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Report No. 9

Final Report
on

FROTHING IN SEWAGE TREATMENT

by
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Laboratories of Hydraulic and Sanitary Engineering

Sponsored by
Association of American Soap and Glycerine Producers, Inc.

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Period Ending June 30, 1957

UNIVERSITY OF WISCONSIN
MADISON

COLLEGE OF ENGINEERING
HYDRAULIC AND SANITARY LABORATORY

March 31, 1958

Subcommittee on Research
Association of American Soap
and Glycerine Producers, Inc.
295 Madison Avenue
New York 17, New York

Gentlemen:

The attached report on "Frothing in Sewage Treatment" is herewith transmitted as the Final Report for the research period, July 1, 1955 to June 30, 1957. Together with the interim reports that have been submitted to you, this report constitutes the record of work performed on this project during the period noted.

The following personnel at the Hydraulic and Sanitary Engineering Laboratories have been associated with the project:

James R. Simpson - Research Assistant
Jay S. Silhanek - Research Assistant
Lawrence B. Polkowski - Project Associate
Gerard A. Rohlich - Project Director

Student assistants were employed on a part-time basis as the needs for their services were required.

I should like to take this opportunity to thank the members of the Subcommittee on Research for their active interest and critical review of the progress of the work throughout the course of the project.

Respectfully submitted,

Gerard A. Rohlich

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Professor

GAR:bas

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I. INTRODUCTION

As part of its program of research, The Association of American Soap and Glycerine Producers established a project at the University of Wisconsin on the subject, "Frothing in Sewage Treatment – Its Causes and Elimination."

The program was initiated on July 1, 1955 and during the period July 1, 1955 to June 30, 1957 the work has been directed to a study of the causes of frothing in sewage treatment. An extension of the project for a third year (July 1, 1957 to June 30, 1958) has been made. During the third year the study will be directed towards methods of elimination of frothing, using as a background of information the results obtained during the first two years.

Progress of the work has been reported in 5 reports of which the findings are summarized in this final report. In addition, this report contains a summary of the progress during the sixth report period.

Initial phases of study included a questionnaire survey of activated sludge-sewage treatment plants in the United States; measurements of froth formation in solutions of known composition; development of methods for the measurement of froth in mixed liquors, and evaluation of syndet determinations in sewage and activated sludge mixtures. From the knowledge gained studies of a more comprehensive nature were made of mixed liquors, both in the laboratory and under field conditions.

The results of the measurements and determinations made in the field and laboratory have been analyzed statistically, both by simple and multiple correlation techniques. This analysis enabled inferences to be drawn of the factors contributing to frothing in sewage treatment. The statistical evaluation also indicated factors which may be useful for the control of frothing.

II. FOAM MEASUREMENT

Reports on frothing in sewage treatment plants, and research on this subject have been limited to visual observations as far as the amount and characteristics of the foam are concerned. Foam height measurements have been recorded under different operating conditions, but other quantitative data on foam characteristics are lacking, particularly regarding froth measurements of mixed liquors.

Basically, foams are complex in nature, and are difficult to measure. The heterogeneity of sewage-sludge mixtures and the influence of suspended solids on bubble collapse further complicate foam measurement. Two methods of foam measurement are presently in use. Although these have provided a basis for correlation studies of frothing, improved methods are needed.

Of the two methods in use one is a "static" measurement, and the other a "dynamic" measurement. "Static" measurements are taken of the foam after the foam has been produced, whereas the "dynamic" method uses measurements of the foam while the foam is being formed. The latter method more nearly represents conditions in the aeration tanks at sewage treatment plants where the froth is formed and continues to build up until the rate of breakdown or decay of the froth is equal to the rate of formation. The dynamic method used is based on this principle, under conditions which permit measurement of the aeration rate and volumes of foam formed.

The "static" foam measurement used is simple and leaves little for human error. In the static method, the foam may be formed by bubbling gas through the liquid or by whipping the liquid. After the foam has formed, observation of the time interval for collapse of the foam is made.

The procedure for the static measurement used is as follows:

A 250 ml portion of mixed liquor is placed in a 500 ml mixing cylinder and is shaken to entrain air by inverting the cylinder 10 times. At the end of the shaking period a timer is started and the measured time interval is terminated when the foam just clears on the liquid surface. The measured time interval is denoted as "persistency". In Figure 1, two mixing cylinders are shown illustrating the conditions of test. The method used may provide an easy method for plant operators to take quantitative data of the frothing conditions in their treatment plants.

The "dynamic" foam measurement used measures the average lifetime of a bubble in the foam. This value is denoted by the symbol "Σ". This foam measurement is made in a specially designed foam meter shown in Figure 2. A photograph of the foam meter is shown in Figure 3, and the complete foam measurement unit is shown in Fig. 4.

The essential parts of the apparatus are the foam meter, a calibrated air-water orifice manometer to regulate air flow rates, a mercury manometer for gage pressure air volume corrections, a wet test displacement meter for measuring the total quantity of air supplied (measures to the nearest 1/1000 cu. ft.), a needle valve for regulation of air flow rates, and a compressed air cylinder as an air source.

The essential parts of the foam meter (Figs. 2 and 3) are an extra coarse 12 mm. OD fritted glass gas dispersion cylinder, a 1-liter erlenmeyer aeration flask, to contain the sample, with inlet and drain, and a column for accumulating the foam for measuring the resulting foam volumes. A manometer attached to the side of the foam column permits measurements of foam density if large quantities of foam are produced.

The relationship between certain easily measured values with the use of the foam meter apparatus provides the basis for comparison of foams by the dynamic method. The following values are used for the calculation of Σ or Σ_c, the latter term representing a dynamic measurement under special conditions:

1. Rate of aeration, $\left(\frac{dVa}{dt}\right)$ – measured by a wet test displacement meter.
2. Rate of foam formation, $\left(\frac{dv}{dt}\right)$ – the volume of foam formed in the foam meter column in an aeration period.

3. Maximum volume of foam produced at a given rate of aeration (V), – the volume of foam at a time when continued aeration does not increase the volume of foam produced.
4. The volume of foam produced over a prescribed period of time at a given rate of aeration (v).

Using various combinations of the foregoing measurements, quantitative values for the comparison of foaming capacities of liquids are determined. There are two ways to compute Σ which has the units of time.

Measure the maximum volume of foam produced at a given rate of aeration with continued aeration. Under this condition foam continues to form at the liquid-foam interface, but the maximum volume of foam has been reached. Equation 1 expresses this condition:

$$\Sigma = \frac{V}{\frac{dVa}{dt}}, \text{ seconds} \qquad (1)$$

Measure the volume of foam produced over a period of time at a given rate of aeration. This volume is divided by the difference between the rate of aeration and the rate of foam formation. Under this condition the foam continues to form at the liquid-foam interface with continued aeration until the liquid is depleted of the foam forming compounds. Equation 2 expresses this condition:

$$\Sigma_c = \frac{v}{\frac{dVa}{dt} - \frac{dv}{dt}} \qquad (2)$$

The volumes of foam are measured after 2 and 5 minutes aeration intervals. The period of time should be as small as practical to avoid alteration of the sample; however, the time should be long enough to produce a measurable quantity of foam with reasonable accuracy. The rate of aeration used varied from 2.0 to 2.5 cc/sec depending on air volume corrections for gage pressure. Preliminary evaluation of the foam meter indicated that comparable results can be obtained for aeration rates from 1.85 to 2.85 cc/sec.

Sample computations for the determination of Σ and Σ_c are illustrated in appendix A.

Experience with the use of the foam meter has indicated difficulty in measuring the volumes of foam produced under certain conditions. The foam-air interface continues to increase in some instances, but coalescence of the foam bubbles is visible at levels closer to the foam-liquid interface. The volume of foam used for calculation of Σ when coalescence occurrs is the volume corresponding to the level where coalescence occurred. Thus, Σ in this instance does not represent the full foam forming ability of the liquid.

Some typical results of foam measurements corresponding to frothing conditions existing at sewage treatment plants are shown in Figures 5 through 9. It is noted that the foam measurements are generally in agreement, but variations are evident when considering suspended solids concentration, rate of aeration, and climatic conditions. For instance, the depressant action of sunlight on the aeration tanks would not appear on measured values of Σ or persistency. Also, lower suspended solids and higher rates of aeration produce greater volumes of froth. The effect of suspended solids concentration would possibly be reflected in the foam measurement whereas rate of aeration would not be accounted for. Times at which the photographs were taken are also noted. It is interesting to note the changes in City C with respect to the buildup of foam as a fog settles down in the evening hours. This is possibly caused by reduced evaporation from the foam film allowing the foam to build up. Another interesting change noted with time is shown Cities A and J in Figures 5 and 9. As the high flow conditions enter the treatment plant and as the sunlight evaporation effects become greater, the amount of frothing decreases.

In order to compare foam measurements, at differing suspended solids concentration, for the correlation studies discussed in a subsequent section of this report the foam measurements were corrected to a common suspended solids concentration. The corrections applied were obtained from Figures 10 and 11. The data used to plot Figs. 10 and 11 are given in Table I. Each line on the correction graph represents a sample of mixed liquor tested at different suspended solids concentrations. The suspended solids concentrations were varied by settling to increase the concentration and by decanting the supernatant which was used as a diluent to decrease the suspended solids. The effect of this procedure on altering the ABS, and organic nitrogen of membrane filtered samples was insignificant, however, the ammonia nitrogen was slightly higher with the higher suspended solids concentrations. (See Table II) In all instances with higher suspended solids concentrations the values of Σ and persistency were lower, according to the equations shown. As noted by the slopes of the lines in Figures 10 and 11 for higher values of Σ and persistency the decrease in Σ and persistency for the same increase in suspended solids concentration is greater than at lower values of Σ and persistency. Thus, where severe frothing conditions are prevalent under low suspended solids conditions, these measurements indicate that increasing the suspended solids would reduce the resulting quantities of foam formed simply by their presence. The effects of increasing the suspended solids in an aeration tank for a six hour aeration period and the changes in the froth forming components are not fully understood at this time.

III. DETERGENT DETERMINATIONS

Concentrations of anionic detergents in sewage and activated sludge are difficult to determine, and the reliability of the results are often questionable. Several procedures have been proposed but an acceptable standard procedure is still lacking.

Several of the proposed methods have been evaluated. Effects of interfering substances, as well as an evaluation of the ability to quantitatively extract detergent from suspended solids, have been made. As yet a reliable method is unavailable for the determination of detergent in the presence of the suspended solids concentration normally used in the activated sludge process.

The Edwards and Ginn (1) modified two-phase titration as well as Finch's (2) modified Longwell and Manice methylene blue method for determination of anionic detergent were tested on samples of synthetic sewage, domestic sewage, supernatant of activated sludge, and distilled water to which known amounts of ABS had been added. Results from the two-phase titration method indicate inconsistent variations as well as the inability to detect an end point when suspended solids are present in concentrations in excess of 500 ppm as normally encountered in activated sludge aeration tanks. Emulsions which are formed are not easily broken.

The methylene blue determination yielded similar variations in results and would require a calibration curve for each sample tested to correct for interferences. However, the spectrophotometric determination as used in this determination is preferred to the two-phase titration method for detecting an endpoint.

The two sources of error, when either of the above methods are applied directly to sewage, are positive interferences caused by the presence of materials other than anionic detergent which form chloroform or hexane extractable dye salts and result in high values; and negative interferences caused by compounds which complex with the anionic detergent and thereby prevent the formation of the anionic detergent – dye complex. Some possible negative interferences in sewage are proteins and organic or inorganic cations.

In order to overcome some of the difficulties present with the use of the foregoing methods, the Monsanto method (3) for the determination of alkylbenzene sulfonate was used. This method is time consuming, but the reliability of results is much improved over the other methods. However, there is the limitation of measuring only one type of anionic detergent, alkylbenzene sulfonate, and the method is quite specific as to the number of carbon atoms in the hydrocarbon group, i.e. it is believed to be specific for ABS with C_{10} or longer (3).

