0	34
28	0.75	210	134	147	147	74	58.0	62.5	34
G	0.75	210	135	147	147	77	58.0	63.0	34
29	2.0	213	140	147	147	122	59.0	70.0	36
30	2.0	214	142	148	148	146	60.0	72.0	36
H	2.0	214	141	148	148	134	60.0	71.0	36

TABLE NO. 4

Data for methyl alcohol (continued)

Run no.	Time min.	Steam rate lbs./hr	Cond. rate lbs./hr	Thermocouples - m.v.					
				1	2	3	4	5	6
17	0			2.50	2.65	2.35	2.55	2.08	1.92
18	5			2.50	2.60	2.38	2.52	2.10	1.98
19	10			2.50	2.60	2.32	2.52	2.10	1.98
20	15			2.50	2.68	2.32	2.52	2.10	1.97
E	-	13.7	17.0	2.50	2.64	2.36	2.53	2.09	1.96
21	0			2.45	2.55	2.22	2.42	1.81	1.30
22	5			2.42	2.60	2.30	2.48	1.90	1.42
23	10			2.43	2.60	2.25	2.45	1.85	1.30
24	15			2.40	2.56	2.22	2.35	1.68	1.22
F	--	7.1	9.5	2.44	2.58	2.26	2.43	1.81	1.31
25	0			1.77	2.01	1.60	1.70	1.05	0.75
26	5			1.78	2.02	1.60	1.68	0.95	0.65
27	10			1.75	1.95	1.58	1.68	0.95	0.60
28	15			1.80	1.95	1.56	1.58	1.00	0.55
G	--	4.9	5.2	1.78	2.00	1.59	1.66	0.99	0.64
29	0			2.55	2.70	2.30	2.58	2.10	1.85
30	5			2.65	2.72	2.40	2.62	2.20	1.90
H	--	--	--	2.60	2.71	2.35	2.60	2.15	1.88

TABLE NO. 5

Date for ethyl alcohol

Run no.	Steam press p.s.i.	Resistance thermometers - deg. F. 1	2	3	4	5	6	7	8
31	1.5	209	159	172	172	80	56.0	60.0	33
32	1.5	210	160	174	173	78	56.0	60.5	33
33	1.5	210	160	174	174	76	56.5	61.5	33
34	1.5	210	160	174	174	74	57.0	61.5	33
I	1.5	210	160	174	173	77	56.5	61.0	33
35	2.0	210	164	174	174	79	57.0	70.0	34
36	2.0	210	166	175	175	96	58.0	71.5	34
37	2.0	212	169	176	176	152	58.0	72.0	34
38	2.0	212	169	176	176	169	58.0	72.5	34
J	2.0	211	167	175	175	124	58.0	72.0	34
39	2.5	212	170	176	176	170	58.0	72.5	34
40	2.5	212	170	176	176	174	58.0	73.5	34
41	2.5	213	176	176	176	174	58.0	74.0	34
42	2.5	214	178	176	176	174	57.5	74.0	34
K	2.5	213	174	176	176	173	58.0	73.5	34
43	2.0	211	174	177	176	156	57.5	73.0	34
44	2.0	211	173	178	178	178	58.0	73.5	34
45	2.0	211	174	178	178	170	57.5	73.5	34
46	2.0	211	180	178	178	167	57.0	74.0	34
L	2.0	211	175	178	178	168	57.5	73.5	34
47	1.5	210	174	174	174	108	56.5	68.0	34
48	1.5	210	170	174	174	99	56.5	69.0	34
49	1.5	210	168	174	174	100	57.0	69.5	34
50	1.5	210	166	174	174	102	57.0	69.5	34
M	1.5	210	170	174	174	102	57.0	69.0	34
51	1.25	209	164	174	174	102	57.0	65.5	34
52	1.25	209	162	174	174	94	57.0	62.0	34
53	1.25	209	161	174	174	87	57.0	62.0	34
54	1.25	209	160	174	174	82	57.0	61.5	34
N	1.25	209	162	174	174	91	57.0	63.0	34

TABLE NO. 6

Data for ethyl alcohol (continued)

Run no.	Time min.	Steam rate lb./hr.	Cond. rate lb./hr.	Thermocouples -- m.v. 1	2	3	4	5	6
31	0			1.40	1.50	1.22	1.20	0.76	0.38
32	5			1.45	1.60	1.30	1.40	0.77	0.35
33	10			1.65	1.80	1.45	1.45	0.83	0.40
34	15			1.70	1.90	1.50	1.50	0.85	0.38
I	--	6.1	5.0	1.55	1.70	1.37	1.39	0.80	0.38
35	0			2.90	3.10	2.68	2.88	2.10	1.45
36	5			3.00	3.15	2.72	2.92	2.25	1.90
37	10			3.08	3.28	2.80	3.00	2.40	1.92
38	15			3.15	3.28	2.85	3.05	2.48	2.05
J	--	11.2	16.7	3.04	3.20	2.76	2.96	2.31	1.83
39	0			3.15	3.28	3.00	3.02	2.50	2.10
40	5			3.25	3.30	2.90	3.05	2.55	2.05
41	10			3.22	3.22	3.00	3.20	2.65	2.10
42	15			3.22	3.30	3.08	3.12	2.70	2.15
K	--	19.5	17.2	3.21	3.28	3.00	3.10	2.60	2.10
43	0			3.22	3.28	3.02	3.08	2.60	2.10
44	5			3.20	3.32	3.05	2.99	2.58	2.10
45	10			3.25	3.35	3.10	3.20	2.68	2.12
46	15			3.22	3.32	3.08	3.18	2.62	2.10
L	--	12.7	17.6	3.22	3.32	3.06	3.00	2.62	2.11
47	0			2.88	3.10	2.60	2.90	2.05	1.12
48	5			2.98	3.15	2.65	2.92	2.00	1.30
49	10			2.99	3.13	2.68	2.88	2.20	1.28
50	15			2.98	3.12	2.65	2.90	2.10	1.20
M	--	8.7	12.2	2.96	3.13	2.65	2.90	2.14	1.25
51	0			1.85	1.92	1.58	1.70	1.10	0.58
52	5			1.81	2.08	1.60	1.55	1.02	0.55
53	10			1.81	1.95	1.60	1.60	1.05	0.50
54	15			1.78	1.95	1.50	1.63	0.92	0.52
N	--	4.8	5.6	1.81	1.99	1.57	1.63	1.04	0.54

TABLE NO. 7

Data for propyl alcohol

Run no.	Steam press p.s.i.	Resistance thermometers - deg. F.							
		1	2	3	4	5	6	7	8
55	2.5	212	177	178	176	172	58.0	71.0	32
56	2.5	212	176	178	178	177	56.0	69.0	32
57	2.5	212	178	178	178	177	55.0	67.0	32
58	2.5	214	210	178	178	177	56.0	70.0	32
O	2.5	213	185	178	178	176	56.5	69.5	32
59	2.5	210	172	177	176	162	55.5	68.0	32
60	2.5	212	178	178	178	176	56.0	69.0	32
61	2.5	212	179	178	178	177	56.0	69.0	32
62	2.5	212	210	178	178	176	56.0	68.0	32
P	2.5	212	185	178	178	173	56.0	68.5	32
63	2.0	210	175	177	177	153	56.0	68.0	32
64	2.0	210	174	178	177	176	56.0	68.5	32
65	2.0	210	175	178	178	177	56.0	69.0	32
66	2.0	210	206	178	178	174	56.0	67.0	32
Q	2.0	210	182	178	178	170	56.0	68.0	32
67	2.0	210	209	178	177	142	56.0	63.0	32
68	2.0	210	209	178	177	118	56.0	60.0	32
69	2.0	210	209	178	177	106	56.0	59.0	32
70	2.0	210	209	178	177	100	56.0	57.0	32
R	2.0	210	209	178	177	117	56.0	60.0	32
71	2.0	210	170	178	176	102	58.0	68.5	32
72	2.0	210	170	178	178	130	58.0	70.5	32
73	2.0	211	173	178	178	160	59.0	72.0	32
74	2.0	210	202	178	178	168	58.0	70.0	32
S	2.0	210	179	178	178	140	58.0	70.0	32
75	1.5	210	208	178	178	134	58.0	61.0	32
76	1.5	210	204	178	178	118	58.0	60.0	32
77	1.5	209	208	178	178	108	58.0	60.0	32
78	1.5	209	208	178	178	102	57.5	59.0	32
T	1.5	210	207	178	178	116	58.0	60.5	32

TABLE NO. 8

Data for propyl alcohol (continued)

Run no.	Time min.	Steam rate lb./hr.	Cond. rate lb./hr.	Thermocouples - m.v.					
				1	2	3	4	5	6
55	0			2.80	3.00	2.26	2.80	1.85	1.70
56	5			2.70	3.00	2.30	2.75	1.85	1.70
57	10			2.70	3.00	2.30	2.75	1.90	1.70
58	15			2.70	3.10	2.30	2.82	1.90	1.70
O	--	21.2	32.1	2.73	3.03	2.30	2.78	1.88	1.70
59	0			2.78	3.02	2.32	2.80	1.90	1.70
60	5			2.75	3.00	2.35	2.80	1.88	1.70
61	10			2.80	3.00	2.30	2.80	1.90	1.70
62	15			2.65	2.90	2.10	2.55	1.55	1.20
P	--	17.0	29.6	2.73	2.98	2.27	2.74	1.81	1.57
63	0			2.70	3.00	2.30	2.75	1.90	1.70
64	5			2.75	3.00	2.30	2.75	1.92	1.70
65	10			2.75	3.00	2.32	2.82	1.95	1.75
66	15			2.50	2.70	2.00	2.35	1.40	1.00
Q	--	11.3	27.4	2.68	2.93	2.23	2.67	1.79	1.54
67	0			1.75	1.95	1.40	1.70	1.00	0.85
68	5			1.38	1.50	1.18	1.35	0.90	0.70
69	10			1.05	1.10	0.95	1.10	0.78	0.62
70	15			0.81	0.90	0.76	0.88	0.62	0.57
R	--	6.5	5.2	1.25	1.36	1.07	1.26	0.85	0.69
71	0			2.75	3.00	2.30	2.80	1.90	1.50
72	5			2.95	3.08	2.30	2.85	2.00	1.78
73	10			2.88	3.10	2.30	2.90	2.05	1.80
74	15			2.65	2.85	2.00	2.50	1.50	1.20
S	--	11.4	20.5	2.81	3.01	2.23	2.76	1.86	1.57
75	0			1.60	1.65	1.18	1.45	1.00	0.80
76	5			1.25	1.30	0.90	1.25	0.90	0.70
77	10			1.10	1.15	0.90	1.15	0.90	0.70
78	15			0.95	0.98	0.78	0.95	0.76	0.62
T	--	4.3	4.9	1.23	1.27	0.94	1.20	0.89	0.71

TABLE NO. 9

Data for butyl alcohol

Run no.	Steam press p.s.i.	Resistance thermometers - deg. F. 1	2	3	4	5	6	7	8
79	20	250	249	214	208	112	57.0	68.0	32.0
80	20	252	251	220	215	104	57.0	68.0	32.0
81	20	252	251	225	220	106	5710	66.0	32.0
82	20	256	255	230	228	108	57.5	68.5	32.0
U	20	253	252	222	218	108	57.0	67.5	32.0
83	24	254	253	234	232	112	57.5	66.0	32.0
84	24	258	257	236	235	111	57.5	68.0	32.0
85	24	258	257	238	237	116	58.0	68.0	32.0
86	24	256	255	239	238	116	57.5	63.5	32.0
V	24	257	256	237	236	114	57.5	66.5	32.0
87	26	255	254	226	212	188	57.0	72.5	32.0
88	26	260	259	226	221	200	57.0	73.0	32.0
89	26	262	261	228	226	196	57.0	72.5	32.0
90	26	266	262	234	234	202	57.0	64.0	32.0
W	26	261	260	229	226	197	57.0	70.5	32.0
91	18	248	247	222	210	74	58.0	61.0	33.0
92	18	248	247	225	214	78	58.0	60.5	33.0
93	18	249	248	228	218	80	58.0	60.0	33.0
94	18	249	248	230	220	81	58.0	60.0	33.0
X	18	249	248	227	216	78	58.0	60.5	33.0
95	20	251	250	232	224	84	58.0	61.5	33.0
96	20	253	251	234	230	89	58.0	62.0	33.0
97	20	252	251	236	232	94	57.0	60.5	33.0
98	20	252	251	237	235	98	57.5	50.5	33.0
Y	20	252	251	235	230	91	57.5	61.0	33.0
99	25	260	259	240	239	111	57.0	68.0	33.0
100	25	262	261	241	240	125	57.5	67.0	33.0
101	25	261	260	241	240	118	57.5	65.0	33.0
102	25	260	259	241	240	112	57.0	59.5	33.0
Z	25	261	260	241	240	116	57.5	65.0	33.0

TABLE NO. 10

Data for butyl alcohol (continued)

Run no.	Time min.	Steam rate lb./hr.	Cond. rate lb./hr.	Thermocouples - m.v. 1	2	3	4	5	6
79	0			2.70	3.00	2.20	2.70	1.68	1.02
80	5			2.70	2.90	2.00	2.60	1.50	1.00
81	10			2.50	2.68	2.02	2.32	1.45	0.90
82	15			2.82	3.00	2.00	2.60	1.30	0.90
U	--	14.7	13.6	2.68	2.90	2.06	2.56	1.48	0.95
83	0			2.40	2.65	1.95	2.30	1.35	0.85
84	5			2.50	2.80	2.00	2.45	1.45	0.92
85	10			2.60	2.95	2.08	2.40	1.40	0.88
86	15			1.22	1.25	0.92	1.28	0.88	0.60
V	--	12.0	14.6	2.18	2.41	1.74	2.11	1.27	0.81
87	0			3.40	3.60	2.75	3.40	2.40	1.95
88	5			3.42	3.62	2.78	3.45	2.42	1.98
89	10			3.55	3.72	2.75	3.52	2.40	1.90
90	15			1.40	1.55	1.20	1.55	1.02	0.68
W	--	20.2	28.6	2.94	3.12	2.37	2.98	2.06	1.63
91	0			1.30	1.50	1.28	1.30	0.70	0.58
92	5			1.18	1.40	1.12	1.20	0.65	0.52
93	10			1.10	1.25	1.10	1.10	0.60	0.60
94	15			1.05	1.15	0.98	1.08	0.55	0.60
X	--	11.4	4.5	1.16	1.33	1.12	1.17	0.63	0.58
95	0			1.30	1.56	1.20	1.40	0.75	0.70
96	5			1.40	1.58	1.25	1.50	0.78	0.75
97	10			1.28	1.50	1.20	1.50	0.80	0.70
98	15			1.32	1.55	1.25	1.48	0.80	0.70
Y	--	11.4	7.2	1.33	1.55	1.23	1.47	0.78	0.71
99	0			3.00	3.40	2.45	2.90	1.50	1.10
100	5			2.35	2.80	1.95	2.45	1.15	0.80
101	10			1.90	2.10	1.45	1.92	1.05	0.75
102	15			1.15	1.32	1.10	1.38	0.90	0.65
Z	--	12.0	13.4	2.10	2.41	1.74	2.16	1.15	0.83

TABLE NO. 11

Date for amyl alcohol

Run no.	Steam press p.s.i.	Resistance thermometers - deg. F.							
		1	2	3	4	5	6	7	8
103	50	290	270	249	245	175	56.0	73.0	34
104	50	294	275	254	254	242	55.0	74.0	34
105	50	294	284	258	257	246	56.0	74.0	34
106	50	292	290	258	258	206	57.0	68.0	34
a	50	293	280	255	254	217	56.0	72.0	34
107	40	283	281	252	250	180	58.0	73.0	34
108	40	282	278	254	253	212	55.0	72.0	34
109	40	282	274	256	254	202	52.5	70.0	34
110	40	282	270	256	256	178	54.5	69.0	34
b	40	282	276	255	253	188	55.0	71.0	34
111	30	270	269	250	248	180	56.0	62.0	34
112	30	266	265	250	250	140	56.0	61.0	34
113	30	268	267	253	252	120	56.0	60.0	34
c	30	268	267	251	250	150	56.0	61.0	34
114	32	271	270	249	247	96	56.0	58.0	32
115	32	271	270	250	250	100	56.0	60.0	32
116	32	271	270	251	250	104	56.0	61.5	32
117	32	271	270	252	251	110	56.0	62.0	32
d	32	271	270	250	250	103	56.0	60.5	32
118	34	273	272	252	252	112	56.0	64.0	32
119	34	274	273	254	253	123	56.0	66.0	32
120	34	273	272	254	253	128	55.5	64.0	32
121	34	274	273	255	254	123	55.5	63.0	32
e	34	274	273	254	253	122	56.0	64.5	32
122	37	276	275	256	255	120	55.5	64.5	32
123	37	278	277	256	255	129	55.5	64.0	32
124	37	278	277	257	256	122	55.5	63.5	32
125	37	277	276	257	256	120	55.5	60.5	32
f	37	277	276	257	256	123	55.5	63.0	32

TABLE NO. 12

Data for amyl alcohol (continued)

Run no.	Time Min.	Steam rate lb./hr.	Cond rate lb./hr.	Thermocouples - m.v. 1	2	3	4	5	6
103	0			4.20	4.55	3.35	4.35	2.70	2.35
104	5			4.30	4.60	3.40	4.40	2.80	2.35
105	10			4.22	4.60	3.30	4.40	2.70	2.35
106	15			2.30	2.70	1.90	2.40	1.30	0.95
a	--	24.1	52.8	3.76	4.11	2.99	3.89	2.38	2.00
107	0			4.20	4.70	3.50	4.35	2.75	2.40
108	5			4.10	4.50	3.30	4.20	2.60	2.30
109	10			4.10	4.20	3.20	4.10	2.40	1.85
110	15			3.60	4.00	2.80	3.60	1.95	1.49
b	--	13.2	39.2	4.00	4.35	3.20	4.06	2.43	2.01
111	0			1.90	2.20	1.60	2.20	1.10	0.90
112	5			1.55	1.90	1.70	1.95	1.10	0.86
113	10			1.20	1.30	1.10	1.40	0.90	0.70
c	--	8.8	10.8	1.55	1.80	1.47	1.75	1.03	0.82
114	0			1.15	1.22	1.00	1.30	0.90	0.70
115	5			1.65	1.85	1.30	1.60	1.02	0.70
116	10			2.00	2.15	1.60	1.95	1.05	0.80
117	15			1.75	1.80	1.25	1.70	1.00	0.75
d	--	11.0	10.9	1.64	1.76	1.29	1.64	0.99	0.74
118	0			2.78	3.15	2.20	2.75	1.50	1.05
119	5			2.90	3.20	2.25	2.70	1.50	1.10
120	10			2.50	2.70	1.90	2.47	1.32	0.90
121	15			2.08	2.20	1.47	2.00	1.10	0.80
e	--	11.2	18.5	2.57	2.81	1.96	2.48	1.36	0.96
122	0			3.00	3.35	2.30	2.90	1.60	1.15
123	5			2.40	2.55	1.72	2.25	1.30	0.90
124	10			2.22	2.40	1.65	2.15	1.20	0.85
125	15			1.62	1.75	1.25	1.60	0.98	0.70
f	--	10.3	15.5	2.31	2.51	1.73	2.23	1.27	0.90

