

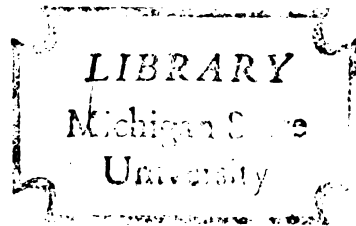


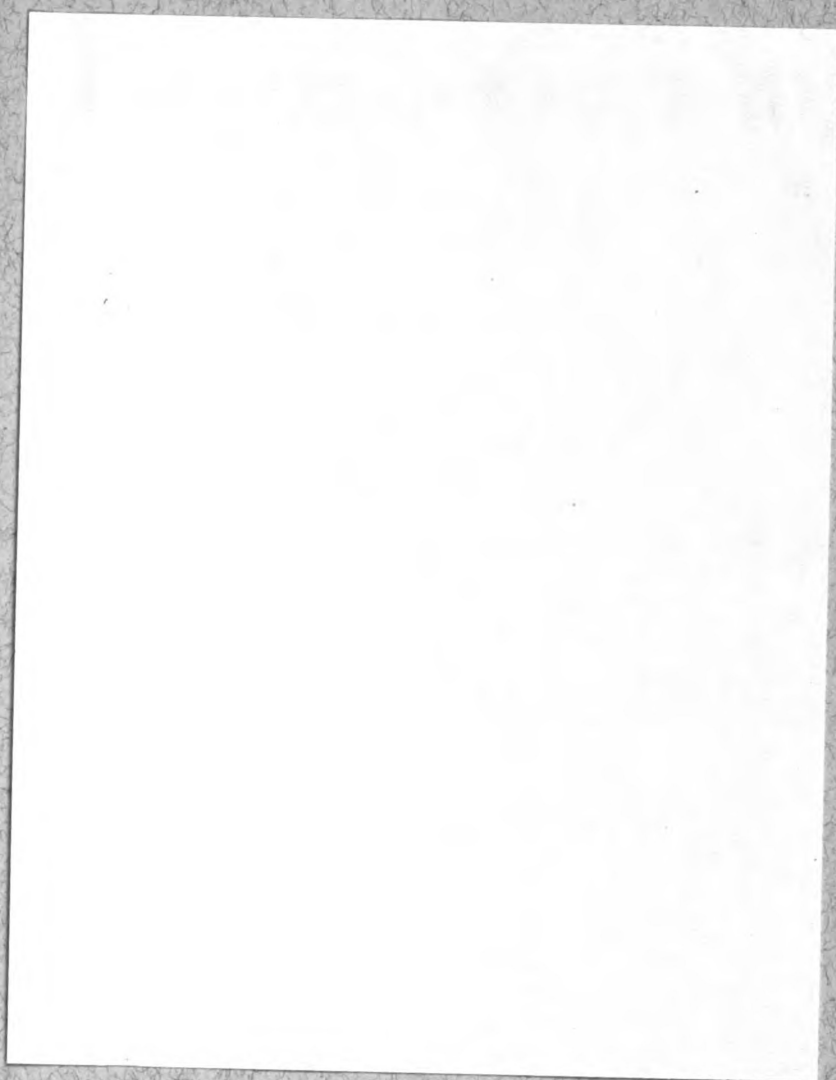
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SOME KINETIC STUDIES ON
THE CATALYTIC HYDROGENATION OF
MONO-ALKYLBENZENES
AT LOW AND HIGH PRESSURE WITH
PLATINUM OXIDE

Thesis for the Degree of M. S.
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SCHEMATIC STUDIES ON THE CATALYTIC HYDROGENATION OF
MONO-ALKYLBENZENES AT LOW AND HIGH PRESSURE WITH
PLATINUM OXIDE

By

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INTRODUCTION

INTRODUCTION

There being no recorded systematic comparison of the hydrogenation of the benzene nucleus at low and high pressure, the purpose of this work was to make such a study. The problem was approached with the belief that a quantitative comparison of velocity constants and apparent energies of activation of a series of compounds, at both high and low pressures, would give some insight into the mechanism of catalytic hydrogenation of aromatic compounds.

The compounds chosen were a homologous series of mono-alkylbenzenes. The solvent used was glacial acetic acid and the catalyst was Adam's platinum oxide catalyst. Hydrogenations were carried out at two different initial pressures. One series of reactions was conducted at an initial pressure of approximately four atmospheres and the other was conducted at approximately eighty atmospheres initial pressure.

HISTORY

HISTORY

The first recorded catalytic hydrogenation of an organic compound took place in 1863 when Debus (1) formed methylamine by passing the vapor of hydrocyanic acid, mixed with hydrogen, over platinum black. The scattered instances of catalytic hydrogenations of organic substances in the following three decades are of minor importance.

In 1897, hydrogenation began to be recognized as one of the major methods of chemical technique, as the result of the exhaustive researches of Sabatier and his associates. This work is described in condensed form in La Catalyse en Chimie Organique (2) and is essentially based on the discovery of the remarkable activity of nickel as a hydrogenation catalyst. The process of passing the vapor of an unsaturated and hydrogen over nickel is known as the method of Sabatier and Senderens. The great value of Sabatier's researches was the demonstration that almost any vaporisable organic compound capable of reduction could be catalytically hydrogenated in the vapor phase, given appropriate temperature conditions and a suitable catalyst.

A second process, developed in 1903, involved the reaction of hydrogen at one to five atmospheres pressure with a solution in which the catalyst and hydrogen were agitated. This method became particularly useful with the development of colloidal platinum, platinum black (2), and platinum oxide or Adams' catalyst (3).

A third process, introduced by Ipatieff in 1904, involved the reaction of hydrogen at high temperatures under pressures of 100 to 300

atmospheres in a heavy steel reaction vessel with the compound in the liquid phase (4).

Few systematic studies of the effect of hydrogen pressure on hydrogenation at solid catalytic surfaces were conducted previous to the studies of Armstrong and Hilditch (5). These workers found that the velocity of hydrogenation is directly proportional to the hydrogen pressure in the absence of disturbing factors. Among these factors may be included slow-acting permanent catalyst poisons, preferential adsorption of gaseous impurities at the catalyst surface, and the presence of a compound containing a functional group not susceptible to hydrogenation but having an affinity for the catalyst surface. It is factors such as these that explain the instances in which earlier workers have found curves suggestive of other than linear hydrogenation time curves.

The use of platinum oxide as a catalyst for the hydrogenation of the benzene nucleus at low pressure and moderate temperatures was in rather general use by 1928. At this time, Adams and Marshall (6) studied the hydrogenation of a number of phenyl substituted compounds in a qualitative manner. Their results indicated increased difficulty of hydrogenation with increasing molecular complexity. Hilton A. Smith and co-workers (7), (8), (9) made a quantitative study, in 1945, of the effect of structure on the hydrogenation of the benzene nucleus with Adams catalyst at low pressures. They showed that, under the experimental conditions employed, the rate of hydrogenation was first order with respect to the hydrogen pressure, zero order with respect

to the hydrogen acceptor, and directly proportional to the amount of catalyst used. Their results substantiated the fact that the hydrogenation rate decreased with increasing molecular complexity.

In 1947, Baker and Schmets (10), in the first recorded use of Adams catalyst by the Ipatieff high pressure method, hydrogenated several benzenoid compounds. They demonstrated that the hydrogenation followed essentially the same kinetics as at low pressure, although the time of hydrogenation was considerably less.

EXPERIMENTAL

EXPERIMENTAL

The reagents used in a study of the kinetics of a reaction catalysed by platinum oxide must necessarily be of high purity because of the poisoning effects of small amounts of foreign materials. The chemicals used in this work were:

Glacial acetic acid
Cyclohexene
Maleic acid
Platinum oxide catalyst
Raney nickel catalyst
Benzene
Toluene
Ethylbenzene
Isopropylbenzene
tert-Butylbenzene
n-Amylbenzene

Maleic acid, Pfanstiehl C. P. grade, was recrystallised twice from hot water. The melting point of the recrystallised material was 130-131° C.

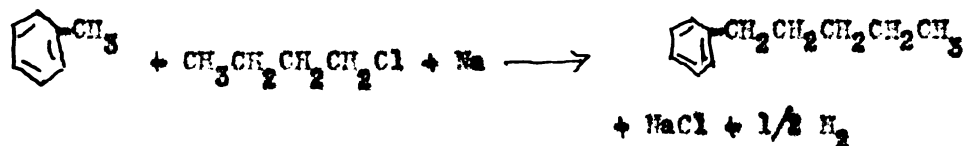
The platinum oxide catalyst used was obtained from two sources. One batch was procured from the American Platinum Works. The other platinum oxide sample used in this investigation was prepared from Chloroplatinic acid by the method of Adams, Voorhees, and Shriner (11). In a 400 ml. beaker, 20 grams of approximately 10% chloroplatinic acid, 10 ml. water, and 40 grams of sodium nitrate were placed. The beaker was supported on a wire screen and the mixture was evaporated to dryness over a mild Bunsen flame with stirring. The temperature was then raised and fusion took place, after which the temperature was gradually raised to the maximum heat output of the Bunsen flame. When the vigorous

evolution of nitric oxides had ceased, as indicated by the disappearance of brown colored fumes, the mixture was digested at maximum heat for an additional 30 minutes. After allowing the digested mass to cool to room temperature, it was treated with 200 ml. water to dissolve the soluble sodium salts. The insoluble brown platinum oxide was filtered and dried in an oven at 108° C. for eight hours. A second quantity of the platinum oxide catalyst was prepared according to the procedure described above. The total yield of platinum oxide obtained in these two preparations amounted to 7 grams.

The Raney nickel catalyst was prepared from a nickel-aluminum alloy, procured from the Central Scientific Company, by the method of Pavlic and Addins (12). In a two-necked three-liter flask equipped with a stirrer and thermometer, 128 grams of sodium hydroxide and 600 ml. of water were placed. The flask was immersed in cold running water and 100 grams of the alloy were added in small portions to the rapidly stirred solution. The temperature was maintained at 50° C. After the addition of the alloy was complete, the suspension was digested for one hour on a water bath at 50° C. The suspension of nickel catalyst was washed by decantation with water about twenty times to remove all alkali and water soluble salts. The resulting finely divided nickel was transferred to a 250 ml. centrifuge tube and washed three times by stirring with 95% ethanol centrifuging after each addition of alcohol. The same procedure was followed with absolute ethanol to remove the last of the water from the catalyst. The product was then stored under absolute ethanol.

Benzene, ethylbenzene, isopropylbenzene, and tert-butylbenzene were obtained as the best grade Eastman chemicals. All of the above mono-alkylbenzenes except isopropylbenzene could be used for kinetic studies after fractionation in a 60 cm., 15 mm. bore column packed with 1/8 inch glass helices. The isopropylbenzene had to be refluxed over Raney nickel for 24 hours and then refractionated. In all cases, middle cuts were used in the hydrogenations. Toluene, reagent grade, was purified by extracting one liter three times with 80 ml. portions of concentrated sulfuric acid according to the method of Fieser (13). The extracted toluene was then washed with water, refluxed for 24 hours over sodium followed by reflux for an additional 24 hours over Raney nickel, followed by fractionation in the column described above.

The *n*-amylbenzene was synthesized by following Horton's modification of the Wurtz-Fittig synthesis (14).



A suspension of 400 grams of sodium sand was prepared by heating sodium metal in one liter of toluene contained in a three-liter, three-necked flask, equipped with a Hershberg stirrer and thermometer. The sodium sand was formed by vigorous stirring of the sodium with toluene at 100° C. After the sand was formed, the suspension of sodium in toluene was stirred and cooled to 70-75° C. and 420 grams of n-butyl chloride were added over a period of two hours. Stirring was continued two hours

after the addition of the alkyl halide was completed. The reaction mixture was then extracted with ether, the ether removed on a steam bath, and the product fractionated in the column previously described. The fraction of n-amylbenzene collected distilled at 201-203° C. at atmospheric pressure. The yield was 107 grams or 16% of the theoretical based on the n-butyl chloride.

Cyclohexene, Eastman practical grade, and glacial acetic acid, Baker's C.P. grade, were found suitable for use after distillation.

The experimental boiling points, corrected to 760 mm. by means of Trouton's Rule and the Clausius-Clapeyron equation, as well as the reported boiling points (15) of the liquid compounds used in this work are recorded in Table I.

TABLE I

Compound	Corrected B.P.	Recorded B. P.
Benzene	80	80
Toluene	110	111
Ethylbenzene	134	136
Isopropylbenzene	151	152
<u>tert</u> -Butylbenzene	168	169
<u>n</u> -Amylbenzene	203	205
Acetic acid	118	118
Cyclohexene	83	83

Low Pressure Hydrogenations

The six monoalkylbenzenes hydrogenated were benzene, toluene, ethylbenzene, isopropylbenzene, tert-butylbenzene, and n-amylbenzene. Each

compound was hydrogenated at four different temperatures, namely; 35°, 45°, 55°, and 65° C.

A standard Parr low pressure apparatus was used for these hydrogenations. The accompanying pressure gauge was graduated in pounds per square inch from which the pressure readings were estimated to the nearest tenth of a pound. The reaction flask, of heavy walled Pyrex glass, was filled with a directly inserted thermometer and a heating jacket controlled by a variac. The temperature control during a hydrogenation was maintained constant with a variation of $\pm 0.5^\circ$ C.

The volume or hydrogen void of the apparatus was determined by hydrogenating an acetic acid solution of maleic acid (Table 1, Appendix). Assuming a quantitative hydrogenation of the olefinic double bond and using the ideal gas law, the hydrogen void was calculated to be 4.35 liters. The value for the void was rechecked by hydrogenating cyclohexene and again calculated to be 4.35 liters (Table 2, Appendix).

Each alkylbenzene hydrogenation was carried out employing a mixture of approximately 0.05 mole of the compound to be hydrogenated, 0.2 gram of platinum oxide catalyst, and 10 ml. of glacial acetic acid solvent at an initial hydrogen pressure of 64.4 pounds per square inch. The procedure used during each hydrogenation was as follows. The reaction flask containing the measured quantities of hydrogen acceptor, catalyst, and solvent was fastened to the apparatus whereupon it was flushed out three times with hydrogen. The flask was then heated to the appropriate temperature and adjusted to the desired initial hydrogen

pressure. When this was completed shaking was started and at the end of definite time intervals corresponding pressure readings were taken.