The principle of this method is to remove the alkylbenzene sulfonates (ABS) from the interfering substances following which a quantitative measurement of the remaining ABS is made by the methylene blue procedure. The negative interferences are eliminated by a selective extraction with a chloroform solution of 1 methylheptylamine of the sample at pH 7.5. The amine salt of ABS, having a carbon chain of C_{10} or longer, and some positive interferences, such as, alkylsulfates of C_{12} and longer, are extracted. Some of the positive interferences, including alkylsulfates are destroyed by hydrolysis with hydrochloric acid. The remaining positive interferences are removed by a hexane solution of 1 methylheptylamine at pH 4.8 which is a highly selective solvent and possible does not remove ABS with a chain length shorter than C_8. These steps followed by the chloroform extraction of the methylene blue-ABS complex constitute the analytical determination.

The procedure is presented in appendix B.

An abridged Monsanto method has been used in these studies to shorten the time required for analysis. Two extractions, rather than three, are used for the chloroform-methylheptylamine and the hexanemethylheptylamine extractions. During acid hydrolysis, reflux for 30 minutes rather than 60 minutes, and the ABS methylene blue complex is extracted once with 30 ml chloroform rather than making 3 extractions with 15 ml.

A calibration curve for the ABS (sample #2389, 62.4% purity obtained from the Colgate-Palmolive Research Laboratory) is shown in Figure 12, for both the methylene blue and abridged Monsanto methods. Apparently the methylene blue method was able to detect more of the ABS or was affected by positive interferences which were not indicated by the Monsanto method. The calibration curve by the Monsanto method was used for the determination of ABS concentrations.

A comparison of the results of the methylene blue and abridged Monsanto methods for determination of detergent was made for the sewage treatment plant at City D, Wisconsin (See Table III). These comparisons were made on screened sewage, primary effluent, and filtered aeration tank mixed liquors, as well as on filtered samples of the liquid of the foam. Using the Monsanto method as a standard, low values were obtained by the methylene blue method for screened and settled sewage as well as of the foam, and high values were obtained on the filtered mixed liquor samples. This indicates the unreliability of the methylene blue method. The methylene blue determination measures both sulfate and sulfonate type detergents yet results are lower in the sewage samples where sulfates are likely to be present. Again, only 17% of the ABS measured by the Monsanto method was recovered by the methylene blue method for the filtered foam sample. Consequently the abridged monsanto method was used for the detergent determination.

TABLE III

SAMPLE	MONSANTO ABS mg/1	METHYLENE BLUE mg/1	DIFFERENCE mg/1
Screened sewage	7.1	6.3	-0.8
Primary effluent	6.0	5.7	-0.3
Influent Aeration (filtered Whatman #41)	1.0	2.6	+1.6
Effluent aeration (filtered Whatman #41)	2.3	2.6	+0.3
Final Effluent	lost	2.9	–
Foam (Gooch filtered)	2000	338	- 1662
Influent Aeration (total)	7.3	–	–
Effluent Aeration (total)	8.2	–	–

Occasional checks on the Monsanto method were made throughout the course of experimentation. Recovery of ABS at 100 μg was within 2% for distilled water solutions. Analysis of samples of mixed liquor which were filtered through an AA milipore membrane indicated recovery within 3% error. However, analysis of mixed liquor samples with and without ABS additions indicated the inability of the method to extract quantitatively in the presence of suspended solids as evidenced by an error of 17%. The limitations of this method are considered in subsequent discussions.

IV. STUDIES CONDUCTED DURING THE PERIOD JULY 1, 1955 TO JANUARY 31, 1957

In addition to a review of the literature, (4) work included a questionnaire survey of activated sludge sewage treatment plants with regard to conditions of frothing at the plants. In addition observations were made of froth formation occurring in organic solutions with and without the presence of ABS. These studies were carried out using a range of concentrations of ABS and organic solutions prepared synthetically.

A field survey at 5 sewage treatment plants helped to eliminate some factors previously suspected but which apparently have no effect on froth formation. Details of this survey are presented in the reports for the periods ending September 30, 1956 and January 31, 1957.

The development of foam measurement and the evaluation of various analytical methods for the determinations of detergents were made during the initial phases of this project.

A summary of each subject is discussed in the following sections of this report.

A. Questionnaire Survey.

A questionnaire was sent to 398 aeration-type sewage treatment plants in the United States in order to obtain operating conditions and certain analytical data coincident with the occurrence of frothing. Figure 13 is a map showing the distribution of the questionnaire and replies received. A copy of the questionnaire was included in the quarterly report dated December 31, 1955.

Of the 116 plants reporting, useful data were obtained from 74 diffused-air and 30 mechanical aeration type plants. Ninety seven of the replies received stated that frothing was present to some degree and four indicated no frothing. Fifty plants reported that frothing was a daily occurrence, while 39 indicated that it was not. Frothing occurs over a wide range of mixed liquor suspended solids, as is shown in Figure 14. Each square in Figure 14 represents a single treatment plant. Thirty-five of the plants shown were operating under 2000 ppm of suspended solids in the mixed liquor in the aeration tanks while 24 were operating with over 2000 ppm mixed liquor solids.

The results of the questionnaire survey, which was made early in the program, have emphasized factors and operating conditions which have been confirmed in subsequent laboratory and field studies. Of the replies received a majority of the operators noted that within their plants greater frothing occurred under reduced suspended solids concentrations and with increased rates of aeration. In the first instance, it has been shown by froth measurements in the laboratory and in the field that if a sample of mixed liquor is allowed to settle and foam measurements are made of the supernatant and the sludge, a marked increase in froth producing ability will be noted in the supernatant sample, as compared with a marked decrease in frothing ability of the sludge. This, of course, does not account for changes which may take place in an aeration tank under periods of extended aeration as a result of increased suspended solids, but nevertheless indicates that the physical presence of suspended solids tends to depress foaming.

Also, if a solution is capable of producing froth, the amount of froth formed is directly related to the rate of aeration. This is the basis for dynamic foam measurement devices, which are discussed in detail in section II of this report.

A pictorial example of the effect of rate of aeration is shown in Figure 15. The photograph of the experimental aeration units shows that as the rate of aeration in the units increases from left to right there is a corresponding increase in the volumes of froth produced.

Consequently a method of control adapted by many of the treatment plants reporting to the survey, was the use of increased suspended solids and, or the application of a reduced rate of aeration. Effectiveness of either method would be limited to the physical conditions of the plant and the degree to which treatment of the sewage is to be affected.

It is to be noted however that of 63 plants reporting measures to control frothing, 26 used sprinkling systems.

Of the treatments plants reporting on the plant efficiency during periods of frothing, 80%

reported there was no change. The remainder noted higher suspended solids and BOD's of the final effluent during frothing.

Frothing was noted to be more prevalent during the late P.M. and early A.M. hours. It is probably at these times that the pollutional load is light, and that detention time in aeration tanks is longer than under other conditions of operation. This may result in a higher degree of treatment along with the associated changes in the composition of the mixed liquor which may influence the amount of frothing. Also, little is known of the depressant action of sunlight and associated higher temperatures during the daylight hours although a noticeable increase in foam height has been observed at sewage treatment plants during the hour preceding sunset and the hour following. Evaporation, wind velocity, humidity, and other meteorlogical factors may have a definite bearing on the accumulation of foam on aeration tanks.

Reports on the daily occurrence of froth indicate the preponderance of frothing on Sunday, Monday and Tuesday. Of the 61 occurrences reported 46 were on these three days. This does not include those 25 plants which recorded frothing every day.

It is also of interest to note that of those reporting with regard to seasons the highest incidence was during fall and winter.

A detailed tabulation of the answers obtained from the questionnaire survey was presented in the report for the period ending March 31, 1956.

B. Frothing Studies of Organic Solutions

During the contract period, two series of studies were conducted to determine the effect of organic substances in synthetic sewages on frothing, with and without alkylbenzene sulfonate (ABS).

The ABS was obtained from the Colgate-Palmolive Research Laboratory and is identified as Sample #2389, 62.4% purity. This sample has been used throughout the course of the research project.

In the first series, a concentration of 10 mg/1 of ABS was used in combination with organic and inorganic compounds. The solutions were tested in the aeration columns shown in Figure 16. The results have been discussed in detail in the report for the period ending March 31, 1956. In summary, these studies indicate that the presence of 10 mg/1 ABS enhanced the frothing ability of organic solutions as evidenced by the volumes and lifetimes of the foams produced. However, for all solutions containing 10 mg/1 ABS, the volumes of foam produced varied markedly with differing combinations of organic substances. Combinations of bacto-peptone and beef extract in the presence of ABS generally produce more stable foams. Various combinations of the organic solutions tested have the ability to froth without ABS, but to a limited extent. Similar results were obtained when the concentration of organic compounds were reduced 90% both with and without the presence of 10 mg/1 ABS, but the maximum volumes of foam produced were generally less when compared with the results of the full strength solutions.

A summary of the results of this series of experiments is presented in Tables IV and V.

A free ABS concentration of 10 mg/1 is an unrealistically high value to expect at present in sewage treatment plants; consequently studies were conducted at reduced concentrations to determine the concentration level necessary to induce a marked increase in frothing. The concentrations of bacto-peptone were varied also and tested. The froth measurements, persistency and average lifetime of the bubble, were used in these studies. It was noted that the frothing ability of the solutions increased markedly at concentrations of 3 mg/1 and greater of ABS in the presence of 300 mg/1 bacto-peptone, as compared to solutions with concentrations less than 3 mg/1 ABS. Similarly, it was noted that the frothing ability increased markedly at concentrations of 15 mg/1 and greater of bacto-peptone in the presence of 3 mg/1 ABS. This concentration of bacto-peptone corresponds to an organic nitrogen concentration of 2.5 mg/1.

Similar studies of frothing with organic compounds in sewage treatment plant effluent revealed that both 300 mg/1 bacto-peptone and 10 mg/1 ABS, when added singly, increase the stability of the froths produced; however, the greatest increase occurred when both ABS and bacto-peptone were added in combination to the plant effluent. Additional information was presented in the report for the period ending January 31, 1957.

Results and discussion of this phase of the study is summarized below.

The ABS content was varied from 0.5 to 10 mg/1 using concentrations of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 5.0, and 10.0 mg/1 in tap water. All samples contained 300 mg/1 bacto-peptone. This concentration of bacto-peptone is the same as that recommended by Butterfield (5) for synthetic sewage. At each concentration of ABS used, 5 replicate foam measurements were made. Each point in Figure 17 represents an average value of the 5 replicates. The results are presented in Table VI. The table also indicates variations in foam measurements for identical samples.

As the concentration of ABS increases, the surface tension decreases; the rate of decrease is greater from 0 to 2 mg/1 ABS than at concentrations in excess of 2 mg/1. The persistency between 0 and 1 ppm ABS, is less than 5 minutes, but at a concentration of 1.5 mg/1 ABS the persistency is about 40 minutes, and continues to increase with higher concentrations of ABS. Similarly, the values of Σ show a marked increase at a concentration of ABS above 3 ppm. With the foam meter a transition in froth formation was noted between concentrations of 2.0 mg/1 and 5.0 mg/1 ABS. At concentrations of ABS less than 3 mg/1, "plugs" of foam form in the meter, resulting in a discontinuous foam column. The volume of foam used for Σ computations with this type foam is the volume between the liquid-foam interface and the point where separation of the plugs occur. At the 3 mg/1 concentration, the column of foam is honey-combed with large air voids, and the volume of foam used for Σ values is the volume between the liquid-foam interface and the level where coalescence of the foam occurs. The level where bubble coalescence occurs is difficult to detect, thus greater variability is noted in the foam measurement. At concentrations of 5 mg/1 ABS and greater, the column of foam was continuous and the volume of foam increased as aeration continued. Values of Σ_c were computed for this type of foam.

Values of Σ_c were computed with results ranging from 2000 to ∞ seconds for the 5 replicates at the 5.0 and 10.0 mg/1 ABS concentrations. At low concentrations of ABS the values of Σ for the 5 replicates had a maximum range of approximately 4 seconds.

In another series of studies the bacto-peptone concentration was varied from 0 to 100 mg/1 in tap water containing 3 mg/1 ABS to determine the influence of bacto-peptone on frothing independent of ABS variation. Measurements of Σ and persistency, as well as of surface tension, were made of the solutions. The results of the measurements are presented in Table VII, in Figure 18.