Table No. 13

Data for methyl acetate

Run no.	Steam press p.s.i.	Resistance thermometers - deg. F. 1	2	3	4	5	6	7	8
126	1.25	209	174	132	132	76	50.0	58.0	32
127	1.25	209	161	134	134	80	50.0	58.0	32
128	1.25	209	160	136	136	85	50.0	58.0	32
129	1.25	209	168	138	138	88	50.0	58.0	32
g	1.25	209	166	135	135	82	50.0	58.0	32
130	2.50	211	202	138	134	116	51.0	60.0	32
131	2.50	213	211	139	138	126	51.0	60.5	32
132	2.50	213	211	139	138	126	51.0	60.0	32
133	2.50	213	212	139	138	110	51.0	58.0	32
h	2.50	213	209	139	137	120	51.0	60.0	32
134	2.00	213	212	145	138	104	51.0	59.0	32
135	2.00	211	210	147	137	98	51.0	56.0	32
136	2.00	211	210	149	135	90	51.0	54.0	32
137	2.00	211	210	150	133	96	51.0	52.0	32
i	2.00	211	210	148	136	95	51.0	55.0	32
138	2.50	212	210	150	138	119	51.0	60.0	32
139	2.50	212	211	150	140	122	51.0	60.0	32
140	2.50	212	212	150	139	106	50.5	56.0	32
141	2.50	212	212	152	135	94	50.0	53.0	32
j	2.50	212	211	150	138	110	51.0	57.0	32
142	4.00	216	216	151	138	115	51.0	60.5	32
143	4.00	217	216	152	140	123	51.0	60.0	32
144	4.00	218	216	154	140	110	51.0	57.0	32
k	4.00	217	216	152	139	115	51.0	59.0	32
145	5.00	220	218	152	138	116	51.0	60.5	32
146	5.00	219	218	153	141	126	51.0	61.0	32
147	5.00	219	218	154	142	117	51.0	58.0	32
l	5.00	219	218	153	140	120	51.0	60.0	32

TABLE NO. 14

Data for methyl acetate (continued)

Run no.	Time min.	Steam rate lb./hr.	Cond. rate lb./hr.	Thermocouples - m. v. 1	2	3	4	5	6
126	0			1.66	1.77	1.55	1.42	1.05	0.80
127	5			1.75	1.85	1.50	1.48	1.15	0.91
128	10			1,82	1.88	1.52	1.60	1.14	0.92
129	15			1.75	1.80	1.45	1.45	1.00	0.85
g	--	7.6	15.4	1.75	1.82	1.51	1.49	1.09	0.87
130	0			2.01	2.10	1.75	1.95	1.60	1.50
131	5			2.02	2.10	1.81	1.80	1.58	1.48
132	10			1.95	2.10	1.75	1.70	1.35	1.00
133	15			1.30	1.50	1.10	1.20	0.90	0.70
h	--	9.3	21.6	1.82	1.95	1.60	1.66	1.36	1.17
134	0			1.65	1.70	1.36	1.30	0.91	0.75
135	5			1.00	1.15	0.82	0.85	0.70	0.60
136	10			0.79	0.82	0.70	0.70	0.60	0.55
137	15			0.50	0.50	0.55	0.50	9.50	0.50
i	--	8.2	7.5	0.98	1.02	0.85	0.84	0.68	0.60
138	0			2.00	2.02	1.65	1.95	1.55	1.40
139	5			1.90	2.00	1.65	1.70	1.30	1.00
140	10			1.25	1.40	1.05	1.05	0.80	0.70
141	15			0.90	0.80	0.80	0.70	0.65	0.50
j	--	7.1	15.4	1.51	1.60	1.31	1.35	1.32	0.90
142	0			2.00	2.05	1.75	1.90	1.60	1.45
143	5			1.92	1.95	1.62	1.68	1.25	1.00
144	10			1.30	1.30	1.10	1.10	0.80	0.60
k	--	7.8	19.7	1.74	1.77	1.49	1.56	1.22	1.02
145	0			2.00	2.08	1.75	1.91	1.56	1.47
146	5			2.02	2.05	1.75	1.95	1.55	1.35
147	10			1.50	1.50	1.25	1.25	0.88	0.75
l	--	8.8	21.3	1.74	1.88	1.58	1.70	1.33	1.19

TABLE NO. 15

Data for ethyl acetate

Run: no.:	Steam press p.s.i.	Resistance thermometers - deg. F. 1	2	3	4	5	6	7	8
148	2.5	212	168	160	159	152	51.0	62.5	32.0
149	2.5	214	210	162	162	156	51.0	52.5	32.0
150	2.5	213	211	163	162	132	51.0	59.5	32.0
151	2.5	214	212	163	161	104	51.0	56.5	32.5
m	2.5	213	200	162	161	136	51.0	60.0	32.5
152	5.0	219	171	160	159	150	51.0	63.0	32.5
153	5.0	221	218	162	162	156	51.0	62.5	32.5
154	5.0	220	218	162	162	145	51.0	59.0	32.5
155	5.0	219	217	162	160	108	51.0	56.5	32.5
n	5.0	220	206	162	161	139	51.0	60.0	32.5
156	1.0	208	184	161	157	87	50.5	52.0	32.5
157	1.0	208	176	160	156	85	50.5	52.0	32.5
158	1.0	208	170	160	156	84	50.5	52.0	32.5
159	1.0	208	164	159	156	82	50.5	52.0	32.5
o	1.0	208	174	160	156	85	50.5	52.0	32.5
160	2.0	211	156	159	158	135	50.0	62.0	32.5
161	2.0	212	130	160	160	154	50.0	62.5	32.5
162	2.0	212	210	160	160	135	50.0	58.0	32.5
163	2.0	212	200	160	159	108	50.5	55.0	32.5
p	2.0	212	187	160	159	133	50.0	59.0	32.5
164	2.5	211	179	157	157	146	51.0	66.0	32.0
165	2.5	213	210	157	157	133	51.0	61.0	32.0
166	2.5	213	212	158	157	110	51.0	57.5	32.0
167	2.5	213	211	158	157	97	51.0	55.5	32.0
q	2.5	213	203	158	157	122	51.0	60.0	32.0
168	2.5	218	200	159	158	136	52.0	60.0	32.0
169	2.5	212	204	160	159	113	52.0	59.0	32.0
170	2.5	214	211	160	159	100	52.0	58.0	32.0
171	2.5	212	210	160	159	91	52.0	56.5	32.0
r	2.5	214	206	160	159	110	52.0	58.0	32.0

TABLE NO. 16

Data for ethyl acetate (continued)

Run no.	Time min.	Steam rate lb./hr.	Cond. rate lb./hr.	Thermocouples - m.v.					
				1	2	3	4	5	6
148	0			2.45	2.55	2.10	2.25	1.82	1.68
149	5			2.25	2.42	1.82	2.10	1.32	0.95
150	10			1.50	1.60	1.20	1.20	0.85	0.70
151	15			1.40	1.35	1.15	1.10	0.75	0.65
m	--	11.3	25.7	1.90	1.98	1.57	1.66	1.19	1.00
152	0			2.50	2.60	2.10	2.45	1.90	1.70
153	5			2.42	2.00	2.05	2.30	1.58	1.15
154	10			1.65	1.75	1.35	1.38	1.00	0.70
155	15			1.45	1.55	1.20	1.20	0.90	0.70
n	--	13.0	22.2	2.01	2.12	1.65	1.65	1.35	1.06
156	0			0.79	0.79	0.70	0.70	0.55	0.48
157	5			0.77	0.77	0.68	0.68	0.58	0.46
158	10			0.68	0.72	0.68	0.68	0.55	0.46
159	15			0.62	0.38	0.62	0.62	0.52	0.44
o	--	2.9	3.5	0.72	0.74	0.67	0.67	0.55	0.46
160	0			2.40	2.32	2.13	2.50	1.84	1.70
161	5			2.40	2.38	2.00	2.15	1.42	1.10
162	10			1.52	1.60	1.30	1.30	0.92	0.68
163	15			1.20	1.20	1.05	1.05	0.80	0.60
p	--	7.4	25.2	1.88	1.92	1.62	1.75	1.25	1.02
164	0			2.38	2.40	2.10	2.20	1.58	1.06
165	5			1.80	1.95	1.62	1.60	1.10	0.70
166	10			1.30	1.28	1.12	1.00	0.75	0.50
167	15			1.02	1.00	0.95	0.90	0.72	0.48
q	--	19.5	15.1	1.62	1.66	1.45	1.43	1.04	0.68
168	0			1.95	2.05	1.80	1.72	1.20	0.90
169	5			1.30	1.40	1.20	1.10	0.88	0.60
170	10			1.45	1.50	1.25	1.15	0.88	0.60
171	15			1.15	1.30	1.05	1.00	0.75	0.52
r	--	27.2	12.5	1.46	1.56	1.33	1.24	0.93	0.52

TABLE NO. 17

Data for propyl acetate

Run no.	Steam press p.s.i.	Resistance thermometers - deg. F. 1	2	3	4	5	6	7	8
172	1.0	210	184	182	180	82	52.5	57.0	32
173	1.0	212	178	185	184	100	52.5	61.0	32
174	1.0	210	172	184	184	93	52.5	56.0	32
175	1.0	210	170	185	185	88	52.5	56.0	32
s	1.0	210	176	184	183	91	52.5	57.5	32
176	3.0	214	210	185	183	174	52.5	68.0	32
177	3.0	214	209	187	186	182	52.5	68.5	32
178	3.0	215	197	187	186	152	52.5	64.0	32
179	3.0	215	211	187	187	115	53.0	58.5	32
t	2.5	215	207	187	186	156	52.5	65.0	32
180	2.5	212	180	184	183	140	52.5	66.0	32
181	2.5	213	207	187	186	178	52.5	68.0	32
182	2.5	215	211	187	186	178	52.5	66.5	32
183	2.5	213	212	187	186	128	52.5	58.5	32
u	2.5	213	203	186	185	156	52.5	65.0	32
184	2.5	213	212	187	186	110	52.5	56.5	32
185	2.5	214	212	187	186	100	52.5	54.5	32
186	2.5	218	216	187	186	96	52.5	54.0	32
v	2.5	215	213	187	186	102	52.5	55.0	32
187	2.0	212	202	186	185	179	51.0	66.5	32
188	2.0	213	212	187	186	174	51.5	66.2	32
189	2.0	212	212	187	186	138	51.5	60.0	32
190	2.0	213	212	187	186	108	52.5	55.0	32
w	2.0	213	210	187	186	150	51.5	62.0	32
191	3.0	214	180	184	183	120	51.5	60.5	32
192	3.0	215	176	186	185	110	51.5	60.5	32
193	3.0	215	175	186	185	105	51.0	60.0	32
194	3.0	216	174	186	186	103	51.5	60.0	32
x	3.0	215	176	186	185	110	51.5	60.0	32

TABLE NO. 18

Data for propyl acetate (continued)

Run no.	Time Min.	Steam rate lb./hr.	Cond. rate lb./hr.	Thermocouples - m. v. 1	2	3	4	5	6
172	0			1.70	1.90	1.45	1.62	0.92	0.70
173	10			0.95	1.00	0.82	1.10	0.70	0.55
174	20			1.20	1.15	0.97	1.15	0.70	0.60
175	30			1.30	1.38	1.05	1.25	0.80	0.65
s	--	7.5	14.2	1.29	1.36	1.07	1.28	0.76	0.63
176	0			3.00	3.10	2.40	3.00	2.00	1.88
177	5			2.98	3.10	2.38	2.95	1.85	1.45
178	10			1.85	2.10	1.55	1.85	1.10	0.90
179	15			1.55	1.55	1.10	1.35	0.85	0.70
t	--	11.5	42.4	2.35	2.46	1.86	2.29	1.45	1.23
180	0			2.95	3.02	2.40	2.98	2.00	1.82
181	5			2.98	3.05	2.38	3.00	2.00	1.85
182	10			2.55	2.70	2.00	2.40	1.35	1.05
183	15			1.20	1.20	1.10	1.30	0.90	0.70
u	—	14.6	52.6	2.42	2.50	1.07	2.42	1.56	1.36
184	0			1.15	1.15	0.95	1.15	0.78	0.62
185	5			0.80	0.75	0.70	0.80	0.61	0.55
186	10			0.65	0.65	0.60	0.70	0.50	0.50
v	--	5.2	5.3	0.87	0.85	0.72	0.88	0.64	0.56
187	0			3.00	3.15	2.55	3.05	2.10	1.90
188	5			2.80	2.85	2.25	3.60	1.50	1.15
189	10			1.55	1.60	1.30	1.40	0.90	0.75
190	15			1.10	1.10	0.90	1.10	0.75	0.60
w	--	8.7	28.6	2.11	2.18	1.75	2.04	1.31	1.10
191	0			2.10	2.20	1.70	2.00	1.25	0.90
192	5			2.15	2.20	1.75	1.88	1.20	0.90
193	10			2.05	2.18	1.70	1.90	1.15	0.85
194	15			2.10	2.25	1.75	1.98	1.20	0.92
x	--	7.3	22.4	2.10	2.21	1.73	1.94	1.20	0.90

TABLE NO. 19

Data for butyl acetate

Run no.	Steam press p.s.i.	Resistance thermometers - deg. F. 1	2	3	4	5	6	7	8
195	30	270	269	249	248	104	51.0	60.0	32
196	30	269	268	249	249	109	51.0	60.5	32
197	30	269	268	249	250	111	51.0	50.0	32
198	30	269	268	251	250	112	51.5	60.5	32
y	30	269	268	250	249	109	51.0	60.0	32
199	30	266	265	251	250	108	52.0	56.0	32
200	30	268	267	251	250	108	52.0	55.5	32
201	30	270	268	251	250	108	52.0	54.0	32
202	30	266	265	251	212	104	51.5	52.0	32
z	30	268	267	251	241	107	52.0	54.5	32
203	35	276	275	234	221	77	53.0	55.5	32
204	35	276	275	242	238	85	53.0	56.5	32
205	35	276	275	247	246	97	53.5	60.6	32
206	35	274	273	250	248	110	54.0	62.0	32
(a)	35	276	275	243	238	92	53.5	58.5	32
207	35	275	274	250	249	112	54.0	63.5	32
208	35	276	275	250	250	111	54.0	60.5	32
209	35	275	274	250	250	107	54.0	56.5	32
210	35	275	274	250	250	105	54.0	55.5	32
(b)	35	275	274	250	250	109	54.0	59.0	32
211	40	276	274	235	235	158	54.0	66.5	32
212	40	281	280	247	247	151	54.0	68.5	32
213	40	281	280	249	249	132	54.0	64.5	32
214	40	281	280	250	250	117	54.0	59.0	32
(c)	40	280	279	245	245	140	54.0	64.5	32
215	40	278	277	228	228	174	54.0	70.0	32
216	40	281	280	244	244	169	54.0	69.5	32
217	40	280	278	249	249	140	54.0	66.5	32
218	40	280	272	250	250	121	54.0	59.0	32
(d)	40	280	277	243	243	157	54.0	66.0	32

TABLE NO. 20

Data for butyl acetate (continued)

Run: no.:	Time min.	: Steam : rate :lb./hr	: Cond. : rate :lb./hr.:	Thermocouples - m.v. 1	2	3	4	5	6
195	0			2.10	2.20	1.70	1.80	1.20	0.90
196	5			2.30	2.60	1.92	1.90	1.30	0.92
197	10			2.30	2.55	1.95	2.10	1.28	0.90
198	15			2.00	2.10	1.60	1.80	1.05	0.80
y	--	10.3	23.6	2.18	2.36	1.79	1.90	1.21	0.88
199	0			1.60	1.65	1.25	1.40	0.85	0.70
200	5			1.10	1.05	0.90	1.20	0.75	0.60
201	10			0.90	0.90	0.70	0.85	0.60	0.55
202	15			0.70	0.60	0.55	0.65	0.45	0.45
z	--	5.0	6.9	1.08	1.05	0.85	1.03	0.66	0.58
203	0			1.10	1.22	0.91	1.22	0.70	0.62
204	5			1.45	1.62	1.18	1.50	0.90	0.70
205	10			2.35	2.50	1.80	2.30	1.22	0.92
206	15			2.10	2.40	1.65	2.08	1.20	0.90
(a)	--	17.9	19.3	1.75	1.94	1.39	1.78	1.01	0.79
207	0			2.20	2.42	1.60	2.00	1.10	0.90
208	5			1.52	1.50	1.00	1.55	0.90	0.70
209	10			1.10	1.10	0.70	1.15	0.65	0.60
210	15			0.90	0.90	0.55	0.95	0.60	0.60
(b)	--	10.5	11.6	1.43	1.48	0.96	1.41	0.81	0.70
211	0			3.55	3.85	2.78	3.65	2.20	1.70
212	5			3.10	3.33	2.30	3.00	1.60	1.25
213	10			2.18	2.18	1.45	1.85	1.02	0.82
214	15			1.40	1.40	0.88	1.40	0.80	0.70
(c)	--	13.5	28.6	2.56	2.70	1.85	2.48	1.41	1.12
215	0			3.60	3.90	2.80	3.70	2.30	1.90
215	5			3.20	3.45	2.35	3.10	1.60	1.30
217	10			2.52	2.60	1.70	2.10	1.10	0.90
218	15			1.40	1.40	1.00	1.40	0.90	0.70
(d)	--	10.2	31.7	2.66	2.84	1.96	2.58	1.48	1.20

TABLE NO. 21

Data for amyl acetate

Run no.	Steam press p.s.i.	Resistance thermometers - deg. F. 1	2	3	4	5	6	7	8
219	60	--	--	272	268	104	54.0	64.5	32
220	60	--	--	274	274	140	54.0	70.5	32
221	60	--	--	276	276	163	54.0	70.0	32
222	60	--	--	276	275	150	54.0	67.0	32
(e)	60	--	--	275	274	139	54.0	68.0	32
223	55	298	297	272	269	120	54.0	64.0	32
224	55	298	297	275	274	144	54.0	69.0	32
225	55	297	296	275	274	156	54.0	70.0	32
226	55	298	296	276	275	149	54.0	67.5	32
(f)	55	298	297	275	273	142	54.0	67.5	32
227	65	--	--	275	268	172	54.0	74.0	32
228	65	--	--	276	274	221	54.0	76.0	32
229	65	--	--	277	276	192	54.0	68.0	32
230	65	--	--	278	277	148	54.0	61.0	32
(g)	65	--	--	276	274	184	54.0	70.0	32
231	58	302	300	274	268	126	55.0	68.0	32
232	58	302	300	276	275	129	54.5	66.0	32
233	58	302	300	276	276	122	54.5	62.5	32
234	58	302	300	276	276	118	54.0	60.0	32
(h)	58	302	300	276	274	123	54.5	64.0	32
235	50	293	292	272	271	109	54.0	60.0	32
236	50	293	292	274	273	116	54.0	64.0	32
237	50	293	292	275	274	120	54.0	63.0	32
238	50	293	292	275	274	120	54.0	64.0	32
(i)	50	293	292	274	273	116	54.0	63.0	32
239	52	295	294	276	268	100	52.0	54.5	32
240	52	295	294	277	275	102	52.5	55.0	32
241	52	295	294	278	276	104	52.5	54.5	33
242	52	295	294	278	270	104	53.0	54.0	33
(j)	52	295	294	277	272	105	52.5	54.0	33

TABLE No. 22

Data for amyl acetate (continued)

Run: no.:	Time Min.	: Steam : rate lb./hr.	: Cond. : rate lb./hr.	Thermocouples - m.v. 1	2	3	4	5	6
219	0			3.50	3.30	2.60	3.45	2.00	1.60
220	5			4.00	4.30	3.00	4.20	2.30	1.80
221	10			3.85	4.10	2.80	3.70	2.10	1.52
222	15			3.25	3.45	2.30	3.90	1.69	1.20
(e)	--	17.5	48.5	3.65	3.91	2.68	3.59	2.00	1.51
223	0			3.45	3.65	2.50	3.50	1.93	1.60
224	5			3.82	4.20	3.00	4.00	2.30	1.80
225	10			3.70	4.00	2.70	3.70	2.10	1.55
226	15			3.00	3.30	2.30	2.90	1.55	1.15
(f)	--	12.6	43.6	3.49	3.79	2.63	3.53	1.97	1.50
227	0			4.50	4.80	3.55	4.70	3.12	2.70
228	5			4.50	4.85	3.30	4.35	3.00	2.50
229	10			3.50	3.70	2.52	3.35	1.70	1.30
230	15			1.85	1.85	1.30	1.80	1.00	0.80
(g)	--	17.4	52.4	3.59	3.80	2.72	3.63	2.21	1.83
231	0			3.10	3.48	2.50	3.10	1.60	1.10
232	5			2.70	3.10	2.10	2.60	1.35	0.90
233	10			2.05	2.30	1.65	2.00	1.00	0.70
234	15			1.70	1.90	1.42	1.80	0.95	0.62
(h)	--	13.4	25.0	2.39	2.70	1.92	2.38	1.23	0.83
235	0			2.22	2.60	1.95	2.30	1.22	0.90
236	5			2.80	3.10	2.30	2.80	1.45	1.00
237	10			2.30	2.30	1.60	2.00	1.05	0.80
238	15			2.35	2.30	1.70	2.20	1.20	0.90
(i)	--	11.0	26.3	2.42	2.58	1.89	2.33	1.23	0.90
239	0			0.85	1.00	0.75	1.15	0.65	0.58
240	5			1.10	1.15	0.90	1.20	0.72	0.60
241	10			0.90	0.95	0.80	1.15	0.75	0.58
242	15			0.70	0.70	0.60	0.80	0.52	0.52
(j)	--	8.4	8.3	0.89	0.95	0.76	1.08	0.76	0.57

