1965

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Recommended Citation

Hernando, Martin Urrutia, "Liquid-liquid equilibria for a butyl acetate-water-acetic acid system" (1965). *Theses and Dissertations*. 5199.
https://preserve.lehigh.edu/etd/5199

LIQUID-LIQUID EQUILIBRIA FOR A BUTYL ACETATE-WATER-ACETIC ACID SYSTEM

By

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A BUTYL ACETATE-WATER-ACETIC ACID SYSTEM

by

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A Research Report
Presented to the Graduate Faculty
of Lehigh University
in Candidacy for the Degree of
Master of Science

Lehigh University
Bethlehem, Pennsylvania
1965

Certificate of Approval

This research report is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science in Chemical Engineering.

(Date)

(Professor in Charge)

(Head of the Department)

Acknowledgement

I wish to express my thanks to my advisor, Professor Curtis W. Clump for his patience and advice, and to the Kennecott Copper Company for their fellowship, which made this work possible.

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ABSTRACT

The purpose of this work is to study experimentally the equilibrium curves, tie-lines and conjugate curves at 20°C, 30°C, and 40°C for the ternary system Acetic acid - Water - Butyl acetate.

The data are presented on equilateral triangular graphs with composition in volume per cent.

INTRODUCTION

A) Acetic Acid

In the field of Organic Chemistry the acetic acid is by far the most important acid from the point of view of quantity used. Also, in this field, the importance of the acetic acid is comparable with the importance of the sulfuric acid in the heavy chemical industry.

Acetic acid is widely used, especially when a cheap organic acid is required. Some of these uses are: Cellulose derivatives (e.g., cellulose acetate and acetate plastics), acetic anhydride, ester solvents, metallic acetates, pigments (e.g., white lead), insecticides (e.g., Paris green), some pharmaceutical products (e.g., aspirins), vinegar, etc.

B) Concentration

There exists several methods of preparation of acetic acid. Most of them produce dilute aqueous solutions (except synthetic process). Also, when acetic acid is used like solvent, large amounts of diluent acid are produced and it is necessary to concentrate it in an economical way.

Distillation along is not practical for recovering the acetic acid from the aqueous solution because the composition of the vapor is not different enough from the composition of the liquid being necessary to build a very long column with a heavy reflux (4).

Hence, mixed methods of liquid-liquid extraction and distillation have been developed to recover the acetic acid in an economic way.

This work studies the action of butyl acetate, as solvent, at certain temperatures that can have industrial interest. These three liquids form a three-component-system or a ternary system.

Most of the industries use ethyl acetate as solvent for the extraction of the acetic acid from aqueous solutions.

TERNARY SYSTEM

Liquid-liquid extraction principle is based on the different solubility of the solute (acetic acid) in the diluent and solvent phases. The mutual solubility of two liquids varies in presence of a third component. Hence, it is necessary to determine the properties of the new system experimentally.

The compositions of a ternary system is usually represented on an equilateral triangle. The different compositions can be expressed in per cent by volume, weight, or molar (1). In Figure 1 a three-component-system is presented in a general manner. Let us assume that point A is the solvent, point B the diluent, and point C the solute. Each of these vertices represents one hundred per cent of the respective component. The perpendicular from each vertex to the opposite side is divided into one hundred parts, then, from the geometrical point of view any point within the triangle represents a composition of a mixture in percentage.

When an intimate mixture of a three component system forms a turbid solution, it is said that the solution consists of two immiscible ternary solutions in equilibrium of A, B, and C (Figure 1). This mixture when plotted on the triangular diagram gives two points of the solubility curve, and the line joined both points is defined as a tie-line.

Any point outside the equilibrium curve represents a homogeneous solution (single phase); any point within this curve represents a mixture of two phases in equilibrium.

In general, for getting a good extraction of the solute (acetic acid from water), one pair of liquids must be as immiscible as possible (solute-diluent and solute-solvent). In this case, the solute will be distributed in both phases forming two equilibrium layers. When the solute is increased, the mutual solubility of the system will increase too (1).

In order to avoid interpolation between a complete set of equilibrium tie-lines the concept of a single conjugate curve was used (5).

THE PHASE RULE

In this work the temperature and the pressure were kept constant for each equilibrium curve determined. The pressure was high enough (1 atm.) to condensate the vapor phase.

Let us define:

v: Number of degrees of freedom or total number of independent variables

p: Number of phases

If each phase of the equilibrium system has C components, its composition is determined by (C-1) concentrations. Hence, there are (C-1) independent variables for each phase, and the total variables in the equilibrium system will be p (C-1). In this case the temperature and the pressure are not variables.

There are (p-1) equilibrium relationships for each component. Hence, the total number of equations between the variables will be C (p-1).

Then, the total number of independent variables or variance, v, will be:

$$v = p\,(C-1) - C\,(p-1)$$

$$v = C - p$$

In this case (ternary system) C = 3, then

v = 3 - P

a) Within the Equilibrium Curve

There are two phases (p = 2) within the equilibrium curve, so that

v = 1

Hence, it is enough to determine the precentage of one component in one of the two phases for describing the system.

b) Outside the Equilibrium Curve

There is one phase (p = 1) outside the equilibrium curve, so that

v = 2

In this region of the graph it is necessary to determine the percentage of two components in order to describe the system.

CHOICE OF SOLVENT AND TEMPERATURES

There are many factors to consider in the selection of a solvent for a ternary system. They are (1) selectivity, cost and availability, inflammability, toxicity, chemical reactivity, freezing point, viscosity, density and interfacial tension, vapor pressure, mutual solubility, and solvent recovery. Some of these factors were considered in the present work.