The surface tension decreased 4 dynes/cm with addition of 5 mg/1 bacto-peptone; thereafter the surface tension remained about the same with higher concentrations of bacto-peptone. There is a marked increase in persistency and Σ at a concentration of 15 mg/1 bacto-peptone corresponding to an organic nitrogen concentration of 2.5 mg/1 based on the composition of the media as given by Difco. The Σ values and similarly the foam persistency continue to increase with higher concentrations of bacto-peptone.

Various compounds bearing organic nitrogen are present in activated sludge mixtures in solution. It is possible that the degraded protein in the polypeptide form would be of sufficient concentration to enhance frothing in these mixtures. The concentrations, in solution necessary for a marked increased in frothing as measured by organic nitrogen is low as evidenced by these tests with tap water solutions.

C. Effect on Froth Formation of Varying Concentrations of ABS in Aeration Tank Mixed Liquor.

To samples of mixed liquor obtained from the Madison Metropolitan Sewage Treatment Plant, ABS was added in concentrations of 1.0, 2.0, 3.0, 5.0, and 10.0 mg/1 in addition to the ABS originally present. Measurements of surface tension and froth were made of the mixed liquor, whereas determinations of ABS, NH_3-N, and organic nitrogen were made of the supernatant of the centrifuged sample. The suspended solids concentrations of the mixed liquor was 1440 mg/1.

The results of these measurements are presented graphically in Figure 19 and tabulated in Table VIII. The free ABS concentration of the unaltered mixed liquor supernatant was 1.85 mg/1 and increased with additions of ABS to a free ABS concentration of 6.5 mg/1 for an addition of 10 mg/1 ABS. The remainder of the ABS is adsorbed to the suspended solids. The surface tension decreased with higher additions of ABS. The persistency increased from a value of 10 seconds in the ABS added at 1 mg/l to a value of 40 seconds with ABS added at 5 mg/1. The latter corresponds to a free ABS concentration of 3.9 mg/1. With an additional increase of 5 mg/1 of ABS the persistency increased to 247 seconds. The Σ value of the mixed liquor was zero initially and was 6 seconds with an added ABS of 1 mg/1. Essentially no further change in Σ was noted with additions of ABS at 2 and 3 mg/1. At additions of 5 mg/1 the Σ value increased from 7.9 to 13.8 seconds, and at 10 mg/1 ABS the Σ value was 17.6 seconds.

The higher persistency and Σ values appear to be related to the free ABS and organic nitrogen concentrations. There is no apparent reason for the increase in organic nitrogen at the 10 mg/1 ABS addition level. The changes in foam measurement were not related to changes in ammonia-nitrogen concentrations.

D. Effect in Varying pH on Froth Formation in Aeration Tank Mixed Liquor.

Preliminary studies of frothing at sewage treatment plants, as well as several incidences reported in the questionnaire survey and literature review, indicate the importance of high pH values on frothing in mixed liquor and final effluents. Thus, more information regarding the changes concommitant with increasing the pH of mixed liquor was needed.

A sample of mixed liquor, obtained from the effluent end of the aeration tanks at the Madison Metropolitan Sewage Treatment Plant, was altered by additions of NaOH to increase the pH in 0.5 unit increments from the initial pH of 7.42 to a pH of 10.0. Froth on the aeration tanks at the plant was approximately 5 feet in depth at the time the sample was taken. After adjustment of pH, the sample of mixed liquor was stirred with a magnetic stirring bar for 10 minutes; thereafter the pH was checked again and the sample was placed in the foam meters. Samples of the mixed liquor were used for persistency and surface tension measurements. Also, the sample of pH adjusted mixed liquor was centrifuged at 2000 RPM for 10 minutes for determinations of NH_3-N, organic-N, and ABS of the supernatant. The suspended solids concentration of the mixed liquor was 1610 mg/1.

The results of this study are presented in Figure (20) and Table IX. The froth persistencies and Σ values remained nearly constant up to and including pH 8.52. At pH 9.0 both the persistency and Σ increase markedly; thereafter, an increase in persistency is noted, but the Σ values increase at pH 9.5 and then decrease at pH 10.0. The surface tension remained essentially the same for all pH values. The ammonia nitrogen concentration varied but did not indicate a general trend. The organic nitrogen increased from 6.6 mg/1 at the initial pH to 8.4 mg/1 at pH 9.0 and then increased to 15.1 mg/1 at pH 9.5. The free ABS concentration increased from 5.4 mg/1 at pH 7.41 to 6.3 mg/1 at pH 9.0, and thereafter decreased slightly to 6.2 mg/1 at pH 10.0

Discussion

The results of these studies indicate those concentrations of ABS and degraded protein (bacto-peptone) in solution which are capable of inducing or enhancing frothing. The concentration of each is relatively low and there is an indication that the combination of the two increases the persistency and lifetime of the bubble in the foam over and above the effects of either alone.

The foam measurements used were generally in good agreement and both methods are used in subsequent studies. Foam measurements in tap water and mixed liquors are not of the same magnitude for similar concentrations of ABS as a result of interference produced by the presence of suspended solids in the mixed liquors. Subsequent multiple correlations remove the effect of suspended solids on foam measurement for comparing mixed liquors. Thus the influence of various factors, such as ABS and organic nitrogen are independently determined.

E. Fractionation and Analyses of Foams.

The fractionation of foam or measurement of accumulations in foam has been used by investors for finding the compound or compounds responsible for the foaming capacity of a solution. Perri and Hazel (6) determined the causative factors for foaming, in partially hydrolyzed soybean protein, by measuring concentrations of the breakdown products in the bulk and in the liquid of the foam. The accumulation of metaprotein and protein in the froth indicated that the foam was mainly caused by these substances.

Preliminary investigation in our studies revealed a preferential accumulation of organic nitrogen in the froth. The experiments indicated also that protein or degraded protein appeared to influence froth formation. Consequently, it was considered desirable to analyze the froth for organic nitrogen compounds.

Studies were made in the laboratory, and analyses were made of the foam collected from the aeration tanks at sewage treatment plants.

1. Laboratory Studies.

A sample, containing 10 mg/1 ABS and 300 mg/1 bacto-peptone in activated sludge acclimated to synthetic sewage, was placed in an inclined 1-liter test tube. The sample was aerated and the froth was collected in two portions. The first sample was collected during the first minute of frothing and the second during the second minute of frothing. Samples of the remaining solution, or bulk, were taken at the end of the aeration intervals. All samples were centrifuged for 10 minutes at 3100 RPM to remove suspended solids and the total organic nitrogen determinations were made on the supernatant. The suspended solids were considered to be merely transported by the foam and not contributory to foam formation. The experiment was repeated and the samples were filtered in place of centrifuging to remove suspended solids.

The results are presented in Table X.

TABLE X

		Samples Treated			
		By Centrifuging		By Filtration	
Aeration Interval	Sample	Total Organic Nitrogen mg/1	% Increase of Total Organic Nitrogen in Froth over Bulk	Total Organic Nitrogen mg/1	% Increase of Total Organic Nitrogen in Froth over Bulk
1st Minute	Froth	56	27	52	21
	Bulk	44		43	
2nd Minute	Froth	75	88	77	83
	Bulk	40		42	

The concentration of total organic nitrogen (TON) in the liquid of the froth is 20 to 30% higher than in the bulk, after 1 minute aeration, and 80 to 90% higher in the second minute aeration interval. It was noted that the frothing ability decreased after the first minute aeration interval. The change in accumulation of organic nitrogen between the 1st and 2nd minute, and in frothing ability, may be accounted for, either by a change in composition of the frother or a change of concentration of the frother. Determinations of ABS concentrations in the froth and in the bulk were not determined.

In a second run, in addition to TON determinations, surface tension, pH, persistency, and density measurements were made at intervals throughout a 70 minute aeration period.

Samples containing 200 mg/1 beef extract, 300 mg/1 bacto-peptone, 50 mg/1 urea, and 10 mg/1

ABS in Madison tap water were placed in four aeration tubes. Each tube was aerated at the same rate and samples of froth as well as samples of bulk were withdrawn from the first aeration tube for pH, surface tension, TON, and foam measurements. The samples withdrawn from the 1st tube were replaced with solution from the 2nd tube, and similarly the 2nd tube depletion replaced with solution from the 3rd tube. Consequently, the depletion of aeration liquid occurred in the 4th tube which minimized depletion effects in the sampling column. Samples of froth and aeration liquid were withdrawn simultaneously at various intervals during the aeration period.

The results are presented in Table XI and Figure 21.

The resulting analyses indicated:

1. An increase in surface tension from 45 dynes/cm to 66 dynes/cm occurred in the aeration liquid.
2. An increase pH from 7.7 to 8.1 occurred in the aeration liquid.
3. A slight decrease of TON in the aeration liquid.
4. The TON content of the liquid of froth remained approximately at the same level (140 mg/1) for the first 35 minutes and then increased to 254 mg/1 at 70 minutes aeration time.
5. The Σ values of the aeration liquid approached infinity and remained high throughout the first 35 minutes of aeration, after which they dropped markedly to approximately 20 seconds for the remaining aeration period.
6. The density of the froth decreased throughout the aeration.

It is worthy of note that the marked increase of TON accumulation in the froth occurred at nearly the same time as the drop in Σ. Apparently fractionation by foaming occurred with a removal of the ionic or molecular species having the greatest frothing tendency during the first 35 minute aeration interval, after which, either by change in composition or concentration of the first frother, the second frother accumulated in the liquid of the foam, in this case, additional compounds containing organic nitrogen. It may be assumed that, in the first aeration period, the liquid of foam contained an accumulation of ABS as evidenced by the steady increase in surface tension in the bulk indicating a depletion of the surface active material in the bulk solution. ABS concentration in the foam and bulk were not determined.

In the preceding experiments the compounds which contain organic nitrogen in the foam and the bulk were unknown. In the experiments described in this section a partial separation of nitrogenous compounds was made in order to determine which group of nitrogenous compounds were most influential in the frothing of the solutions tested.

Compounds which may contribute to the organic nitrogen content are proteins, polypeptides, amino acids, urea, NH_3, and amines. Proteins, and peptides larger than 50 amino groups, which can be precipitated with 5% trichloroacetic acid, were removed prior to organic nitrogen determinations.

A sample of mixed liquor, obtained from the influent end of the aeration tanks at the Madison Metropolitan Sewage Treatment Plant, was placed in a container and aerated. Samples of the froth, removed in three portions, and a sample of the bulk were filtered through a Gooch crucible with an asbestos mat to remove the suspended solids. Total organic nitrogen (TON) determinations of the filtrate are presented in Table XII under column heading "untreated". The remaining filtrates were precipitated with 5% trichloroacetic acid and filtered through a Gooch crucible after which TON determinations were made of the filtrates. The results are presented under the column headed "ppt with trichloroacetic acid" in Table XII.

The TON concentration did not significantly increase in the first two portions of the froth in the untreated samples, however; by comparison with the treated samples it will be noted for example for the 1st portion of the froth the TON in the untreated sample was 27.5 mg/1 and after treatment was 21.6 mg/1 indicating a removal of TON of 21.5%. This indicates that protein compounds, which are precipitated by trichloroacetic acid, may contribute to the formation of froth of the mixed liquor. The last portion of froth had an increase of TON, both in the treated and untreated samples. Of the TON determined, protein compounds increased approximately 36%, indicating a greater preferential accumulation of protein as the aeration continued.

TABLE XII

Sample Mixed Liquor Σ_c = 19.8 sec.	Vol. of Sample cc	TON mg/1 Untreated	TON mg/1 Filtrate after PPT with trichloro-acetic acid	% TON Removal by acid treatment
Bulk	15000	30.8	30.4	1.3
Froth 1st portion	15	27.5	21.6	21.5
Froth 2nd portion	12	32.8	28.9	11.9
Froth 3rd portion	15	80.0	51.1	36.2

2. Analysis of froths from sewage treatment plants

The analysis of samples of foam collected at sewage treatment plants have shown accumulation of ABS in the foam liquid in concentrations ranging from 950 to 2630 mg/1. Total organic nitrogen concentrations in the foams ranged from 139 to 371 mg/l. After dialysis of the foam liquid, approximately 63.5% of the ABS was retained and approximately 50% of the total organic nitrogen (TON) was retained. Assuming that the TON retained represented protein and degraded protein, the weight ratio of ABS to protein like compounds was 1.51:1. The retained ABS may have been associated with the proteins and higher peptides possibly bound by the dissociating side chain amino groups of proteins (7).