TABLE NO. 22A

Data for mixed vapor (butyl acetate and water)

Run no.	Steam press p.s.i.	Resistance thermometers - deg. F. 1	2	3	4	5	6	7	8
243	10	238	194	192	192	100	59	70	32
244	10	228	220	194	194	96	59	73	32
245	10	229	226	193	193	102	59	74	32
246	10	228	224	193	193	122	59	72	32
(k)	10	228	209	193	193	105	59	72	32
247	15	240	238	193	193	178	59	74	32
248	15	242	240	193	193	190	59	74	32
249	15	242	240	194	194	192	59	75	32
250	15	240	238	194	194	192	59	76	32
(l)	15	241	238	194	194	188	59	75	32
251	5	222	220	192	192	116	60	66	33
252	5	220	218	193	192	98	60	65	33
253	5	218	216	193	193	91	60	64	33
254	5	220	218	193	193	88	60	64	33
(m)	5	220	218	193	193	98	60	65	33

Run no.	Time min.	Steam rate lb./hr.	Cond. rate lb./hr.	Thermocouples -m.V. 1	2	3	4	5	6
243	0			3.15	3.20	2.90	3.20	2.10	1.60
244	5			3.20	3.25	2.75	3.20	2.20	1.75
245	10			3.25	3.30	2.95	3.21	2.35	2.02
246	15			3.00	3.05	2.55	2.90	1.90	1.30
(k)	--	17.7	25.1	3.20	3.20	2.81	3.13	2.14	1.66
247	0			3.12	3.25	2.92	3.22	2.40	2.10
248	5			3.25	3.25	2.92	3.25	2.40	2.10
249	10			3.28	3.32	3.00	3.22	2.40	2.10
250	15			3.30	3.30	2.95	3.30	2.40	2.20
(l)	--	22.2	32.8	3.24	3.28	2.98	3.26	2.40	2.13
251	0			2.50	2.60	2.20	2.25	1.10	0.70
252	5			2.60	1.85	1.40	1.55	0.80	0.55
253	10			1.60	1.92	1.38	1.45	0.75	0.55
254	15			1.95	2.05	1.80	1.80	0.89	0.60
(m)	--	9.5	7.6	2.60	2.11	1.70	1.76	0.89	0.60

TABLE NO. 22B

Data for mixed vapor (propyl alcohol and ethyl acetate)

Run no.	Steam press p.s.i.	Resistance thermometers - deg. F. 1	2	3	4	5	6	7	8
255	2.5	213	158	160	160	92	58	68	32
256	2.5	213	156	160	160	118	58	70	32
257	2.5	213	156	160	160	132	58	70	32
258	2.5	213	158	161	161	146	58	70	32
(n)	2.5	213	157	160	160	122	58	69	32
259	1.5	210	152	159	158	109	58	61	32
260	1.5	210	150	160	160	98	58	62	32
261	1.5	210	148	160	160	93	58	63	32
262	1.5	210	147	160	160	93	58	62	32
(O)	1.5	210	149	160	160	98	58	62	32
263	5.0	216	152	160	160	126	58	68	32
264	5.0	218	164	160	160	156	58	70	32
265	5.0	218	164	160	160	156	58	69	32
(p)	5.0	218	160	160	160	145	58	69	32

Run no.	Time min.	Steam rate lb./hr.	Cond. rate lb./hr.	Thermocouples - m. v. 1	2	3	4	5	6
255	0			2.38	2.70	2.10	2.60	1.90	1.50
256	5			2.60	2.75	2.12	2.62	2.00	1.70
257	10			2.60	2.75	2.12	2.62	2.00	1.75
258	15			2.62	2.78	2.15	2.65	2.00	1.71
(n)	--	10.6	26.5	2.55	2.75	2.12	2.62	1.98	1.67
259	0			1.55	1.75	1.20	1.40	1.00	0.80
260	5			1.45	1.82	1.30	1.42	1.05	0.85
261	10			1.72	1.88	1.40	1.55	1.10	0.82
262	15			1.65	1.88	1.25	1.50	1.02	0.80
(o)	--	5.0	10.2	1.59	1.83	1.29	1.47	1.04	0.82
263	0			2.69	2.80	2.22	2.62	2.00	1.80
264	5			2.60	2.80	2.22	2.60	2.00	1.75
265	10			2.60	2.80	2.22	2.61	2.00	1.77
(p)	--	19.2	20.1	2.62	2.80	2.22	2.61	2.00	1.77

Sample Calculations

Using Run No. 18

Calculations of overall coefficient - U

Water into heat exchanger - 59° F   Thermometer No. 6

Water out of heat exchanger - 71° F   "   " 7

Vapor temperature - - - - - 148° F   "   " 4

$$\text{log mean } \Delta t_1 = \frac{\Delta t_1 - \Delta t_2}{\ln \frac{\Delta t_1}{\Delta t_2}}$$

Δt_1 = No. 4 - No. 7 = 77° F.

Δt_2 = No. 4 - No. 6 = 88° F.

$\Delta t_1 - \Delta t_2$ = 11° F.

log mean Δt = 82° F.

q = water rate x t of cooling water

= 60 x 8 lbs/hr x (#7 - #6) = 8 x 60 x 12

$= 5{,}750 \ \frac{\text{Btu}}{\text{hr.}}$

$q = U A \Delta t$

A = outside area = DN = 0.825 sq. ft.

$$U = \frac{q}{A \Delta T} = \frac{5750}{0.825 \times 82} = 85 \ \frac{\text{Btu}}{\text{hr-sq. ft. - °F}}$$

Calculation of Reynolds No.

$$Re = \frac{DG}{z} = \frac{9960}{2} = 3980$$

Calculation of Prandtl No.

$$Pr. = \frac{Cz}{K} = 7.29$$

Calculation of water film coefficient - hw

$$\frac{h_w D}{K} = 0.0225 \ (Re)^{0.8} \ (Pr.)^{0.4}$$

An alignment chart made by the author was used to give this valve.

$$hw = 1805 \frac{Btu.}{hr - sq.\ ft. - oF}$$

Calculation of actual vapor film coefficient - hv

$$U = \frac{1}{\frac{1}{hw} - \frac{D_1 l}{D_{AV}.K} - \frac{D_1}{D_2 hv}}$$

$$hv = 62.9 \frac{Btu.}{hr. - sq.\ ft. - oF}$$

Calculation of Nusselt vapor film coefficient - hv

$$hv - 0.943 \left(\frac{K^3 P^2 g \lambda}{M L \Delta T}\right)^{0.25}$$

An alignment chart made by the author was used to give these values.

$$hv - 340 \frac{Btu}{hr - sq.\ ft. - oF}$$

Nomenclature

dQ - differential quantity of heat

$d\theta$ - differential quantity of time

K - thermal conductivity - Btu/(hr) (Sq. ft.) (dig.F/ft.)

A - Total surface of body exposed to heat, sq. ft.

dt - differential of temperature

dl - differential of path of heat flow

q - quantity of heat per unit time - Btu/hr.

Δt - temperature difference dq.F

ΔT - temperature drop across vapor film deq.F

L - thickness of tube wall - ft.

x, y, z - distances

∂t - partial differential of temperature

$\partial^2 t$ - second partial differential of temperature

C - specific heat, Btu/(lb.) (oF)

P - density, lb./cu. ft.

$F(A)$ - angle factor

$F(E)$ - black body factor

U - overall coefficient   Btu/(hr.) (sq.Ft.) (oF)

h_w - water film coefficient, Btu/(hr.) (Sq. ft.) (oF)

h_v - average vapor film coefficient, Btu/(hr.) (Sq.ft.) (oF)

D - diameter of tube, ft.

G - mass velocity, lbs/hr.

Z - viscosity, lb./(ft.) (hr.)

g - gravitational constant ft./(hr.) (hr.) = 4.18×10^8

λ - latent heat of condensation, Btu/lb.

N - length of tube, ft.

Formula for "Solox", manufactured by United States Industrial Alcohol, Inc.

Ethyl alcohol	95.2 gallons
Approved wood alcohol	4.8 gallons
Ethyl acetate	5.0 gallons
Aviation gasoline	1.0 gallons

Results

The results are presented in sequence, the calculated results and graphical data of each material included in one place. The runs are numbered in the order steam, methyl, ethyl, propyl, butyl, amyl alcohols; methyl, ethyl, propyl, butyl, amyl acetates. Figures represent 5 minute readings and letters represent a 15 minute average.

The data of Morrison (34) is included in the graphical data.

TABLE NO. 23

Calculated results for steam

Run No.	Reynolds no.	Prandtl no.	hw	U	hv actual	hv Nusselt	Δt	$\frac{K^3\rho^2 g\lambda}{N z\Delta t} \times 10^{-10}$
1	4110	7.01	1840	324	281	1000	26	127.0
2	3580	8.22	1800	123	93	700	79	30.4
3	3380	8.78	1785	62	45	605	126	17.0
4	3320	8.96	1790	44	32	600	122	16.4
A	3580	8.22	1800	137	104	670	88	25.5
5	4410	6.50	1880	348	306	1230	11	290.0
6	4240	6.79	1860	291	246	1240	10	299.0
7	4410	6.50	1880	357	315	890	35	79.4
8	4190	6.80	1840	336	394	800	52	51.9
B	4270	6.72	1855	331	288	990	25	122.0
9	4240	6.79	1860	159	122	900	32	83.0
10	4020	7.25	1830	153	118	2300	1	3540.0
11	4110	7.01	1840	146	112	1230	9	290.0
12	3900	7.45	1810	101	76	800	48	51.9
C	4060	7.13	1830	128	97	1000	22	127.0
13	4410	6.50	1880	198	157	1790	3	1060.0
14	3440	8.64	1815	305	262	605	119	17.0
15	4190	6.80	1840	159	123	1420	5	515.0
16	3740	7.82	1820	120	91	710	67	32.2
D	3900	7.45	1810	130	98	800	46	51.9

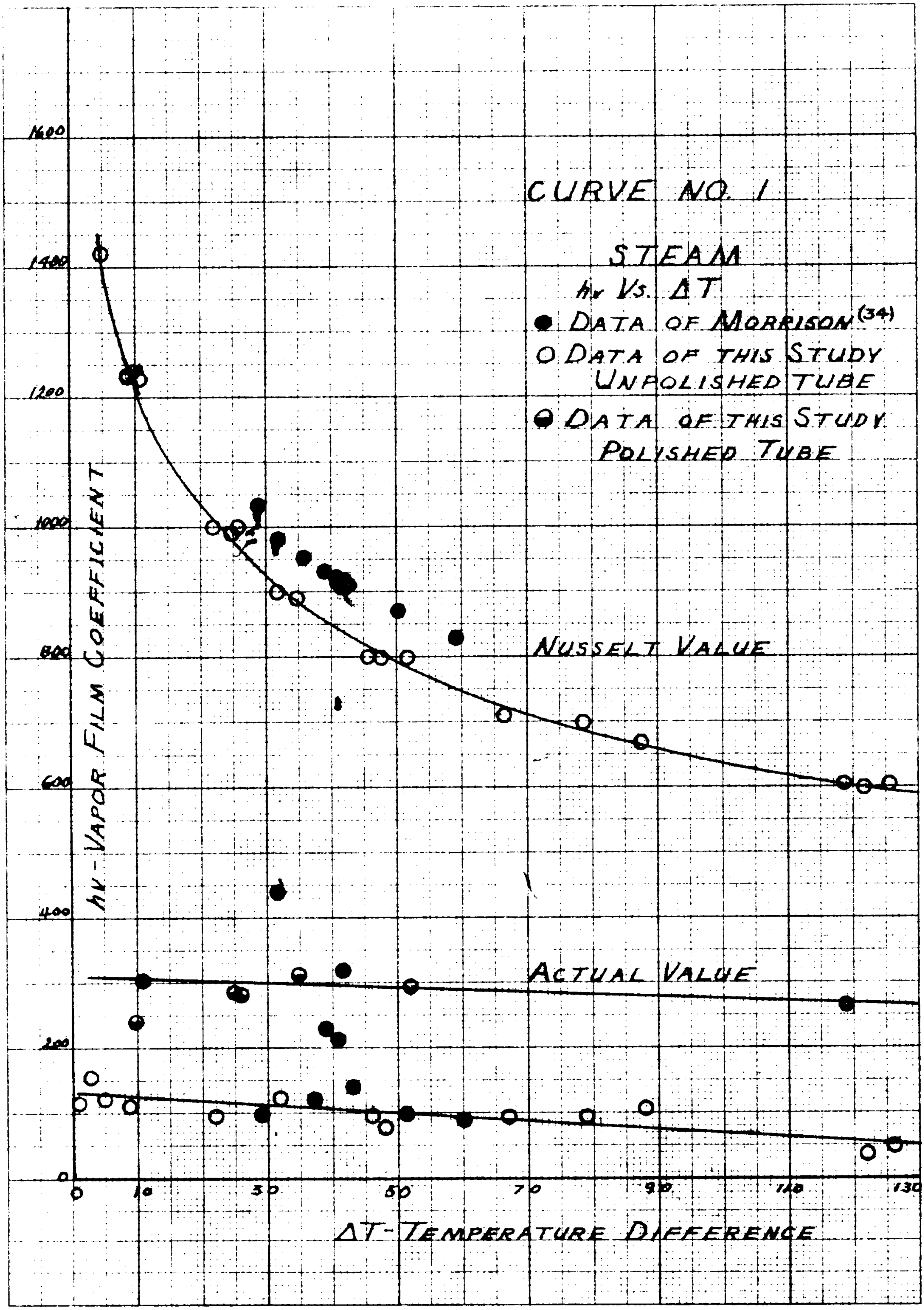

CURVE NO. 1
STEAM
hv Vs. ΔT
● DATA OF MORRISON(34)
○ DATA OF THIS STUDY UNPOLISHED TUBE
⊖ DATA OF THIS STUDY POLISHED TUBE
NUSSELT VALUE
ACTUAL VALUE
hv - VAPOR FILM COEFFICIENT
ΔT - TEMPERATURE DIFFERENCE
1600
1400
1200
1000
800
600
400
200
0
0
10
30
50
70
90
110
130

TABLE NO. 24

Calculated results for methyl alcohol

Run no.	Reynolds no.	Prandtl no.	hw	U	hv actual	hv Nusselt	Δt	$\frac{K^3\rho^2 g \lambda}{N z \Delta t} \times 10^{-6}$
17	3900	7.45	1810	87	65	350	11	19000
18	3980	7.29	1805	85	63	340	12	16900
19	3900	7.45	1810	80	58	340	12	16900
20	3900	7.45	1810	84	62	340	12	16900
E	3900	7.45	1810	81	60	340	12	16900
21	3830	7.60	1810	67	49	290	21	8960
22	3830	7.60	1810	95	61	310	18	18700
23	3830	7.60	1810	109	82	300	19	10300
24	3830	7.60	1810	112	84	290	22	8960
F	3830	7.60	1810	91	58	290	21	8960
25	3740	7.82	1820	67	42	250	47	4950
26	3740	7.82	1820	65	48	230	49	3540
27	3740	7.82	1820	69	51	225	50	3250
28	3690	7.95	1820	64	46	220	51	2970
G	3740	7.82	1820	67	49	230	49	3540
29	3980	7.29	1805	92	68	350	11	19000
30	4020	7.23	1830	87	64	380	8	26400
H	4020	7.23	1830	86	63	360	10	21300

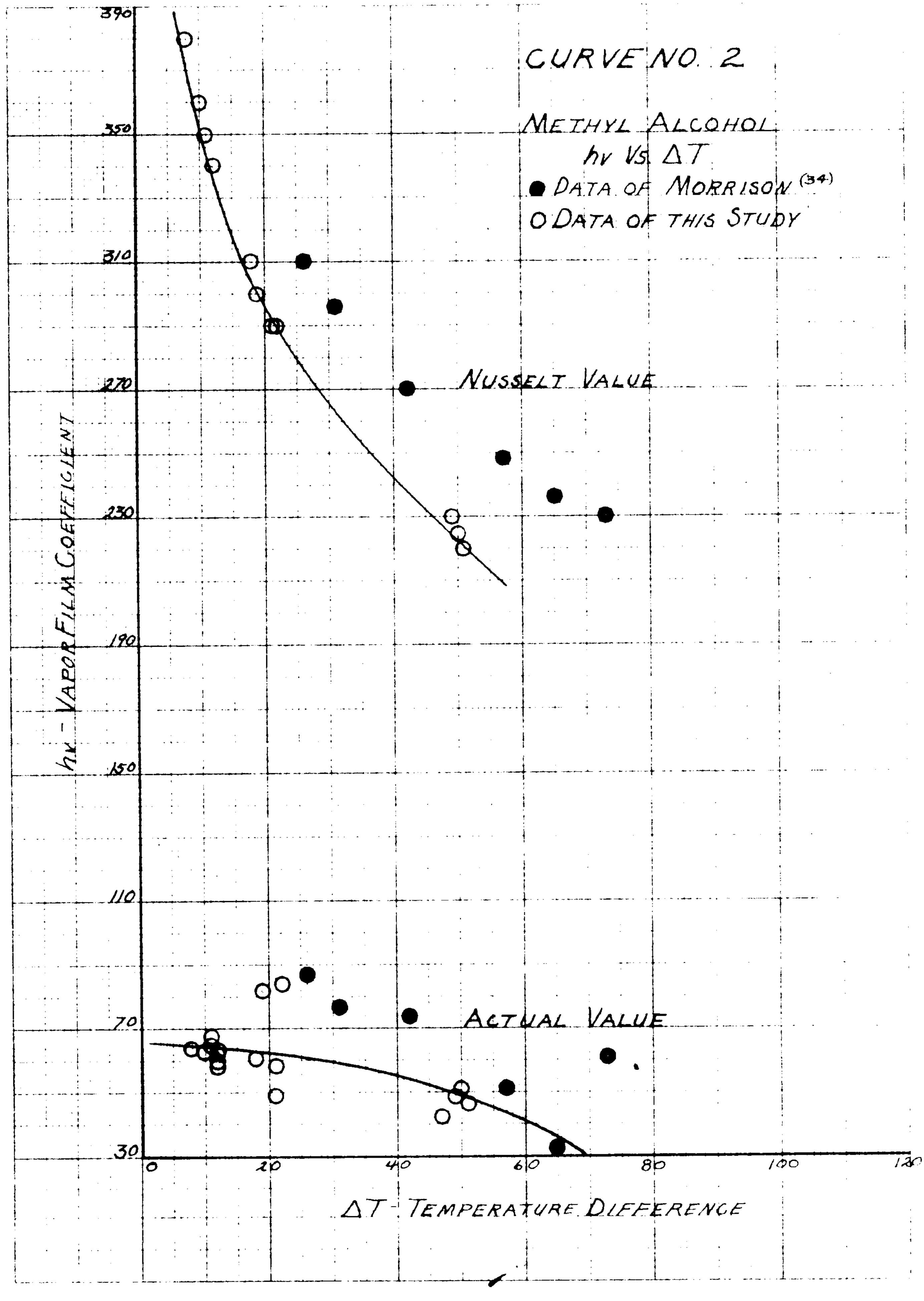

CURVE NO. 2
METHYL ALCOHOL
hv Vs ΔT
● DATA OF MORRISON (34)
○ DATA OF THIS STUDY
NUSSELT VALUE
ACTUAL VALUE
hv - VAPOR FILM COEFFICIENT
390
350
310
270
230
190
150
110
70
30
0
20
40
60
80
100
120
ΔT TEMPERATURE DIFFERENCE