At the outset of the work, some difficulty was encountered because of unexpected deviations from linear hydrogen-time curves (Tables 3, 4, and 5, Appendix). The difficulty was found to be caused by the use of too large an amount of glacial acetic acid solvent, 50 ml. Apparently, not the rate of hydrogenation but the rate of diffusion through the solvent was being measured. When the quantity of solvent was reduced to 10 ml., the expected first order curves were obtained. The records of subsequent low pressure hydrogenations are summarized in Tables 6-29 (Appendix).

High Pressure Hydrogenations

The standard Parr high pressure apparatus was used for the hydrogenations. All the runs were made with a bomb of 60 ml. void and a 20 ml. glass liner. The accompanying pressure gauge was graduated in 10 pounds per square inch units and was read as such. The temperature was controlled by the standard attached heater and was measured by a thermocouple attachment. The temperature during a hydrogenation was maintained constant with a variation of $\pm 1^{\circ}$ C.

The volume or hydrogen void of the apparatus was determined by hydrogenating an acetic acid solution of cyclohexene (Table 30, Appendix). Assuming quantitative hydrogenation of the olefinic double bond and using the ideal gas law, the hydrogen void was calculated to be 65 ml.

Each alkylbenzene hydrogenation was carried out on a mixture of approximately 0.025 mole of hydrogen acceptor, 5 cc. of glacial acetic

acid, and 0.1 gram of platinum oxide at an initial hydrogen pressure of 1200 pounds per square inch. Thus the ratio of moles of hydrogen acceptor to grams of catalyst was approximately 0.25, the same ratio as in the low pressure hydrogenations.

The procedure used during each hydrogenation was as follows. The liner containing the measured amounts of hydrogen acceptor, solvent, and catalyst was placed in the bomb which was sealed and attached to the shaker. The bomb was then heated to the desired temperature at which time the initial hydrogen pressure was adjusted to 1200 pounds per square inch. Shaking was started and corresponding readings of time and pressure were taken as in the work on low pressure hydrogenations. The data on these hydrogenations at three different temperatures for each compound are summarized in Tables 31-48 (Appendix).

It should be noted here that different batches of catalyst were used for the low and high pressure hydrogenations. The platinum oxide procured from the American Platinum Works was used for the low pressure runs and the prepared platinum oxide for the high pressure runs. Since the activity of separate batches of catalyst differs, it would have been preferable to use only one catalyst batch. However, as is indicated by Table II, the apparent activation energies of the monoalkylbenzenes, and presumably of any hydrogen acceptor, vary with the particular catalyst used. Table II indicates also that the relative apparent activation energy values of the monoalkylbenzenes, i.e., the position of one compound in the series in the order of increasing apparent activation

energies, do not change. Therefore, by comparing the activation energies of one or more compounds hydrogenated over two different samples of catalyst, all values are referred to a single catalyst batch.

TABLE II
APPARENT ACTIVATION ENERGY CAL./MOLE

Compound	Cat. A	Cat. B
Ethylbenzene	4900 ^a	2700 ^c
Toluene	3600 ^b	1800 ^d

a Data in Tables 14-17 (Appendix)

b " " " 10-13 "

c " " " 49-51 "

d " " " 52-54 "

CALCULATIONS AND RESULTS

CALCULATIONS AND RESULTS

It has been demonstrated in this and other (7), (8), (9) studies that the hydrogenation of benzene derivatives over platinum oxide in glacial acetic acid solvent is first order with respect to the hydrogen pressure, zero order with respect to the concentration of the hydrogen acceptor, and directly proportional to the amount of catalyst used. It has also been shown that in the kinetic study of heterogeneous reactions, the rate constants depend on the volume of the gaseous system used (16). Therefore, the rate of the reaction for a given amount of catalyst can be expressed by the equation

$$\frac{-dP_{H_2}}{dt} = \frac{k}{V} P_{H_2}$$

which, when integrated and converted from natural logarithms to logarithms on the base ten, gives

$$\log \frac{P_{H_2}^0}{P_{H_2}} = \frac{kt}{2.303V}$$

where k is the velocity constant, t is the time, V is the hydrogen void, $P_{H_2}^0$ is the initial hydrogen pressure, and P_{H_2} is the hydrogen pressure at time, t .

Thus to calculate the values of k , the slopes of the lines obtained by plotting $\log P_{H_2}^0/P_{H_2}$ against t were multiplied by 2.303V. These constants, determined from different amounts of catalyst must then be referred to one gram of catalyst in order that all values may be comparable.

All the velocity constants determined in this manner are recorded in Table III. The plots used to calculate these rate constants are shown in Figures 1-14.

TABLE III

Compound	$k \times 10^3$ at 4 atm				$k \times 10^3$ at 80 atm ^g		
	35°	45°	55°	65°	37°	55°	70°
Benzene	94.6	108	124	140	9.18	12.2	14.6
Toluene	74.0	98.5	109	130	8.06	11.4 ^b	13.7
Ethylbenzene	80.4	102	128	161	10.7	12.3 ^c	13.6
Isopropylbenzene	59.3	74.0	83.2	115	7.13	9.02	10.1
Butylbenzene	41.4	57.5	74.9	94.0	5.55	6.69 ^c	7.36
n-Amylbenzene	60.5	67.9	81.0	98.5	7.58	8.44	10.2
Toluene ^a	59.5 ^d	63.6	70.0 ^e	---	---	---	---
Ethylbenzene ^a	81.0	103	---	137 ^f	---	---	---

a Compound was hydrogenated with same catalyst used at 80 atmospheres

b At 37° C.

c At 40° C.

d At 39° C.

e At 57° C.

f At 63° C.

g Values are corrected to sample of catalyst used at 4 atmospheres

Since the rate constants for each compound, at both high and low pressures were determined at several temperatures, an apparent activation energy can be calculated from the Arrhenius equation

$$k = Ae^{-E/RT}$$

where E is the apparent activation energy, T is the absolute temperature, R is the gas constant, and A is the Arrhenius frequency factor. This equation may also be represented as

$$\log k = - \frac{E}{2.303 RT} + \log A$$

Thus, a plot of $\log k$ versus $1/T$ should result in a straight line whose slope when multiplied by $2.303 R$ is the apparent activation energy. These plots are shown in Figures I and II, for low and high pressure, respectively. Once the apparent activation energy has been determined, the frequency factor, A , can be obtained by resubstitution in the Arrhenius equation.

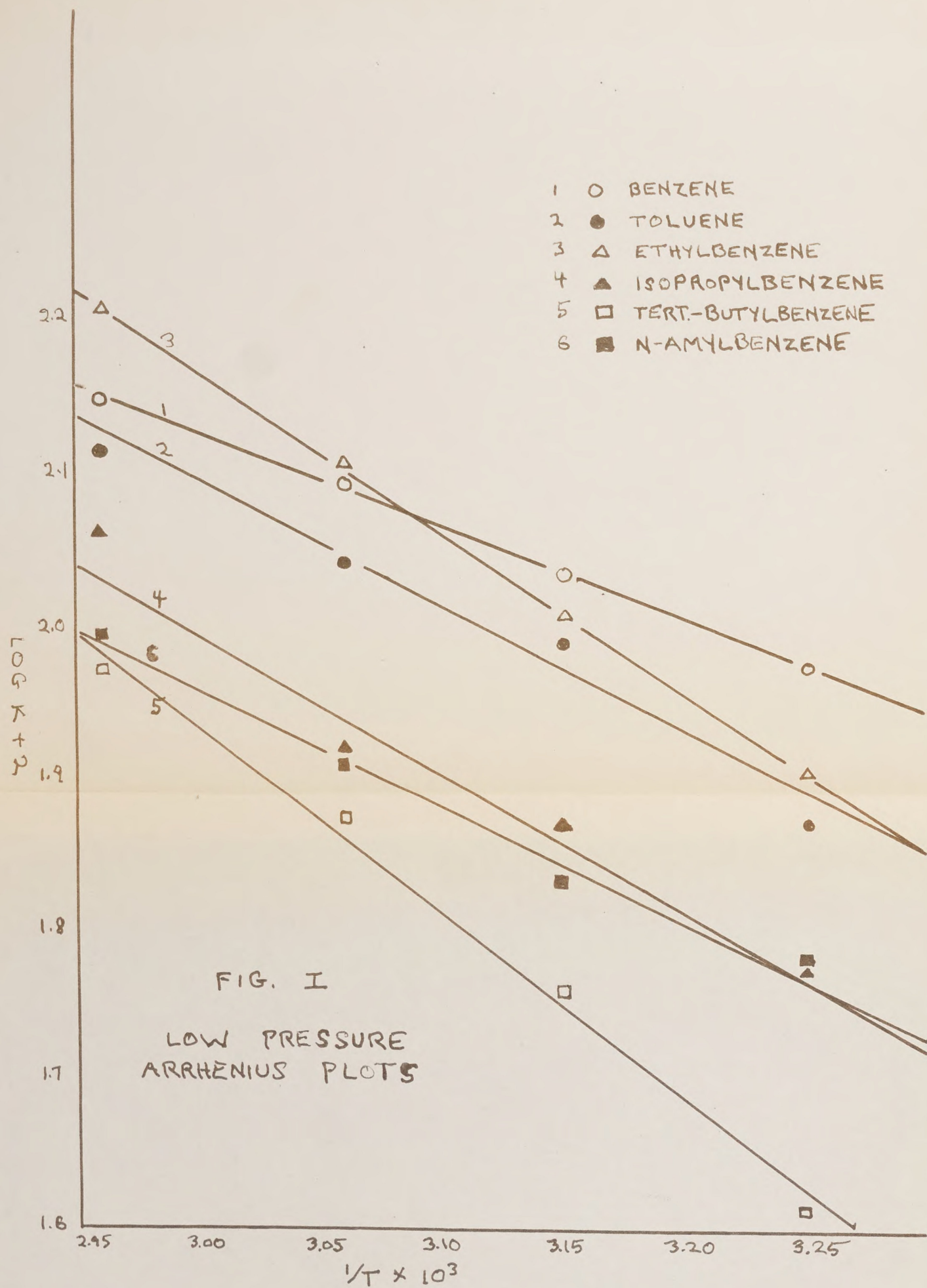
The values shown for both the apparent activation energies and the frequency factors were checked by calculating them by the method of averages (17) and are found to be quite accurate, the mean deviation being less than 3% in all cases. These values are listed in Table IV.

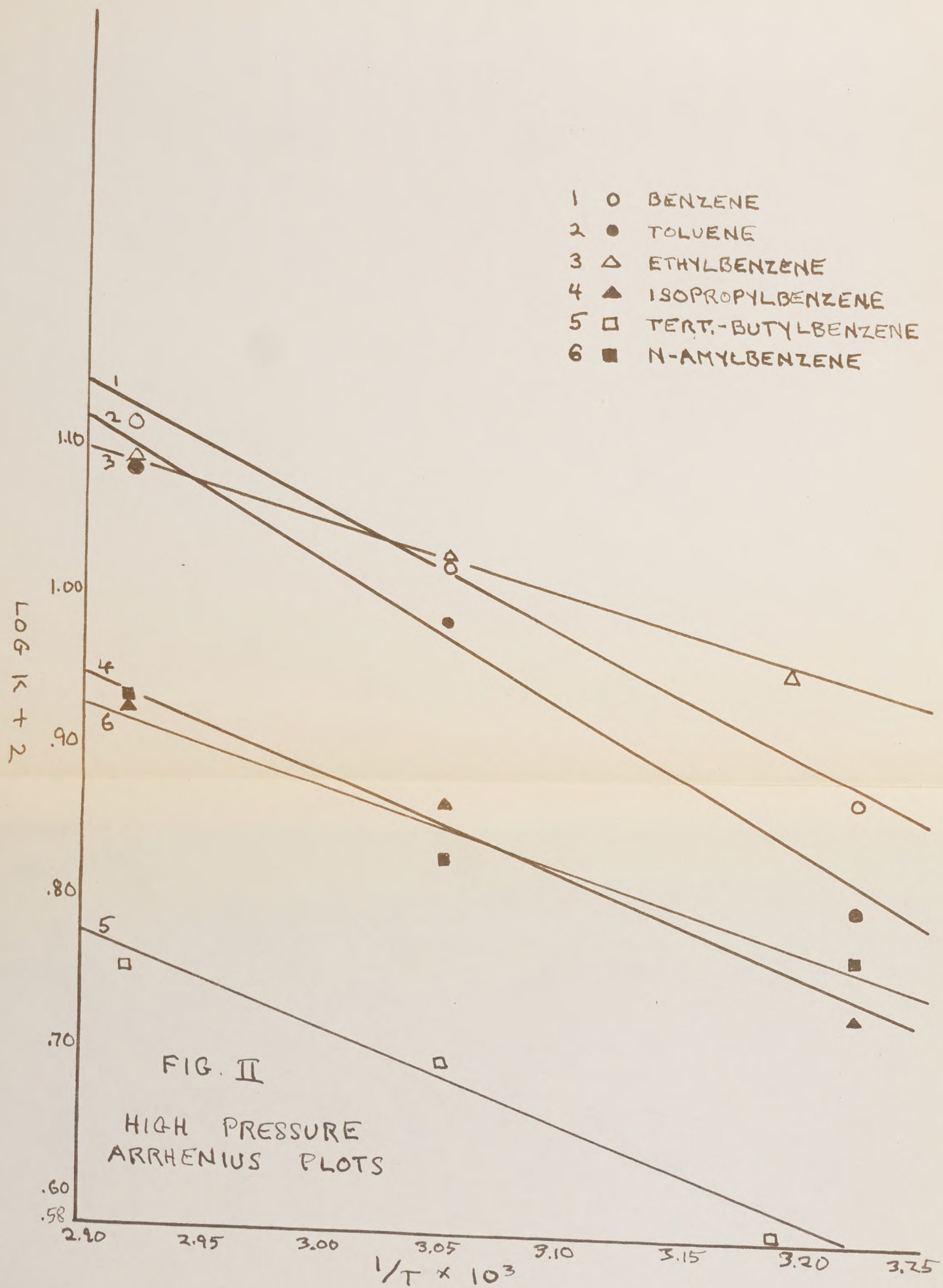
TABLE IV

Compound	4 Atmospheres		80 Atmospheres	
	$\frac{\text{g Cal.}}{\text{Mole}}$	Log A	$\frac{\text{g Cal.}}{\text{Mole}}$	Log A ^a
Benzene	2800	0.99	7000	2.92
Toluene	3600	1.43	8400	3.61
Ethylbenzene	4900	2.41	3900	0.88
Isopropylbenzene	4200	1.74	5600	1.82
t-Butylbenzene	5800	2.74	5500	1.59
n-Propylbenzene	3600	1.29	4800	1.25
Toluene ^b	1600	---	---	---
Ethylbenzene ^b	2800	---	---	---

a Values corrected to the same batch of catalyst
used at 4 atmospheres

b Hydrogenated over the same batch of catalyst
used at 80 atmospheres





DISCUSSION

DISCUSSION

An interesting observation may be made using the apparent activation energies shown in Table II. The results obtained in this investigation indicate that the apparent activation energies of the compounds studied vary with the particular sample of platinum oxide catalyst used, and that these variations can be of a considerable magnitude. The theoretical basis behind this observation depends on the fact that the energy of activation of a surface catalyzed reaction may be composed of several factors. If we assume with Hinshelwood (18) that the rate determining step in a surface reaction is a simultaneous reaction on and desorption from the surface, then the magnitude of E will depend on the energy of reaction and the energy of desorption, both surface dependent factors. Adsorption based on the active center theory of a catalytic surface proposed by H. S. Taylor (19) and extended by A. A. Balandin (20) would account for the changing values of E with different catalyst samples. The variation would be due to the difference in active center spacing in different catalyst samples.