Selectivity is one of the most important technical factors to be considered in the selection of a solvent. A solvent is selective if the concentration of the solute, C, is higher in the solvent phase, S, than the diluent phase, D. In this work, the diluent is water, B, and the solute is acetic acid, C.

Let us define:

X_{CS} = concentration of acetic acid in the solvent phase

X_{BS} = concentration of water in the solvent phase

X_{CD} = concentration of acetic acid in the diluent phase

X_{BW} = concentration of water in the diluent phase

Selectivity is defined as (1):

$$\beta = \frac{X_{CS}}{X_{BS}} / \frac{X_{CD}}{X_{BD}}$$

$$\beta = \frac{X_{CS}}{X_{CD}} \cdot \frac{X_{BD}}{X_{BS}}$$

The distribution coefficient for a specific component i is defined as

$$K_i = \frac{\text{concentration of i in the S phase}}{\text{concentration of i in the D phase}} = \frac{X_{iS}}{X_{iD}}$$

Then, the selectivity can be expressed as:

$$\beta = \frac{K_C}{K_D}$$

The equilibrium distribution of a component i between two phases at constant pressure and temperature is the equality of the fugacities in both phases.

$$f_{iS} = f_{iD}$$

$$a_i^S f_{iS}^o = a_i^D f_{iD}^o$$

f^o = fugacity in the standard state
a = activity
γ = activity coefficient

The standard state will be chosen at the pressure and temperature of the system and the pure component in the liquid phase. Then,

$$f^o_{iS} = f^o_{iD}$$

$$a_{iS} = a_{iD}$$

$$\gamma_{iS}\, X_{iS} = \gamma_{iD}\, X_{iD}$$

Therefore, the distribution coefficient can be expressed as:

$$K_i = \frac{X_{iS}}{X_{iD}} = \frac{\gamma_{iD}}{\gamma_{iS}}$$

Then, the selectivity can be written in terms of activity coefficients:

$$\beta = \frac{\gamma_{CD} \cdot \gamma_{BS}}{\gamma_{CS} \cdot \gamma_{BD}}$$

and $K_C = \dfrac{\gamma_{CD}}{\gamma_{CS}}$

A good selective solvent will be one that has $K_C \gg 1$. The magnitude of the activity coefficients, γ_{CS} and γ_{CD}, will be determined by the nature of the interactions of the solute (acetic acid) with water and the solvent. When $\gamma_{CS} < 1$, the solute has been saturated by the solvent, and in most of the cases, ad additional attraction between solute and solvent molecules can occur if hydrogen bonds exist and the equilibrium will be displaced towards the solvent phase.

Ewell, Harrison and Berg (2) classified liquids in five different groups based on their potentialities for forming hydrogen bonds. Water was classified in Class I, these liquids are capable of forming three dimensional networks of strong hydrogen bonds, and the acetic acid was classified in Class II, these liquids also form three dimensional networks of hydrogen bonds, but these bonds are much weaker. Acetic acid (Class II) and water (Class I) form a solution that has a positive deviation from Raoult's law.

The ideal solvent must have a solvent phase with a negative deviation from Raoult's law, $\delta_{CS} < 1$. This is applied to the liquids of Class III, these liquids are composed of molecules containing donor atoms but not active hydrogen atoms. Esters, ethers, ketones and aldehydes are some liquids that belong to this group.

The water and the solvent should be as immiscible as possible in order to increase the degree of separation.

Difference in densities between water and solvent contribute to get better and faster separation of the two layers.

Butyl acetate was chosen as the solvent since it shows negative deviation from Raoult's law, $\gamma < 1$ (Class III). It is immiscible with water but miscible with acetic acid in all proportions. Its freezing point (4) is at -76.3°C, and its density in comparison with the densities of the water and acetic acid (3) is:

	Butyl Acetate	Acetic Acid	Water
20°C	0.8716	1.0499	0.9982
30°C	0.8615	1.0387	0.9957
40°C	0.8510	1.0274	0.9922

Some other properties, such as, inflammability, toxicity, chemical reactivity, viscosity and solvent recovery, were considered qualitatively in this work.

Temperatures with some industrial interest were chosen. They were at 20°C, 30°C, and 40°C.

At 24°C it was found that the equilibrium curve was determined by eleven points (6). In this article the source of the original research is not mentioned.

Since little work on the acetic acid, butyl acetate, and water was found, it was decided to measure phase equilibria and solubility locus at several temperatures.

Equipment

The equipment used was almost the same for the determination of the equilibrium curves and the tie-lines. Each sample was put in a flask of 125 c.c.

A) Temperature Control

The 125 c.c. Erlenmeyer flask was in a thermostat consisting of a large reservior of water heated by an electrical coil. The different temperatures were controlled with a variac and two thermometers (one in the water and the other one in the sample.)

B) Stirring

The temperature of the water bath was kept uniform with an electrical stirrer and its speed was controlled with a variac. The sample of the ternary system was kept homogeneous by means of a magnetic stirrer with its own speed control.

C) Additional Equipment

Four burettes, one for each liquid of the ternary system and another for the sodium hydroxide, were used. Also used were a Westphal balance, glasses, pipets, etc.

For analyzing the acetic acid (titration), sodium hydroxide was used. Phenolthalien was used as the indicator.

The components used for the work were: butyl acetate (Fisher Reagent), acetic acid (A.C.S. specifications), and distilled water.

Experimental Procedure

A) Equilibrium Curve

The Othmer method was used in the determination of the equilibrium curve (6). This method is shown in Figure 1. The points A, B, and C represent the solvent, water, and solute respectively. Let us assume an initial solution at point Q, then, B is added until turbidity results. This means that one point on the equilibrium curve has been obtained (Point R). Point R is on the straight line joining Q and B. A new amount of solute C is added to the rupture R and a clear solution results again (Point S). This procedure is repeated and several points of the left side of the equilibrium curve are obtained (Points T, V, and W). The right side of the curve is gotten by starting with a mixture with a greater amount of B, and the method for determinating this side of the curve is the same as that used for the left side.