TABLE NO.25

Calculated results for ethyl alcohol

Run No.	Reynolds no.	Prandtl no.	hw	U	hv actual	ĥv Nusselt	Δt	$\frac{K^3\rho^2 g\lambda}{N\,z\,\Delta t}\times 10^{-6}$
31	3580	8.22	1800	41	29	150	90	641
32	3580	8.22	1800	47	34	151	88	658
33	3640	8.08	1810	56	40	154	84	711
34	3640	8.08	1810	52	38	158	82	789
I	3640	8.08	1810	49	35	157	86	769
35	3900	7.45	1810	143	110	200	31	2030
36	3980	7.29	1805	121	91	225	26	3250
37	3980	7.29	1805	85	63	230	23	3540
38	3980	7.29	1805	81	60	240	20	4021
J	3980	7.29	1805	98	73	230	24	3540
39	3980	7.29	1805	80	59	235	20	3860
40	4020	7.23	1830	84	62	240	19	4021
41	4020	7.23	1830	87	64	250	16	4950
42	4020	7.23	1830	90	66	255	15	5350
K	4020	7.23	1830	85	63	250	17	4950
43	4020	7.23	1830	88	65	248	18	4790
44	4020	7.23	1830	79	58	240	19	4021
45	4020	7.23	1830	90	66	250	16	4950
46	4020	7.23	1830	96	71	248	18	4790
L	4020	7.23	1830	91	67	248	18	4790
47	3830	7.60	1810	89	66	208	34	2370
48	3830	7.60	1810	106	79	210	30	2460
49	3830	7.60	1810	106	79	210	30	2460
50	3830	7.60	1810	103	77	210	32	2460
M	3830	7.60	1810	99	73	210	31	2460
51	3740	7.82	1820	69	50	164	76	916
52	3690	7.95	1820	43	31	164	76	916
53	3690	7.95	1820	47	34	160	78	829
54	3640	8.08	1810	45	33	160	78	829
N	3690	7.95	1820	54	39	162	77	905

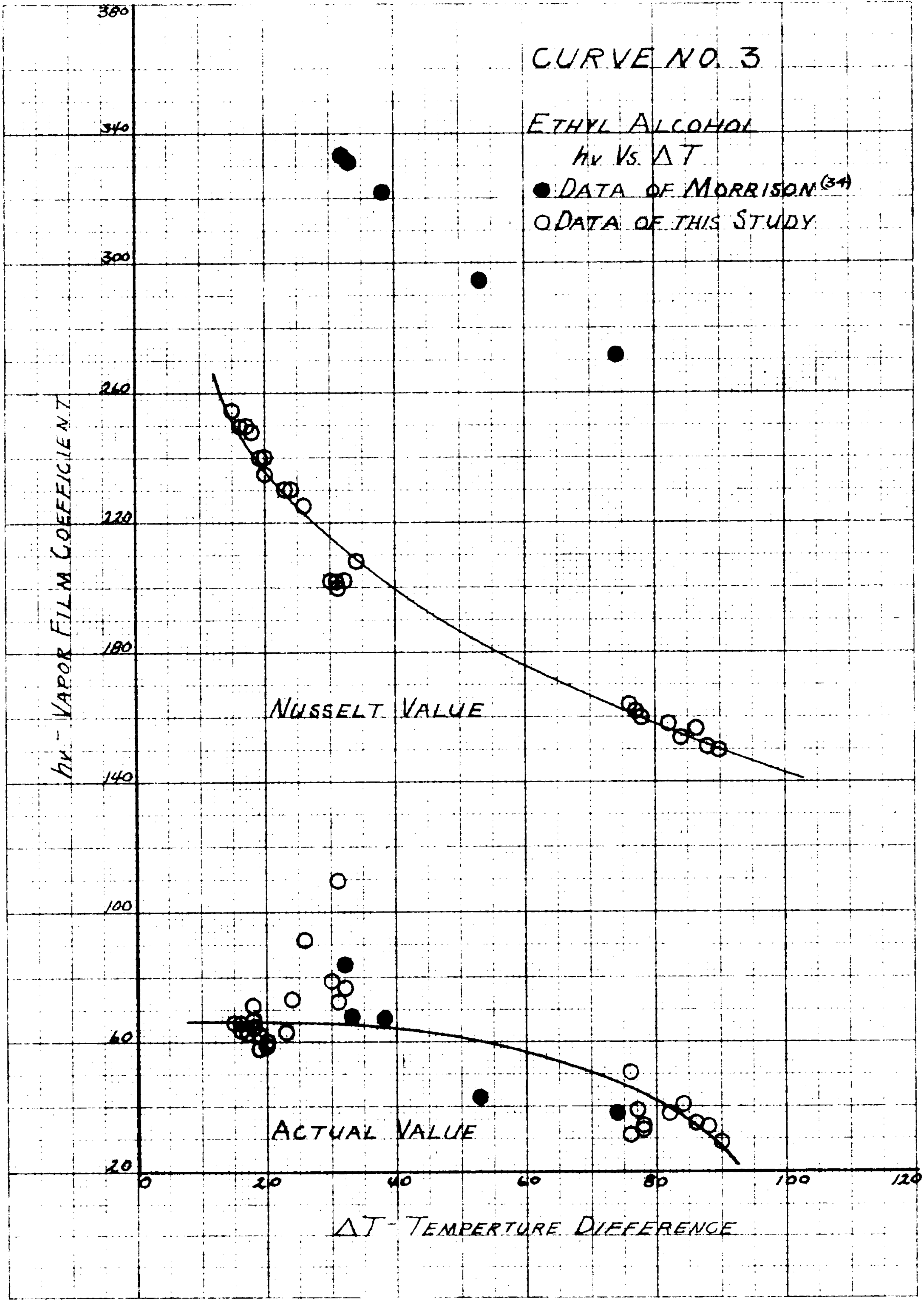

CURVE NO. 3
ETHYL ALCOHOL
hv Vs. ΔT
● DATA OF MORRISON(34)
○ DATA OF THIS STUDY
NUSSELT VALUE
ACTUAL VALUE
hv - VAPOR FILM COEFFICIENT
ΔT - TEMPERTURE DIFFERENCE
380
340
300
260
220
180
140
100
60
20
0
20
40
60
80
100
120

TABLE NO.26

Calculated results for propyl alcohol

Run no.	Reynolds no.	Prandtl no.	hw	U	hv actual	hv Nusselt	Δt	$\frac{K^3 \rho^2 g}{N \times \Delta t} \lambda \times 10^{-6}$
55	3980	7.29	1805	73	53	161	30	851
56	3830	7.60	1810	66	48	150	40	641
57	3740	7.82	1820	61	44	150	40	641
58	3830	7.60	1810	71	52	149	39	624
O	3830	7.60	1810	66	48	150	38	641
59	3780	7.70	1815	72	53	151	37	[illegible]
60	3830	7.60	1810	66	48	150	40	641
61	3830	7.60	1810	65	48	149	39	624
62	3780	7.70	1815	60	44	140	50	488
P	3830	7.60	1810	62	45	147	42	591
63	3780	7.70	1815	70	51	149	39	624
64	3780	7.70	1815	63	46	149	39	624
65	3830	7.60	1810	66	48	149	39	624
66	3740	7.82	1820	53	38	134	57	408
Q	3780	7.70	1815	69	50	144	44	545
67	3690	7.95	1820	42	30	119	80	254
68	3580	8.22	1800	27	19	112	91	199
69	3580	8.22	1800	22	16	110	101	185
70	3530	8.35	1805	8	5	105	109	154
R	3580	8.22	1800	27	19	111	95	192
71	3830	7.60	1810	86	64	150	38	641
72	3900	7.45	1810	83	61	153	36	694
73	4020	7.23	1830	74	54	155	35	731
74	3900	7.45	1810	69	51	139	52	473
S	3900	7.45	1810	75	55	150	40	641
75	3580	8.22	1800	36	26	112	87	199
76	3640	8.08	1810	14	10	111	97	192
77	3640	8.08	1810	15	10	111	100	189
78	3640	8.08	1810	8	5	108	106	172
T	3640	8.08	1810	21	15	111	98	189

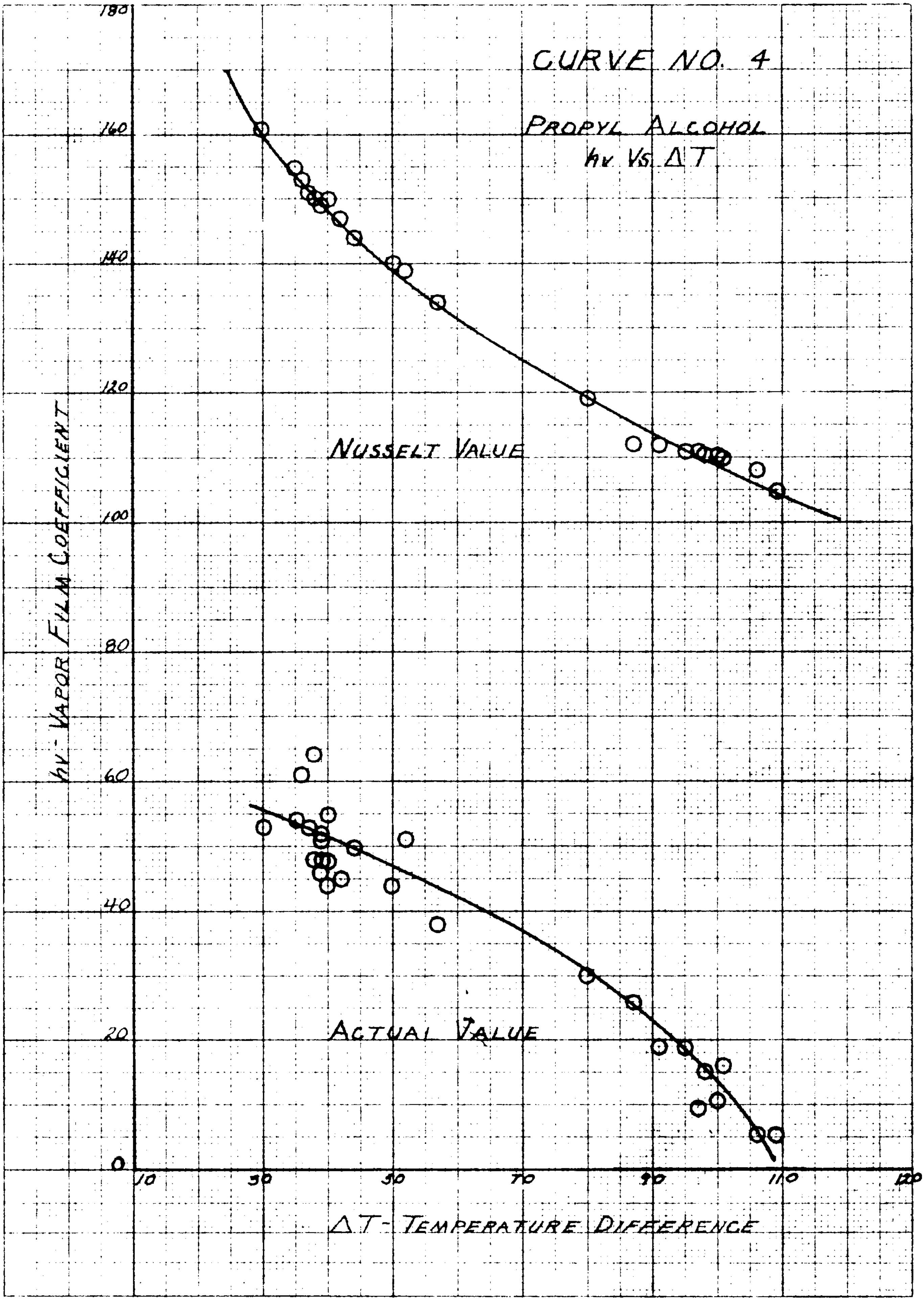

CURVE NO. 4
PROPYL ALCOHOL
hv Vs. ΔT
NUSSELT VALUE
ACTUAL VALUE
hv - VAPOR FILM COEFFICIENT
ΔT - TEMPERATURE DIFFERENCE
180
160
140
120
100
80
60
40
20
0
10
30
50
70
90
110
120

TABLE NO. 27

Calculated results for Butyl alcohol

Run No.	Reynolds no.	Prandtl no.	hw	U	hv actual	hv Nusselt	Δt	$\frac{K^3\rho^2 g\lambda}{N\ x\ \Delta t} \times 10^{-6}$
79	3780	7.70	1815	70	51	118	78	246
80	3780	7.70	1815	73	53	113	89	206
81	3780	7.70	1815	57	41	110	100	185
82	3830	7.60	1810	68	50	115	103	221
U	3780	7.70	1815	67	49	112	92	199
83	3740	7.83	1820	50	36	109	114	179
84	3780	7.70	1815	61	44	111	113	192
85	3830	7.60	1810	56	41	111	112	192
86	3690	7.95	1820	33	24	91	158	87
V	3780	7.70	1815	51	37	108	125	172
87	3980	7.29	1805	66	48	145	52	560
88	3980	7.29	1805	73	54	151	59	658
89	3980	7.29	1805	61	45	150	63	641
90	3740	7.82	1820	26	18	97	145	112
W	3900	7.45	1810	55	40	130	82	361
91	3690	7.95	1820	29	21	92	127	91
92	3640	8.08	1810	22	16	91	135	87
93	3640	8.08	1810	17	12	91	141	87
94	3640	8.08	1810	17	12	91	146	87
X	3640	8.08	1810	22	16	91	138	87
95	3690	7.95	1820	28	20	93	139	95
96	3690	7.95	1820	29	21	91	142	87
97	3650	8.08	1810	23	17	93	147	95
98	3640	8.08	1810	19	14	95	149	103
Y	3640	8.08	1810	28	20	95	144	103
99	3780	7.70	1815	63	46	126	101	319
100	3780	7.70	1815	50	36	110	122	186
101	3740	7.82	1820	41	29	102	139	137
102	3640	8.08	1810	14	10	92	158	91
Z	3740	7.82	1820	41	30	109	130	179

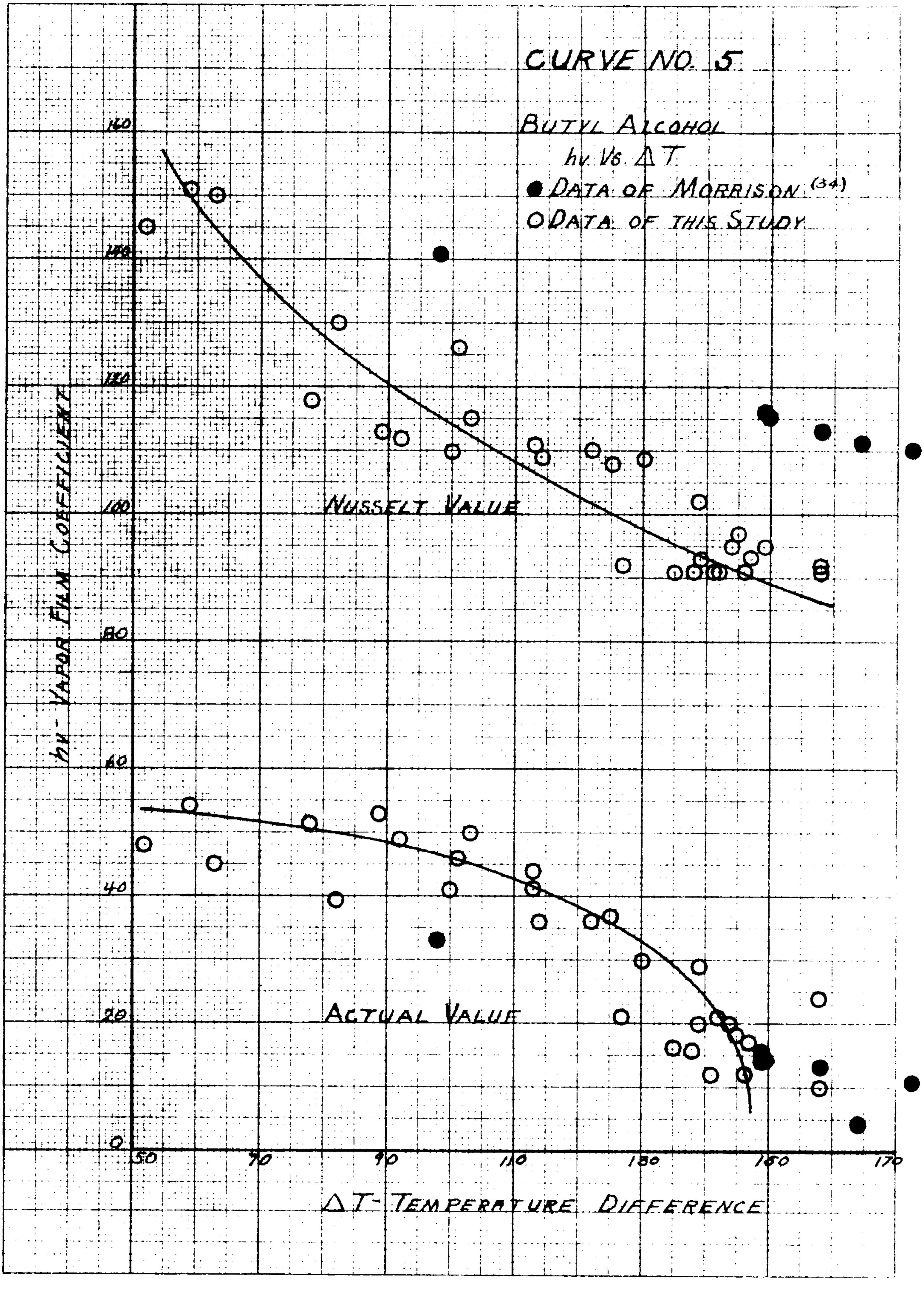

CURVE NO. 5
BUTYL ALCOHOL
hv Vs. ΔT
● DATA OF MORRISON (34)
○ DATA OF THIS STUDY
NUSSELT VALUE
ACTUAL VALUE
hv - VAPOR FILM COEFFICIENT
ΔT - TEMPERATURE DIFFERENCE
160
140
120
100
80
60
40
20
0
50
70
90
110
130
150
170

TABLE NO. 28

Calculated results for amyl alcohol

Run no.	Reynolds no.	Prandtl no.	hw	U	hv actual	hv Nusselt	Δt	$\frac{K^3\rho^2 g\lambda}{N z \Delta t} \times 10^{-6}$
103	3980	729	1805	70	51	130	57	361
104	3980	729	1805	62	45	128	64	340
105	3980	729	1805	59	43	125	69	309
106	3780	7.70	1815	39	28	88	140	76
a	3900	7.45	1810	53	38	112	87	199
107	4020	7.23	1830	65	47	130	59	361
108	3900	7.45	1810	58	42	121	69	271
109	3740	7.82	1820	63	46	113	78	206
110	3740	7.82	1820	55	40	109	95	179
b	3830	7.60	1810	60	43	117	75	237
111	3640	8.08	1810	23	16	82	142	57
112	3640	8.08	1810	23	16	81	150	55
113	3580	8.22	1800	20	14	77	170	45
c	3640	8.08	1810	21	15	80	153	52
114	3530	8.35	1805	12	9	77	167	45
115	3580	8.22	1800	23	17	80	156	52
116	3640	8.08	1810	31	22	81	146	55
117	3640	8.08	1810	32	23	81	156	55
d	3580	8.22	1800	26	18	81	156	55
118	3690	7.95	1820	43	31	91	120	87
119	3740	7.82	1820	50	36	91	120	87
120	3690	7.95	1820	41	29	89	133	79
121	3640	8.08	1810	37	26	83	149	60
e	3690	7.95	1820	43	31	90	130	83
122	3690	7.95	1820	45	33	93	118	95
123	3690	7.95	1820	40	29	88	140	76
124	3640	8.08	1810	39	28	85	146	66
125	3580	8.22	1800	25	18	81	163	55
f	3640	8.08	1810	37	26	85	142	66