F. Syndet Distribution Studies

A limited investigation of the fate of ABS in mixed liquors was made, but measurements of ABS in mixed liquors in the presence of suspended solids has left some question as to the validity of results because of the inability to extract ABS quantitatively. However, it was noted that the amount of ABS associated with the suspended solids is quite high, approximately 70 to 90%.

Investigations at sewage treatment plants indicate that the percentage of ABS associated with the suspended solids is lower after aeration. Apparently this is caused by a shift in equilibrium of the amount of ABS adsorbed to the suspended solids when the air phase is introduced. The air bubbles rising through the liquid also have an affinity for ABS. Thus as the air bubbles emerge and break at the surface the adsorbed ABS remains in solution, causing a slight increase in the free ABS concentration. By increasing the rate of aeration and air bubble contact surface, this effect may become more pronounced.

Studies to determine the per cent of ABS associated with the suspended solids in the aeration tank during high and low flow and changes from influent to effluent ends were made at 2 activated sludge sewage treatment plants. The results are presented in the following Table, XIII additional information was presented in the report for the period ending January 31, 1957.

TABLE XIII ABS (Monsanto) mg/l

Sample	Total	Supernatant after centrifuging at 2300 RPM for 10 min.	% Adsorbed
High flow			
Influent Aeration	6.5	0.7	89
Effluent Aeration	7.3	2.0	73
Low flow			
Influent Aeration	8.6	0.9	90
Effluent Aeration	6.4	1.3	80

The total ABS concentrations of the mixed liquor were determined and a portion of each sample was centrifuged at 2300 RPM 10 minutes, and the ABS determinations were made on the supernatants. The per cent adsorbed or associated with the solids was calculated in each instance and are in reasonable agreement. It is noted from Table XIII above that at the influent about 90% of the ABS is associated with the suspended solids, and as aeration continues the per cent adsorbed decreases, until at the effluent between 73 and 80% of the ABS is adsorbed. This is in agreement with the studies carried out at another plant. Also, it is noted that the ABS concentration in the supernatant was low in both instances and frothing was not evident at the plant throughout this study.

G. Summary of Field Studies

The five sewage treatment plants selected for field study ranged in design capacities from less than 1 MGD to 200 MGD. Four of the plants use diffused air aeration and one plant used mechanical aeration. Grab samples were taken with due allowance for detention times in the various units. The samples were obtained at five points in the treatment processes during both high and low flows. Samples were taken at the following points:

1. After screening and grit removal, but before primary sedimentation,
2. The effluent of the primary sedimentation units,
3. The mixed liquor at a point in the influent end of the aeration unit,
4. The mixed liquor at a point in the effluent end of the aeration unit,
5. The final effluent from the final sedimentation unit.

The following analyses were made of each sample:

1. pH
2. Temperature
3. Alkalinity
4. Hardness
5. Suspended solids
6. Total solids
7. Dissolved oxygen
8. Electrode potential
9. Surface tension
10. Total organic nitrogen
11. Biochemical oxygen demand
12. Alkylbenzene sulfonate
13. Foam measurements

Also, samples of the mixed liquor were altered by increasing and decreasing the pH to determine these effects on frothing ability. ABS adsorption studies, froth analyses, and comparisons of the Monsanto method with the methylene blue determinations for detergent determinations were made.

The data for the five treatment plants were summarized by correlating the dependence of Σ, used as a measure of frothing ability, on the results of the chemical and physical analyses for each sample. For instance, all Σ values for screened sewage were plotted against the corresponding pH values, and likewise against electrode potential, temperature, etc. Thus, the values of each sampling point for all treatment plants were correlated with the corresponding Σ values. In addition, all values, with no regard to sampling point, for each determination were correlated with the corresponding Σ values. ABS concentrations were correlated also with suspended solids concentrations in the aeration units.

The results of the final effluent sampling points provided the most useful information. The analysis of the final effluent provides an estimate of the soluble constituents at the effluent end of the aeration unit. It is assumed that these constituents, in part, are capable of contributing to froth formation.

The values of Σ vs. pH of the final effluent are shown in Figure 22. The regression line is drawn for all values with the exception of City A. The values of City A were not included because the plant was overloaded on a flow volume basis and excessive amounts of grease were present. The grease tends to retard froth formation. The regression line is highly significant at the 99% confidence level unless a one in one hundred mischance in sampling has occurred. If the values of City A are included, the regression line is insignificant. The correlation coefficients were -0.101 and 0.930 corresponding to the values including City A and excluding City A respectively. Positive correlation indicates that high values of Σ are correlated to high values of pH and a negative value indicates the converse. Values near zero indicate no correlation. The increase in Σ with increase in pH is in agreement with studies on varying pH in the mixed liquors.

Similarly the field data were used to make correlations between Σ and corresponding values of total organic nitrogen (TON) and ABS of the final effluent. These data were presented and discussed in the report for the period ending January 31, 1957.

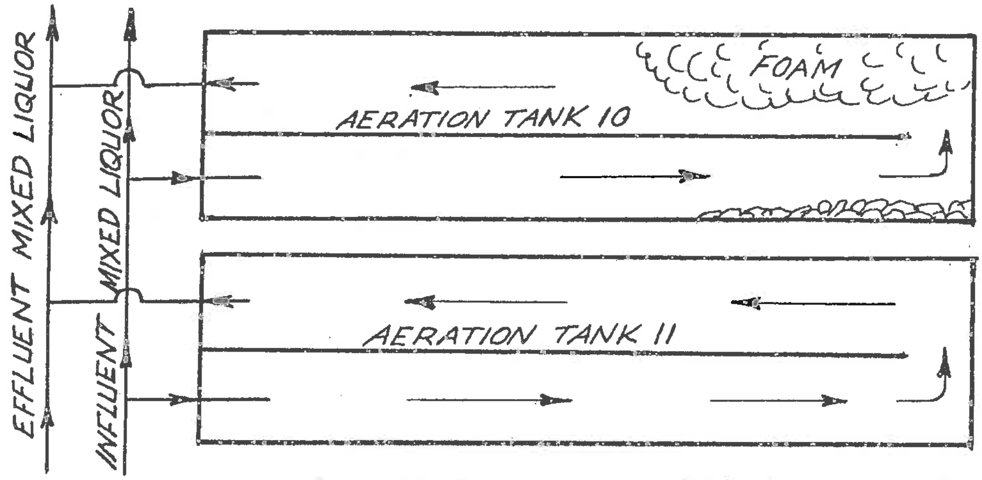
Because of the limited amount of data available for the statistical study it was felt that additional investigations were required before final interpretations and conclusions could be made. These additional studies were made and are presented in a subsequent section of this report.

The field study data however, did indicate a positive correlation between total organic nitrogen and ABS in relation to frothing as measured by the Σ value. Perhaps the most important gain from the field studies was the indicated importance of the soluble organic constituents of the mixed liquors, and the physical effect of the suspended solids.

In Figure 23 ABS concentrations in the mixed liquor were plotted against the suspended solids concentrations for both the influent and effluent end of the aeration tanks. A highly significant regression line results at the 99% confidence level and the resulting correlation coefficient is 0.935. This indicates higher concentrations of ABS in the mixed liquor with higher suspended solids concentrations. For a given suspended solids concentration it is well to note the range of ABS concentrations one may expect.

There are many unaccountable factors which influence the presence of frothing in sewage treatment plants. It was observed during the studies that the presence of floating greasy materials depress frothing in the aeration units. Sunlight and the resulting increased temperature differential across the foam film affect the evaporation and consequential thinning of the foam film, resulting in less quantity of froth on the aeration units. Air temperature, humidity and wind velocities also affect the quantities of foam on aeration units. Other factors such as industrial wastes may greatly influence the frothing tendency of the mixed liquor. These are a few of the conditions which influence frothing in sewage treatment and are difficult to evaluate. It was noted in one instance that the frothing subsides, or is not in evidence after periods of rain.

At one plant on November 3, 1956, frothing was noted on aeration units of a portion of the plant. Not all of the individual aeration units frothed however, and adjacent units were noted to differ in the amount of froth formation. A schematic sketch of the aeration units observed is shown in the sketch below.



The aeration rate to each unit, for all practical purposes, was essentially the same; 3300 cu ft./min. in tank 10, and 3500 cu. ft./min. in tank 11. However, the distribution of the air did not appear to be uniform as was noted by the movement of the liquid at the surface in each unit. Tank 11 with no foaming appeared to have uniform distribution of air whereas in tank 10 the distribution of air did not appear to be uniform. Greater surface velocities occurred where the froth formation was greatest as noted on the sketch.

The effect of increased mixing on froth formation is not known at this time. Froth on tank 10 accumulated as noted in the schematic sketch to depths of 3 to 4' whereas no accumulation of foam was noted on tank 11.

H. Effect of ABS on Rate of Oxygen Uptake in Water

A series of experiments were conducted to determine the effect of ABS on the rate of reaeration in tap water. The studies were conducted in several lucite columns one of which is shown diagrammatically in Figure 24. This apparatus was described in detail in the report for the quarter ending September 30, 1955.

The air supply to each column is individually metered by a calibrated orifice. Calibration of the orifice with a wet test meter permits accurate measurement of the air flow. All air flow measurements are adjusted to standard conditions of temperature and pressure. The rates of air flow selected for initial experimentation were 0.5, 1.0, and 1.5 cu.ft./gal. for a six hour aeration period. However, 1.5 cu.ft./gal. was used solely for experimental work because the bubble diameters were more constant than at the other two rates. The air to each tube was introduced through piping equipped with a needle valve. A tee was inserted in the piping to permit the use of nitrogen gas to strip the oxygen from the water.

Samples for dissolved oxygen determinations were collected in 150 ml. portions at time intervals of ½, 1, 2, 3, 4, 5, 10, 20, and 30 minutes.

The sampling cocks were inserted one meter from the bottom of the tubes. This was a convenient height at which to obtain the sample since the bubbles were well dispersed by this time in their travel to the surface of the water.

The sample of ABS used for the experimental work was Alkylate Mix 1, Sulfonation #1, Sample #2389, 4/20/55, Research and Development Dept., Colgate-Palmolive Co., Jersey City, N.J. The defoamer used to stop foaming of the ABS solution was made by the Hodag Chemical Company, Chicago, Ill., and carried the name, Hodag Antifoam, "KCM".

A photographic method was used to determine the bubble size for each run. The pictures were taken on reference points located two feet from the bottom of the tube. Pictures were taken of all seven tubes with tap water alone, and then defoamer and ABS were introduced to the tubes. After a five minute interval pictures again were taken.

In the study concentrations of ABS of from 0 to 7 ppm were used. One drop of antifoam was found necessary for control with concentrations of ABS of from 1 to 4 ppm. At 5 ppm ABS two drops of antifoam were needed, and with 6 and 7 ppm of ABS, three drops were required.

Runs were made also with only the antifoam present to determine its effect on the rate of oxygen solution.

Figure 25 illustrates the differences in bubble size when ABS is added to tap water. For determining the bubble sizes the photographs were enlarged and measurements were made directly from the photographs. The contact area was calculated from the bubble size and the instantaneous volume of air. These measurements were used in the determination of the oxygen transfer coefficient.

At least three runs were made at each concentration of ABS.

Results

Graphs were drawn showing per cent saturation of dissolved oxygen against time for all runs. For those runs in which no detergent or antifoam were present very little difference in the plottings was noted, indicating that there was no significant difference between tubes.

A summary graph of all the data taken is shown as Figure 26. With concentrations of 1 to 5 ppm ABS, indications are that the oxygen uptake is at a lesser rate than when no ABS is present. The graph indicates that at an ABS concentration of 5 ppm the oxygen uptake is at a greater rate than that obtained with lesser concentrations, but is still less than that when no ABS is present.

At ABS concentrations 6 and 7 ppm, the graph indicates that the oxygen uptake is greater than with no ABS present.

From the experimental data obtained computations of values of oxygen transfer coefficient were made using the procedure proposed by Ippen and Carver. (8).