Into a 125 c.c. Erlenmeyer flask was put a solution of known volumes of water, acetic acid and butyl acetate forming a clear solution (one phase). Water was added, drop by drop, until turbidity was seen. At that point, an equilibrium point was gotten. Acetic acid was added in order to get a clear solution again and to determine another point. This method was repeated until the curve was completed. The volumes were expressed in percentage and plotted. (1)

B) Tie-Lines

Tie-lines represent the connection between two coexisting phases (equilibrium layers). Two of these tie-lines have been drawn in Figure 1, between R and M, and T and N. Any point inside the equilibrium curve represents a solution of two phases in equilibrium. These points, inside the equilibrium curve, have a variance equal to one (phase rule) and it would be sufficient to determine the percentage of one of the components in one phase to determine the system. In order to check the tie-lines both layers were analyzed for acetic acid.

A solution of 50 per cent of butyl acetate and 50 per cent of water was placed in a 125 c.c. Erlenmeyer flask. Different amounts of acetic acid were added in each observation in order to get a set of tie-lines. During four hours the mixture was kept homogeneous by means of a magnetic stirrer, at constant temperature. During an additional four hours, at the same temperature, the mixture was allowed to settle. After this procedure some samples were taken for analyzing the acetic acid (titrated with NaOH). Densities were measured by means of a Westphal balance.

Results and Errors

The results obtained are presented in the appendix. In part one (P-I) the values of the focus of saturation, and in part two (P-II) the values of the tie-lines can be found.

In part I-A the different values of the saturation curve for each temperature are presented in four columns. The first one shows the number of the run, and the other three the concentration of Butyl acetate, Acetic acid, and water. These values were ordered with respect to butyl acetate (from high to low concentration). In part I-B the initial concentration of each run is represented.

In part II, three tables (A, B, and C) are presented for each temperature. Table A contains the initial compositions of each run, and tables B and C the equilibrium points for each tie-line.

The different values of Part I and Part II were plotted in Figures 3, 4, and 5. In Figure 2 the three equilibrium curves at 20°C, 30°C, and 40°C can be seen, besides this, the curve cited by Othmer for the same ternary system at 24°C was drawn for comparison (6).

In Figures 3, 4, and 5 the solubility curves, several tie-lines, and its conjugate curve for each temperature were plotted.

A comparison between the experimental data obtained and theoretical data was not possible since there are no complete theoretical data available.

It is important to note that the determination of the solubility curve at high concentration of butyl acetate or water was not very precise, since it was very difficult to distinguish between the two phases solution and the clear solution.

Since during the measurement the top of the flask had to be removed, a change of temperature of the system was noticed. This error is tabulated below.

A) Solubility Curve

At 20°C	Negl.
30°C	1.0°C
40°C	2.0°C

B) Tie-lines

At 20°C	0.5°C (estimated)
30°C	2.0°C
40°C	4.0°C

The experimental error using solubility curve, focus of the tie-lines, and deviation from initial composition were estimated to be approximately

At 20°C	0.5%
30°C	2.0%
40°C	5.0%

APPENDIX

Part I

A_1) Saturation Locus at 20°C

Run No.	Butyl Acetate	Water	Acetic Acid
		Volume Per Cent	
1	91.6	2.7	5.7
1	90.3	3.0	6.7
1	87.7	3.6	8.7
1	86.3	4.0	9.7
1	85.0	4.3	10.5
1	83.9	4.6	11.5
1	82.7	4.9	12.4
2	82.3	4.5	13.2
1	80.7	5.3	14.0
1	78.2	6.1	15.7
3	77.9	5.9	16.2
1	76.4	6.5	17.1
1	74.5	6.9	18.6
1	72.8	7.3	19.9
2	72.4	7.6	20.0
1	71.6	8.1	20.3

Run No.	Butyl Acetate	Water	Acetic Acid
		Volume Per Cent	
2	67.2	9.5	23.3
3	66.3	9.8	23.9
4	65.8	10.0	24.2
2	60.3	12.6	27.1
5	57.0	14.0	29.0
2	54.4	15.8	29.8
4	54.2	15.5	30.3
5	52.4	16.7	30.9
1	54.1	15.3	30.6
2	49.3	19.0	31.7
3	48.3	18.9	32.8
1	46.6	19.2	33.2
3	46.6	20.0	33.4
5	45.8	21.1	33.1
2	45.2	22.0	32.8
4	43.2	22.7	34.1
5	43.0	22.7	34.3
2	42.5	24.6	32.9
3	41.6	23.4	35.0

Run No.	Butyl Acetate	Water	Acetic Acid
2	38.7	25.4	35.9
3	38.7	26.9	34.4
5	37.1	27.1	35.8
2	35.6	29.4	35.0
3	35.4	28.0	36.6
3	34.6	30.4	35.0
3	31.8	30.6	37.6
3	29.8	32.2	38.0
4	29.5	32.7	37.8
5	26.5	35.0	38.5
6	23.2	37.2	39.6
6	18.0	42.1	39.9
6	14.6	45.5	39.9
6	11.9	48.9	39.2
6	8.2	54.2	37.6
6	5.8	59.0	35.2
7	3.0	84.1	12.9
6	2.2	75.3	22.5
7	1.6	91.1	7.3
7	1.5	91.6	6.9
7	0.9	92.9	6.2
7	0.8	93.9	5.3

B_1) Initial Compositions

Run No.	Butyl Acetate	Water	Acetic Acid
1	40 c.c.	1 c.c.	2 c.c.
2	25	1	1
3	25	1	1
4	34	3	13
5	12	3	10
6	1	40	10
7	0.5	60	2.5