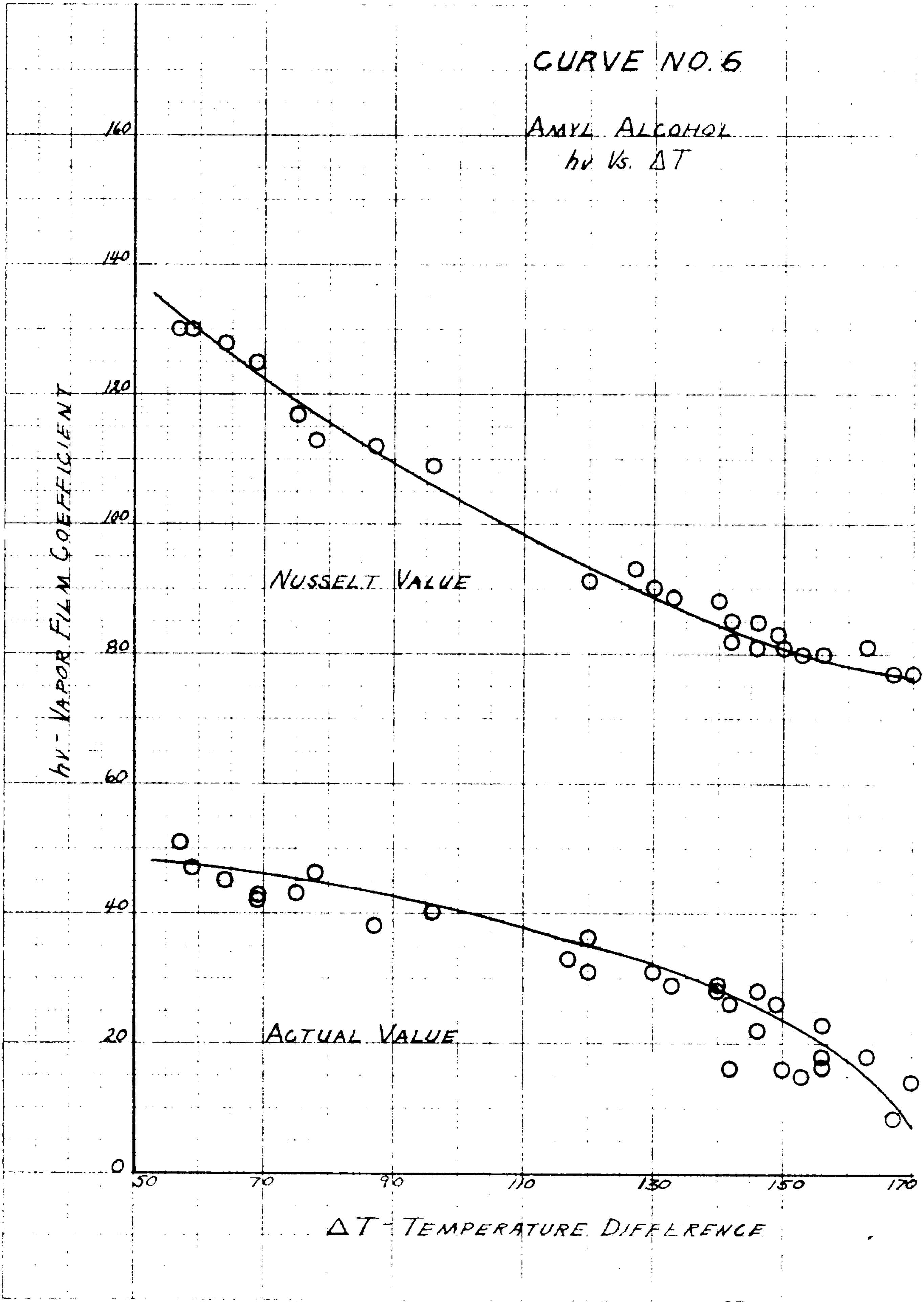

CURVE NO. 6
AMYL ALCOHOL
hv Vs. ΔT
NUSSELT VALUE
ACTUAL VALUE
hv - VAPOR FILM COEFFICIENT
0
20
40
60
80
100
120
140
160
50
70
90
110
130
150
170
ΔT - TEMPERATURE DIFFERENCE

TABLE NO. 29

Calculated results for methyl acetate

Run no.	Reynolds no.	Prandtl no.	hw	U	hv actual	hv Nusselt	Δt	$\frac{K^3 \rho^2 g \lambda}{N z \Delta t} \times 10^{-6}$
126	3320	8.96	1790	75	55	165	39	939
127	3380	8.78	1785	94	70	166	38	961
128	3380	8.78	1785	87	64	161	38	851
129	3380	8.78	1785	82	61	155	44	731
g	3380	8.78	1785	91	67	158	40	789
130	3500	8.46	1780	76	56	177	21	1240
131	3500	8.46	1780	72	53	172	25	1110
132	3500	8.46	1780	69	50	164	33	916
133	3440	8.64	1815	60	44	153	56	694
h	3440	8.64	1815	67	50	163	34	894
134	3440	8.64	1815	72	53	156	49	750
135	3380	8.78	1785	45	32	147	66	591
136	3320	8.96	1790	30	22	150	71	641
137	3260	9.15	1765	11	8	144	78	545
i	3320	8.96	1790	30	22	149	66	624
138	3500	8.46	1780	73	54	170	27	1060
139	3500	8.46	1780	71	52	160	37	829
140	3320	8.96	1790	47	33	151	60	658
141	3260	9.15	1765	29	20	148	70	608
j	3380	8.78	1785	50	36	158	48	789
142	3500	8.46	1780	80	59	172	26	1110
143	3500	8.46	1780	68	50	157	38	769
144	3380	8.78	1785	50	36	148	61	608
k	3440	8.64	1815	65	47	159	42	809
145	3500	8.46	1780	77	57	171	26	1080
146	3500	8.46	1780	79	58	165	30	939
147	3440	8.64	1815	54	39	145	64	560
l	3500	8.46	1780	71	52	153	40	694

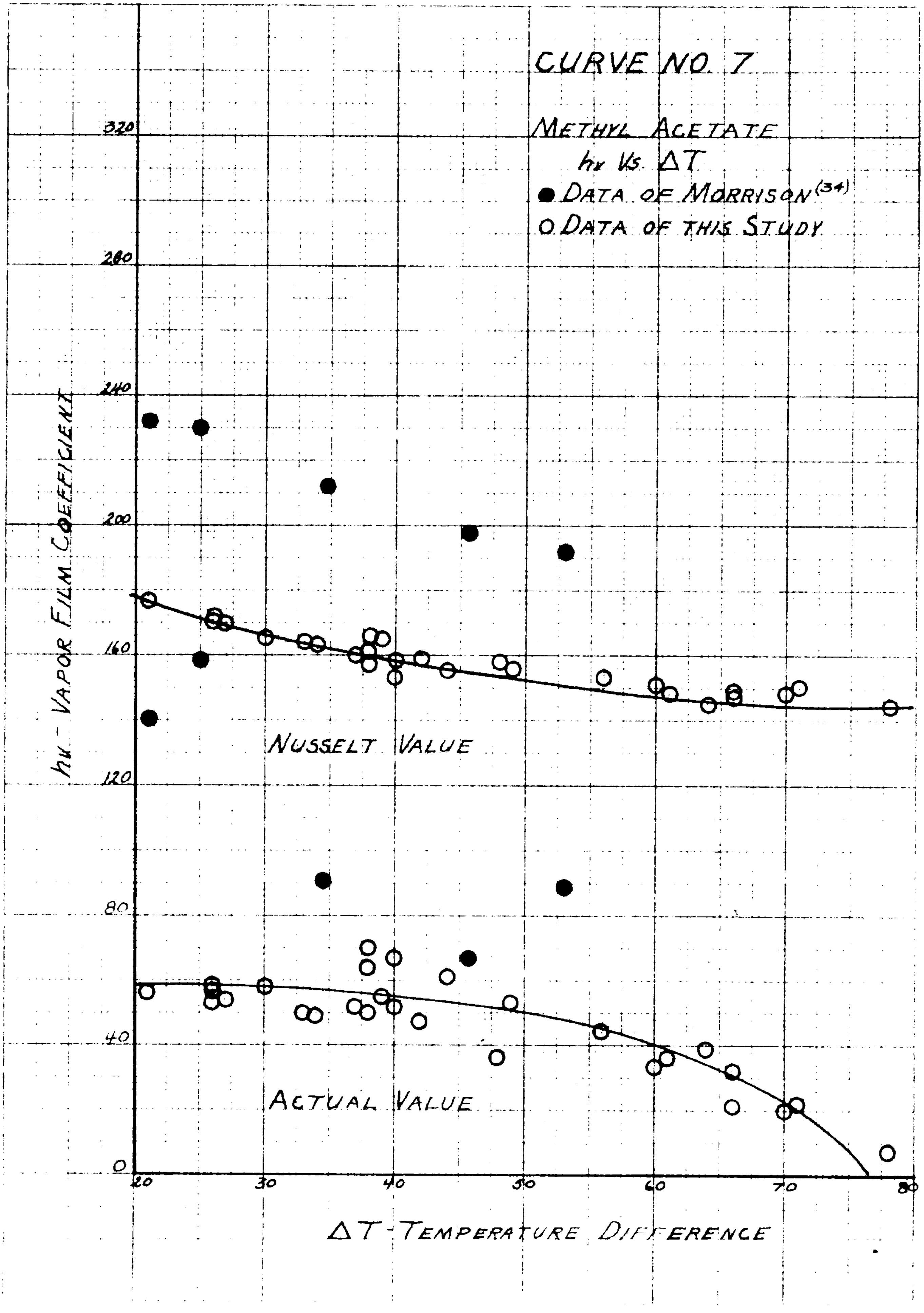

CURVE NO. 7
METHYL ACETATE
hv Vs. ΔT
● DATA OF MORRISON(34)
○ DATA OF THIS STUDY
320
280
240
200
160
120
80
40
0
hv - VAPOR FILM COEFFICIENT
NUSSELT VALUE
ACTUAL VALUE
20
30
40
50
60
70
80
ΔT - TEMPERATURE DIFFERENCE

TABLE NO. 30

Calculated results for ethyl acetate

Run no.	Reynolds nol	Prandtl no.m	hw	U	hv actual	hv Nusselt	Δt	$\frac{K^3\rho^2 g\lambda}{N z \Delta t} \times 10^{-6}$
148	3530	8.35	1805	82	60	160	32	829
149	3530	8.35	1805	65	48	140	50	488
150	3440	8.64	1815	59	43	136	77	433
151	3380	8.78	1785	42	30	132	81	384
m	3500	8.46	1780	57	41	139	60	473
152	3530	8.35	1805	69	50	161	29	851
153	3530	8.35	1805	65	48	148	40	608
154	3440	8.64	1815	48	35	137	72	446
155	3380	8.78	1785	41	29	133	76	396
n	3500	8.46	1780	56	41	141	54	500
156	3210	9.30	1770	14	10	132	94	384
157	3210	9.30	1770	14	10	132	94	384
158	3210	9.30	1770	14	10	131	95	373
159	3210	9.30	1770	14	10	131	97	373
o	3210	9.30	1770	14	10	131	96	373
160	3500	8.46	1780	78	57	165	29	939
161	3500	8.46	1780	82	61	149	44	624
162	3380	8.78	1785	50	36	138	73	459
p	3440	8.64	1815	59	43	138	57	459
164	3640	8.08	1810	86	63	152	39	676
165	3500	8.46	1780	65	48	139	60	473
166	3380	8.78	1785	48	35	135	81	420
167	3320	8.96	1790	37	27	133	87	396
q	3500	8.46	1780	64	46	140	66	488
168	3500	8.46	1780	52	38	140	55	488
169	3500	8.46	1780	52	37	137	79	446
170	3440	8.64	1815	49	35	137	76	446
171	3380	8.78	1785	40	28	131	84	373
r	3440	8.64	1815	45	33	138	74	459

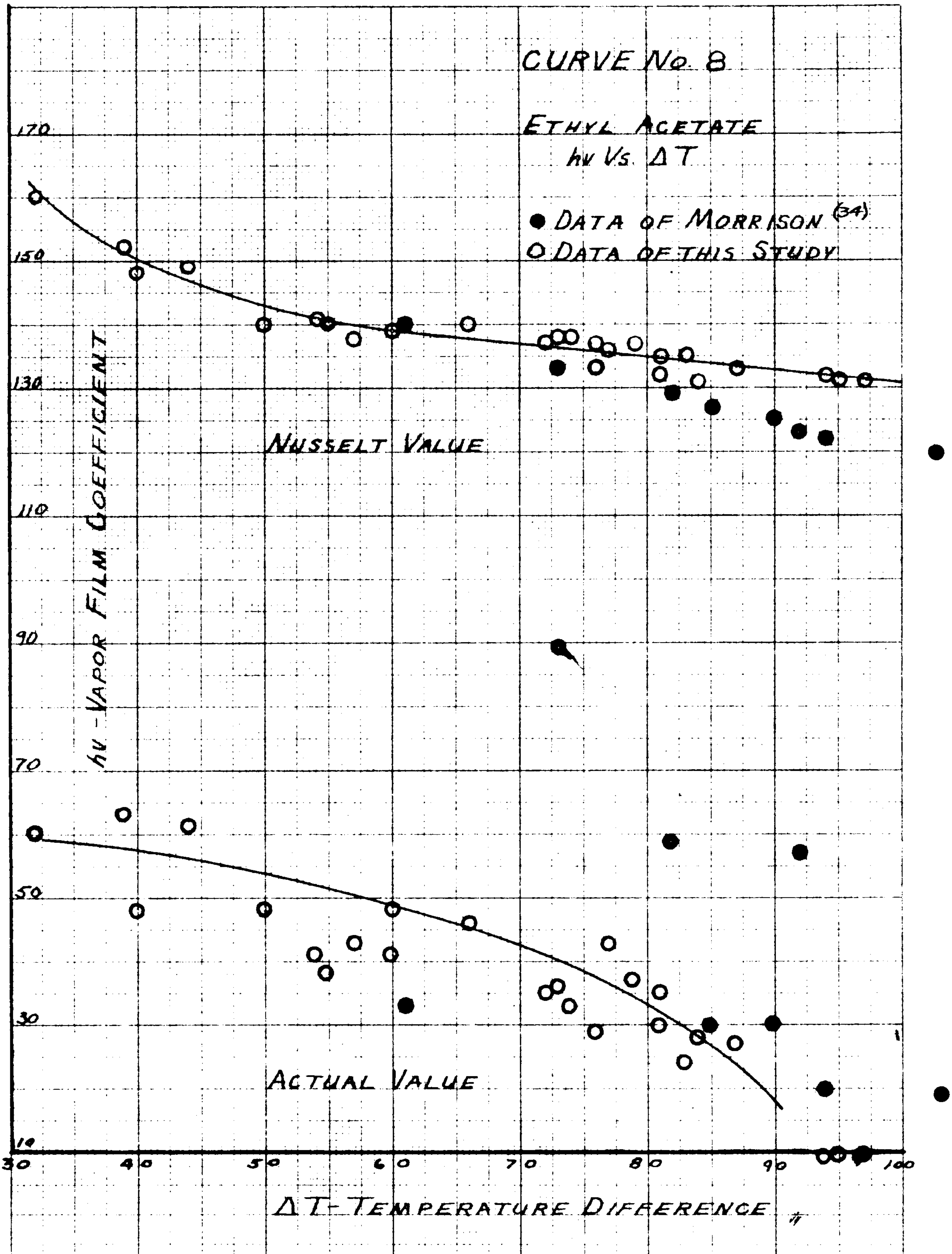

CURVE No. 8
ETHYL ACETATE
hv Vs. ΔT
● DATA OF MORRISON (34)
○ DATA OF THIS STUDY
NUSSELT VALUE
ACTUAL VALUE
hv - VAPOR FILM COEFFICIENT
ΔT - TEMPERATURE DIFFERENCE
170
150
130
110
90
70
50
30
10
30
40
50
60
70
80
90
100

TABLE NO. 31

Calculated results for propyl acetate

Run no.	Reynolds no.	Prandtl no.	hw	U	hv actual	hv Nusselt	Δt	$\frac{K^3\rho^2 g\lambda}{N z \Delta t} x10^{-6}$
172	3440	8.64	1815	40	30	114	86	214
173	3530	8.35	1805	63	46	105	113	154
174	3380	8.78	1785	27	19	107	119	166
175	3380	8.78	1785	28	20	110	105	185
s	3440	8.64	1815	40	28	111	103	192
176	3440	8.64	1815	63	46	147	38	591
177	3740	7182	1820	74	54	141	45	500
178	3640	8.08	1810	63	46	117	85	237
179	3500	8.46	1780	35	25	111	102	192
t	3640	8.08	1810	63	46	124	68	309
180	3690	7.95	1820	81	59	147	39	591
181	3740	7.82	1820	66	48	145	41	560
182	3690	7.95	1820	66	48	127	65	329
183	3500	8.46	1780	35	25	109	106	179
u	3640	8.08	1810	67	49	128	63	340
184	3440	8.64	1815	26	19	108	110	172
185	3380	8.78	1785	14	10	102	122	137
186	3380	8.78	1785	11	8	101	126	132
v	3380	8.78	1785	18	12	102	120	137
187	3640	8.08	1810	77	57	148	37	608
188	3640	8.08	1810	57	41	132	56	384
189	3500	8.46	1780	48	35	110	98	185
190	3380	8.78	1785	20	14	109	112	179
w	3530	8.35	1805	62	45	119	76	204
191	3500	8.46	1780	57	41	120	76	263
192	3500	8.46	1780	60	43	119	78	254
193	3500	8.46	1780	59	43	119	80	254
194	3500	8.46	1780	63	46	118	78	246
x	3500	8.46	1780	57	41	118	78	246

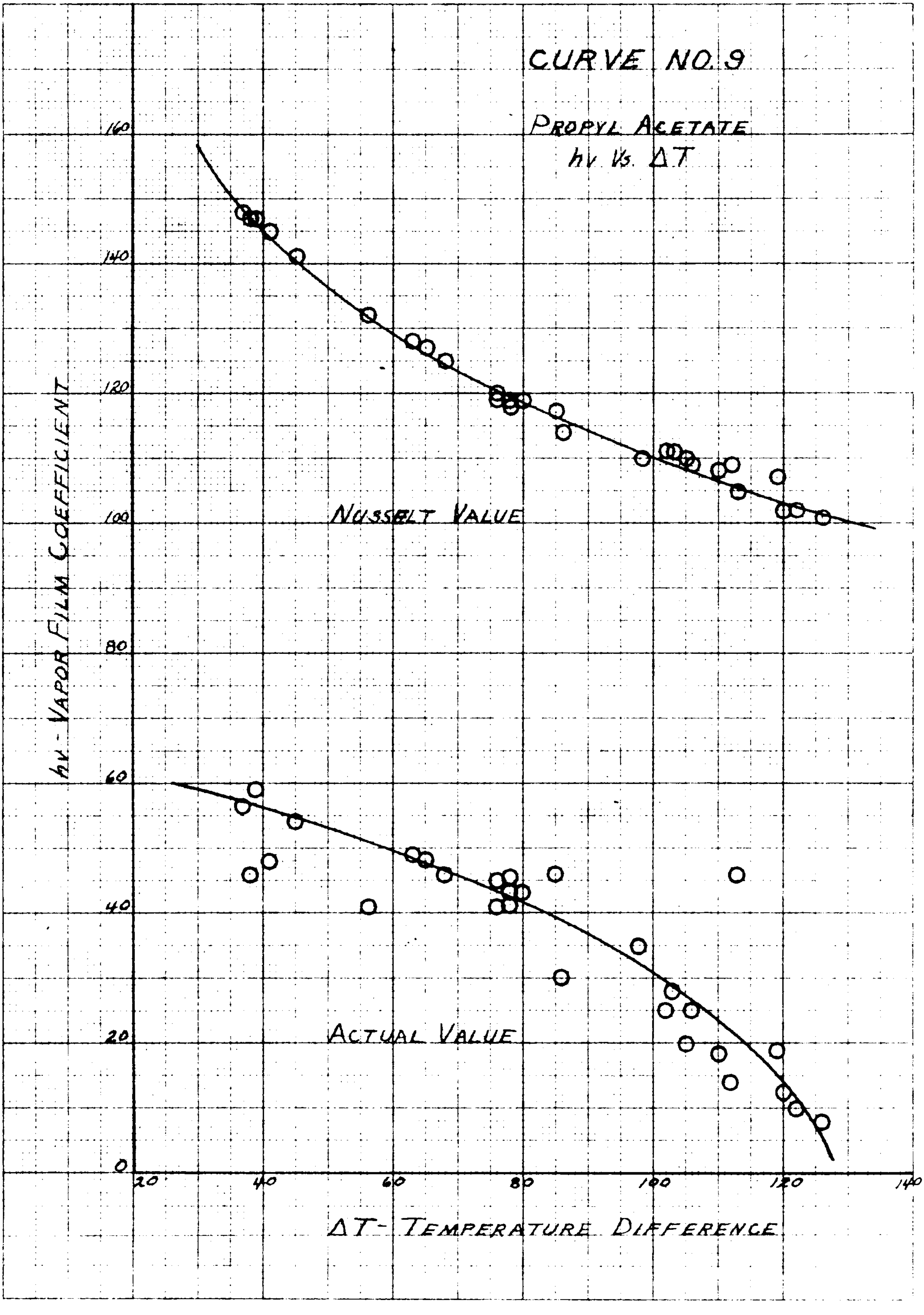

CURVE NO. 9
PROPYL ACETATE
hv Vs. ΔT
NUSSELT VALUE
ACTUAL VALUE
hv - VAPOR FILM COEFFICIENT
ΔT - TEMPERATURE DIFFERENCE
160
140
120
100
80
60
40
20
0
20
40
60
80
100
120
140