Nevertheless, there are many instances in the literature where experimenters compare apparent energies of activation without referring the values to a single catalyst batch. In addition, there has been a tendency to regard individual values of apparent activation energies as accurate in the absolute sense. As recently as 1949, Smith and Maricwether (21) suggest, on the basis of such absolute values, that in the following reaction path for the hydrogenation of benzene, the first

step is rate determining. Data on the heats of hydrogenation show



that the energy of reaction for this step is 5600 calories per mole from which it follows that the energy of activation of benzene cannot be less than this value, catalytically or otherwise. Smith and Moriwether then indicate how remarkably close their values for E are to 5600 calories per mole. Yet, the value determined in the present work for the apparent energy of activation of benzene hydrogenation with a different catalyst sample is 2800 calories per mole.

Turning to a consideration of Table III, it is seen that the velocity constants decrease by a factor of ten when the hydrogen pressure is raised from four to eighty atmospheres initial pressure. This decrease is in accordance with the Evans-Polanyi transition state treatment of the effect of pressure on reaction velocity (22). They derive the equation

$$\frac{d \ln k}{dp} = \frac{(V_1 - V_T)}{RT}$$

where V_1 is the volume of reactants in solution and V_T is volume of the transition state complex. They indicate that in a reaction of the type $A + B \rightarrow AB$, of which hydrogenation is an example, V_T is much closer to the value of V_2 , the volume of the products, than it is to V_1 . Therefore, the above relation may be modified to give

$$\frac{d \ln k}{dp} = \frac{(V_1 - V_2)}{RT}$$

Since the density is inversely proportional to the volume, densities may be substituted in the above equation to give

$$\frac{d \ln k}{dp} = \frac{(d_2 - d_1)}{RT}$$

As can be seen from Table V, the difference in densities (23) gives a negative value for all the reactions studied, thus validating the experimental decrease in velocity constant with increasing pressure. Quantitative agreement is not to be expected, since the relation is an approximation.

TABLE V

Reactant and Product	d_1	d_2	$d_2 - d_1$
Benzene-Cyclohexane	.879	.779	-.100
Toluene-Methylcyclohexane	.866	.769	-.097
Ethylbenzene-Ethylcyclohexane	.867	.788	-.079
i-Propylbenzene-i-Propylcyclohexane	.862	.790	-.072
t-Butylbenzene-t-Butylcyclohexane	.867	.813	-.054
n-Amylbenzene-n-Amylcyclohexane	.858	.802	-.056

The variation of apparent activation energies at four atmospheres pressure with the structure of the alkylbenzene appears to be related to the molecular complexity of the compound. The decrease of the rate constant with molecular complexity has been noted by several workers (6),(7)

who, in general, ascribe this decrease in rate to steric factors. The apparent activation energy would be expected to be a better criterion of the influence of structure upon reactivity than is the velocity constant. The apparent activation energy values determined in this work show that steric factors cannot completely explain the relative rates of hydrogenation of the homologous series. For example, ethylbenzene has a much higher apparent activation energy than n-arylbenzene, isopropylbenzene has a lower apparent activation energy than ethylbenzene. These facts cannot be reconciled by steric effect alone. A better explanation can be made on the basis of electronic effects, although isopropylbenzene remains as a discrepancy.

The dipole moment being a measure of the electronic nature of a molecule, should show a relationship to the activation energy, if electronic effects are regarded as influencing reaction rate. Nathan and Watson (24) have proposed the expression

$$E = E_0 + 135 (\mu + 43\mu^2)$$

for functional group reactions of substituted benzenes. E_0 is the activation energy of the unsubstituted molecule, E is that of the substituted molecule, μ is the dipole moment in Debye units, and the constants are dependent upon the individual series studied. Applying the expression to the data of this work, relative apparent activation energies have been calculated and are compared to the experimental values in Table VI.

TABLE VI

Compound	Moment (25)	Exptl.	Calc.
Benzene	0.00 D	2800	2800
Toluene	0.57 D	3600	3600
Ethylbenzene	0.58 D	4200	4800
Isopropylbenzene	0.65 D	4200	5200
<u>tert</u> -Butylbenzene	0.70 D	5800	5900
<u>n</u> -Amylbenzene	0.4 D	3600	3600

The agreement between the experimental and calculated values is good with the one exception mentioned before, isopropylbenzene. No explanation can be advanced for the apparent activation energy of the latter compound on the basis of the present work or on any information available in the literature.

Next, the changes in activation energy with increase in pressure are to be considered. These values at 80 atmospheres are so random in their relation to one another that they appear to be incapable of explanation. In order that the relationship between the high and low pressure values may be better seen, they are listed in Table VII as ratios for the velocity constants and frequency factors and as differences for the apparent activation energies.

TABLE VII

Compound	k_{80}/k_4 @ 55° C.	$E_{80} - E_4$	Δ_{80}/Δ_4
Benzene	0.156	- 4200	85.1
Toluene	0.163	- 4800	151.
Ethylbenzene	0.152	- 1000	0.0295
Isopropylbenzene	0.163	- 1400	1.32
<u>tert</u> -Butylbenzene	0.123	- 300	0.0708
<u>n</u> -Amylbenzene	0.163	- 1200	0.912

The only conclusion that can be presently drawn is that a considerable change is produced in the apparent activation energies by the simple expedient of raising the initial pressure. Finally, the data in Table III indicates that the order of ease of hydrogenation of the mono-alkylbenzene as determined by the rate constant is essentially the same at both high and low initial hydrogen pressure.

SUMMARY

1. Rate constants, apparent energies of activation, and Arrhenius frequency factors have been determined for the catalytic hydrogenation of benzene and some of its mono-alkyl homologs over platinum oxide.
2. It has been shown that the apparent activation energy of the reaction varies with the particular catalyst sample used.
3. An explanation of the effect of molecular structure upon hydrogenation has been made.
4. The decrease of velocity constant with increasing pressure has been accounted for on the basis of the change in volume between reactants and products in chemical reactions.

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APPENDIX

HYDROCLIMATION TABLES

Table 1

Maleic Acid 0.0473 moles		Low Pressure 0.0595 g. PbO_2	
Time (Min.)	Temp. ($^{\circ}\text{C}.$)	Press. (P.S.I.)	$\text{Log } \frac{P_0}{P}$
0	32	60	.0000
16	32	58	.0141
31	33	57	.0220
65	33	57	.0220
100	33	56	.0298
135	33	56	.0298
165	33	56	.0298

Table 2

Cyclohexane 0.1428 moles		Low Pressure 0.1 g. PbO_2	
Time (Min.)	Temp. ($^{\circ}\text{C}.$)	Press. (P.S.I.)	$\text{Log } \frac{P_0}{P}$
0	28	64.4	---
5	28	60.4	---
17	28	52.7	---
20	28	52.6	---

Table 3

Benzene 0.0552 moles		Low Pressure 0.1141 g. PbO_2	
Time (Min.)	Temp. ($^{\circ}\text{C}.$)	Press. (P.S.I.)	$\text{Log } \frac{P_0}{P}$
0	35	64.4	.0000
5	36	63.0	.0090
10	36	62.1	.0154
26	34	60.5	.0265
40	34	60.2	.0294
57	35	60.1	.0298

Table 4

Benzene 0.0686 moles		Low Pressure 0.1213 g. PTO ₂	
Time (Min.)	25 ml. acetic acid		Log $\frac{P_0}{P}$
	Temp. (°C.)	Press. (P.S.I.)	
0	35	64.4	.0000
5	35	63.0	.0090
10	35	61.8	.0195
15	35	60.3	.0226
20	34	59.4	.0346
25	35	58.6	.0410
35	34	57.7	.0465
55	35	57.0	.0527

Table 5

Stylobenzene 0.0492 moles		Low Pressure 0.2037 g. PTO ₂	
Time (Min.)	50 ml. acetic acid		Log $\frac{P_0}{P}$
	Temp. (°C.)	Press. (P.S.I.)	
0	28	64.4	.0000
10	28	63.1	.0086
20	27	62.2	.0154
30	28	61.8	.0204
40	28	61.1	.0224
50	28	60.5	.0261

Table 6

Benzene 0.0550 moles		Low Pressure 0.1973 g. PTO ₂	
Time (Min.)	10 ml. acetic acid Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	35	64.4	.0000
6	35	62.7	.0116
11	35	61.4	.0208
15	35	60.3	.0286
20	35	59.1	.0374
30	35	56.5	.0555
37	35	55.0	.0682
45	35	53.4	.0813
50	35	53.4	.0813

Table 7

Benzene 0.0552 moles		Low Pressure 0.1950 g. PTO ₂	
Time (Min.)	10 ml. acetic acid Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	45	64.6	.0000
13	45	60.4	.0282
16	44	59.5	.0342
22	45	57.7	.0477
27	45	56.4	.0573
32	45	55.2	.0671
37	45	53.8	.0770
42	45	53.1	.0828
45	45	53.1	.0828

Table 8

Benzene 0.0557 moles		Low Pressure 0.2065 g. PbO_2	
Time (Min.)	Temp. ($^{\circ}\text{C}.$)	10 ml. acetic acid Press. (P.S.I.)	$\text{Log } \frac{P_0}{P}$
0	55	64.4	.0000
10	55	60.9	.0245
15	55	59.1	.0370
20	55	57.3	.0504
30	54	54.0	.0759
35	55	52.5	.0828
41	53	52.3	.0896

Table 9

Benzene 0.0555 moles		Low Pressure 0.2088 g. PbO_2	
Time (Min.)	Temp. ($^{\circ}\text{C}.$)	10 ml. acetic acid Press. (P.S.I.)	$\text{Log } \frac{P_0}{P}$
0	65	65.2	.0000
5	65	63.3	.0133
10	64	61.3	.0268
15	65	59.3	.0414
25	65	55.4	.0712
30	65	53.2	.0825
35	61	52.8	.0910

Table 10

Toluene 0.0554 moles		Low Pressure 0.2095 g. PTO_2	
Time (Min.)	10 ml. acetic acid Temp. ($^{\circ}\text{C}.$)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	35	64.5	.0000
10	35	62.2	.0158
15	35	61.0	.0249
20	35	60.0	.0310
35	35	58.8	.0542
45	35	58.0	.0689
55	35	57.3	.0724
64	34	52.1	.0927
66	32	52.1	.0927

Table 11

Toluene 0.0549 moles		Low Pressure 0.1967 g. PTO_2	
Time (Min.)	10 ml. acetic acid Temp. ($^{\circ}\text{C}.$)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	45	64.4	.0000
5	45	62.9	.0095
10	45	61.5	.0199
15	44	60.2	.0290
32	45	55.7	.0622
40	45	53.5	.0799
45	43	52.2	.0906
47	43	52.1	.0910

Table 12

Toluene 0.0664 moles		Low Pressure 0.1988 g. PTO_2	
Time (min.)	10 ml. acetic acid		$\text{Log } \frac{P_0}{P}$
	Temp. ($^{\circ}\text{C}.$)	Press. (P.S.I.)	
0	55	64.4	.0000
5	56	62.7	.0107
10	55	61.3	.0212
15	53	59.6	.0326
25	55	56.7	.0554
40	55	52.6	.0871
49	53	51.8	.0938

Table 13

Toluene 0.0630 moles		Low Pressure 0.2021 g. PTO_2	
Time (min.)	10 ml. acetic acid		$\text{Log } \frac{P_0}{P}$
	Temp. ($^{\circ}\text{C}.$)	Press. (P.S.I.)	
0	65	64.4	.0000
5	65	62.6	.0120
16	65	59.0	.0378
20	66	56.7	.0546
30	64	53.4	.0810
40	65	51.5	.0966
43	64	51.3	.0980

Table 14

Ethylbenzene 0.0459 moles		Low Pressure 0.2067 g. PTO ₂	
Time (Min.)	10 ml. acetic acid Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	35	64.6	.0000
5	35	63.3	.0078
15	35	60.8	.0245
20	35	59.6	.0330
30	35	57.4	.0498
35	35	56.4	.0573
40	35	55.4	.0648
45	35	54.5	.0719
50	35	53.7	.0788
55	35	53.6	.0792