A_2) Saturation Locus at 30°C

Run No.	Butyl Acetate	Water	Acetic Acid
		Volume Per Cent	
1	85.2	5.6	9.4
2	85.0	5.5	9.5
2	82.1	6.6	11.3
1	74.8	9.5	15.7
1	71.2	11.1	17.7
2	70.2	11.4	18.4
3	68.0	12.7	19.3
3	64.4	15.0	20.6
2	64.1	14.1	21.2
3	61.1	16.7	22.2
4	58.5	18.3	23.2
2	57.8	19.9	24.3
3	53.2	21.7	25.1
4	52.6	22.0	25.4
1	48.9	24.8	26.3
3	46.6	26.2	27.2
1	45.0	27.6	27.4
1	43.7	28.3	28.0
1	38.8	32.0	29.2
4	37.9	32.2	29.9
2	36.0	33.3	30.7

Run No.	Butyl Acetate	Water	Acetic Acid
1	33.1	36.2	30.7
2	32.4	36.1	31.5
1	28.8	39.4	31.8
3	25.5	42.1	32.4
1	24.2	43.0	32.8
2	20.6	46.0	33.4
4	16.6	50.4	33.0
6	15.5	50.8	33.7
5	14.9	51.1	34.0
6	13.1	53.5	33.4
5	12.7	53.9	33.4
5	11.7	55.1	33.2
5	11.0	56.0	33.0
6	10.2	57.2	32.6
5	9.8	58.3	31.9
5	9.0	60.1	30.9
5	8.6	60.5	30.9
5	7.8	62.0	30.2
5	7.1	64.7	28.2
6	6.8	65.5	27.7
5	6.7	65.0	28.3
6	5.0	70.8	24.2
5	4.9	70.2	24.9

Run No.	Butyl Acetate	Water	Acetic Acid
5	4.1	73.4	22.5
5	3.6	75.1	21.3
6	2.5	86.2	11.3
6	1.9	90.0	8.1

B_2) Initial Composition

Run. No.	Butyl Acetate	Water	Acetic Acid
1	20 c.c.	1 c.c.	1.6 c.c.
2	20	1	1.5
3	21	3	6
4	20	1	6
5	0.5	19.0	3.5
6	0.5	30	2.5

A_3) Saturation Locus at 40°C

Run No.	Butyl Acetate	Water	Acetic Acid
1	87.3	6.0	6.7
2	86.0	6.9	7.1
1	80.5	9.5	10.0
2	79.1	10.2	10.7
1	76.8	11.4	11.8
2	75.7	12.1	12.2
1	70.8	14.6	14.6
2	70.3	15.5	14.2
2	62.8	19.0	18.2
1	61.8	19.9	18.3
3	61.4	20.4	18.2
3	60.0	21.0	19.0
2	55.0	24.0	21.0
2	51.5	26.6	21.9
3	49.6	23.0	27.4
1	49.0	28.7	22.3
2	48.9	28.8	22.3
1	47.6	29.4	23.0
1	45.3	31.0	23.7

Run No.	Butyl Acetate	Water	Acetic Acid
2	41.0	34.6	24.4
3	40.8	34.5	24.7
1	40.7	34.8	24.5
1	38.1	37.0	24.9
1	35.9	38.4	25.7
2	33.1	40.5	26.4
1	30.6	42.5	26.9
1	28.2	44.6	27.2
3	27.1	46.1	26.8
1	25.4	46.7	27.9
1	23.0	49.1	27.9
2	22.5	49.4	28.1
1	22.0	50.0	28.0
4	16.9	54.1	29.0
5	15.7	55.8	28.5
4	14.3	57.7	28.0
5	11.8	61.3	26.9
4	10.5	63.4	26.1
4	7.9	68.8	23.3
5	7.2	70.0	22.8
5	6.1	72.5	21.4
5	5.7	73.6	20.7

Run No.	Butyl Acetate	Water	Acetic Acid
4	5.2	75.0	19.8
5	4.9	75.7	19.4
5	4.0	80.1	15.9

B_3) Initial Compositions

Run No.	Butyl Acetate	Water	Acetic Acid
1	44 c.c.	1.5 c.c.	3.5 c.c.
2	41	2	6
3	17	3	5
4	1	19.5	5
5	0.8	41	8

1) **Equilibrium Tie Lines at 20°C**

A_1) Initial Compositions

Run No.	Butyl Acetate	Water	Acetic Acid
		Volume Per Cent	
1	45.0	45.0	10.0
2	43.1	43.1	13.8
3	39.6	39.6	20.8
4	37.5	37.5	25.0
5	35.1	35.1	29.8
6	33.5	33.5	32.8
7	32.3	32.3	35.4
8	32.0	32.0	36.0

B_1) **Solvent Phase**

Run No.	Butyl Acetate	Water	Acetic Acid
1	91.0	2.2	6.8
2	86.5	3.4	10.1
3	81.0	5.0	14.0
4	76.4	6.3	17.3
5	66.2	9.7	24.1
6	59.3	12.8	27.9
7	49.4	18.6	32.0
8	47.4	19.9	32.7

C_1) **Water Phase**

Run No.	Butyl Acetate	Water	Acetic Acid
1	1.6	85.4	13.0
2	2.1	80.1	17.8
3	3.0	71.0	26.0
4	4.7	63.2	32.1
5	6.6	58.1	35.3
6	8.4	54.1	37.3
7	10.8	50.5	38.7
8	12.1	48.6	39.3