The oxygen transfer coefficient K is expressed as

$$K = \frac{2.3\,W}{10^6\,A} \qquad \frac{\log_{10}\left(C_i - C_o / C_i - C_L\right)}{t}$$

where

A = instantaneous contact area of bubbles in ft^2

C_i = equilibrium concentration of oxygen at the gas liquid interface, ppm

C_L = concentration of oxygen in liquid at any time, ppm

K = coefficient of oxygen transfer-lbs of oxygen per hr per square foot per unit concentration difference

t = aeration time in hours

W = weight of water in aeration column in lbs.

C_o = initial concentration of dissolved oxygen in the liquid at $t = t_o$, in ppm

Table XIV presents a summary of the K values. The presence of defoamer lower the K value from a value of 155 cm/hr (the value obtained in tap water without defoamer) to 95.5 cm/hr (the value obtained with defoamer, but without ABS).

TABLE XIV

VALUES OF K OBTAINED BY COMPUTATION AND CORRECTED FOR PRESENCE OF DEFOAMER

ABS	DEFOAMER PRESENT	OBSERVED K	K CORRECTED FOR AVERAGE EFFECT OF DEFOAMER	K CORRECTED FOR DEFOAMER
ppm	drops	cm/hr	cm/hr	cm/hr
0	0	155	155	
0	1	104.9		
0	2	83.2		
0	3	80.2		
0	average of defoamer	95.5		
1	1	69.5	129	119.6
2	1	58.5	118	108.6
3	1	53.7	113.2	103.8
4	1	47.6	107.2	97.7
5	2	54.2	113.7	126
6	3	54.3	113.8	129.1
7	3	46.7	106.2	121.5

The use of the defoamer markedly affects the rate of oxygen uptake as evidenced by values of oxygen transfer coefficient K. To properly evaluate the effects of ABS additional data are needed using a defoamant that does not have so great an effect on the K values.

The data indicate that ABS lowers the oxygen transfer coefficient up to a value of 4 ppm. Above this concentration K begins to increase. This may be the result of the increased contact area that occurs when ABS is added.

V. FROTHING IN ACTIVATED SLUDGE-SEWAGE MIXTURES

As noted in the literature review and questionnaire survey, the frothing characteristics change from influent to effluent as the mixed liquor passes through the aeration tank. This indicates a change in the froth forming constituents of the mixed liquor. In order to more fully study some of these changes with respect to aeration time, three experimental aeration units were designed for batch operation. With the three units, three levels of a variable were studied during a single test period. Thus, samples could be withdrawn after a prescribed period of aeration and analyzed for factors which might contribute to froth formation.

A. Experimental Apparatus.

In the design of the experimental aeration units, primary consideration was given to the physical characteristics of the sludge. There is a tendency in the operation of an experimental aeration unit to over-aerate the activated sludge mixture in order to keep the particulate matter in suspension. Over-aeration usually results in dispersion of the floc which may change the physical characteristics. It was desired to aerate the sewage-sludge mixture at a rate comparable with general field practice, i.e. in the range of 0.5 to 1.5 cu. ft./gal/6 hr aeration. For small volumes of activated sludge-sewage mixtures the rate of aeration becomes small and the suspended solids may not be kept in suspension. In preliminary studies consideration was given to the use of a column which would permit the lower aeration rates. However, it was found that stratification of the suspended solids resulted.

Consequently, a unit was designed which was large enough volumetrically to permit aeration within the usual range and was equipped with mechanical mixing baffles to keep the solids in suspension. The units were designed for an operating volume of 45 liters. This was considered large enough to minimize the effects of depletion in volume resulting from taking samples.

The aeration tanks were constructed of stainless steel with a lucite front. Fillets were placed in the bottom corners to prevent accumulation of solids. The sampling outlet and drain was located in the center of the bottom. Figure 27 is a detailed drawing of one of the aeration tanks.

The four blade mixing baffles were constructed of lucite mounted on stainless steel shafts which extended through the back wall to the drive mechanisms. The baffles were rotated between 8 and 10 RPM throughout the experimental runs. A chain sprocket was attached to the end of each shaft with the center unit having two sprockets. Drive chains were connected to each of the side units from the center unit shaft which also was connected to the drive mechanism. The drive mechanism consisted of an electric motor connected to a Vickers hydraulic transmission which is capable of output with variable speed and direction, from constant speed input.

The air supply was individually valved and metered for each aeration tank through air-water manometers. Capillary tubing served as an orifice and the head-discharge curves were obtained by calibration with a wet test meter capable of reading to 1/1000 of a cubic foot. Air-mercury manometers were placed on the discharge side of the orifice to measure the gage pressure for subsequent air volume corrections to standard conditions. The metered air was distributed along the bottom on one side of the aeration tanks through three spherical diffuser stones. The porous stones were matched for head-discharge characteristics within each aeration tank to insure uniform distribution. In order to increase bubble contact time, the mixing baffles were rotated in a direction counter to the rise of the air bubbles. This caused the bubbles to traverse a path from the diffusers to the center of rotation and then to the surface. This is clearly noted in Figure 29 with water in the aeration tank.

A schematic sketch of the physical set up for the three aeration units is shown in Figure 30. Photographs of the aeration units including air measurement devices are shown in Figure 28.

B. Experimental Procedure.

Although the methods for processing samples and taking measurements were similar in both laboratory and field studies, a detailed discussion of the methods used is presented in sections 1 and 2. The laboratory studies utilized the experimental aeration units presented in the foregoing section, whereas the field studies were carried out using samples of mixed liquor from aeration tanks at the sewage treatment plants visited.

1. Laboratory Studies

The activated sludge was obtained from the sludge return box at the Nine Springs Sewage Treatment Plant, Madison, Wisconsin. The suspended solids concentration of the sludge ranged from 5,600 to 10,500 ppm and was procured approximately 16 hours prior to use within the experimental aeration units. The activated sludge was processed by screening with a 16 mesh screen at the time of procurement and aerated in a container prior to use in the aeration tanks.

The sewage substrate used in the experimental units was procured, approximately 2 hours before a run was made, from the effluent end of the primary sedimentation tanks at the Nine Springs Plant. The settled sewage also was screened prior to placement in the experimental units.

One hour before the run was started, 15 liters of the activated sludge were placed in each of the three experimental aeration tanks, followed by the addition of settled sewage to bring the total volume to 45 liters. The activated sludge and sewage in each of the three units were mixed with the rotating baffle mechanism at approximately 8-10 RPM without air application for 20 to 30 minutes preceding run time. The RPM used was adequate to keep the particulate matter in suspension, both prior to and throughout the experimental run.

Three-liter samples were withdrawn from the bottom sampling cock of each experimental unit before aeration was started and after 1, 2, 3, 4, and 6 hours of aeration. The aeration rate used in each unit for all runs, with one exception, was 1.0 cu. ft./gal of mixed liquor/ 6 hr. aeration period. In the one exception, the rate of aeration was varied among the units. Measurements of electrode potential and temperature were made simultaneously with sampling from each unit. For each of the 3-liter samples, approximately 400 ml was processed and used for chemical and biological analyses, the remainder was used for physical measurements, i.e., foam and surface tension measurements, and then returned to their respective units. The 400 ml portion for six sampling times represents an approximate depletion of activated sludge-sewage mixture of 2500 ml in each unit of the original 45 liter volume.

Three 250 ml portions from each 3 liter sample were used for the foam persistency measurements and 1250 ml was used for the determination of Σ in the foam meters. Persistency values used in the final analysis are averages of the 3 individual observations, whereas Σ values represent a single observation. The mixed liquor was returned to the aeration units after the foam measurements were made.

A portion of the 3-liter sample, approximately 50 ml, was used for surface tension measurements. These were made with the use of a Cenco Du Nouy tensiometer. Three samples were used on the surface tension measurements and the recorded values are the average of the three readings. The sample was returned to the experimental units. Similarly, the mixed liquor was returned after single observations of pH for each 3-liter sample.

Samples of mixed liquor were taken from each unit after 0,3 and 6 hours of aeration time and were preserved by refrigeration for subsequent suspended solids determinations. Suspended solids concentrations for the sample times after 1, 2, and 4 hours aeration were obtained by interpolation.

Portions of each 3-liter sample were processed for 5-day BOD, ammonia nitrogen (NH_3–N), organic nitrogen (Org. –N), and alkylbenzene sulfonate (ABS) determinations. Two-200 ml portions were centrifuged at 2000 RPM for 5 minutes followed by filtration of the supernatant through a Whatman #41 paper. The BOD dilutions were made of this filtrate immediately following filtration according to the methods prescribed by *Standard Methods*. The remaining filtrate, approximately 100 ml, was further processed by filtration through an AA milipore filter membrane and preserved by refrigeration for the ammonia nitrogen, organic nitrogen, and ABS determinations. The analyses of the clear filtrates were made two days after the samples were processed. The ABS determinations were made within a week after sample processing. The filtrate was kept refrigerated and remained clear throughout the analyses period.

Chemical and biological analyses were made of the primary effluent, and return sludge before their mixture. Samples of the "final effluent" were obtained by quiescent settling of the mixed liquor for a one hour period.

In order to study some of the operating conditions which may influence froth formation, as measured by foam measurements, certain conditions were varied to simulate operating conditions in the field. Descriptions of the operating conditions for the six runs are given below.

Run No. 1. This run was to serve as a control to determine the variation among experimental units for all determinations under presumably identical operating conditions. The run was incomplete as a result of mechanical operating difficulties.

An aeration rate of 1.0 cu. ft./gal/6 hr. was used and the mixed liquor consisted of 15 liters of return sludge and 30 liters of primary effluent.

Run No. 2. This run was similar to run no. 1 to determine the variation among experimental units over an 8 hour aeration period. The aeration rate was 1.0 cu. ft./gal/6 hr. and 15 liters of return sludge with 30 liters of primary effluent were used.

Run No. 3. The suspended solids concentration of the mixed liquor was varied in this experimental run. The return sludge was settled and aeration unit I received 15 liters of the supernatant (low suspended solids) and unit III received 15 liters of the more concentrated sludge to increase the suspended solids. Unit II received 15 liters of the return sludge before settling and each unit received 30 liters of primary effluent. The resulting suspended solids concentrations for the corresponding units I, II, III were approximately 2400, 3400, and 4300 ppm.

The aeration rate for all units was 1.0 cu. ft./gal/6 hr.

Run No. 4. The ABS concentration was increased above the concentration initially present in the primary effluent. Unit I received the primary effluent *per se*, whereas units II and III received primary effluent with ABS additions equivalent to 3 mg/l and 5 mg/l respectively. Each unit received 15 liters of return sludge and 30 liters of primary effluent. The aeration rate was 1.0 cu. ft./gal/6 hrs.

Run No. 5. Digester supernatant was added to two of the experimental units with the other serving as a control. Unit II received 30 liters of primary effluent whereas units I and III received 27 and 24 liters of primary effluent respectively. The remainder of the 30 liters in units I and III, i.e., 3 and 6 liters, was digester supernatant which had been settled for 12 hours. These amounts of digester supernatant correspond to 10 and 20% by volume of the primary effluent. The supernatant was obtained from the Nine Springs Sewage Treatment Plant.

An aeration rate of 1.0 cu. ft/gal/6 hr and 15 liters of return sludge were used in each experimental unit.

Run No. 6. The rate of aeration was varied from 0.5 to 1.5 cu. ft./gal/6 hr. in this run. The rates of aeration were 0.5, 1.0, and 1.5 cu. ft./gal/6 hr. for units I, II, and III respectively. As in the previous runs the rates of aeration were corrected for pressure and temperature to standard conditions. Each unit received 15 liters of return sludge and 30 liters of primary effluent.

The results of these runs are presented in section V C.

2. Field Studies

In order to include data from other sewage treatment plants, field surveys of 7 treatment plants in Wisconsin were made. The procedures for determinations were similar with slight modifications in a few instances. Three sets of observations were desired from each treatment plant and grab samples of mixed liquor were taken from influent end, effluent end, and an intermediate point in the aeration tanks.

Measurements of electrode potential were made at the sampling points within the aeration tanks. In some instances, photographs of the frothing conditions at the time of sampling were made.