Table 15

Ethylbenzene 0.0473 moles		Low Pressure 0.2073 g. PTO ₂	
Time (Min.)	10 ml. acetic acid Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	45	64.4	.0000
5	45	63.0	.0095
15	45	59.7	.0326
20	45	58.3	.0426
30	45	55.5	.0641
35	45	54.3	.0734
38	45	53.6	.0792
40	45	53.3	.0821

Table 16

Ethylbenzene 0.0520 moles		Low Pressure 0.2064 g. PTO ₂	
Time (Min.)	Temp. (°C.)	10 ml. acetic acid Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	55	64.4	.0000
5	55	62.5	.0128
10	54	60.6	.0257
20	55	57.0	.0527
25	55	55.3	.0652
30	56	53.5	.0799
35	55	52.4	.0898
36	52	52.3	.0899

Table 17

Ethylbenzene 0.0478 moles		Low Pressure 0.2110 g. PTO ₂	
Time (Min.)	Temp. (°C.)	10 ml. acetic acid Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	65	64.4	.0000
6	65	61.5	.0199
10	65	59.5	.0338
15	65	57.2	.0508
20	65	55.2	.0663
25	65	53.1	.0831
31	61	52.9	.0857

Table 18

i-Propylbenzene 0.0427 moles		Low Pressure 0.2013 g. PTO ₂	
Time (Min.)	10 ml. acetic acid		Log $\frac{P_0}{P}$
	Temp. (°C.)	Press. (P.S.I.)	
0	38	64.4	.0000
5	36	63.4	.0065
15	36	61.6	.0183
25	34	60.0	.0308
36	36	58.2	.0438
43	36	57.2	.0512
53	36	55.7	.0626
60	36	55.1	.0674
66	34	54.6	.0712

Table 19

i-Propylbenzene 0.0464 moles		Low Pressure 0.1975 g. PTO ₂	
Time (Min.)	10 ml. acetic acid		Log $\frac{P_0}{P}$
	Temp. (°C.)	Press. (P.S.I.)	
0	45	64.4	.0000
5	45	63.2	.0078
10	44	62.2	.0149
20	45	60.2	.0290
31	44	57.9	.0457
41	45	56.0	.0603
50	45	54.8	.0697
58	45	53.7	.0788
63	45	53.4	.0810

Table 20

1-Propylbenzene 0.0467 moles		Low Pressure 0.2045 g. PTO ₂	
Time (Min.)	Temp. (°C.)	10 ml. acetic acid	
		Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	55	64.4	.0000
5	55	63.1	.0082
16	54	60.4	.0245
20	55	59.5	.0338
35	55	56.2	.0584
45	55	54.1	.0748
50	55	53.3	.0821
55	52	53.8	.0821

Table 21

1-Propylbenzene 0.0465 moles		Low Pressure 0.2005 g. PTO ₂	
Time (Min.)	Temp. (°C.)	10 ml. acetic acid	
		Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	65	64.4	.0000
5	64	62.8	.0112
20	65	57.7	.0469
27	65	55.5	.0641
35	65	53.6	.0792
36	65	53.6	.0792

Table 22

t-Butylbenzene 0.0452 moles		Low Pressure 0.1988 g. PTC ₂	
Time (Min.)	Temp. (°C.)	10 ml. acetic acid Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	35	64.4	.0000
5	35	63.5	.0052
15	35	62.4	.0133
25	35	61.3	.0212
35	35	60.2	.0290
46	35	59.0	.0378

Table 23

t-Butylbenzene 0.0455 moles		Low Pressure 0.1994 g. PTC ₂	
Time (Min.)	Temp. (°C.)	10 ml. acetic acid Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	45	64.4	.0000
5	44	63.4	.0070
10	45	62.5	.0128
15	45	61.6	.0179
25	45	60.1	.0294
38	45	58.4	.0422
45	45	57.3	.0504
55	45	56.2	.0588
60	45	55.6	.0637

Table 24

t-Butylbenzene 0.0473 moles		Low Pressure 0.2000 g. PTO ₂	
Time (Min.)	Temp. (°C.)	10 ml. acetic acid Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	55	63.8	.0000
5	54	64.5	.0026
10	55	63.3	.0106
20	55	61.2	.0314
30	55	59.1	.0461
41	55	57.1	.0607
50	53	55.6	.0720
60	55	54.5	.0821

Table 25

t-Butylbenzene 0.0531 moles		Low Pressure 0.2044 g. PTO ₂	
Time (Min.)	Temp. (°C.)	10 ml. acetic acid Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	65	64.4	.0000
5	64	62.9	.0099
15	65	60.2	.0294
20	65	58.7	.0398
30	65	56.3	.0581
40	65	54.2	.0748
50	65	52.5	.0888
55	62	52.5	.0888

Table 26

n-Amylbenzene 0.0490 moles		Low Pressure 0.1997 g. P ₂ O ₅	
10 ml. acetic acid			
Time (Min.)	Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	35	64.9	.0000
5	36	63.9	.0070
10	35	63.0	.0128
15	35	62.1	.0183
25	35	60.4	.0310
43	35	57.4	.0531
50	35	56.3	.0611
62	35	54.5	.0756

Table 27

n-Amylbenzene 0.0483 moles		Low Pressure 0.2012 g. P ₂ O ₅	
10 ml. acetic acid			
Time (Min.)	Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	45	64.4	.0000
5	45	63.3	.0073
10	45	62.3	.0145
15	45	61.3	.0216
25	45	59.4	.0350
35	45	57.5	.0488
45	45	55.9	.0611
55	45	54.5	.0719
65	45	53.3	.0821

Table 28

n-Amylbenzene 0.0491 moles		Low Pressure 0.2051 g. PTC ₂	
10 ml. acetic acid			
Time (Min.)	Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	65	65.5	.0000
5	64	64.2	.0066
10	65	63.0	.0166
20	65	60.6	.0338
30	65	58.2	.0512
45	65	55.2	.0741
63	65	54.1	.0826
65	65	54.1	.0828

Table 29

n-Amylbenzene 0.0464 moles		Low Pressure 0.2028 g. PTC ₂	
10 ml. acetic acid			
Time (Min.)	Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	65	64.4	.0000
5	64	63.0	.0094
10	65	61.5	.0200
20	66	58.5	.0410
30	65	56.1	.0592
40	65	53.7	.0785
42	63	53.4	.0810
44	63	53.3	.0814

Table 30

Cyclohexene 0.0621 moles		High Pressure 0.1 g. PTO ₂	
4 ml. acetic acid			
Time (Min.)	Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	30	1200	.0000
5	30	1110	.0338
10	30	1050	.0577
20	30	910	.1202
36	30	850	.1498
55	30	810	.1706
76	30	810	.1706

Table 31

Benzene 0.0285 moles		High Pressure 0.1096 g. PTO ₂	
5 ml. acetic acid			
Time (Min.)	Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	37	1200	.0000
3	37	1140	.0216
6	37	1090	.0414
10	37	1030	.0660
15	37	960	.0969
20	37	890	.1300
25	36	830	.1608
30	38	780	.1872
38	38	700	.2345
45	38	670	.2531
47	38	670	.2531

Table 32

Benzene 0.0277 moles		High Pressure 0.1004 g. PTO_2	
Time (min.)	5 ml. acetic acid Temp. ($^{\circ}\text{C}.$)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	55	1200	.0000
3	56	1120	.0294
6	56	1070	.0492
10	55	980	.0881
16	55	890	.1300
20	55	830	.1608
25	55	770	.1929
35	53	680	.2470
38	54	680	.2470

Table 33

Benzene 0.0252 moles		High Pressure 0.1018 g. PTO_2	
Time (min.)	5 ml. acetic acid Temp. ($^{\circ}\text{C}.$)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	71	1200	.0000
4	71	1070	.0496
8	70	980	.0881
11	69	920	.1156
15	69	860	.1452
20	70	780	.1875
25	69	710	.2279
28	69	700	.2345

Table 34

Toluene 0.0286 moles		High Pressure 0.1010 g. PTO_2	
Time (Min.)	Temp. ($^{\circ}\text{C.}$)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	39	1200	.0000
3	39	1150	.0172
6	39	1100	.0374
12	39	1010	.0752
16	38	955	.0993
24	38	870	.1399
30	38	800	.1761
37	37	740	.2101
45	37	670	.2533
55	37	660	.2601

Table 35

Toluene 0.0261 moles		High Pressure 0.1009 g. PTO_2	
Time (Min.)	Temp. ($^{\circ}\text{C.}$)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	55	1200	.0000
3	55	1130	.0257
6	55	1070	.0492
10	54	970	.0835
15	55	920	.1156
25	56	770	.1929
30	55	710	.2279
33	54	690	.2403
35	54	690	.2403

Table 36

Toluene 0.0252 moles		High Pressure 0.1056 g. PTO_2	
Time (Min.)	5 ml. acetic acid Temp. ($^{\circ}\text{C}.$)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	70	1200	.0000
3	70	1100	.0374
6	69	1030	.0683
10	68	950	.1014
15	71	870	.1396
25	71	720	.2222
28	70	700	.2338
30	69	700	.2338

Table 37

Ethylbenzene 0.0249 moles		High Pressure 0.1091 g. PTO_2	
Time (Min.)	5 ml. acetic acid Temp. ($^{\circ}\text{C}.$)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	41	1200	.0000
3	41	1130	.0261
6	40	1070	.0492
10	40	1000	.0792
16	40	920	.1153
20	39	850	.1498
26	39	790	.1818
30	39	750	.2039
33	39	730	.2159
35	39	720	.2222
38	39	720	.2222

Table 38

Ethylbenzene 0.0249 moles		High Pressure 0.1045 g. PTO_2	
Time (Min)	Temp. ($^{\circ}\text{C}.$)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	55	1200	.0000
3	55	1130	.0257
6	55	1060	.0535
10	55	980	.0878
15	55	890	.1300
20	55	810	.1706
25	55	740	.2098
31	55	720	.2219
36	55	720	.2219

Table 39

Ethylbenzene 0.0246 moles		High Pressure 0.1055 g. PTO_2	
Time (Min.)	Temp. ($^{\circ}\text{C}.$)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	69	1200	.0000
3	69	1110	.0338
6	71	1040	.0615
10	71	950	.1011
15	72	860	.1446
20	71	780	.1875
25	70	720	.2219
27	70	710	.2276

Table 40

1-Propylbenzene 0.0225 moles		High Pressure 0.1009 g. PTO ₂	
Time (Min.)	Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	37	1200	.0000
5	37	1140	.0220
10	37	1080	.0457
16	37	1020	.0708
20	37	930	.0835
30	38	810	.1202
40	38	640	.1553
47	38	610	.1709
51	38	790	.1818
55	38	780	.1872

Table 41

1-Propylbenzene 0.0240 moles		High Pressure 0.1002 g. PTO ₂	
Time (Min.)	Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	55	1200	.0000
3	55	1140	.0218
8	54	1000	.0535
15	56	900	.0881
25	56	870	.1399
33	55	800	.1761
47	54	720	.2219
49	54	720	.2219

Table 42

1-Propylbenzene 0.0242 moles		High Pressure 0.1056 g. PTO ₂	
Time (Min.)	5 ml. acetic acid		Log $\frac{P_0}{P}$
	Temp. (°C.)	Press. (P.S.I.)	
0	71	1200	.0000
4	71	1100	.0374
10	70	1000	.0792
18	69	940	.1068
20	71	880	.1348
26	70	810	.1706
30	69	780	.1878
35	70	740	.2098

Table 43

t-Butylbenzene 0.0219 moles		High Pressure 0.0995 g. PTO ₂	
Time (Min.)	5 ml. acetic acid		Log $\frac{P_0}{P}$
	Temp. (°C.)	Press. (P.S.I.)	
0	37	1200	.0000
5	37	1140	.0216
10	37	1100	.0374
20	37	1020	.0860
30	43	960	.0969
41	43	890	.1300
50	42	840	.1550
61	40	810	.1706
68	40	800	.1761

Table 44

t-Butylbenzene 0.0233 moles		High Pressure 0.1073 g. PTC ₂	
Time (Min.)	Temp. (°C.)	5 ml. acetic acid Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	55	1200	.0000
3	55	1150	.0179
11	54	1060	.0538
15	53	1030	.0660
24	57	950	.1014
30	56	910	.1202
36	55	860	.1452
45	55	810	.1706
55	55	760	.1987
60	54	750	.2039
62	54	750	.2039

Table 45

t-Butylbenzene 0.0237 moles		High Pressure 0.1050 g. PTC ₂	
Time (Min.)	Temp. (°C.)	5 ml. acetic acid Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	70	1200	.0000
3	70	1150	.0179
8	70	1090	.0418
15	69	1030	.0663
25	71	960	.0969
35	69	900	.1248
45	70	850	.1498
55	69	800	.1761
65	70	760	.1987
73	71	740	.2098
77	71	740	.2098

Table 46

n-Amylbenzene 0.0224 moles		High Pressure 0.1070 g. P ₂ O ₅	
Time (Min.)	Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	37	1200	.0000
4	37	1140	.0216
9	37	1080	.0457
16	36	1010	.0752
22	36	940	.1065
30	37	860	.1452
35	37	820	.1662
45	36	780	.1872
48	37	780	.1872

Table 47

n-Amylbenzene 0.0224 moles		High Pressure 0.1072 g. P ₂ O ₅	
Time (Min.)	Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	55	1200	.0000
3	55	1140	.0216
7	55	1090	.0414
10	55	1050	.0577
18	57	950	.1014
25	55	870	.1399
32	54	800	.1761
37	55	770	.1929
40	55	770	.1929

Table 48

n-Amylbenzene 0.0230 moles		High Pressure 0.0998 g. PTO_2	
8 ml. acetic acid			
Time (Min.)	Temp. ($^{\circ}\text{C}.$)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	70	1200	.0000
3	70	1130	.0257
6	70	1080	.0457
10	71	1020	.0708
15	71	950	.1014
20	70	890	.1300
25	69	830	.1605
36	70	750	.2039
41	69	740	.2101

Table 49

Toluene 0.0475 moles		Low Pressure 0.2057 g. PTO_2	
10 ml. acetic acid			
Time (Min.)	Temp. ($^{\circ}\text{C}.$)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	39	64.4	.0000
5	39	63.2	.0082
10	39	62.2	.0154
20	39	60.5	.0278
30	39	59.2	.0370
40	39	57.7	.0481
56	39	55.7	.0630
60	39	55.3	.0656