2) Equilibrium Tie Lines at 30°C

A_2) Initial Compositions

Run No.	Butyl Acetate	Water	Acetic Acid
1	48.0	48.0	4.0
2	47.05	74.05	5.9
3	43.1	43.1	13.8
4	40.8	40.8	18.4
5	39.2	39.2	21.6
6	38.0	38.0	24.0
7	37.2	37.2	25.6
8	36.85	36.85	26.3
9	36.7	36.7	26.6
10	36.05	36.05	27.9

B_2) Solvent Phase

Run No.	Butyl Acetate	Water	Acetic Acid
1	96.8	2.0	1.2
2	92.5	2.8	4.7
3	84.3	5.9	9.8
4	80.0	7.5	12.5
5	76.8	8.8	14.4
6	72.1	10.9	17.0
7	65.7	14.1	20.2
8	64.1	14.9	21.0
9	60.3	17.2	22.5
10	57.0	19.2	23.8

C_2) **Water Phase**

Run No.	Butyl Acetate	Water	Acetic Acid
1	1.5	90.3	8.2
2	1.8	88.1	10.1
3	4.3	74.8	20.9
4	5.5	69.5	25.0
5	7.2	63.0	29.8
6	8.4	60.8	30.8
7	9.5	58.5	32.0
8	10.9	56.5	32.6
9	11.2	56.1	32.7
10	12.9	54.1	33.0

3) Equilibrium Tie Lines at 40°C

A_3) Initial Compositions

Run No.	Butyl Acetate	Water	Acetic Acid
		Volume Per Cent	
1	46.3	46.3	7.4
2	42.45	42.45	9.1
3	43.9	43.9	12.2
4	43.1	43.1	13.8
5	42.4	42.4	15.2
6	41.65	41.65	16.7
7	41.0	41.0	18.0
8	40.3	40.3	19.4
9	40.3	40.3	19.4
10	39.7	39.7	20.6
11	39.45	39.45	21.1

B_3) **Solvent Phase**

Run No.	Butyl Acetate	Water	Acetic Acid
1	93.1	3.2	3.7
2	88.4	5.5	6.1
3	85.8	7.0	7.2
4	82.8	8.4	8.8
5	81.6	9.0	9.4
6	76.9	11.5	11.6
7	76.7	11.6	11.7
8	74.3	12.9	12.8
9	71.4	14.6	14.0
10	69.6	15.6	14.8
11	66.1	17.6	16.3

C_3) **Water Phase**

Run No.	Butyl Acetate	Water	Acetic Acid
1	2.2	85.7	12.1
2	3.2	81.6	15.2
3	4.6	77.1	18.3
4	5.2	75.5	19.3
5	6.8	71.4	21.8
6	7.3	70.0	22.7
7	9.2	66.2	24.6
8	10.5	64.0	25.5
9	10.5	64.0	25.5
10	12.7	60.5	26.8
11	12.0	61.8	26.2