Foam measurements, pH, temperature, and surface tension were determined on the mixed liquor sample at the sewage treatment plant. A portion of the mixed liquor was iced for subsequent suspended solids determinations in the laboratory. The portion of sample processed for BOD did not receive centrifuging as in the laboratory studies, but was filtered through Whatman #41 filter paper, preserved by icing, and the BOD dilutions were made upon return to the laboratory. The portion of the sample for the organic nitrogen, ammonia nitrogen, and ABS determinations was filtered through a Whatman#41 paper and a type AA milipore membrane filter in the field. The filtrate was preserved by refrigeration until analyzed in the laboratory.

The nitrogen and BOD analyses were made within a day after the samples were collected and the ABS determinations were made within a week.

C. Results

The results of the aeration tank studies are presented graphically for each run in Figures 31 to 40. The changes in the values of the various factors are plotted with respect to aeration time. The summary tables, including the treatment plant survey, are presented in Tables XV through XXI.

Certain measurements were made on the membrane filtrate of the mixed liquor samples and others on the mixed liquor samples. Concentrations of ABS, ammonia-nitrogen, and organic nitrogen are of the AA milipore membrane filtrate. Determinations of BOD were made on filtrate through Whatman #41. All other measurements were made of the mixed liquor samples, excepting "persistency (2000)" and (3000)" and "Σ (2000)" and (3000)". These were obtained by applying a correction for suspended solids concentration using figures 10 and 11 in the following manner.

For any measured value of persistency in seconds and corresponding suspended solids concentration, a point was located on Figure 10 and a line was drawn through this point on a slope approximately the same as that of the adjacent lines. The corrected persistency value was read for the points corresponding to the intersection of the line drawn and the ordinate drawn at the 2000 and 3000 mg/l suspended solids concentration. Similarly, values of Σ were corrected to the 2000 and 3000 mg/l suspended solids concentration by the use of Figure 11.

A study of each run showed the following:

Run No. 1. Each aeration unit was prepared and operated under similar conditions to serve as a control. The run was incomplete as a result of mechanical difficulties ~~and~~ the data available were inadequate to warrant discussion.

Run No. 2. This run was the complete test for control purposes and the results are presented in Figs. 31 and 32, and Table XVI. The three aeration units gave similar results for corresponding aeration times with the exception of pH values in Unit I. No apparent explanation is available for this variation. Persistency and Σ values indicate the amount of variation one can expect in the measurement of these values for similar aeration times and units. The results from the three units checked each other within limits that were considered satisfactory. As a result of this run it was concluded that parallel operation of the units gives comparable results.

Run No. 3. The suspended solids concentration was varied at three levels for this run. The concentrations for units I, II, and III, respectively were 2400, 3370, and 4260 ppm. The results are presented in Figs. 33 and 34 and Table XVII. Higher values of NH_3–N are noted with the higher suspended solids concentrations. Froth persistency measurements are lower for higher suspended solids concentrations. However, this is not true of values of Σ. Other factors such as NH_3–N may influence Σ more so than they influence persistency measurements. It has been noted in some instances, that the suspended solids are transported to the foam when the sample is undergoing aeration for the Σ measurement. These solids tend to obscure the observation of the foam-air interface. This effect become more pronounced at higher suspended solids concentrations. The electrode potential measurements are lower for the higher concentrations of suspended solids for the same aeration interval.

Run No. 4- The results of run no. 4 are presented in Figs. 35 and 36, and Table XVIII. The ABS concentration was increased in two of the experimental units. Unit I served as a control and contained approximately 2 ppm of free ABS. To Unit II 3 mg/l of ABS and to Unit III 5 mg/l were added. Higher concentrations of free ABS are reflected in the persistency values. Other factors are relatively unaltered under the test conditions.

Run No. 5. Digester supernatant was added to units I and III. The results are shown in Figs. 37 and 38 and in Table XIX. The presence of digester supernatant decreases the persistency values after 2 hours of aeration as noted in comparing units I and III with the control unit II.

Run No. 6. In this run the rate of aeration was varied for the three units. Aeration rates were for Units I, II, & III, respectively 0.5, 1.0, and 1.5 cubic feet of air per gallon of mixed liquor for the six hour aeration period. The plotted data are shown in Figs. 39 and 40, and are given in Table XX. In general, the persistency values are lower for aeration unit III than for units I and II and similarly the free ABS concentrations are lower for the higher rates of aeration.

D. Simple Correlation Studies

The simultaneous sets of data used in the correlation studies are given in the summary data tables XV through XXI. Complete sets of data for all factors are essential for correlation work, therefore, not all the data were used where missing values occurred. The data for City C, Wisconsin Table XXI was not used because defoamant was applied during the sampling period. Data in which the foam measurement Σ_c rather than Σ was computed were not used in the correlation studies.

Measured values of persistency and Σ, without regard to suspended solids concentration, as well as values of persistency and Σ corrected to 2000 and 3000 mg/l suspended solids concentration were used in the correlation studies. A preliminary plot of the data revealed that persistency was related to various factors exponentially. Therefore logs of persistency values were correlated with the various factors considered also. Persistency, log persistency and Σ values, with and without correction for suspended solids for two different values were used as the dependent variables, thus 9 dependent and 8 independent variables were used. The 8 independent variables were ABS, NH_3–N, organic nitrogen, pH, B.O.D., electrode potential, temperature and suspended solids. In addition, correlation computations were made with and without the data on mixed liquor samples containing digester supernatant from run No. 5. These values are denoted by a + in the tables XV through XXI for the column headed, "data used in correlation studies."

The simultaneous sets of data were punched on IBM cards and the correlation computations were made with an IBM type 650 magnetic drum data processing machine in the Numerical Analysis Laboratory of the University of Wisconsin. The correlation routine used computes correlations according to the Pearson formula:

$$r_{yx} = \frac{N\Sigma YX - \Sigma Y\Sigma X}{\sqrt{[N\Sigma Y^2 - (\Sigma Y)^2][N\Sigma X^2 - (\Sigma X)^2]}}$$

Other results obtained in this procedure are:

ΣY, ΣY^2, $\bar{y}$, σ_y, N, ΣX, ΣX^2, $\bar{x}$, σ_x,

and ΣYX for each pair of factors x and y.

Where:

r_{yx} = simple correlation coefficient
ΣY = sum of the Y observations
ΣY^2 = sum of the squared Y observations
$\bar{y}$ = mean of the Y observations
σ_y = standard error of Y
N = number of observations
ΣX = sum of the X observations
ΣX^2 = sum of the squared X observations
$\bar{x}$ = mean of the X observations
σ_x = standard error of X
ΣYX = sum of the products of X and Y

The results of the simple correlations are presented in Table XXII. This table contains the simple correlation coefficients for many combinations of factors, some of which, possible, should not be correlated. The significance of the correlations is indicated by one or two asterisks corresponding to the 95% and 99% confidence levels.

The data are plotted for various combinations of factors and the computed regression lines for the data were drawn. These graphs are presented in figures 41 through 95. Two regression lines are drawn for each graph. The solid line represents the regression line for 104 sets of data which includes all the data for samples of mixed liquor noted in tables XV to XXI. The broken line represents the regression line for 92 sets of data which excludes the data for samples of mixed liquor from Run No. 5 which contained digester supernatant.

With reference to Table XXII the correlation coefficient limits for the 104 and 92 sets of data are presented in the note at the bottom of the table. For each correlation coefficient the two factors are found in the row and column where the value appears.

The simple correlation coefficient r measures the amount of co-relationship between the two variables and may vary in magnitude from a −1 to +1. For values of r close to +1, one finds high values of one factor for corresponding high values of the other factor and likewise, low values of one for low values of the other. Also, for values of r close to −1, one finds low values for one factor for corresponding high values of the other factor. A correlation coefficient of +1 or −1 indicates all the data lie on a straight line. For values of r near 0 a random assortment of data is indicated. In some instances, the variable measured may not have a direct influence on frothing but may represent conditions which are associated with frothing.

Discussion.

1. A highly significant correlation was obtained between the foam measurements, Σ and persistency, as indicated by the r values, 0.529 and 0.524, corresponding to 92 and 104 sets of data. The correlation coefficients between the two foam measurements increase markedly when logs of the persistency values are correlated with the corresponding Σ values. The r values for

measured Σ and log persistency were 0.776 and 0.759 for 92 and 104 sets of data respectively.

When Σ and persistency were corrected for suspended solids to the 3000 mg/l concentration, the agreement between the two measurements improves as evidenced by the increase in r to 0.602 and 0.597, however, no change in r is noted at the 2000 mg/l suspended solids level. Values of r for log of persistency and Σ measurements decrease when the suspended solids correction is applied. The greatest decrease is noted at the 2000 mg/l suspended solids concentration which indicates that the corrections applied can not be considered representative for the mixed liquor samples used. The average suspended solids concentration of the mixed liquor samples was closer to 3000 mg/l than to 2000 mg/l suspended solids. This may account for the higher r values at the corrected 3000 mg/l level than for the values at the corrected 2000 mg/l level. If the corrections applied were representative of the effect of suspended solids on foam measurements, than one would expect that corrections for suspended solids concentration to either 3000 or 2000 mg/l, would result in values of r of the same magnitude. Therefore, these results indicate that the corrections applied for suspended solids concentration in the mixed liquor samples is invalid.

Although the foam measurements are in good agreement, the following discussion of the effects of various factors on the foam measurements, indicate that the factors measured affect the two different foam measurements persistency and Σ to a different degree, and in some instances in a completely opposite manner. Data for this correlation are plotted on Figs. 41 through 46.

2. A highly significant correlation is obtained between the free ABS concentration and the froth measurements persistency and Σ, with and without correction for suspended solids. This highly significant correlation was noted for both 104 and 92 sets of observations. The correlation was higher for the measured values of persistency and Σ than for the values corrected for suspended solids concentrations.

The free ABS in the mixed liquors ranged from 0.41 to 3.35 mg/l.

Data for these correlations are plotted on Figures 47 through 55.

3. A highly significant correlation is obtained between froth measurements and the ammonia nitrogen concentration of the membrane filtrate of mixed liquor samples excepting those samples containing digester supernatant from run No. 5. The ammonia nitrogen concentration of the mixed liquor filtrates for this correlation ranged from 1.0 to 36.5 mg/l.

Data for these correlations are plotted on Figures 56 through 64.

When the data for mixed liquor samples containing digester supernatant are included, a highly significant correlation was obtained between ammonia nitrogen and the corrected values of Σ. Significant correlation was noted for the measured value of Σ and one corrected value of persistency. Because ammonia nitrogen is correlated to suspended solids, a correction for suspended solids applied to the foam measurements may account for the higher value of r for the corrected foam measurements.

When measured values of foam measurement are used and the digester supernatant data are included, the correlation coefficients between foam measurements and ammonia nitrogen are less significant. The ammonia nitrogen concentrations ranged from 1.0 to 79.6 mg/l when the samples containing digester supernatant were included.

An explanation for the highly significant correlation of ammonia nitrogen to frothing is unavailable. The highly significant correlation may be a result of conditions or characteristics of the sewage, factors which were not measured in this correlation, that tend to enhance frothing when ammonia nitrogen concentrations are high.

Preliminary studies of varying concentrations of NH_4Cl in tap water containing 3.0 mg/l ABS have indicated only minor changes in frothing ability. Also, the ammonia nitrogen concentration of digester supernatant does not correlate significantly with foam measurements. This may be the result of other compounds present in digester supernatant which may tend to inhibit frothing.

4. The results obtained from the correlation of organic nitrogen concentrations to the two froth parameters were not in agreement. There is a tendency, with no significance, for lower values of persistency to be correlated with higher concentrations of organic nitrogen as evidenced by the negative correlation coefficients.

Data for these correlations are plotted in Figures 65 through 70.

A significant positive correlation is obtained between organic nitrogen and corrected values of Σ. It is noted, however, that the organic nitrogen values are positively correlated with the suspended solids concentrations and therefore would influence the correlation results when the corrected foam values are used.

The organic nitrogen concentrations in the mixed liquor filtrates ranged from 1.5 to 10.7 mg/l.