Table 50

Toluene 0.0554 moles		Low Pressure 0.2075 g. PTO ₂	
10 ml. acetic acid			
Time (Min.)	Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	48	64.4	.0000
5	44	63.2	.0082
10	46	62.1	.0158
20	46	60.3	.0286
30	45	58.5	.0414
46	45	56.1	.0596
56	45	54.4	.0726
66	45	53.0	.0839
75	45	51.6	.0959
83	43	51.3	.0923

Table 51

Toluene 0.0507 moles		Low Pressure 0.2074 g. PTO ₂	
10 ml. acetic acid			
Time (Min.)	Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	58	64.4	.0000
5	57	63.0	.0095
10	56	62.0	.0162
20	58	60.1	.0298
31	57	58.0	.0453
40	57	56.4	.0577
50	57	64.4	.0726
63	56	52.3	.0899
65	55	52.3	.0899

Table 52

Ethylbenzene 0.0403 moles		Low Pressure 0.2006 g. PTO ₂	
Time (Min.)	10 ml. acetic acid Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	35	64.4	.0000
5	36	63.3	.0073
10	35	62.3	.0141
20	35	59.9	.0322
40	35	55.3	.0556
60	32	54.5	.0726

Table 53

Ethylbenzene 0.0473 moles		Low Pressure 0.2137 g. PTO ₂	
Time (Min.)	10 ml. HAc Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	45	64.4	.0000
5	46	62.8	.0112
10	46	61.1	.0224
20	45	57.9	.0461
30	44	55.4	.0652
42	44	52.6	.0878
52	40	52.6	.0878

Table 54

Ethylbenzene 0.0547 moles		Low Pressure 0.2035 g. PTO ₂	
Time (Min.)	10 ml. HAc Temp. (°C.)	Press. (P.S.I.)	Log $\frac{P_0}{P}$
0	63	64.4	.0000
5	63	62.2	.0158
10	63	59.7	.0330
20	63	55.7	.0630
31	64	52.4	.0896

HYDROXYMATION GRAPHS

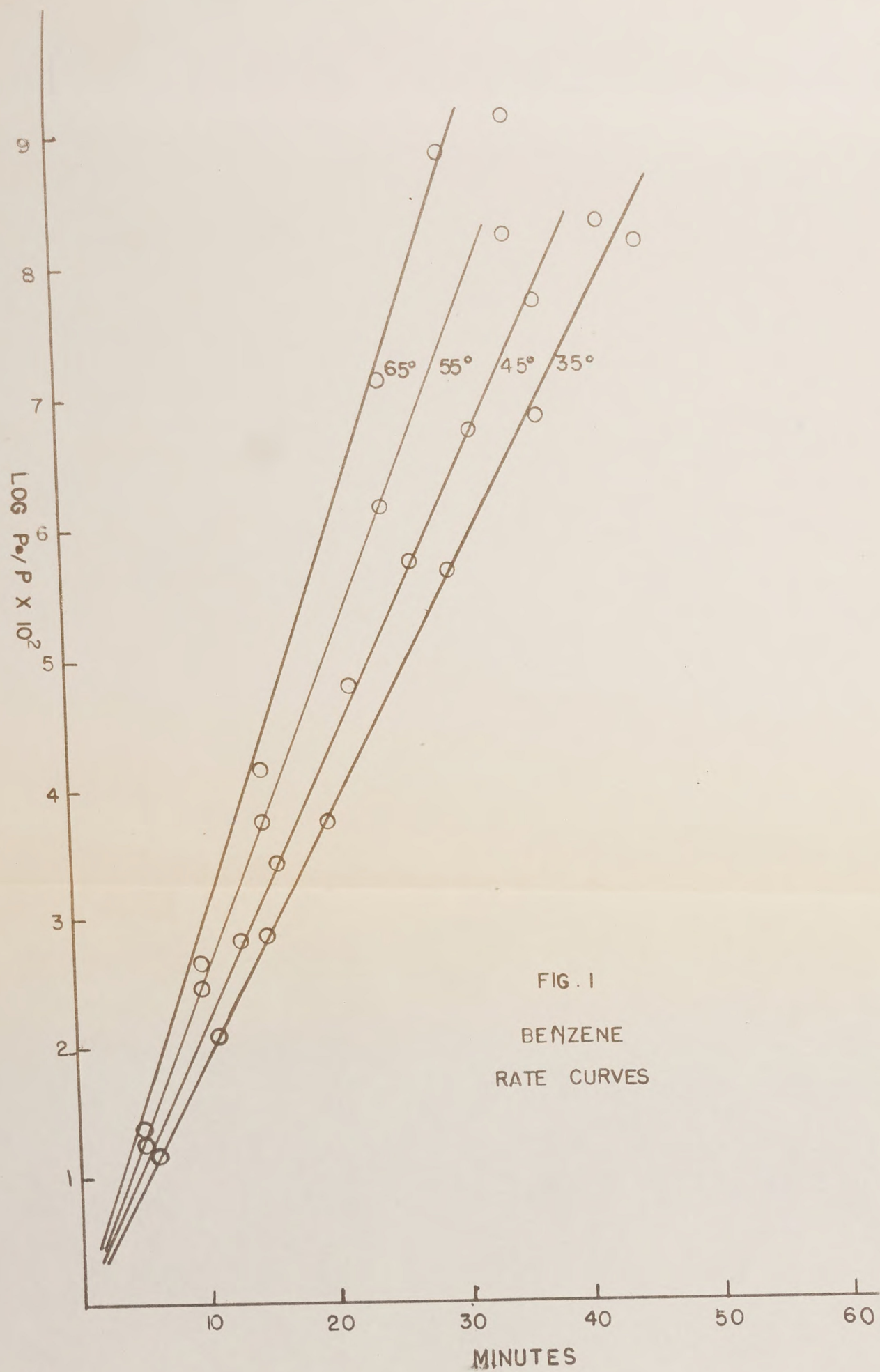
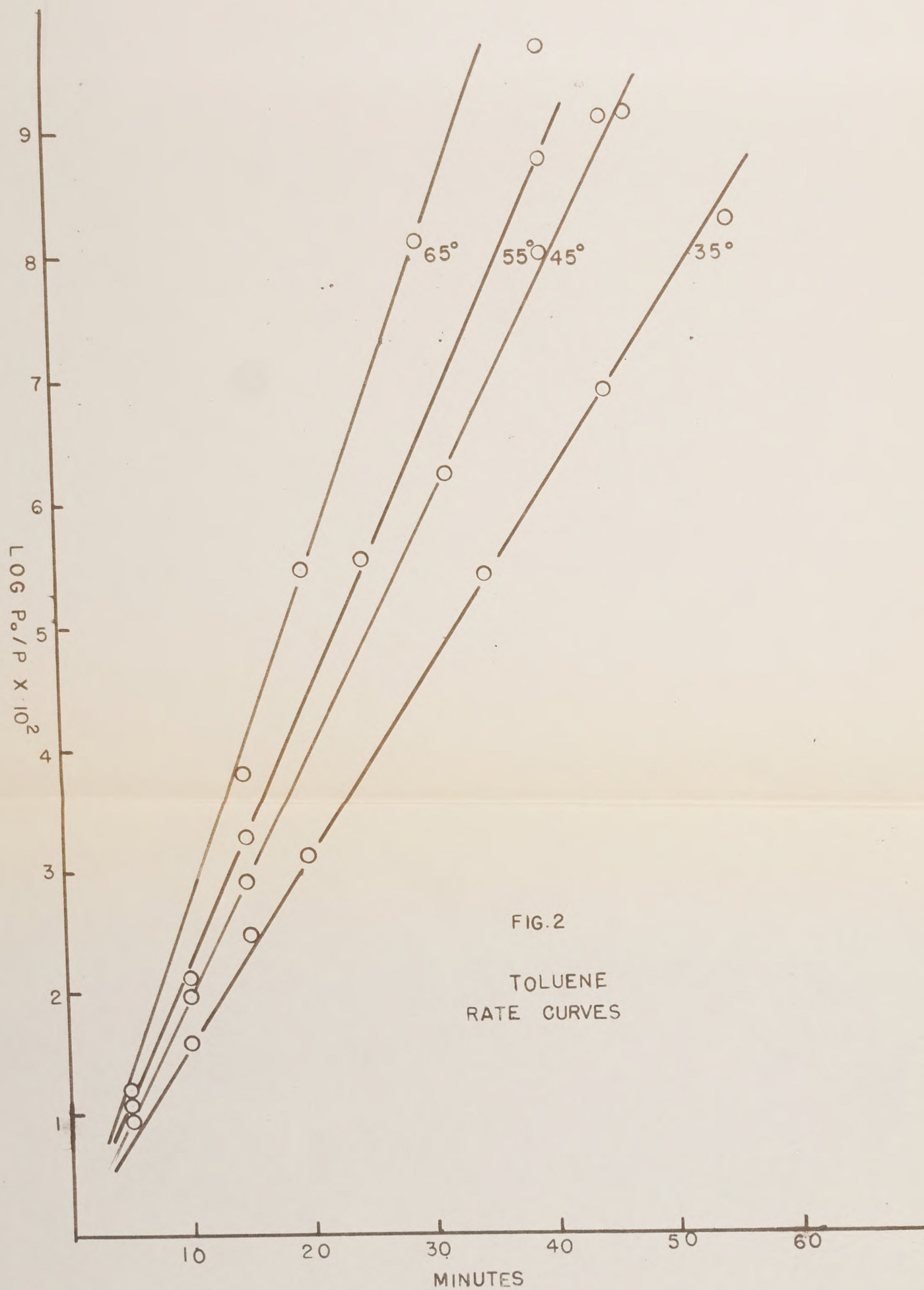