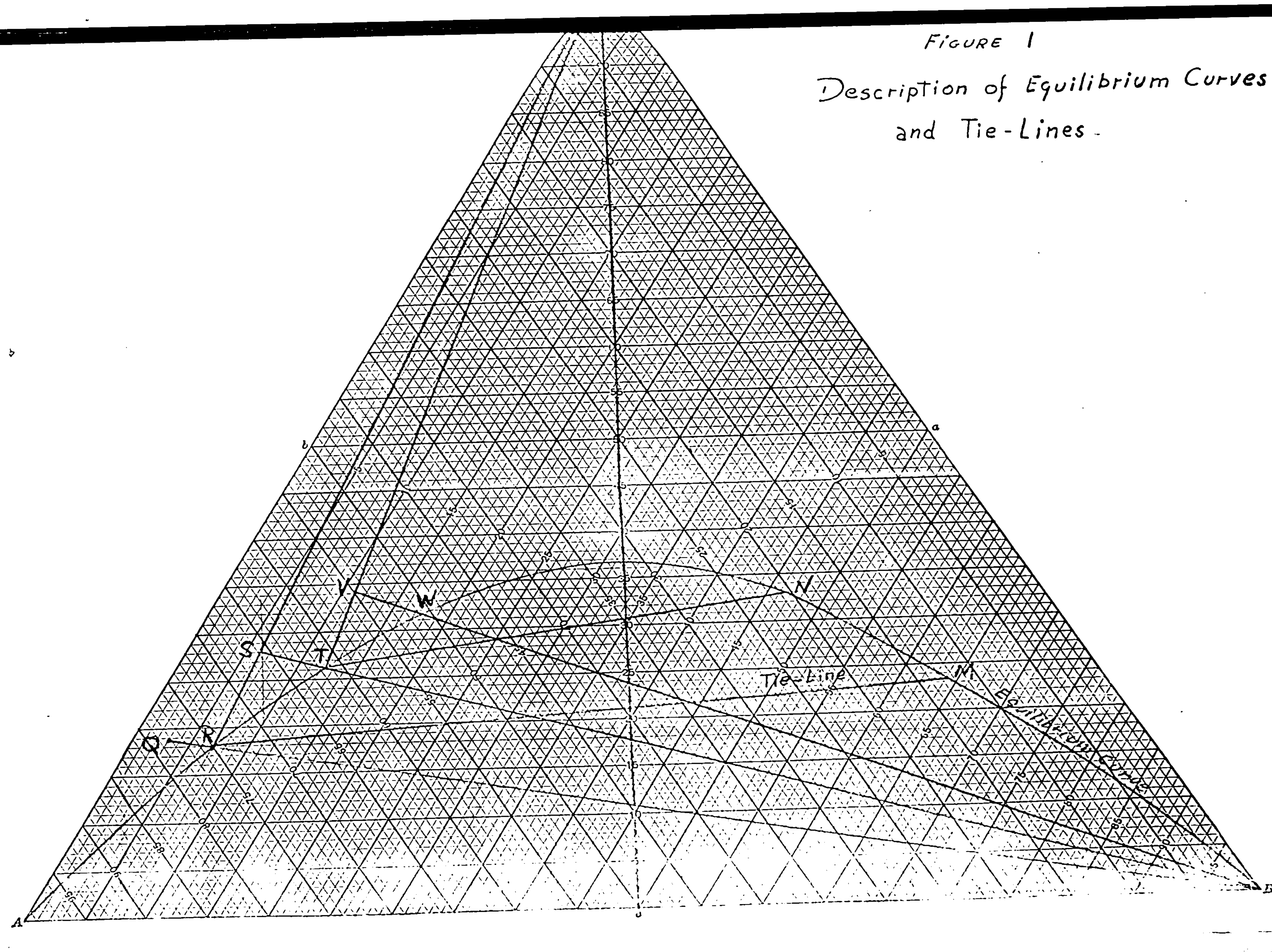
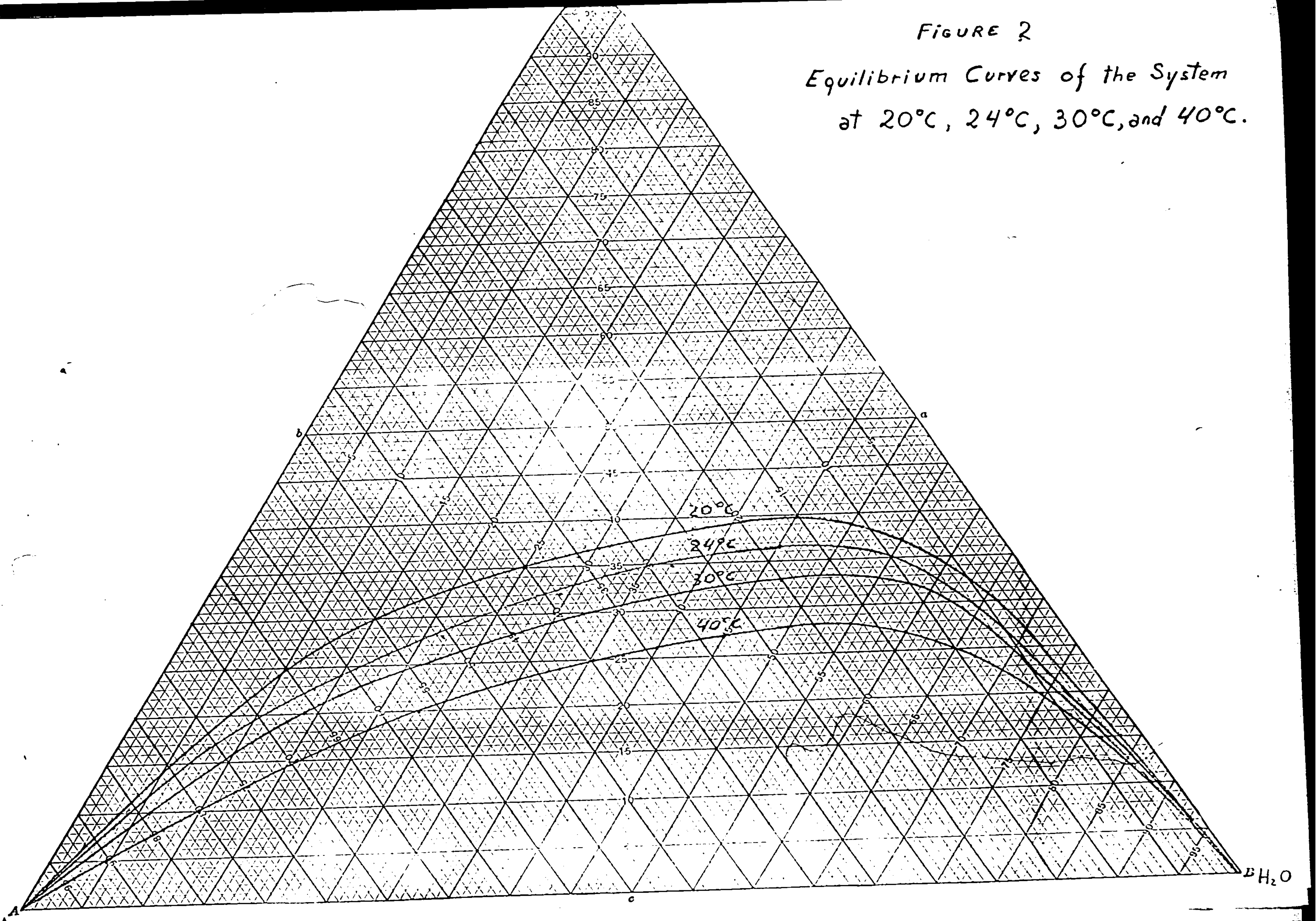


FIGURE 1
Description of Equilibrium Curves and Tie-Lines.

FIGURE 2

Equilibrium Curves of the System at 20°C, 24°C, 30°C, and 40°C.