TABLE NO.32

Calculated results for butyl acetate

Run no	Reynolds no.	Prandtl no.	hw	U	hv actual	hv Nusselt	Δt	$\frac{K^3\rho^2 g\lambda}{N z \Delta t} \times 10^{-6}$
195	3500	8.46	1780	49	36	153	142	694
196	3500	8.46	1780	50	36	161	135	851
197	3500	8.46	1780	46	33	161	135	851
198	3500	8.46	1780	47	34	160	147	829
y	3500	8.46	1780	47	34	160	139	829
199	3380	8.78	1785	21	15	155	161	731
200	3380	8.78	1785	18	13	139	174	473
201	3320	8.96	1790	10	7	140	182	488
202	3260	9.15	1765	3	2	128	152	340
z	3320	8.96	1790	14	10	140	168	488
203	3380	8.78	1785	20	14	142	144	515
204	3500	8.46	1780	24	17	148	149	608
205	3530	8.35	1805	42	30	157	131	769
206	3580	8.22	1800	43	31	159	138	899
(a)	3500	8.46	1780	32	23	152	140	676
207	3640	8.08	1810	51	36	160	141	829
208	3530	8.35	1805	34	25	147	162	591
209	3440	8.64	1815	13	9	140	176	488
210	3440	8.64	1815	8	6	133	182	396
(b)	3530	8.35	1805	27	19	146	166	576
211	3690	7.95	1820	54	39	205	73	2240
212	3740	7.82	1820	63	46	181	108	1360
213	3640	8.08	1810	50	36	160	145	829
214	3530	8.35	1805	25	18	141	168	500
(c)	3640	8.08	1810	48	35	166	123	969
215	3780	7.70	1815	68	50	210	63	2470
216	3780	7.70	1815	63	46	185	102	1480
217	3690	7.95	1820	57	41	165	137	939
218	3530	8.35	1805	25	18	161	166	851
(d)	3590	7.95	1820	53	38	167	117	985

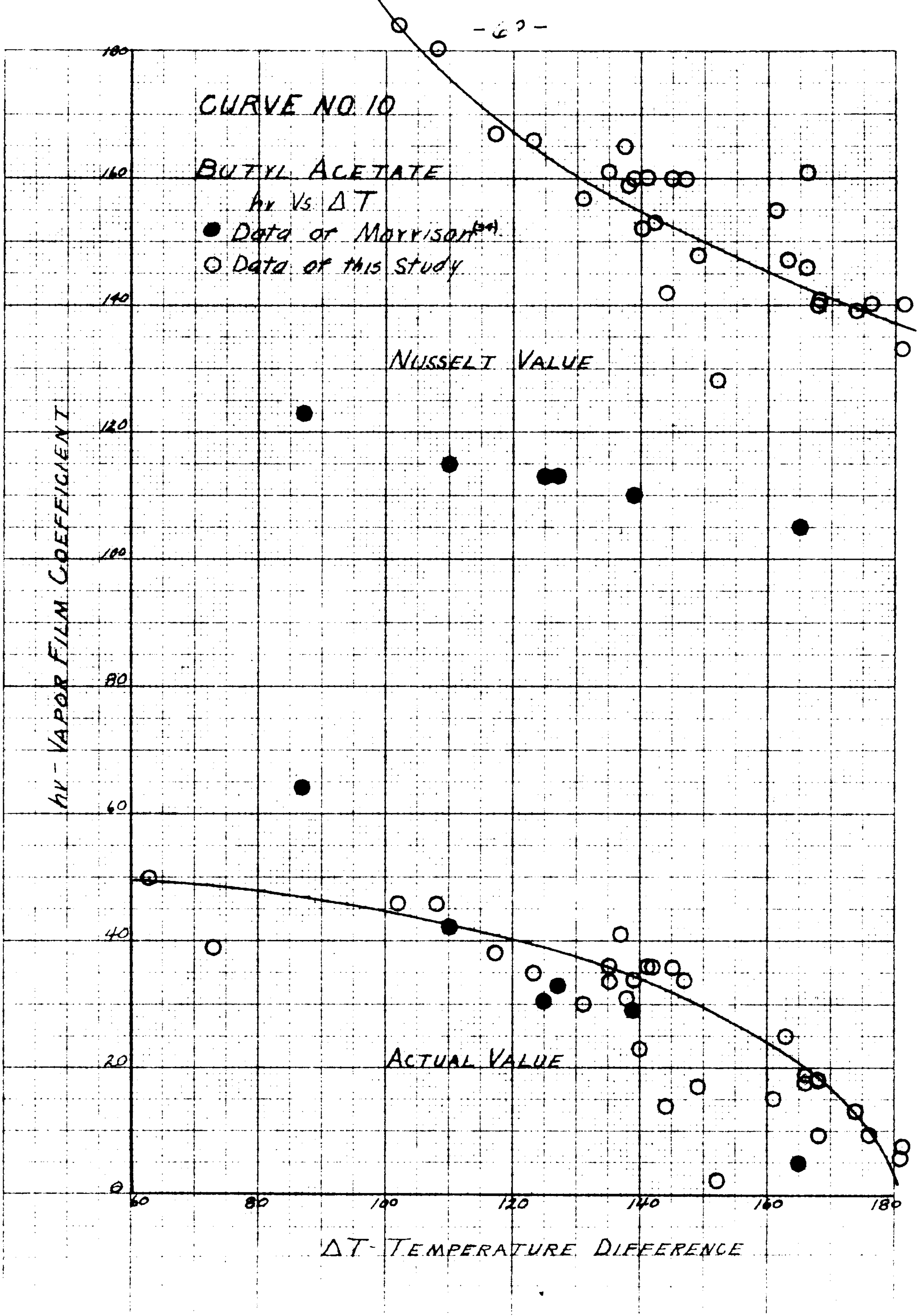

CURVE NO. 10
BUTYL ACETATE
hv Vs ΔT
● Data of Morrison(34)
○ Data of this Study
NUSSELT VALUE
ACTUAL VALUE
hv - VAPOR FILM COEFFICIENT
ΔT - TEMPERATURE DIFFERENCE
180
160
140
120
100
80
60
40
20
0
60
80
100
120
140
160
180

TABLE NO. 33

Calculated results for amyl acetate

Run no.	Reynolds no.	Prandtl no.	hw	U	hv actual	hv Nusselt	Δt	$\frac{K^3 \rho^2 g \lambda}{N z \Delta t} \div 10^{-6}$
219	3640	8.08	1810	56	41	117	112	237
220	3780	7.70	1815	68	50	123	99	290
221	3780	7.70	1815	61	45	117	112	237
222	3740	7.82	1820	57	41	110	135	172
(e)	3740	7.82	1820	60	43	115	115	221
223	3640	8.08	1810	47	34	115	115	221
224	3780	7.70	1815	62	45	118	102	246
225	3780	7.70	1815	63	46	117	112	237
226	3740	7.82	1820	56	40	107	139	166
(f)	3740	7.82	1820	57	41	111	117	192
227	3900	7.45	1810	77	56	135	66	420
228	3980	7.29	1805	72	53	131	76	373
229	3740	7.82	1820	48	35	111	126	192
230	3580	8.22	1800	28	20	98	180	117
(g)	3780	7.70	1815	57	41	117	112	237
231	3780	7.70	1815	61	44	112	126	199
232	3690	7.95	1820	52	37	107	148	166
233	3640	8.08	1810	37	26	99	171	121
234	3530	8.35	1805	28	20	98	180	117
(h)	3640	8.08	1810	44	32	100	156	127
235	3530	8.35	1805	30	22	103	154	142
236	3640	8.08	1810	48	35	107	142	166
237	3640	8.08	1810	42	30	100	164	127
238	3500	8.46	1780	47	34	101	162	132
(i)	3500	8.46	1780	43	31	100	156	127
239	3640	8.08	1810	13	9	91	197	87
240	3640	8.08	1810	13	9	92	199	91
241	3690	7.95	1820	10	7	91	204	87
242	3690	7.95	1820	5	4	89	206	79
(j)	3690	7.95	1820	10	7	91	201	87

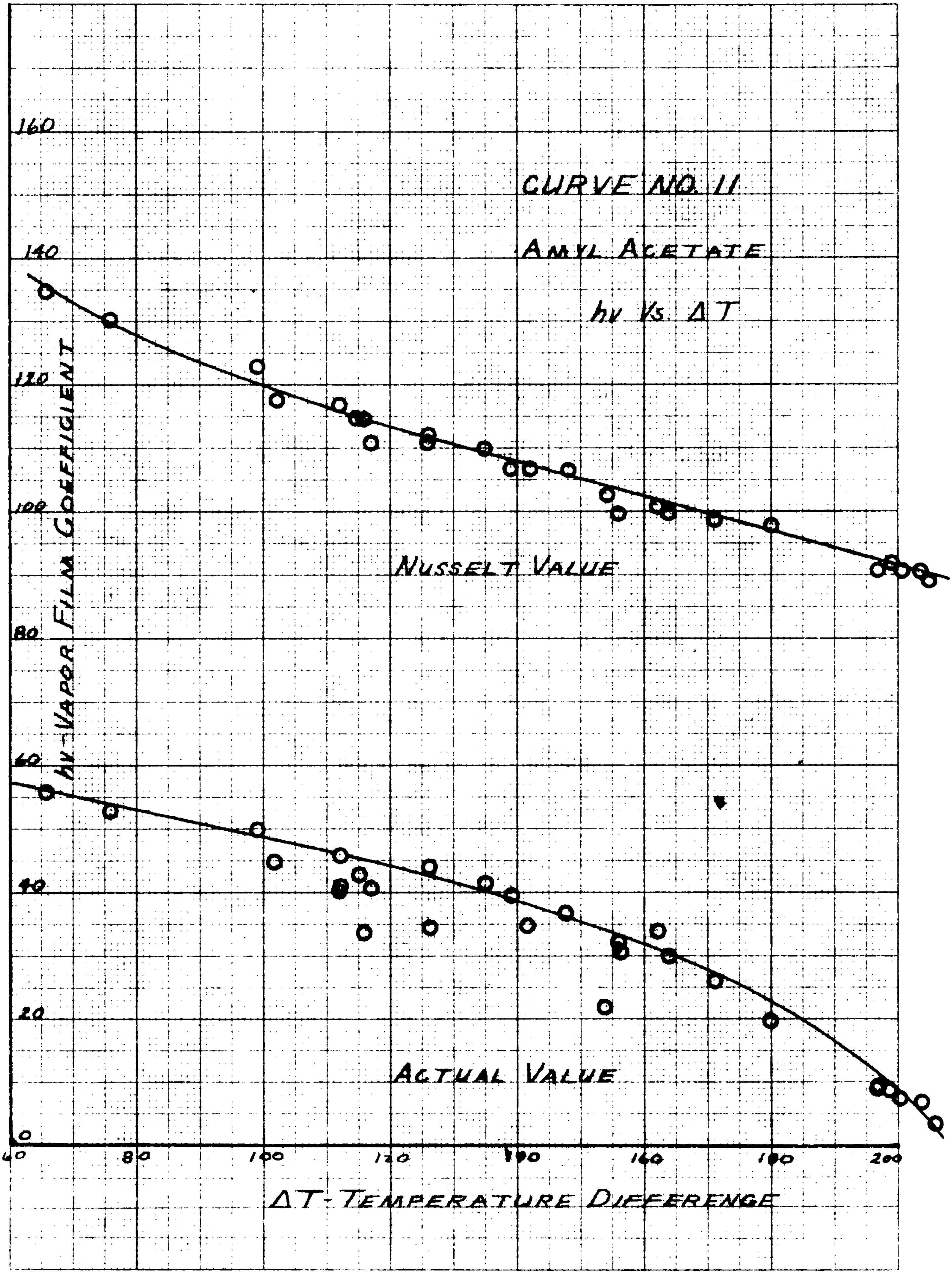

CURVE NO. 11
AMYL ACETATE
hv Vs. ΔT
NUSSELT VALUE
ACTUAL VALUE
hv-VAPOR FILM COEFFICIENT
ΔT-TEMPERATURE DIFFERENCE
160
140
120
100
80
60
40
20
0
60
80
100
120
140
160
180
200

TABLE NO. 34

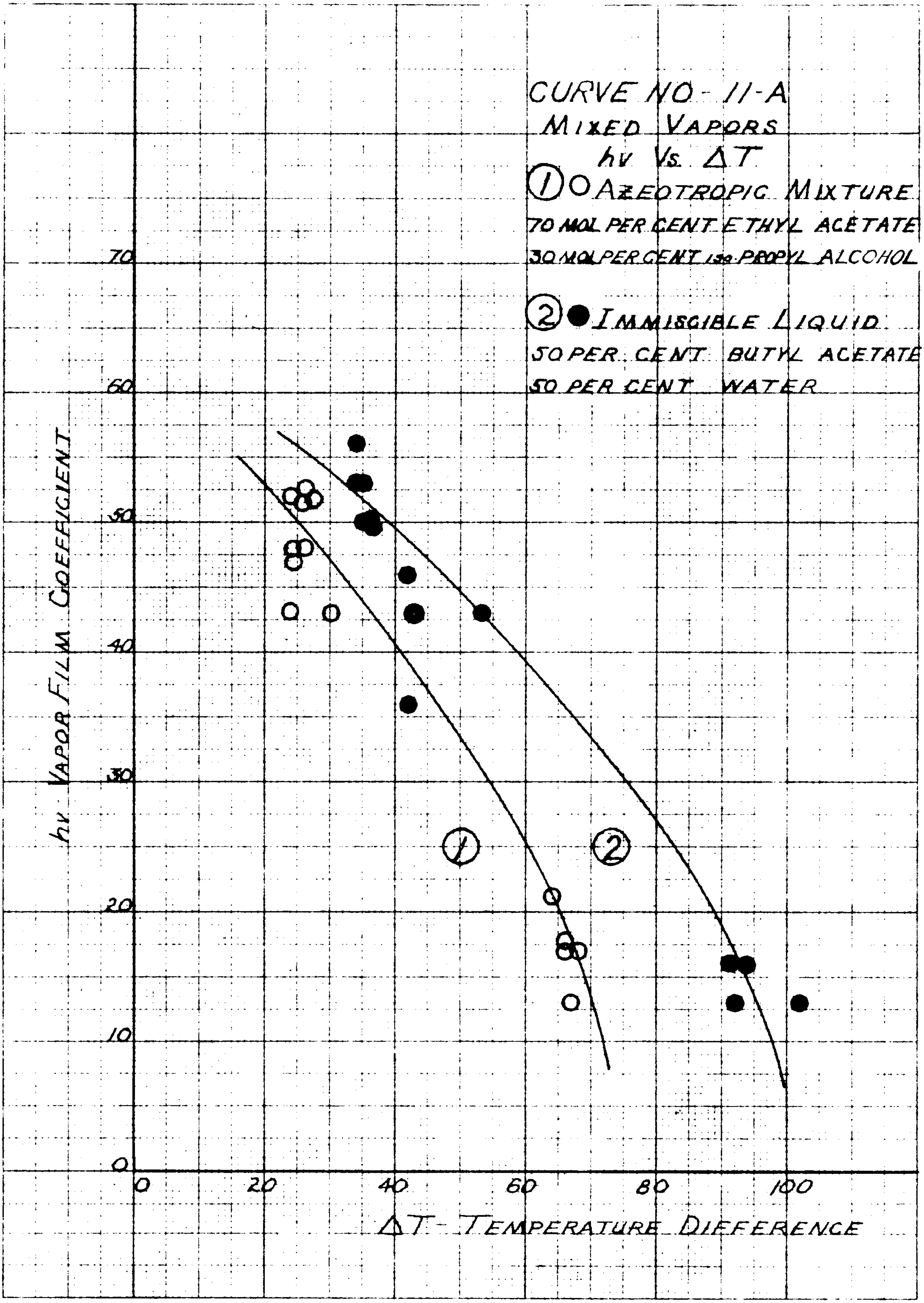
Calculated results for mixed vapor (butyl acetate and water)

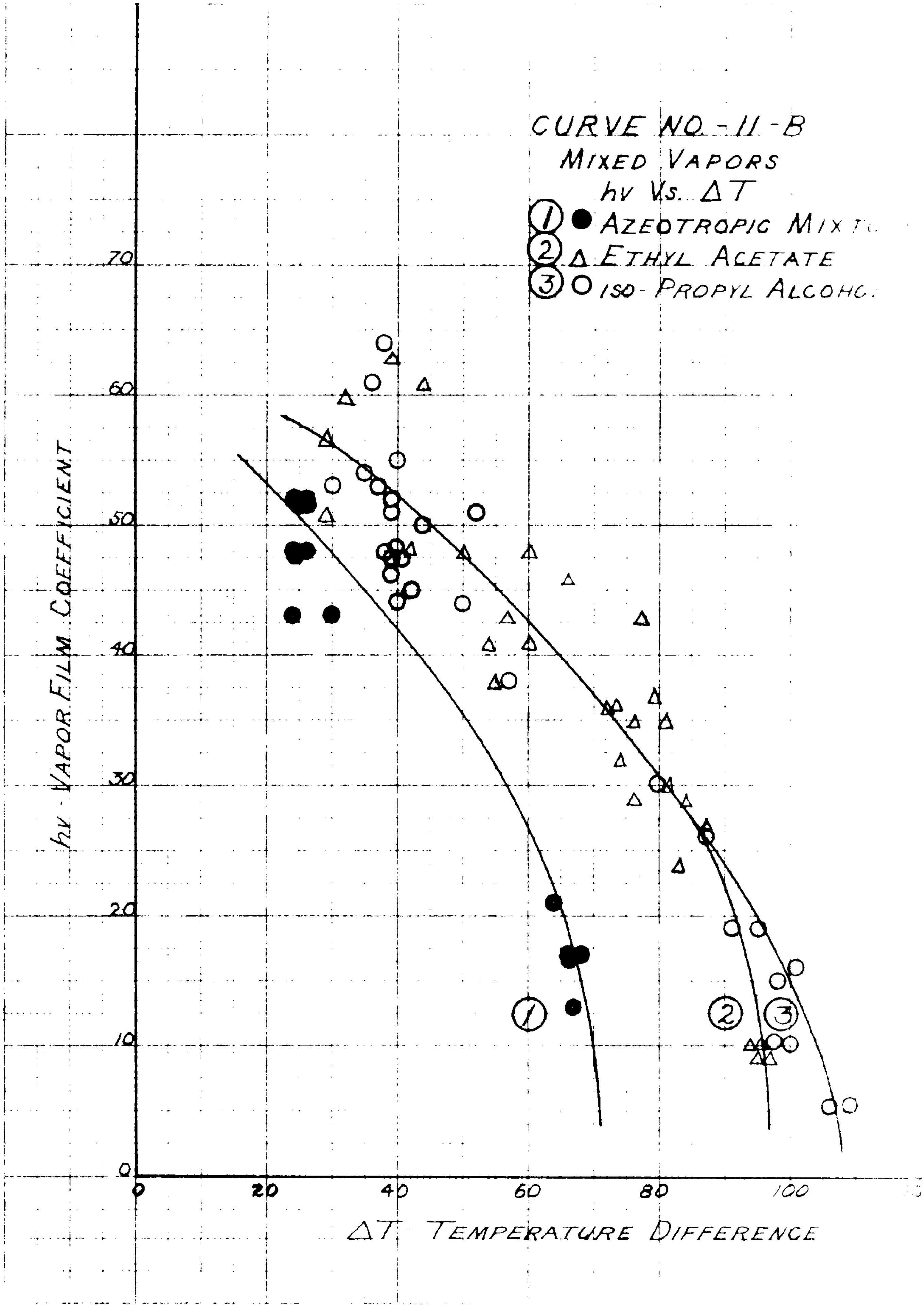
Run no.	Reynolds no.	Prandtl no.	hw	U	hv actual	t
243	3980	7.29	1805	50	36	42
244	4020	7.23	1830	64	46	42
245	4060	7.13	1830	69	50	36
246	4020	7.23	1830	59	43	53
(k)	4020	7.23	1830	59	43	43
247	4060	7.13	1830	69	50	36
248	4060	7.13	1830	69	50	35
249	4060	7.13	1830	73	53	34
250	4110	7.01	1840	78	56	34
(l)	4060	7.13	1830	73	53	35
251	3830	7.60	1810	27	20	32
252	3830	7.60	1810	22	16	94
253	3780	7.70	1815	18	13	102
254	3780	7.70	1815	18	13	92
(m)	3830	7.60	1810	22	16	91