FIG. 1
BENZENE
RATE CURVES



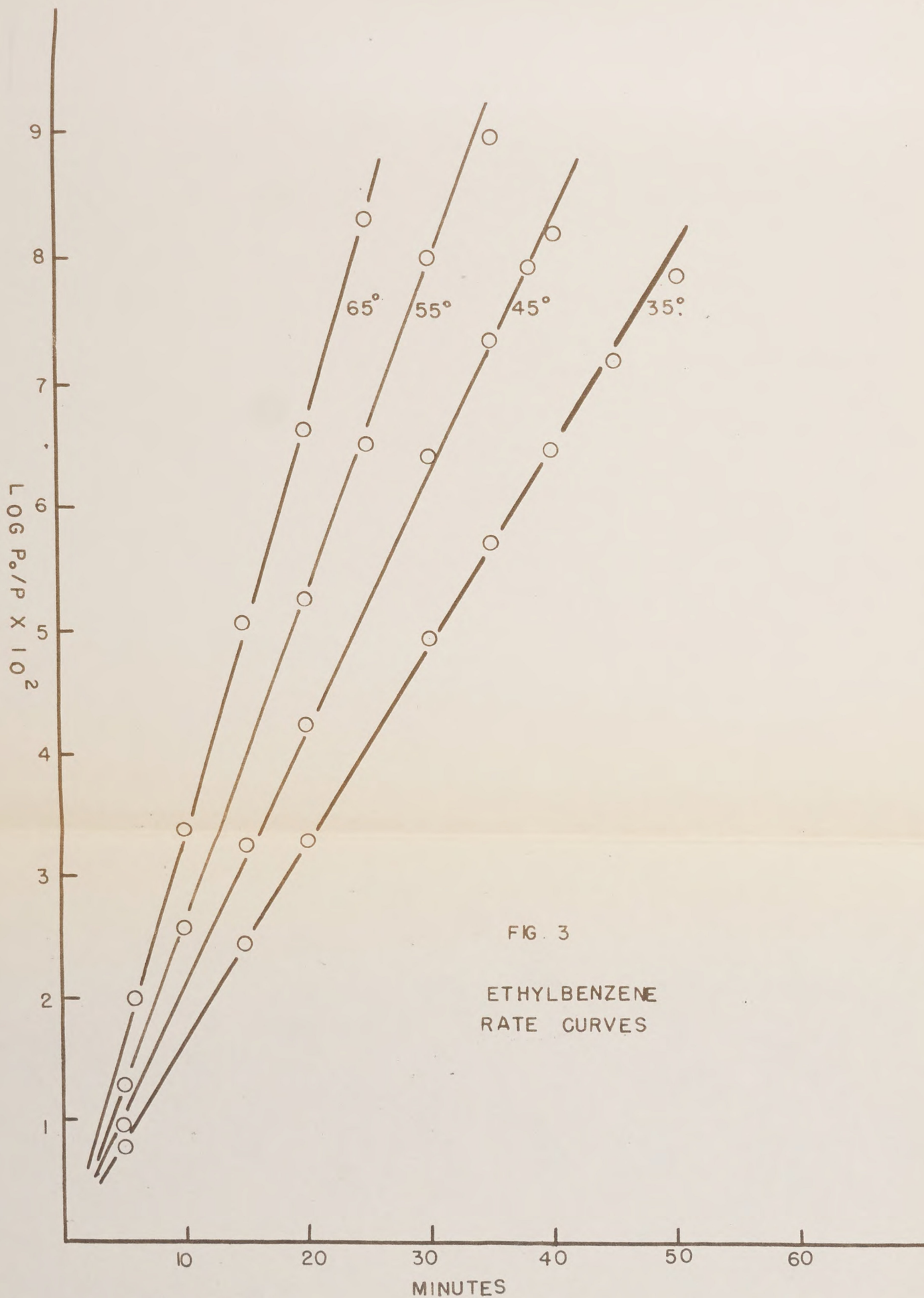


FIG. 3
ETHYLBENZENE
RATE CURVES

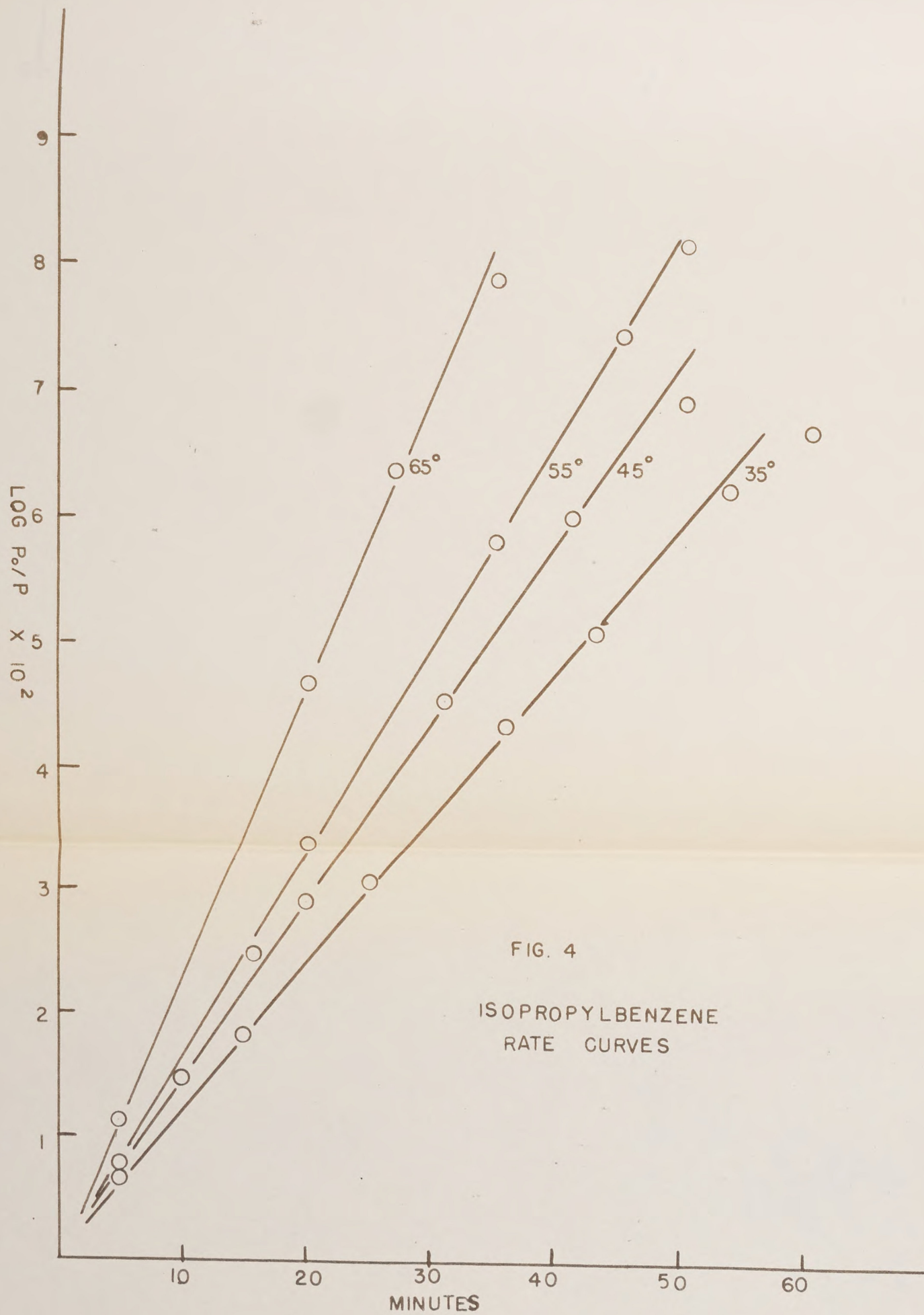
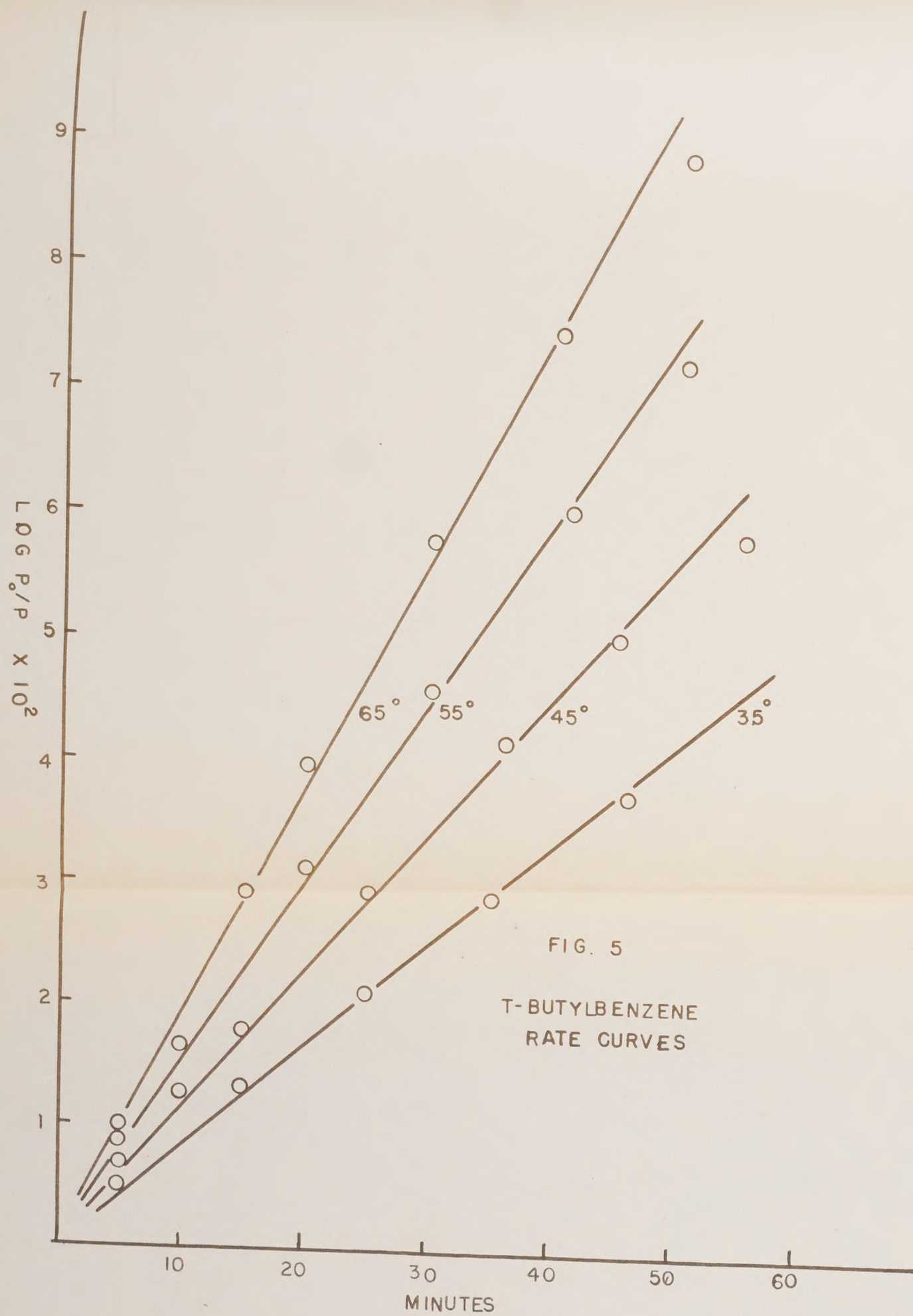


FIG. 4
ISOPROPYLBENZENE
RATE CURVES



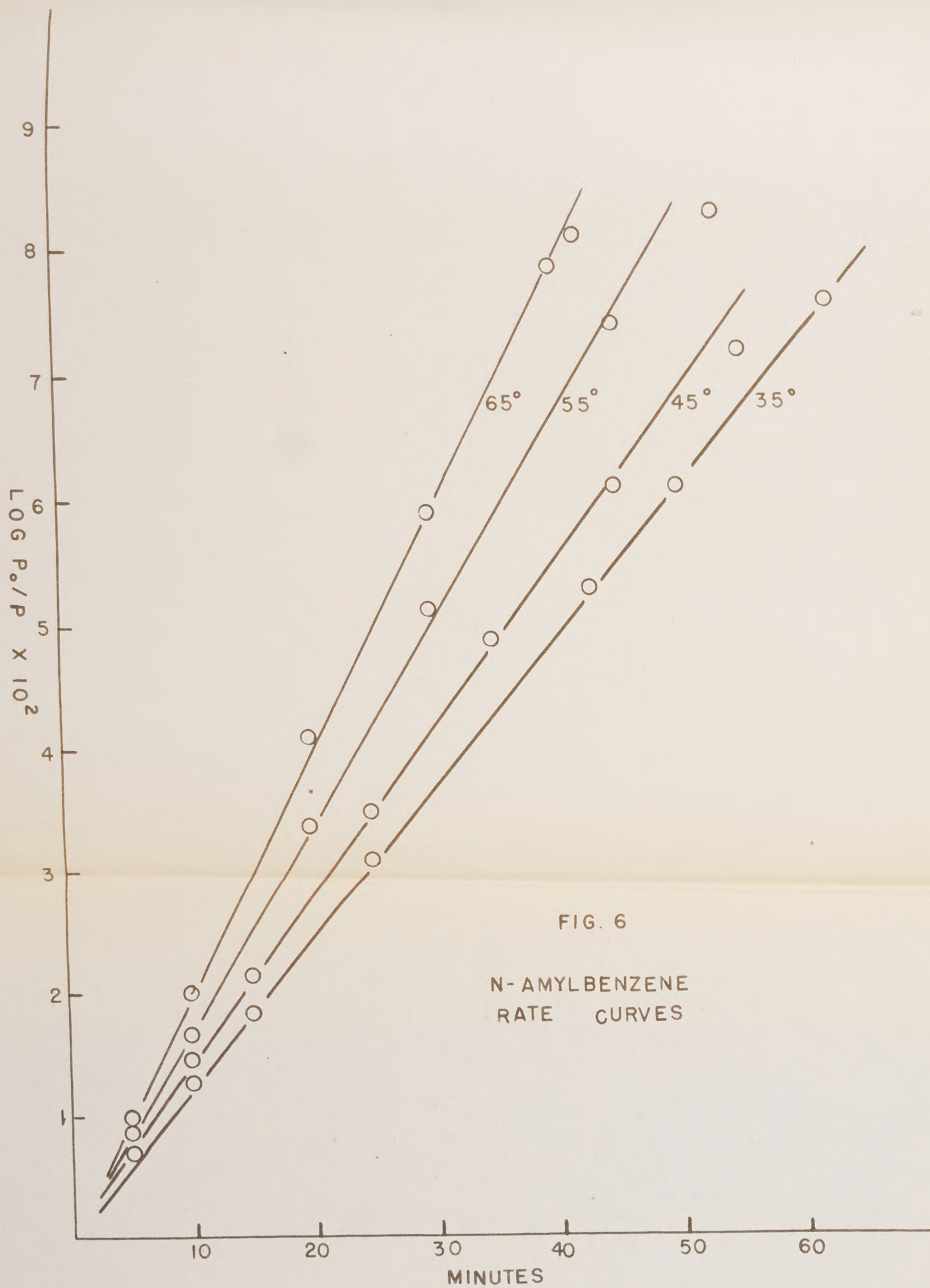
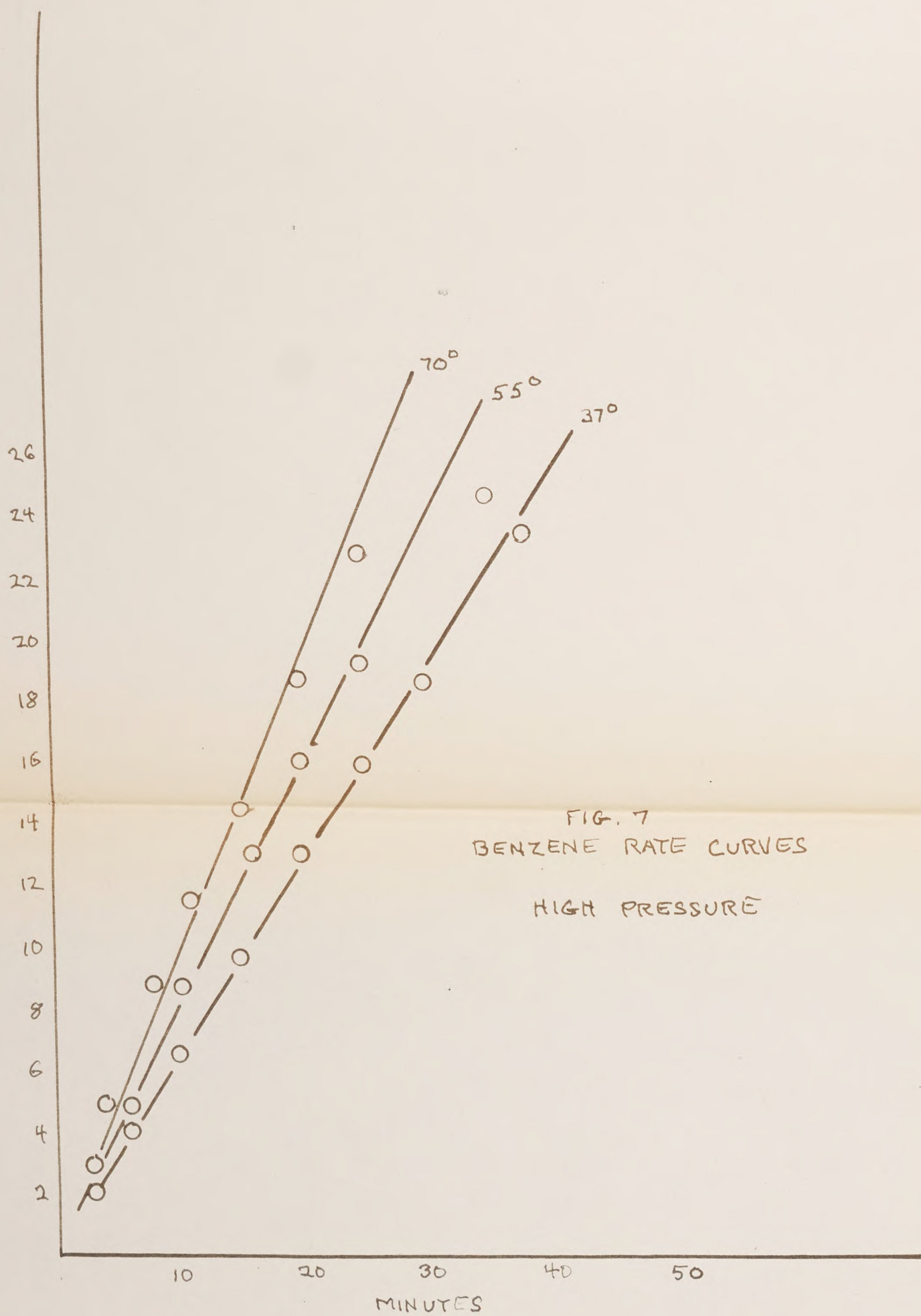