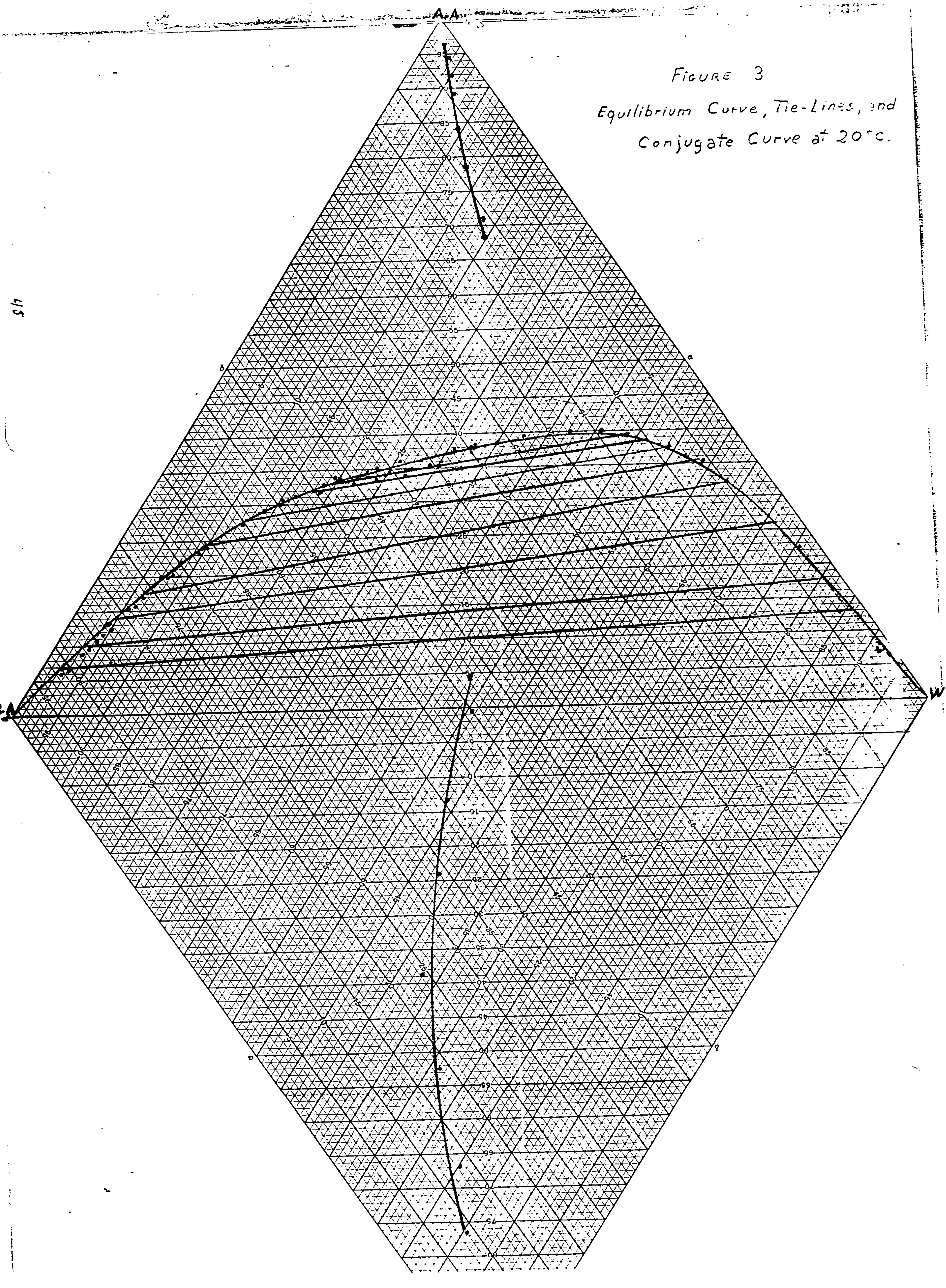
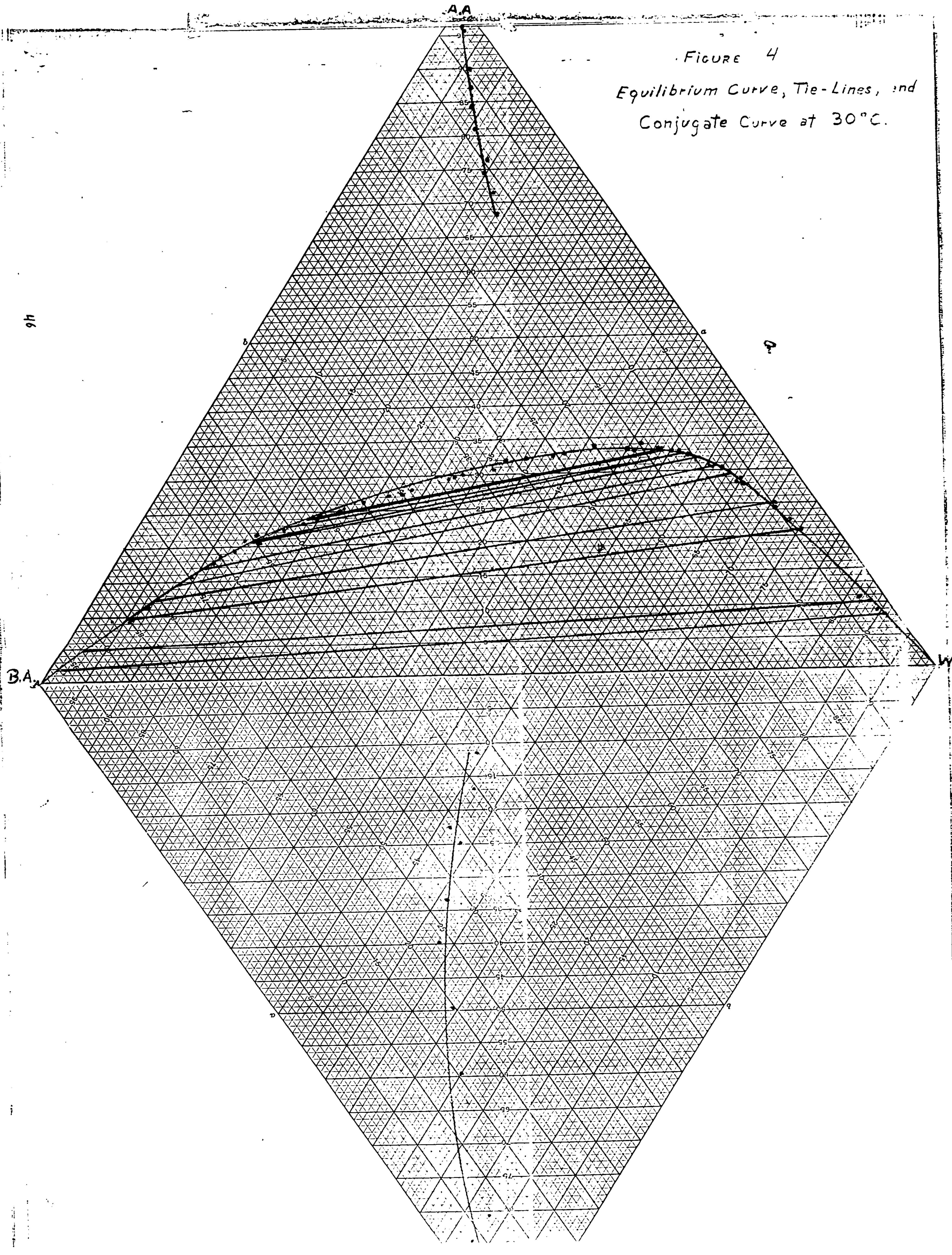