In general, the data indicate that the effect of organic nitrogen is insignificant. This is not in agreement with previous studies of frothing using organic solutions containing peptides and degraded protein products, i.e. bacto-peptone, which indicated higher stabilizing effects on froths with higher concentrations of bacto-peptone. However, the organic nitrogen determination made of the mixed liquor filtrates is a gross measurement of many forms of organic compounds containing nitrogen, some of which, may inhibit froth formation. The type of organic compounds which were measured as organic nitrogen in the mixed liquor filtrate were unknown. A detailed analysis of the filtrate would be of value for use in evaluating the influence of protein degraded products on froth formation in mixed liquors. The range of concentrations of organic nitrogen encountered in these mixed liquor samples was low. Concentrations of organic nitrogen of mixed liquor in excess of 11 mg/l have been encountered in preliminary studies.

In the studies discussed in section IV, there was a marked increase in frothing at a concentration of 15 mg/l bacto-peptone. This concentration corresponds to 2.5 mg/l of organic nitrogen. For sewage this is considered to be a low concentration. However, the bacto-peptone represented by this organic nitrogen concentration has been shown to be capable of enhancing foaming, but bacto-peptone is not representative of a number of the compounds which contribute to the organic nitrogen of mixed liquor filtrates.

5. A highly significant correlation was obtained for persistency and log persistency with pH for a range of pH values from 7.2 to 8.1.

Data for these correlations are plotted in Figures 71 through 76. A significant relationship was not obtained for Σ and pH values, although a positive correlation is indicated. These results are in agreement with incidences of frothing reported in the literature, as well as with observations of frothing made by plant operators, that were reported in the questionnaire survey. (See Section IV)

The positive correlation of frothing to pH may be a result of higher concentrations of free ABS with the higher pH values. The anionic ABS tends to desorb at higher pH values. Other characteristics of the mixed liquor may contribute to frothing at the higher pH values.

6. The BOD of the filtered samples is not correlated to the persistencies but a significant positive correlation is obtained with Σ.

Data for these correlations are plotted in Figures 77 through 79. The BOD concentrations of the #41 Whatman filtrates of mixed liquor samples ranged from 1 to 197 mg/l. It is noted that the BOD of the mixed liquor samples decreased with respect to aeration time. Thus, the significant positive correlation of frothing (Σ) to BOD, indicates that frothing is less as treatment is affected which is not in agreement with reports in the literature of greater frothing of the mixed liquor at advanced stages of aeration.

However, in simple correlations, the effects of other factors are not taken into consideration. For example, in the laboratory studies, the free ABS concentration decreased as the aeration interval became longer and similarly the foams produced became less persistent. But in studies at activated sludge-sewage treatment plants where sampling was controlled to allow for detention within the aeration tank, the concentration of free ABS of the mixed liquor in the influent end was lower than the free ABS of the mixed liquors in the effluent end. This may account for part of the increase in frothing with an increase in aeration time under treatment plant conditions. In laboratory units, the surface area to volume ratio is much higher, as well as the ratio of side wall length to unit volume which may account for the decrease in free ABS with an increase in aeration time. The froth produced in the laboratory aeration units, which is high in ABS content, would adhere to the walls of the aeration vessel tending to reduce the overall free ABS concentration in the mixed liquor.

7. A highly significant negative correlation was obtained between the electrode potential, E_h and values of Σ and logs of persistency.

These data are plotted in Figures 80 through 88.

The persistency values as measured were negatively correlated, but were not significant at the 95% confidence level. The range of E_h values used in this correlation was from +75 to +393.

In activated sludge-sewage treatment processes the electrode potential is higher with longer intervals of aeration. Thus the highest potential would be found at the effluent end of the aeration tanks. The negative correlation, indicates that frothing would be at a minimum at this point.

As noted in the foregoing item 6 for BOD these results do not agree with many observations indicating maximum frothing at or near the effluent. However, other reports in the literature (9) have indicated less frothing with a higher degree of treatment and nitrification. The degree of nitrification was not determined in these studies.

8. The temperature of the mixed liquor samples is highly significantly correlated to persistency, but not to values of Σ. The range of temperatures of the mixed liquor samples was from 12°C to 22°C.

Data for these correlations are plotted in Figures 89 through 94.

The reason for the positive significant correlation to persistency and not to Σ is not readily apparent. However, the persistency measurement was made within a stoppered vessel where evaporation effects of the foam film were minimized as opposed to the open end column used in the Σ measurement. Also, a greater temperature differential would result between the sewage and the air surrounding the foam which may increase evaporation effects in the Σ measurement. Possibly a greater influence of temperature effects on foam measurements would be noted if air temperatures were used rather than sewage temperatures.

9. A significant negative correlation was obtained for suspended solids and measurements of persistency for 104 sets of observations. The correlation coefficient was –0.208. When log persistency values were used there was no correlation with suspended solids, and similarly there was no apparent relationship with Σ.

The variation in suspended solids was from 360 mg/l to 4260 mg/l.

These results are not in agreement with those obtained in the section on foam measurement. In Section II it was shown that, for a single mixed liquor sample, if the suspended solids was varied, this would have a direct relationship on resulting foam measurements. That is, the correlation would closely approximate 1. However, the results of these studies indicate that the relationship between suspended solids and foam values for different mixed liquor samples are not the same.

The Σ measurements are positively correlated to suspended solids but not significantly. A more thorough evaluation of the affects of suspended solids will be evident from the multiple correlation results.

10. A significant negative correlation for free ABS concentration of the mixed liquor to suspended solids concentration indicates that free ABS is lower for higher suspended solids concentrations. See Figure 95. This is important in its relationship to the control of frothing in sewage treatment plants. It has been noted in various sewage treatment plants that, by increasing the

suspended solids, frothing was reduced. This may have been a result of the lowering of the free ABS concentration by increasing the suspended solids and consequently decrease persistencies. The combined effect of lower free ABS concentrations and higher suspended solids concentrations may accomplish the decrease in persistency.

It may be possible, under certain plant operating conditions, through more rapid growth of suspended solids, to adsorb additional ABS and through subsequent wasting of sludge lower the free ABS concentration and thus reduce frothing. It should be noted in Fig. 95 that the amount of free ABS varies considerably for a given suspended solids concentration. This may be the result of variations in rates of aeration and in the adsorptive capacity of the suspended solids at different plants.

11. A simple correlation was made to determine the affect of free ABS on surface tension in mixed liquor samples. Two correlations were made for concentrations of ABS from 1 to 2.6 mg/l and for concentrations in excess of 2.6 up to a concentration of 6.5 mg/l. In both instances, a highly significant correlation was obtained. The results of this correlation are presented in Figure 96. The correlation coefficient for the ABS concentrations in the range of 1 to 2.6 was a –0.833 and the correlation coefficient for the ABS concentrations in the range 2.6 to 6.5 was –0.802.

The results of this study indicate quite clearly that the free ABS concentration has a marked influence on the surface tension of mixed liquors. The effect is more pronounced for concentrations less than 2.6 ppm. as noted by the slopes of the regression lines in Figure 96.

E. Multiple Correlation Studies.

The limitation of simple correlations are readily apparent when more than two independent factors tend to be positively or negatively related to the dependent variable which, in this case, is frothing. Thus, it is more desirable to evaluate the results by multiple linear correlation techniques. From the results obtained, inferences regarding the relationship and significance of each variable, independent of the other measured variables, can be drawn.

A summary of the results obtained are presented in Table XXIII.

The dependent variables used as frothing parameters were persistency and Σ as measured, log of measured persistency, persistency and Σ corrected to 3000 mg/l suspended solids concentration. Eight independent variables; ABS, ammonia nitrogen, organic nitrogen, pH, BOD, E_h, temperature, and suspended solids were used excepting when the corrected values of persistency and Σ to 3000 mg/l suspended solids concentration were used as the dependent variable. When the foam measurements were corrected for suspended solids then the independent variable, suspended solids, was not included.

The multiple correlation computations were made for 104 simultaneous sets of data, including mixed liquor samples containing digester supernatant from run No. 5, and for 92 sets of data, excluding samples of mixed liquor containing digester supernatant from run No. 5. In addition, persistency and Σ, as measured, were correlated for 94 and 82 sets of data. The 94 sets includes all mixed liquor samples, excepting those obtained from the sewage treatment plant survey presented in Table XXI. The 82 sets includes all samples, excepting those from the sewage treatment plant survey presented in Table XXI, and those samples of mixed liquor containing digester supernatant from run No. 5.

For each multiple correlation the factors are evaluated on the basis of the partial correlation coefficients $r_{12.34--9}$ with the significance indicated by asterisks; the multiple coefficients of determination $R^2_{1.2--9}$; the multiple regression equation, with the partial regression coefficients $b_{12.3--9}$; the constant $A_{1.23--9}$ in the regression equation; and the standard error of the partial regression coefficient $S_{b_{12.3--9}}$.

The coefficient of partial correlation, $r_{12.3--9}$, is useful for determining the importance of each variable individually in relation to the dependent factor thus eliminating the association with the remaining variables.

The multiple coefficient of determination, $\bar{R}^2_{1.2--9}$, is useful in determining the amount of variation of the dependent variable which can be explained by the independent factors considered. For example, in the first multiple correlation A, for 104 sets of data using persistency as the dependent variable, $\bar{R}^2_{1.234--9} = 0.597$, or in other words, 59.7 per cent of the variation in the dependent variable is explained by the 8 measured independent factors and thus 40.3% of the variation remains unexplained. Part of the unexplained variation in the dependent variable is a result of the variation in the foam measurement used.

The multiple regression equation, has the general form

$$\hat{Y}_1 = A + f_1(X_1) + f_2(X_2) + f_3(X_3) \ . \ . \ . \ . \ . \ . \ . + f_8(X_8)$$

which is useful in determining the relationship between the dependent and independent variables. This equation serves to sum up the evidence into a single statement which applies for the range of each variable used. The partial regression coefficients, or net regression coefficients, $b_{12.3--9}$, $b_{13.2--9}$, etc. gives the average increase or decrease depending on sign (+ or –) in the foam measurement for increases in the independent variables such as ABS, ammonia nitrogen, etc. For each of the partial regression coefficients the standard errors $S_{b_{12.34--9}}$ are also determined. For example, in equation A in Table XXIII, the partial regression coefficient $b_{12.34--9}$ for factor X_1, (ABS), is 29.2 sec for each mg/l of ABS with a standard error $S_{b_{12.34--9}}$ equal to $\pm$ 4.97, or $b_{12.34--9}$ is expected to lie within the range of +24.2 to 34.2 seconds increase in persistency for each mg/l increase in ABS. It is noted that for the factors which are not significantly correlated to persistency, as indicated by the partial correlation coefficients, the standard error $S_{b_{13.245--9}}$ is greater than, or large in proportion to, the partial regression coefficient $b_{13.245--9}$. For example, in multiple correlation A Table XXIII, the standard error $S_{b_{13.245--9}}$, 2.22, the factor X_3, organic nitrogen, is 55 times greater than the partial regression coefficient $b_{13.245--9}$; – 0.041.

The highest multiple coefficient of determination $\bar{R}^2_{1.2--n}$, was obtained in multiple correlation D when logs of persistency were used as the dependent variable. This was a 9 variable multiple correlation without the data for mixed liquor samples containing digester supernatant from run No. 5. This value was 0.788 or 79% of the variation in the independent variable, persistency, was explained by the measured factors. When Σ was used as the dependent variable, the highest $\bar{R}^2_{1.2--n}$, value (0.670) was obtained when the data from mixed liquor samples containing digester supernatant were excluded. It appears that when the data from the samples of mixed liquor containing digester supernatant are included in the correlation, additional variation is noted in the dependent variable. This is a result of introducing a condition or compounds which are evidently not accounted for in the measured independent variables. This adverse affect on the frothing parameter is not understood at this time.

When both measurements of persistency and Σ are used as the dependent variable for the multiple correlations similar results are obtained as evidenced by the $\bar{R}^2_{1.2--n}$ values for correlations A, B, C, D, and F, all of which are in excess of 0.597. A 60% accountability for the variation in these foam measurements is high considering the difficulty in reproducing foam measurements in the interpretation of the values measured, and because of the heterogeneity of the mixed liquor samples tested.

The accountability of the variation in the dependent variable decreases when the foam measurements were corrected for suspended solids concentration to the 2000 and 3000 mg/l concentration level. In these correlations, the suspended solids variable was excluded, thus, 8 rather than 9 variables in the multiple correlations were used. This reduction in $\bar{R}^2_{1.2--n}$ reconfirms the results of the simple correlations, that the correction applied to the foam measurements is invalid.