FIG. 6

N-AMYL BENZENE
RATE CURVES



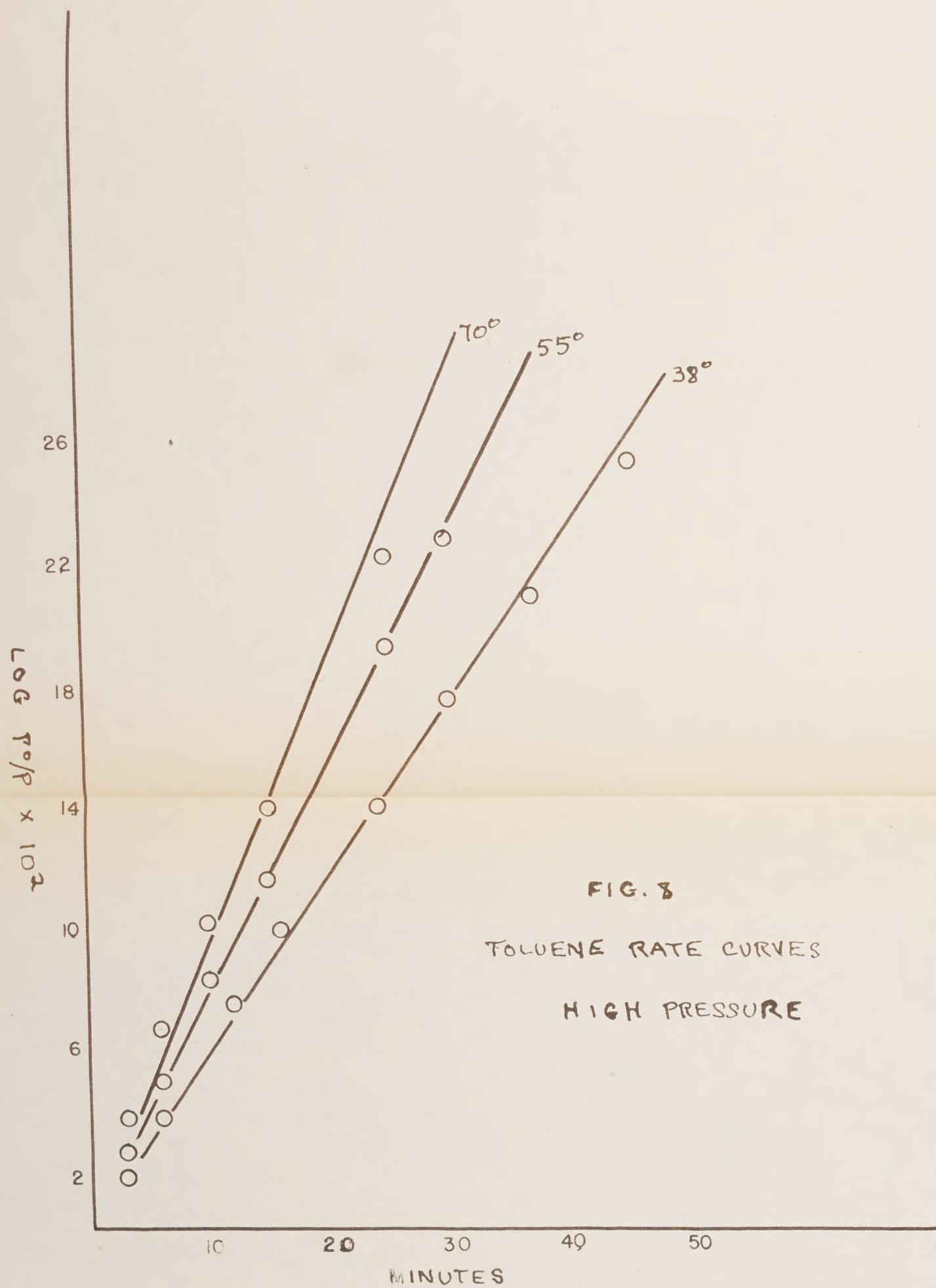


FIG. 8
TOLUENE RATE CURVES
HIGH PRESSURE

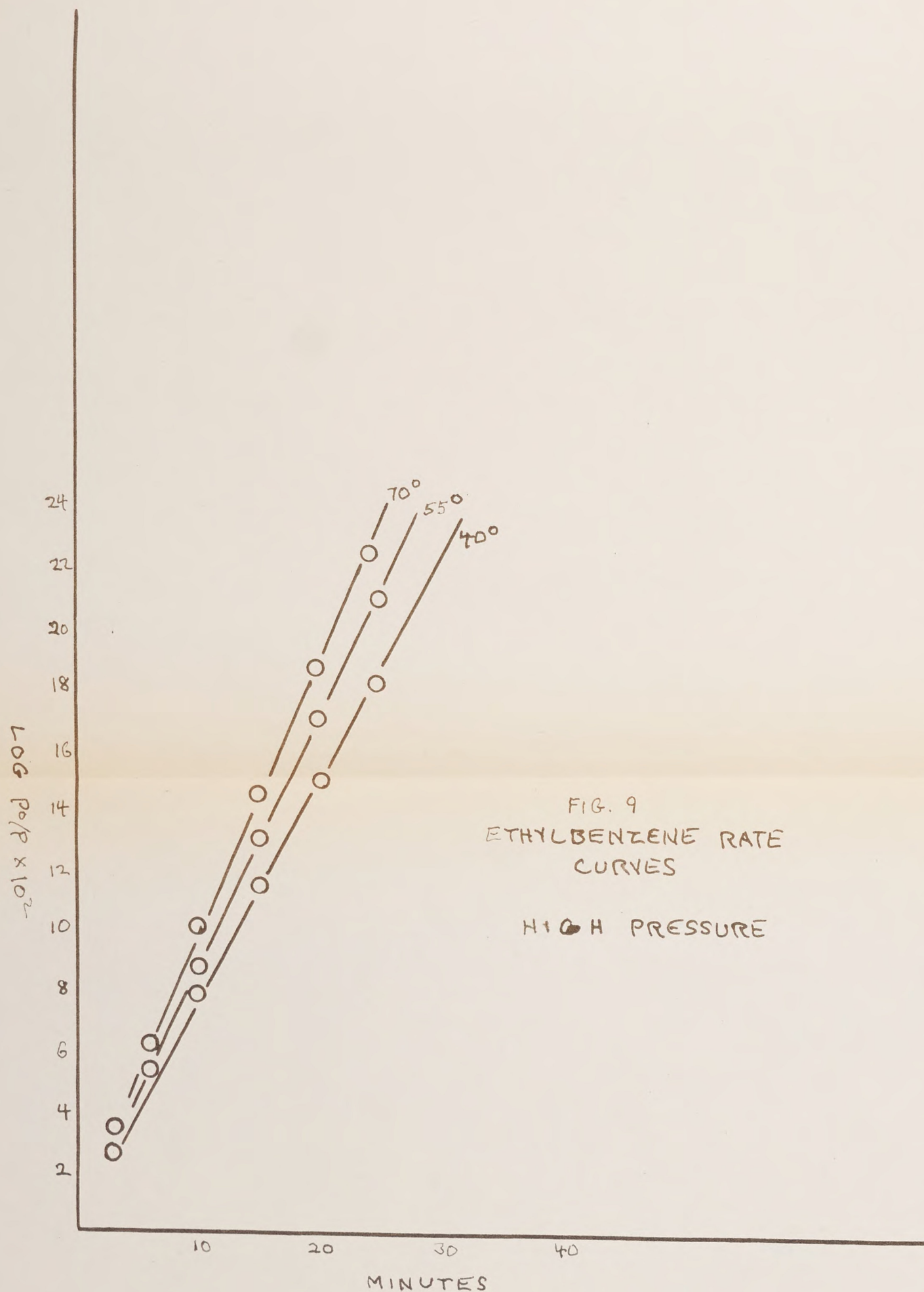
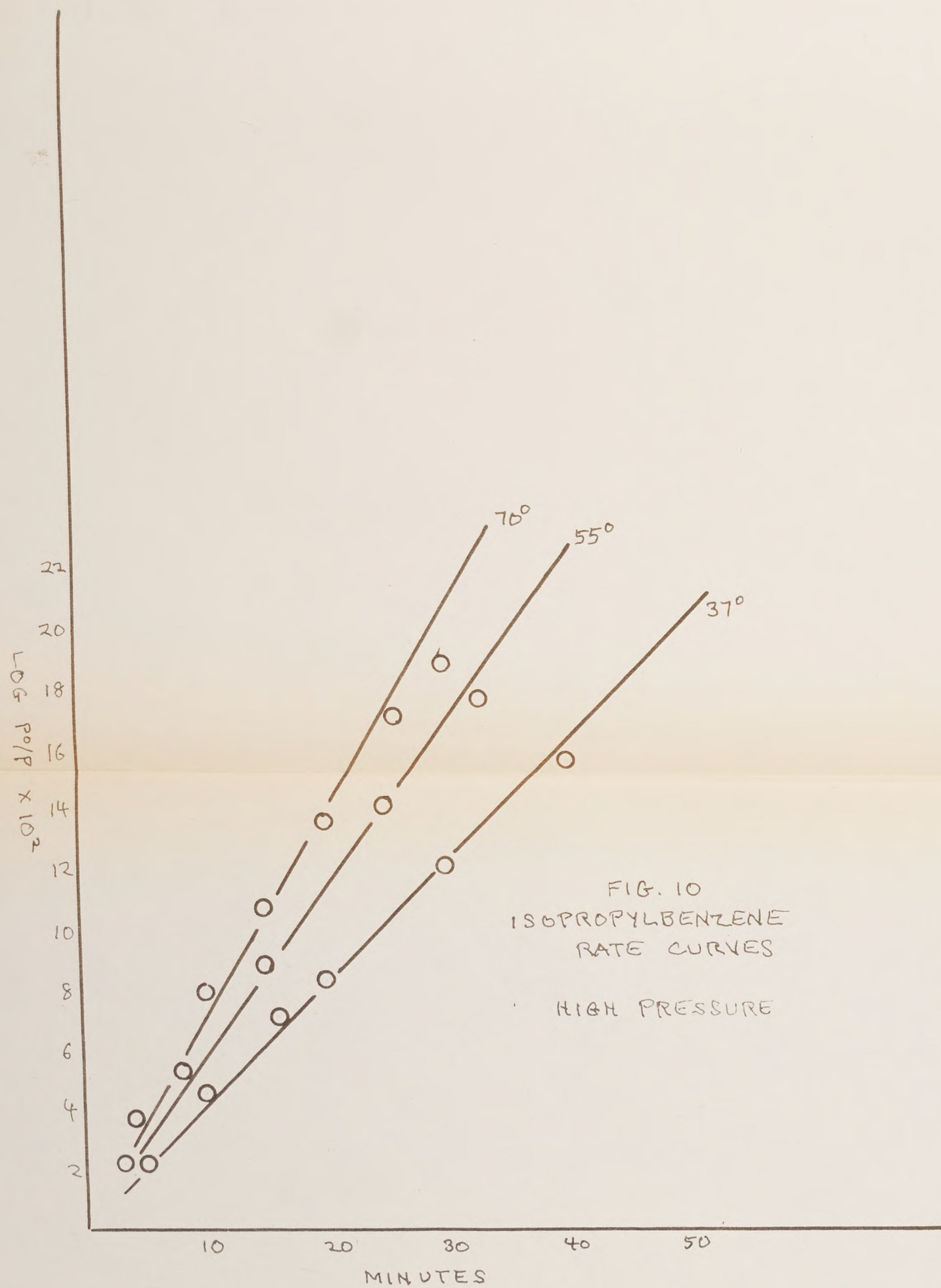