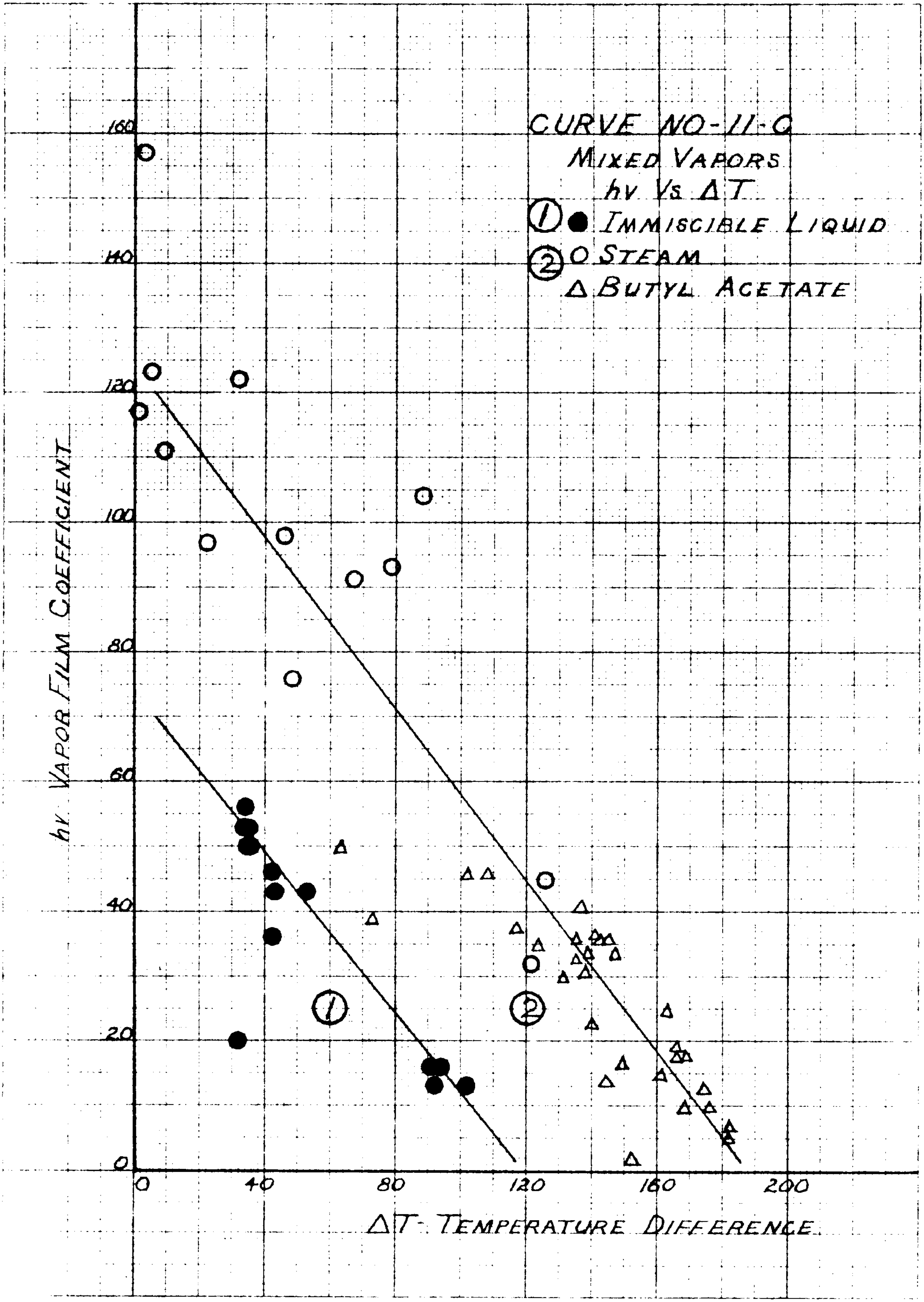
TABLE NO. 35

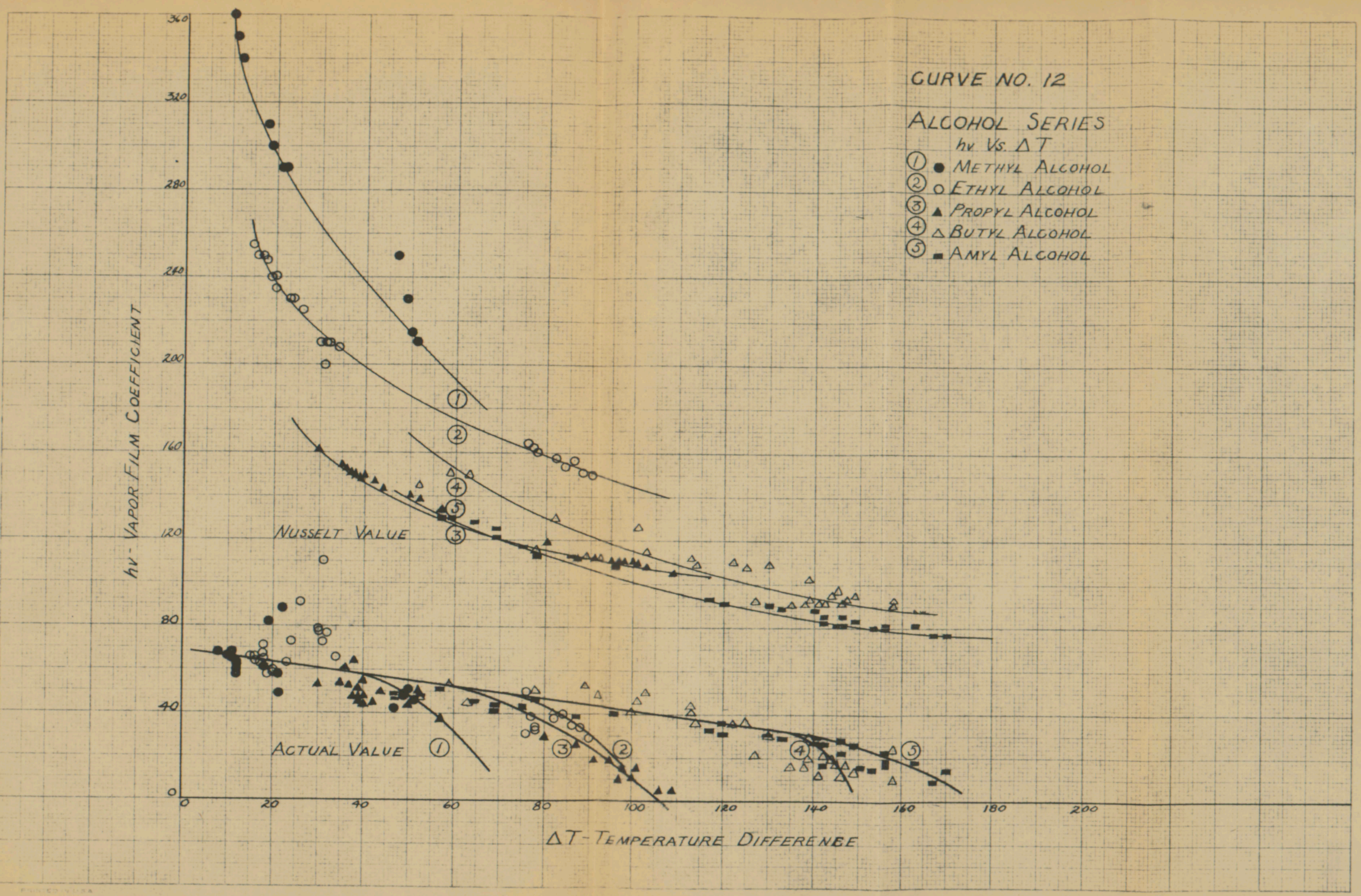
Calculated results for mixed vapor (propyl alcohol and ethyl acetate)

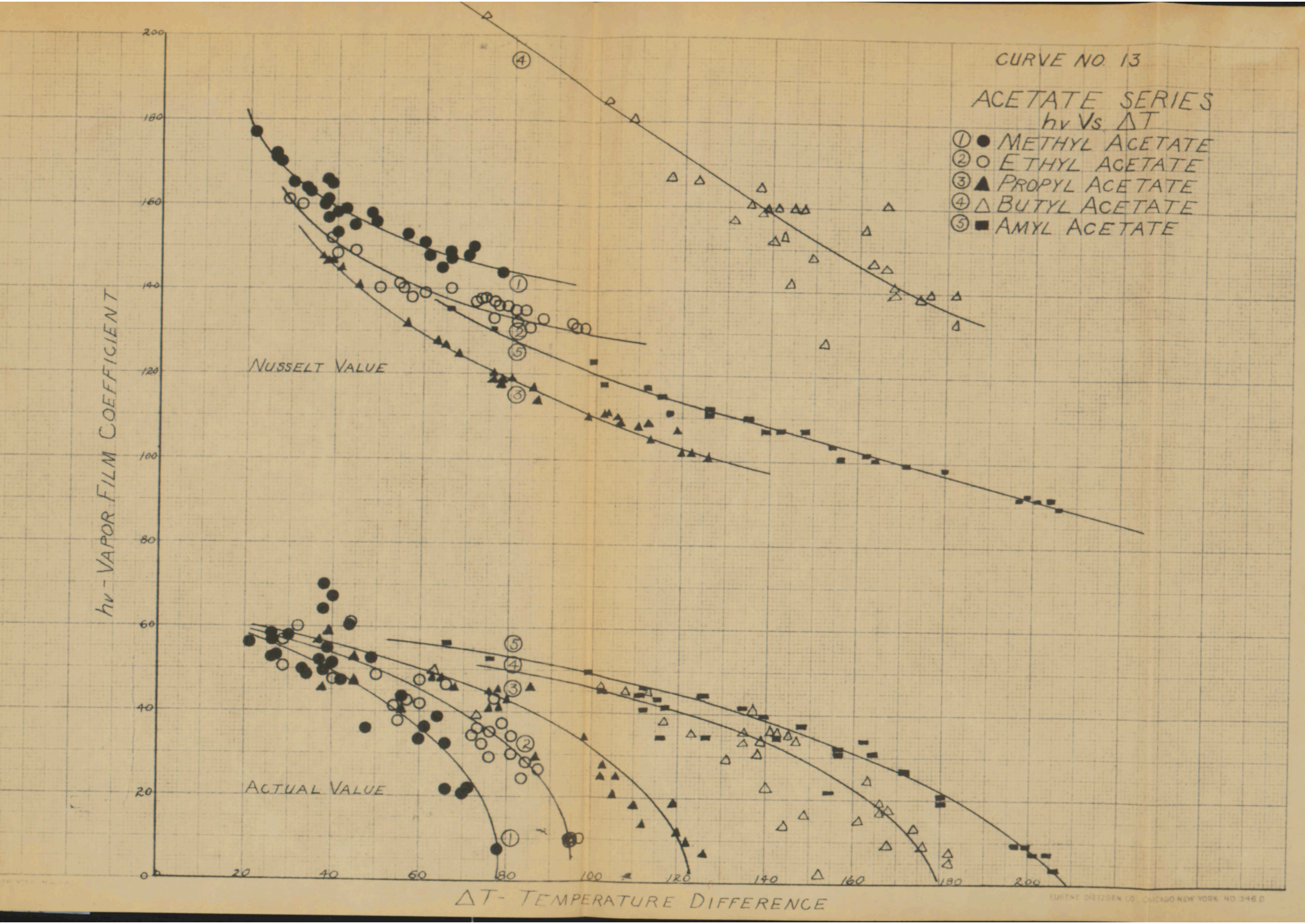
Run no.	Reynolds no.	Prandtl no.	hw	U	hv actual	t
255	3830	7.60	1810	60	43	30
256	3900	7.45	1810	73	52	26
257	3900	7.45	1810	73	52	26
258	3900	7.45	1810	72	52	26
(n)	3900	7.45	1810	66	48	26
259	3690	7.95	1820	18	13	67
260	3690	7.95	1820	23	17	68
261	3740	7.82	1820	29	21	64
262	3690	7.95	1820	23	17	66
(o)	3690	7.95	1820	23	17	66
263	3830	7.60	1810	60	43	24
264	3900	7.45	1810	73	52	24
265	3900	7.45	1810	66	48	24
(p)	3900	7.45	1810	66	48	24


CURVE NO - 11-A
MIXED VAPORS
hv Vs. ΔT
① ○ AZEOTROPIC MIXTURE
70 MOL PER CENT ETHYL ACETATE
30 MOL PER CENT iso-PROPYL ALCOHOL
② ● IMMISCIBLE LIQUID
50 PER CENT BUTYL ACETATE
50 PER CENT WATER
hv VAPOR FILM COEFFICIENT
0
10
20
30
40
50
60
70
0
20
40
60
80
100
ΔT - TEMPERATURE DIFFERENCE
①
②


CURVE NO.-11-B
MIXED VAPORS
hv Vs. ΔT
① ● AZEOTROPIC MIXT
② △ ETHYL ACETATE
③ ○ ISO-PROPYL ALCOHO
hv - VAPOR FILM COEFFICIENT
ΔT TEMPERATURE DIFFERENCE
0
10
20
30
40
50
60
70
0
20
40
60
80
100
①
②
③

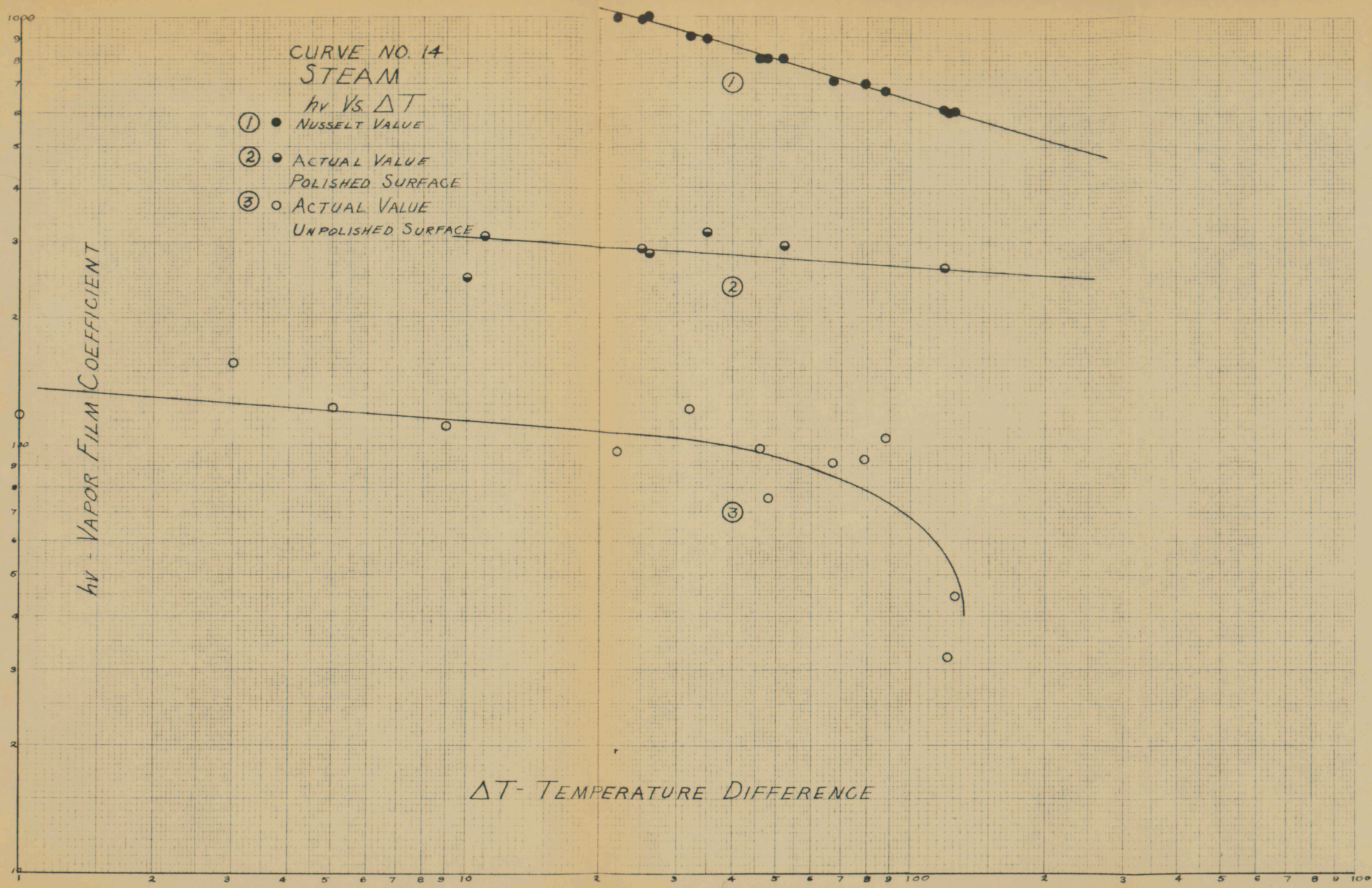

CURVE NO-11-C
MIXED VAPORS
hv Vs ΔT
① ● IMMISCIBLE LIQUID
② ○ STEAM
Δ BUTYL ACETATE
hv VAPOR FILM COEFFICIENT
ΔT TEMPERATURE DIFFERENCE
0
20
40
60
80
100
120
140
160
0
40
80
120
160
200
①
②