Figure 3

Equilibrium Curve, Tie-Lines, and Conjugate Curve at 20°c.

FIGURE 4

Equilibrium Curve, Tie-Lines, and Conjugate Curve at 30°C.



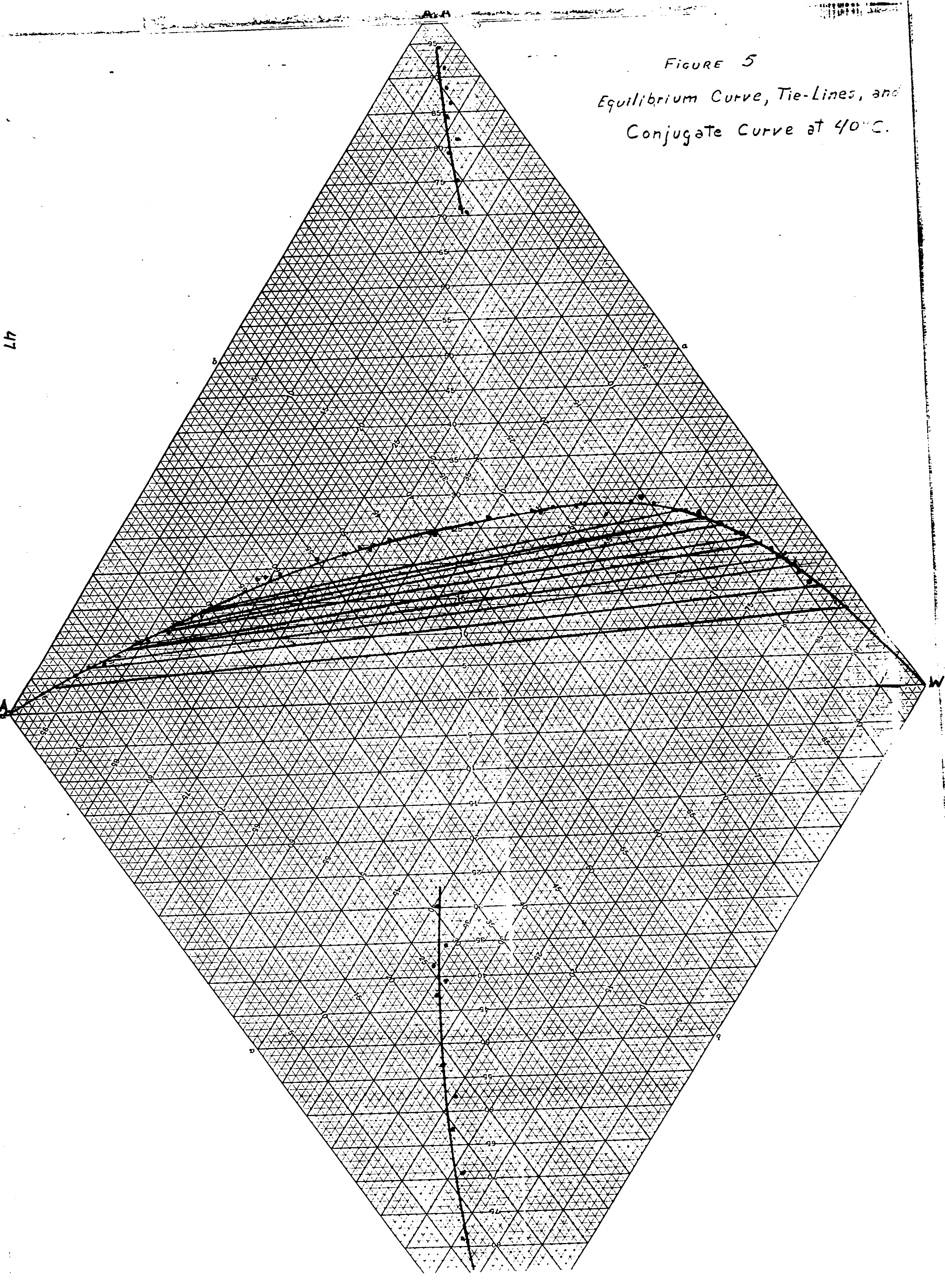


FIGURE 5

Equilibrium Curve, Tie-Lines, and Conjugate Curve at 40°C.

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Vita

The author was born in Viña del Mar, Chile, on April 23, 1939, the son of Mr. and Mrs. Martin Urrutia.

Upon graduation from Sagrados Corazones of Viña del Mar, Chile, in 1956, he enrolled at the Universidad Catolica de Valparaiso, Chile. He graduated from that University in 1963 with the degree of Ingeniero Quirnico.

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