FIG. 9
ETHYLBENZENE RATE
CURVES
HIGH PRESSURE



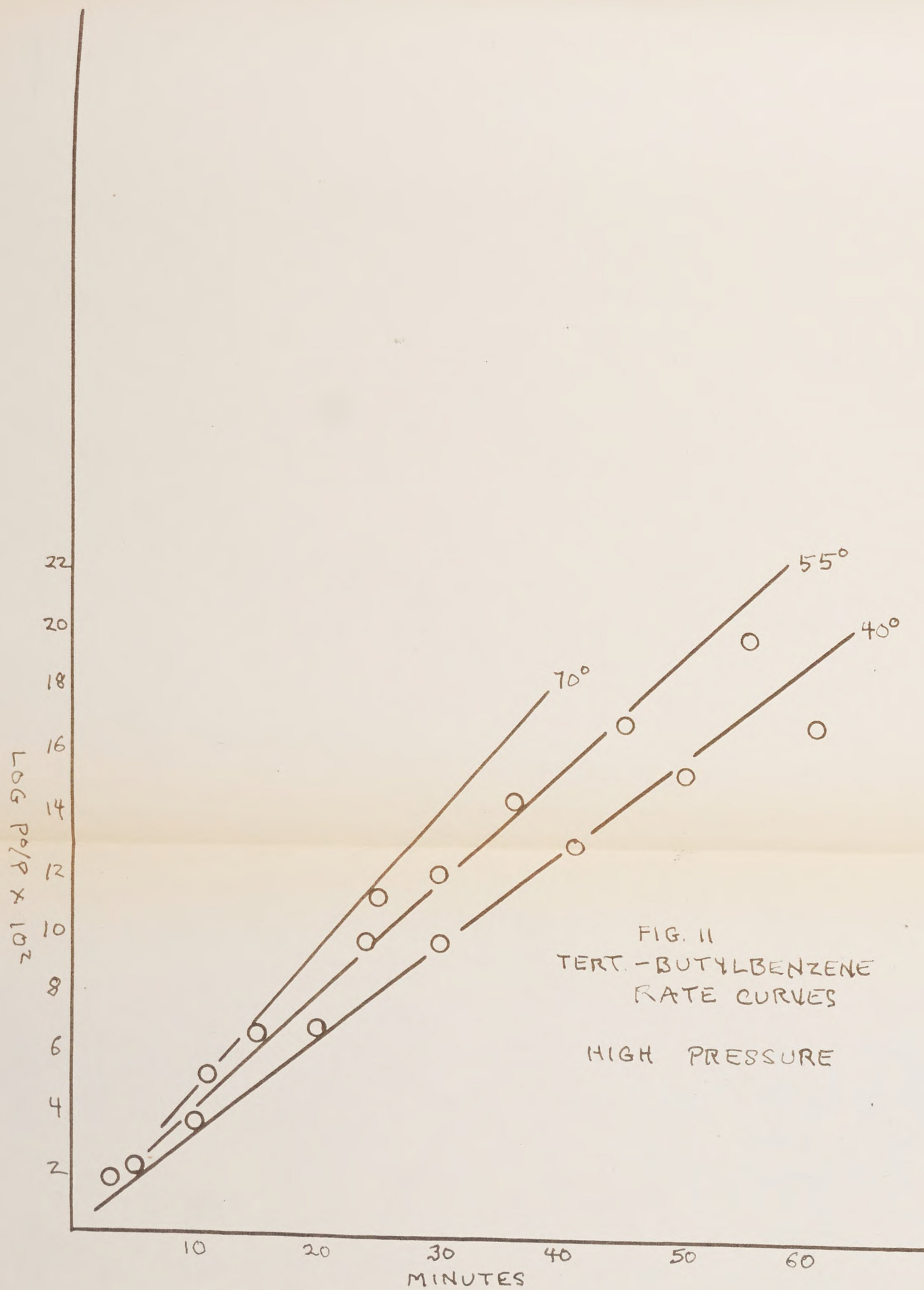
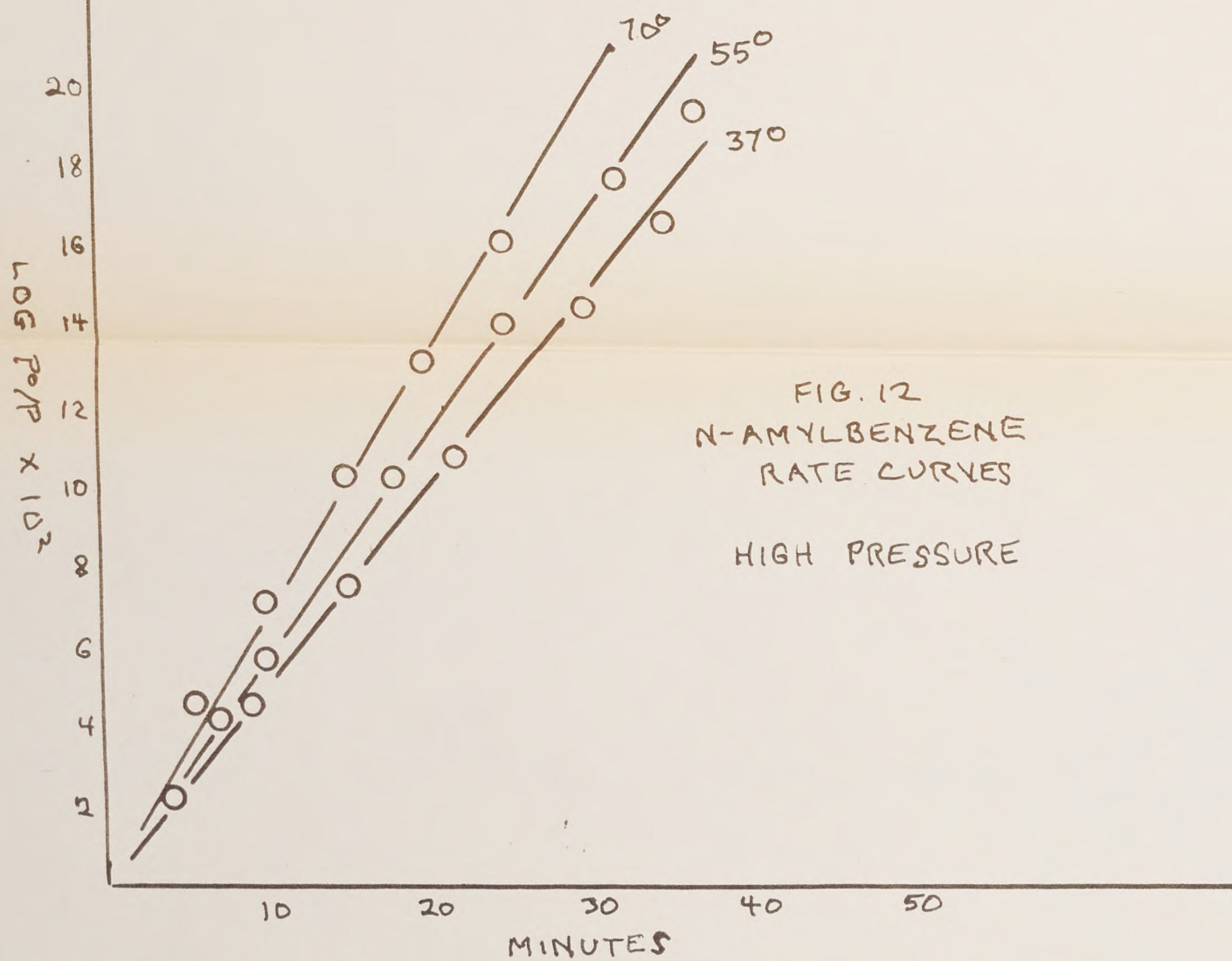


FIG. 11
TERT.-BUTYLBENZENE
RATE CURVES
HIGH PRESSURE



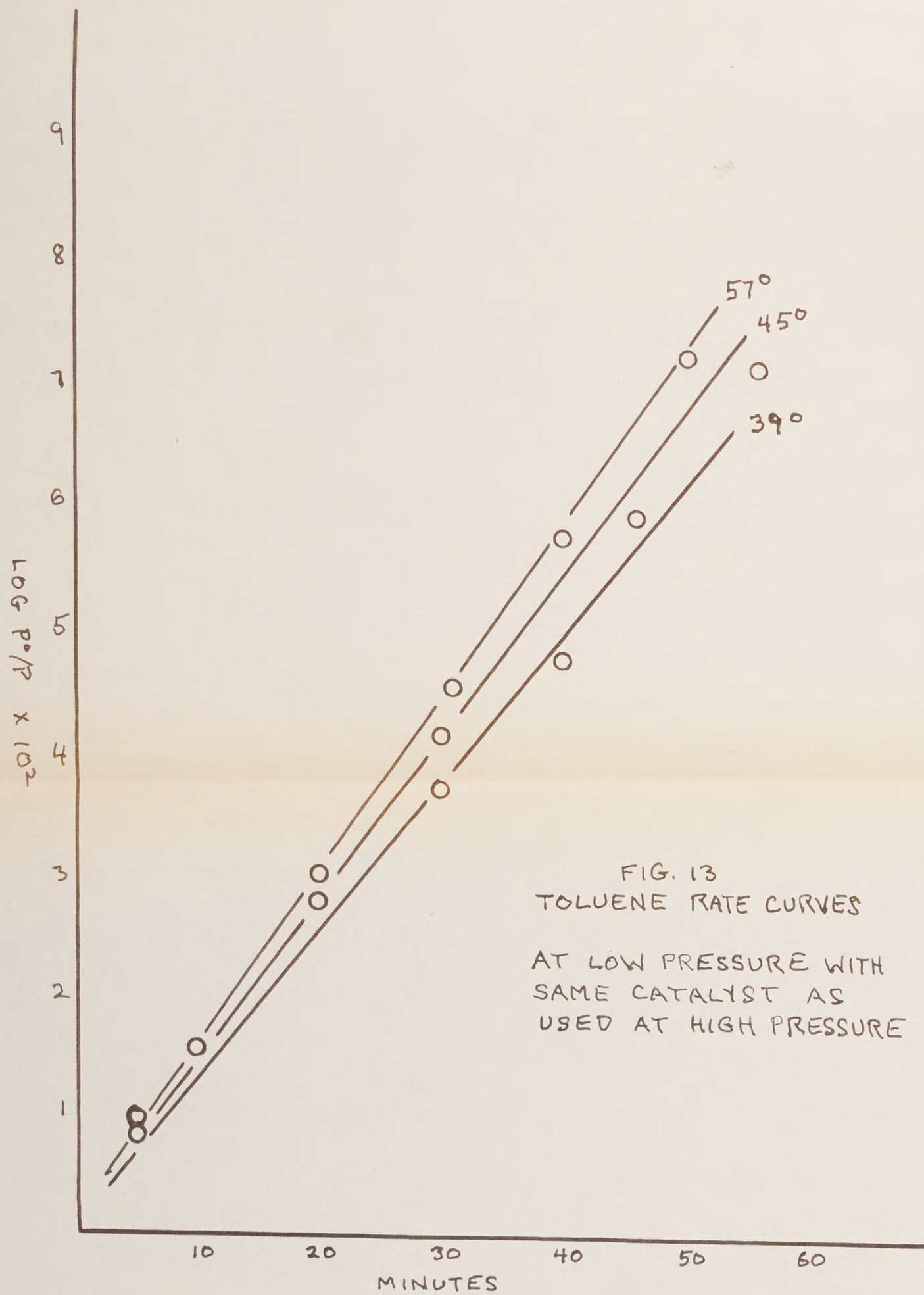


FIG. 13
TOLUENE RATE CURVES
AT LOW PRESSURE WITH
SAME CATALYST AS
USED AT HIGH PRESSURE

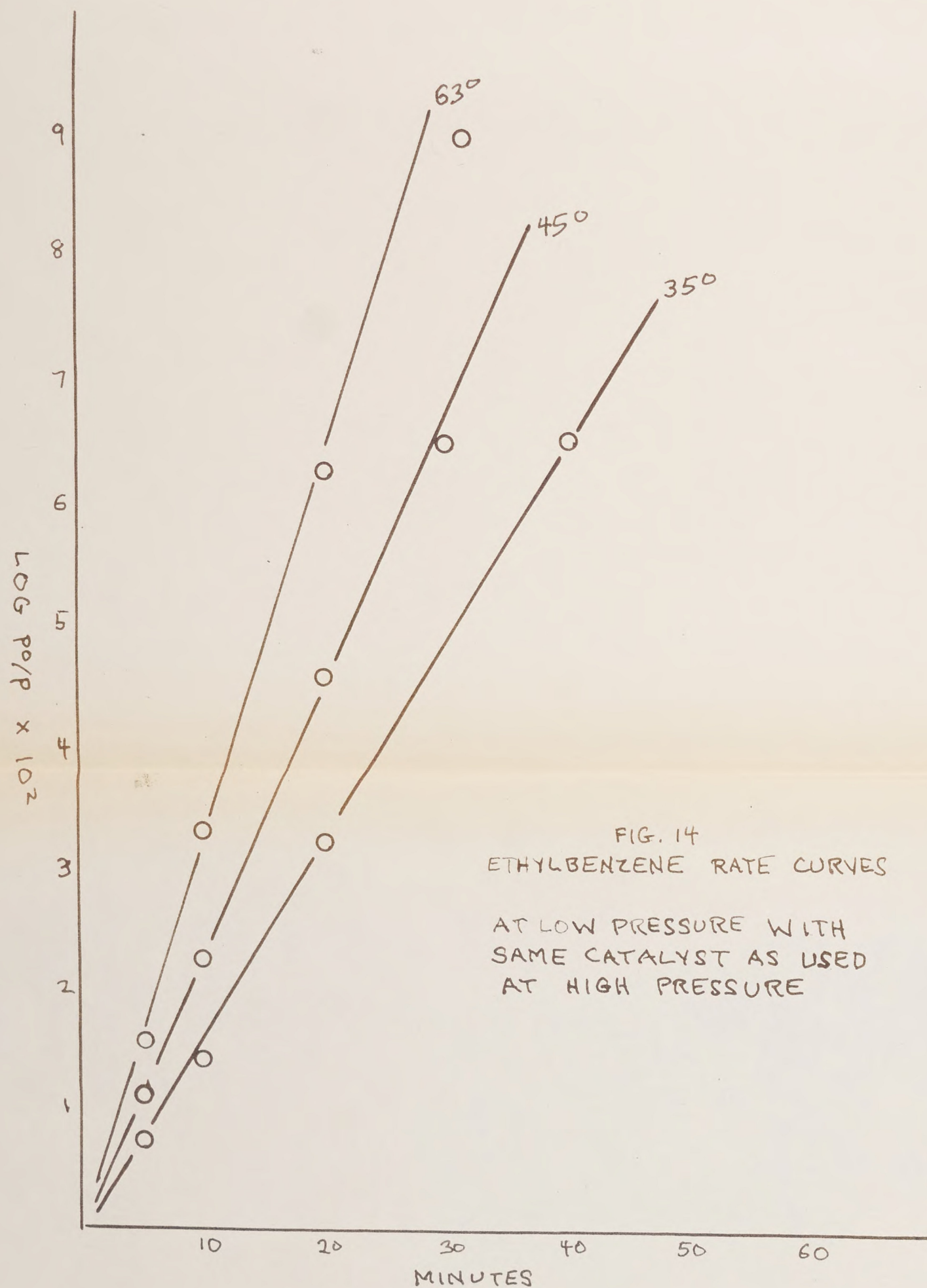


FIG. 14
ETHYLBENZENE RATE CURVES

AT LOW PRESSURE WITH
SAME CATALYST AS USED
AT HIGH PRESSURE