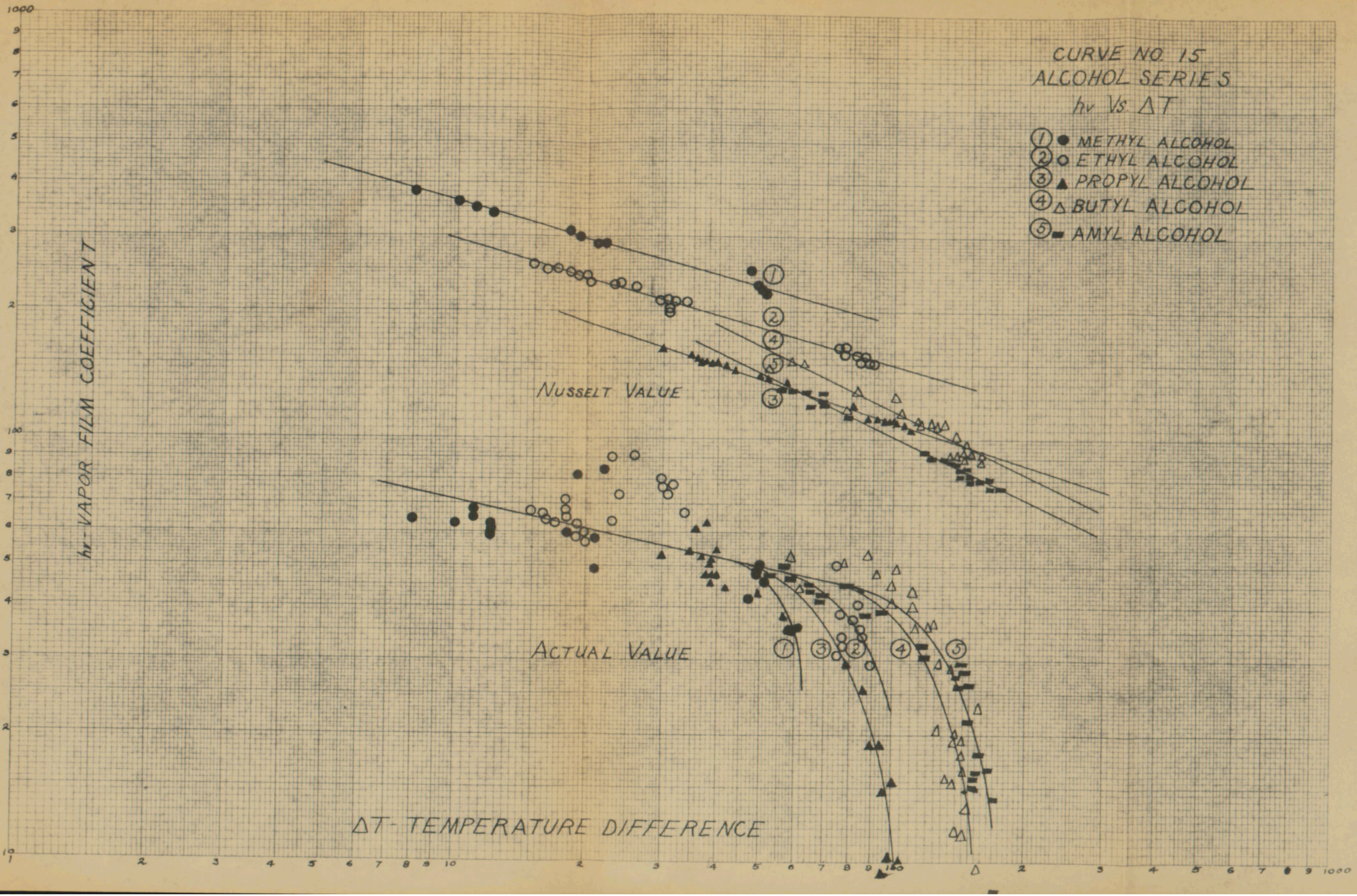

CURVE NO. 12
ALCOHOL SERIES
hv Vs. ΔT
① ● METHYL ALCOHOL
② ○ ETHYL ALCOHOL
③ ▲ PROPYL ALCOHOL
④ △ BUTYL ALCOHOL
⑤ ▬ AMYL ALCOHOL
hv - VAPOR FILM COEFFICIENT
ΔT - TEMPERATURE DIFFERENCE
NUSSELT VALUE
ACTUAL VALUE
①
②
③
④
⑤
0
40
80
120
160
200
240
280
320
360
0
20
40
60
80
100
120
140
160
180
200



CURVE NO. 13

ACETATE SERIES
hv Vs. ΔT


CURVE NO. 14
STEAM
hv Vs. ΔT
① ● NUSSELT VALUE
② ◒ ACTUAL VALUE POLISHED SURFACE
③ ○ ACTUAL VALUE UNPOLISHED SURFACE
hv - VAPOR FILM COEFFICIENT
ΔT - TEMPERATURE DIFFERENCE
①
②
③
1000
9
8
7
6
5
4
3
2
100
9
8
7
6
5
4
3
2
10
1
2
3
4
5
6
7
8
9
10
2
3
4
5
6
7
8
9
100
2
3
4
5
6
7
8
9
1000


CURVE NO. 15
ALCOHOL SERIES
hv Vs ΔT
① ● METHYL ALCOHOL
② ○ ETHYL ALCOHOL
③ ▲ PROPYL ALCOHOL
④ △ BUTYL ALCOHOL
⑤ ▬ AMYL ALCOHOL
hv - VAPOR FILM COEFFICIENT
ΔT - TEMPERATURE DIFFERENCE
NUSSELT VALUE
ACTUAL VALUE
①
②
④
⑤
③
①
③
②
④
⑤
1000
9
8
7
6
5
4
3
2
100
9
8
7
6
5
4
3
2
10
1
2
3
4
5
6
7
8
9
10
2
3
4
5
6
7
8
9
100
2
3
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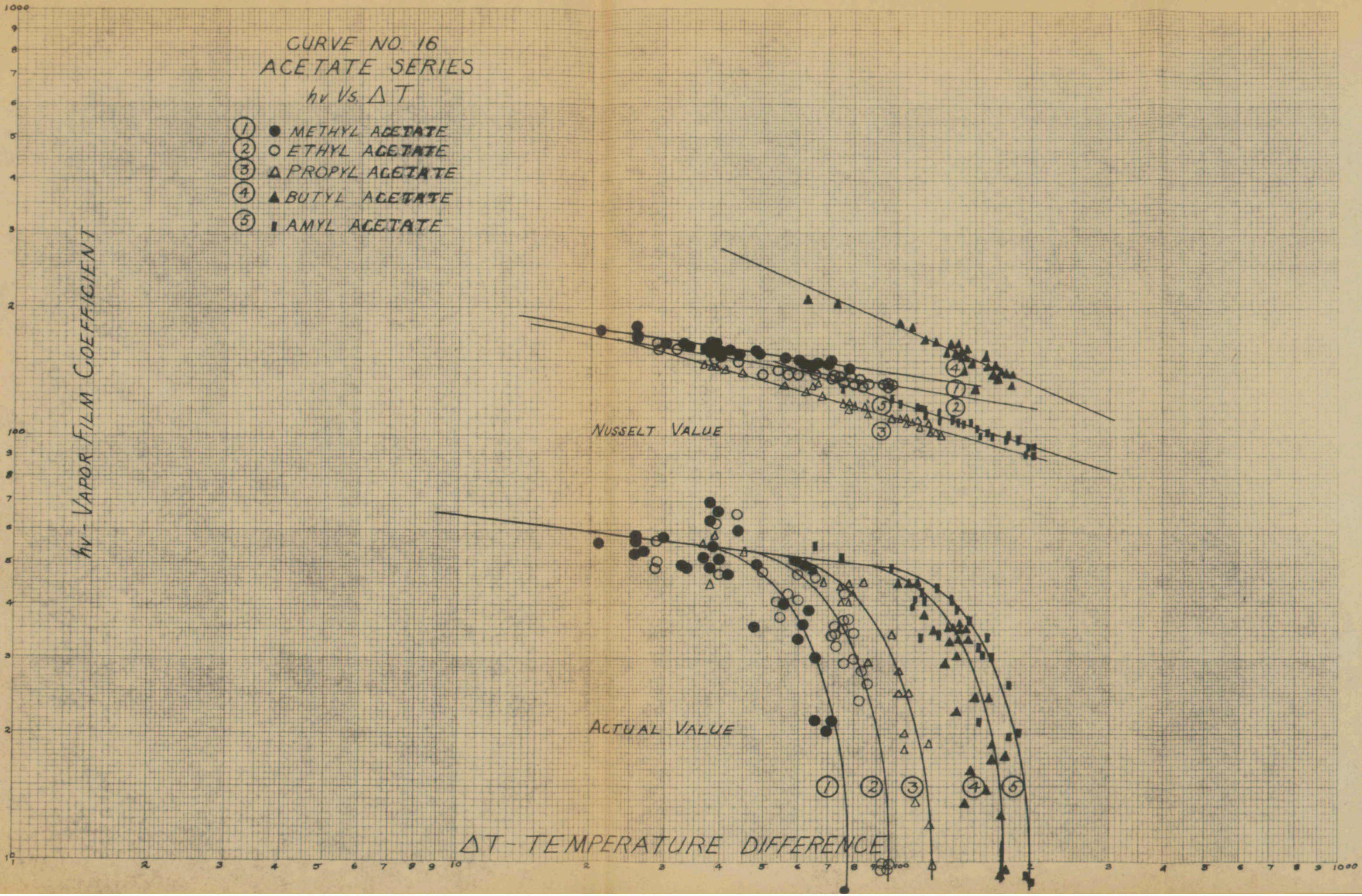
CURVE NO. 16
ACETATE SERIES
hv Vs. ΔT
① ● METHYL ACETATE
② ○ ETHYL ACETATE
③ △ PROPYL ACETATE
④ ▲ BUTYL ACETATE
⑤ ▮ AMYL ACETATE
hv - VAPOR FILM COEFFICIENT
ΔT - TEMPERATURE DIFFERENCE
NUSSELT VALUE
ACTUAL VALUE
④
①
②
⑤
③
①
②
③
④
⑤
1000
9
8
7
6
5
4
3
2
100
9
8
7
6
5
4
3
2
10
1
2
3
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7
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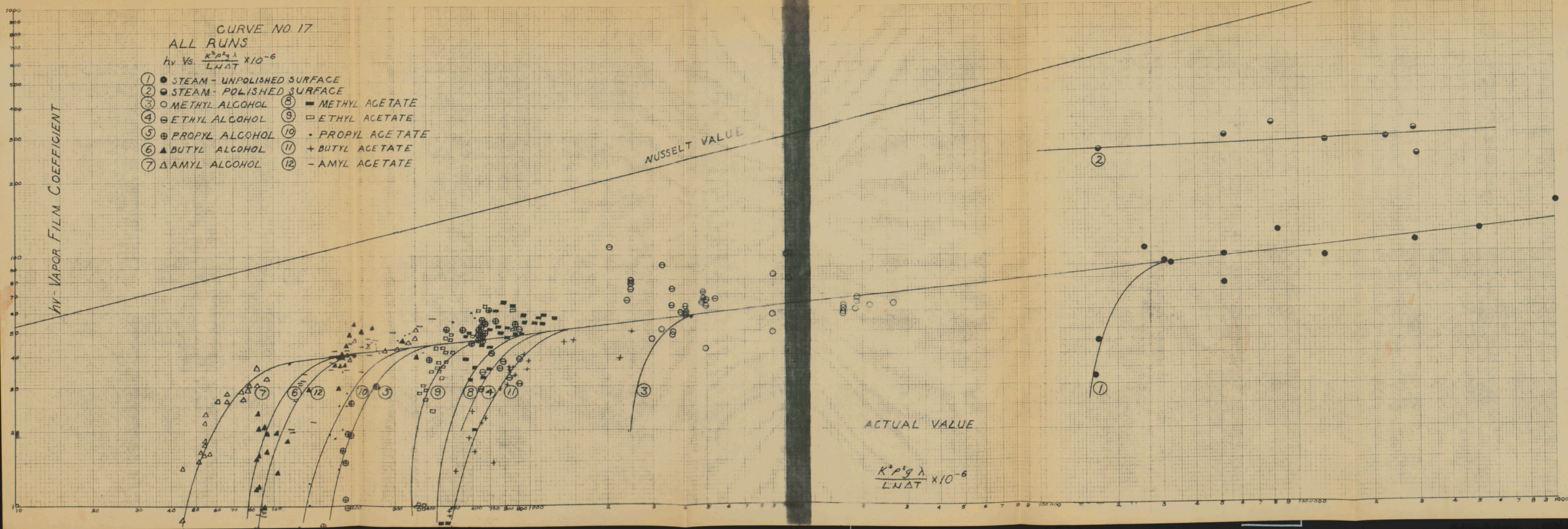

CURVE NO. 17

ALL RUNS

h_v Vs. $\frac{K^3\rho^2 g\lambda}{L\mu\Delta T}\times 10^{-6}$

DISCUSSION

The type of condensation observed in all cases was film condensation, except in the case of steam condensing on a semi-polished surface, which gave a type of condensation described by Kirkbride (23) as film-drop-wise. This film was observed to be in turbulent motion near the bottom of the tube at the high rates of vapor flow. The vapor film was found to be the controlling resistance in all cases.

From curves 1-11 it may be seen that the data taken by Morrison (34) with this same apparatus on steam and methyl, ethyl, and butyl acetates and alcohols checks fairly close. The reason for the deviation in most cases is probably due to the fact that in his work the results were presented for a cooling water rate of five pounds per hour which, in some cases, gave values of the Reynolds number in the critical region. In almost all cases the values of Morrison which do not check are higher than those found in this study.

The sharp drop of the vapor film coefficients at high temperature differences, as shown in all curves, may be explained by a comparison with a plot of friction factor versus Reynolds number in fluid flow. The plot of friction factor versus Reynolds number consists of two straight lines of different slope, one for the case of viscous flow and one for the case of turbulent flow. In this investigation the plot of film coefficient versus temperature difference could have been represented by two straight lines of different slope, one in the case of high temperature differences when the vapor was flowing in viscous flow and one for low temperature differences when the vapor was flowing in turbulent flow.

In the plot of film coefficient versus temperature differences for the alcohol and acetate series it is noted that the critical temperature differences, the point at which the slope of the line changes, increases as the molecular weight increases within the series. Carrying on the analogy between this and fluid flow, it is known that the critical Reynolds number is effected by the physical properties. It is seen that the critical temperature difference is effected by the physical properties of the condensing film. It may be noted that ethyl alcohol does not fall in order for the case of viscous flow and critical temperature differences. This is explained by the fact that the ethyl alcohol used was denatured (see page 47) and was only 90 per cent pure.

There are only two accepted equations for predicting the film coefficient of condensing vapors on a vertical tube, the Nusselt equation and an equation advanced by Badger, Monrad and Diamond (2-A) for condensing diphenyl vapors. From the results found in this investigation it is seen that these equations do not give the actual vapor film coefficients of the materials studied. The equation of Badger, Monrad and Diamond (2-A) is a linear equation in vapor film coefficient and temperature difference which was clearly not the case in this investigation. It is seen that the Nusselt equation gives values much higher than was actually found. The Nusselt equation was derived neglecting the vapor velocity. In this investigation it was found that the vapor velocity can not be neglected. In the case of turbulent flow of vapor an equation similar to the Nusselt equation was found to hold. It is:

$$h_v = 5.41 \left(\frac{K^3 p^2 g \lambda}{Nz \Delta t}\right)^{0.107} \qquad (10)$$

In the case of viscous flow of the vapor it was found that there is a different equation for each alcohol and acetate depending on its position in the series, of the general form.

$$h_v = a \Delta t^m \qquad (10A)$$

where a is a large number and m is of the order -0.1.

Recommendations

If further work is to be done on this subject with the same apparatus, I would recommend that a reflux line be constructed from the condenser to the still. This would enable the investigator to study higher vapor velocities, to make runs over a longer period of time and with the added advantage of keeping a constant head in the still. For a complete investigation of the alcohols and acetates studied, every possible variable should be varied to determine its relative effect on the vapor film coefficient. The water rate should be varied to give Reynolds numbers from the viscous region through critical region and well into the turbulent region. The vapor velocity should be varied over a greater range and the surface of the tube should be varied from highly polished to very dull. The tube should be varied both in diameter and especially in length. The outside shell of the condenser could also be varied to give a variation in voulume of vapor flow. If these factors were varied and their effect determined then a complete solution of the problem could be obtained. However, it is known that the temperature difference is the controlling factor, so this study gives a close approximation to the solution of the problem.

Auxillary equipment to facilitate a more accurate control of steam pressure and steam condensate rate is also recommended.

Limitations

The limitations of this experiment are the weaknesses that were recommended changed. The main weakness in the investigation as carried out was the fact that due to the change in head of the liquid in the still, and the resulting dropping off of the vapor velocity through the condenser, runs of only 15 minutes duration could be made with constant readings. Another weakness was evident in the fact that the secondary condenser was not large enough to investigate a wide range of high vapor velocities due to loss of material through vaporization. An accurate control of the steam pressure and steam condensate rate could not be acquired with the apparatus as used, but this had only the disadvantage that regular intervals of vapor velocity could not be attained.

CONCLUSIONS

1. In the condensation of organic vapors on a vertical copper tube with the cooling water in turbulent flow the vapor film coefficient is the controlling factor.

2. The actual vapor film coefficient of an organic vapor condensing on a vertical tube is much less than the Nusselt value for the same temperature drop across the vapor film.

3. The values of the film coefficients check with values found with the same apparatus by other investigators.

4. The film coefficient decreases with an increase in the temperature drop across the vapor film.

5. Steam condensing on a polished surface gives a higher film coefficient and a different type condensation than when condensing on unpolished surface.

6. Above a given temperature difference the film coefficient drops very rapidly. This value of temperature difference increases as the molecular weight increases in the alcohol and acetate series.

7. For alcohols and acetates at low values of film coefficient it requires a greater temperature difference to produce the same film coefficient as the molecular weight increases.

8. Within specific ranges of temperature difference the film coefficients of all materials vary in the same manner.

9. At low values of temperature difference film coefficients are the same for all alcohols and acetates. The temperature difference varies directly with the film coefficient on a log-log plot. The relation is therefore

$$hv = a\Delta t^{n} \qquad (11)$$

where a and m are constants and m is ~~less than zero~~ a negative value. The slope m approximates that of the Nusselt values.

10. For high values of film coefficient or low values of temperature difference the film coefficient increases directly on log-log paper as $\frac{K^3p^2g\lambda}{Nz\Delta T}$ increases. This relation may be represented by an equation

$$hv = a\left(\frac{K^3p^2g\lambda}{Nz\Delta T}\right)^n \qquad (12)$$

where a and n are constants. The slope n is in the general range of that of the Nusselt equation. From the plot the equation is

$$hv = 5.41\left(\frac{K^3p^2g\lambda}{Nz\Delta T}\right)^{0.107} \qquad (10)$$

11. Below a definite value of $\frac{K^3p^2g\lambda}{Nz\Delta T}$, different for each material, there is a sharp drop in the film coefficient. This value of $\frac{K^3p^2g\lambda}{Nz\Delta T}$ decreases as the molecular weight increases in the alcohol and acetate series.

12. It requires a greater value of $\frac{K^3p^2g\lambda}{Nz\Delta T}$ to give the same film coefficient as the molecular weight increases in the alcohol and acetate series, at low values of film coefficient or corresponding high temperature differences.

13. The vapor film coefficient of an azeotropic mixture varies with the temperatue drop across the vapor film in the same manner as its components.

14. The film coefficient of an azeotropic mixture is lower than either of its components for the same temperature drop.

15. The same conclusions may be drawn for the case of condensing immisciable vapors as in condensing azeotropic mixtures.

SUMMARY

In this investigation steam, and the alcohol and acetate series, through the amyl group were studied. A total of 64 fifteen minute runs were made with data being taken every five minutes. This gave from 20 to 30 values of the vapor film coefficient for each liquid at various values of temperature difference.

The vapors of the materials studied were supplied by a simple still of approximately 10 gallon capacity, the heat being supplied by an inserted steam coil. These vapors condensed on a 38 inch section of 18 gage ¾ inch vertical~~e~~ copper pipe inclosed in a three foot section of four inch pyrex glass pipe, the vapors flowed into the annular space. Cooling water from a constant head tank flowed upward inside the copper pipe at a constant rate. The temperature of the tube was measured by copper constantan thermocouples placed six inches apart and insulated with capillary glass tubing. All other temperatures were measured with resistance thermometers.

The actual vapor film coefficients were calculated by breaking up the overall resistance into its individual resistances. The water film coefficient being calculated by the Dittus and Boelter$^{(10)}$ equation. The Nusselt equation was used to give another value of the film coefficient.

There are presented individual plots of the film coefficient against temperature difference for each material. Similar plots of the alcohol series and another of the acetate series are plotted, on plain and log-log coordinate paper. A plot of vapor film coefficient versus the factor $\frac{K^3 \rho^2 g \lambda}{\mu z \Delta T}$ is presented for all data in order to correlate the experimental results with the Nusselt equation.

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[redacted]