The $\overline{R}^2_{1.2--n}$ values are not decreased appreciably when data from the sewage treatment plant survey are excluded, however, the $\overline{R}^2_{1.2--n}$ values drop considerably for the multiple correlations using Σ as the dependent variable, exclusive of digester supernatant and sewage treatment plant survey samples. This is a result of eliminating the samples of mixed liquor having low ammonia nitrogen concentrations in the sewage treatment plant survey samples. These low ammonia nitrogen samples also had low Σ values, which were interrelated in the positive correlation results between Σ and ammonia nitrogen values.

The following discussion of the independent variables will be exclusive of the multiple correlations which used persistency and Σ values as corrected for suspended solids, as the dependent variables. Table XXIII is used as the reference for this discussion:

1. In all correlations excepting one, i.e. multiple correlation D, free ABS was highly significantly correlated to the froth measurements, Σ and persistency.

The ABS concentrations encountered, ranged from 0.41 to 3.35 mg/l. The partial regression coefficients for ABS and persistency ranged from 25.4 to 30.7 seconds of persistency per mg/l of free ABS of the mixed liquor samples tested. Considering standard errors, this range of partial regression coefficients for persistency can be extended from 20.0 to 36.8 seconds per mg/l free ABS.

The range of partial regression coefficients for Σ, when it is used as the dependent variable, was 2.7 to 3.4 seconds per mg/l ABS. This range becomes larger when considering the standard errors of the regression coefficients. This range is from 2.2 to 4.0 seconds per mg/l of ABS.

2. A significant correlation between ammonia nitrogen and frothing, as measured by Σ and persistency, is not evident when all simultaneous sets of observations are used in the multiple correlations. However, when the data from run No. 5 for samples of mixed liquor containing digester supernatant are excluded, a highly significant positive partial correlation coefficient is obtained. This is noted in correlations D and F when logs of persistency and Σ are used as the dependent variables. The partial regression coefficients for Σ, in correlation F, range from 0.187 to 0.287 seconds per mg/l of ammonia nitrogen. The ammonia nitrogen concentrations used in correlations D and F ranged from 1.0 to 36.5 mg/l with nearly all the observations in the concentration range of 28 to 35 mg/l.

When the data from the sewage treatment plant survey were excluded for correlations K and M, highly significant negative partial correlation coefficients result between the ammonia nitrogen and the foam measurements, persistency and Σ.

The grouping of the data and the effects of excluding data in part explain the apparent anomaly of these results. For instance, in Figure 62, the data for samples of mixed liquor containing digester supernatant from run No. 5 are represented by a + symbol. These data are in two groups of six samples: one group with the concentration range of 50 to 56 mg/l ammonia nitrogen for aeration unit I and the other group with the concentration range of 74 to 80 mg/l for aeration unit III. When these data are excluded in the multiple correlation; a positive correlation is obtained between the remaining values of Σ and ammonia nitrogen. However, when the data for the samples of mixed liquor containing digester supernatant are included, the correlation between Σ and ammonia nitrogen is insignificant. This is true also for multiple correlations A and C. The ammonia nitrogen concentrations ranged from 1.0 to 80 mg/l when all the data are included.

Regarding the effects of including or excluding the data from the sewage treatment plant survey, the ammonia nitrogen concentrations of these samples range from 1.0 to 31.9 mg/l representing 10 samples. When these data are included in the absence of data from samples containing digester supernatant from run no. 5 a highly significant positive correlation results between ammonia nitrogen and frothing measured as Σ and logs of the persistency values (see correlations D and F). However, when these data are excluded in the absence of data for samples of mixed liquor containing digester supernatant a non-significant correlation results between ammonia nitrogen and frothing as indicated by multiple correlations L and N. The range of ammonia nitrogen concentration for these correlations representing 82 samples was from 28 to 35 mg/l. When the data for samples of mixed liquor from the sewage treatment plant survey are excluded and the data for samples of mixed liquor containing digester supernatant are included, a highly significant negative correlation results between ammonia nitrogen and Σ or persistency as indicated in multiple correlations K and M. The ammonia nitrogen concentrations ranged for this combination of data from 28 to 80 mg/l.

Data grouped in this manner are not readily adapted to statistical evaluation. Further analyses of equilibrium mixtures would have to be made to determine the relationship of ammonia nitrogen concentrations to frothing.

3. As in the simple correlation, the results for the multiple correlations between frothing and organic nitrogen are insignificant. The discussion presented in the simple correlation section applies here also.

4. A highly significant positive correlation was obtained between pH and persistency measurements for both correlations A and B, which represent data for the samples of mixed liquor with and without the presence of digester supernatant. When logs of the persistency values were used as the dependent variable, a significant correlation was obtained as shown in correlation D. The Σ values are not significantly correlated to pH values.

A narrow range of pH values were encountered and the partial regression coefficients for persistency and pH were high, i.e. from 61.9 to 67.4 seconds per unit of pH. The pH operating range in sewage treatment plants are usually limited also. The high partial regression coefficients indicate the relative importance of high pH values when related to the persistency in frothing. These results confirm the field experience where severe frothing conditions are noted with high operating pH's as a result of seasonal treatment of alkaline wastes.

The pH factor accounts for most of the negative multiple correlation constants in the regression equation. For example, in multiple correlation A, the constant of the multiple regression equation is -559 seconds and the partial regression coefficient for pH is equal to 62 seconds per pH unit. Thus for the pH range of 7.2 to 8.1 for the samples of mixed liquor used in this correlation, the pH factor accounts for $7.2 \times 62 = 446$ to $8.1 \times 62 = 502$ seconds of the negative constant of the multiple regression equation.

5. A highly significant negative correlation was obtained for BOD of the Whatman #41 filtrates and logs of the persistency values when all data are included. This was the only significant partial correlation coefficient for this factor in the multiple correlations made. The multiple correlations between frothing and BOD are generally lower when compared to the results of the simple correlations. The multiple correlation has removed some of the inter relationship between the independent variables and the froth parameters.

In general, the results of these multiple correlations indicate the lack of association of frothing to the BOD.

6. Highly significant negative multiple correlation coefficients are obtained between electrode potential E_h, and the froth parameters, persistency, log persistency, and Σ when all the data representing mixed liquor samples are included in the multiple correlation. These results are presented in multiple correlations A, C, and E. However, when the data for the samples containing digester supernatant are excluded or when the data for the 10 samples of mixed liquor from the sewage treatment plants are excluded, the partial multiple correlation coefficients for E_h, and frothing are insignificant. These results were obtained in multiple correlations B, F, K. L, M and N.

Additional data would be required to establish the relationship between the frothing parameters and the electrode potential of the mixed liquors.

7. Similar to the simple correlation results, highly significant positive partial correlation coefficients were obtained between temperature and persistency or log persistency. These results were obtained in multiple correlations ABC and D for all data representing samples of mixed

liquor, and for all the data for mixed liquor samples except those samples containing digester supernatant. When the data for the samples of mixed liquor obtained in the sewage treatment plant survey are excluded, the correlations between temperature and persistency are insignificant.

The froth measurement Σ is not correlated to the temperature in these studies. A discussion regarding the effects of temperature on the froth parameters, persistency and Σ, is presented in the simple correlation section.

8. Significant negative partial correlation coefficients were obtained between suspended solids and the froth parameters, persistency and log persistency for multiple correlations K, L, and D. Multiple correlations K and L include all data excepting treatment plant survey data. In correlation L, data for samples of mixed liquor containing digester supernatant were also excluded. Multiple correlation D is for all data excepting data for mixed liquor samples containing digester supernatant. The results obtained from the sewage treatment plant surveys and those containing digester supernatant do not show a relationship between suspended solids and persistency. This may be because grouping of the mixed liquor samples from different plants may not be justified. Correlations of suspended solids and persistency should be evaluated for each plant rather than in a generalized manner.

An opposite relationship between frothing and suspended solids is obtained with a significant positive partial correlation coefficient for Σ and suspended solids. This was noted for multiple correlation E which contains all the data for the samples of mixed liquor tested. The difficulty in detecting the maximum volume of foam formed as a result of the accumulation of suspended solids in the foam for the Σ measurement is possibly reflected in these results. Correlation E was the only correlation in which Σ was significantly correlated to suspended solids.

The results of this correlation indicate the need for further evaluation of the effects of suspended solids in frothing.

VI. SUMMARY

The study of frothing in aeration type sewage treatment plants is complex and a combination of factors should be considered when evaluating the foams occurring in mixed liquors. There are many factors which are difficult to evaluate, such as the atmospheric conditions and their effects on bubble collapse, the presence of certain compounds and substances which may tend to decrease or retard frothing, the concentration of suspended solids, and others. Not only should the presence of various substances be considered, but also, the physical or physical-chemical form in which these substances occur in mixed liquors may be of significance. For example, for the anionic detergent alkylbenzene sulfonate, should the detergent adsorbed to the particulate matter be considered as capable of directly contributing to the frothing, or is the frothing more directly related to the free or unassociated detergent concentrations. Our studies indicate that the latter is more nearly correct.

In order to evaluate the various factors related to foaming in mixed liquors, two froth parameters were used. One foam measurement, persistency, measures the time for a foam to collapse whereas the other foam measurement, Σ, measures the average lifetime of a bubble in the foam. Results have shown that the two measurements are in general agreement although they are different in magnitude. Both measurements may be used to approximate the degree or severity of frothing from one sewage treatment plant to another. Under certain conditions of test, the foams formed in the foam meter devised for the measurement of Σ are difficult to measure and improved methods are needed.

Studies of water solutions containing ABS and degraded protein products indicate a marked increase in foam volume and stability when these materials are both present as compared to the froths formed by each separately.

The analysis and fractionation of foams indicated that both ABS and protein type compounds accumulate in the foam liquid filtrate. It was noted also that the chemical composition of the froth as well as the ability of the froth to form changed with respect to aeration time.

In order to evaluate some of the factors which may be related to frothing in mixed liquors, or conditions which may be present when frothing occurs, simple and multiple statistical correlations obtained from a study of the factors related to foaming were made. The mixed liquor samples used, included samples from laboratory studies as well as from four activated sludge-sewage treatment plants in Wisconsin.

Two different froth determinations, persistency and the average lifetime of a bubble in the foam, were made of mixed liquor samples. Measurements of ABS, ammonia nitrogen, organic nitrogen, electrode potential, pH, suspended solids, temperature and BOD were made. Some of these determinations were made on the mixed liquor, and some on mixed liquor filtrates, in order to relate these factors to the persistency and average lifetime of the bubble.

The results of these studies statistically analyzed, by the use of an IBM 650 computer, show that approximately 60 to 70% of the variation in the foams were accounted for, by the measured factors. The remaining or unaccountable variation must be a result of other factors, and in part the variability in the measurements of foam that were used.

The ABS concentration of the filtrate was highly significantly correlated to the foam measurements, independent of the other measured factors, but similarly, ammonia nitrogen concentrations in the filtrate from the activated sludge mixed liquors were also significantly correlated—excepting when large ammonia concentrations existed as a result of the presence of digester supernatant. It is not clear, whether ammonia nitrogen in the foam as it occurs in sewages is directly involved in the frothing process, or whether the high ammonia nitrogen is associated with some other characteristic of the waste or conditions which may be present and correlated with frothing.

Studies of solutions containing degraded protein and 3 mg/l ABS have indicated that increased concentrations of the degraded protein increase the frothing ability of the solution. However, the concentration of organic nitrogen in filtrates from mixed liquor samples from sewage treatment plants was not significantly correlated to frothing. It should be pointed out, however, that the measurements used in the latter studies were determinations of organic nitrogen rather than of the individual protein breakdown products composing the total organic nitrogen. In other words, specific degraded protein compounds are probably related to frothing intensities, whereas the gross organic nitrogen measurement was not found to be related in the range of concentrations determined. In any event, a simplified evaluation of the variations in frothing in sewage treatment is not evident.

Some of the variations in frothing at different plants may be related to the fact, that for the same suspended solids concentration and the same total ABS concentration, there is a variation in the free or unassociated ABS values. This has been observed, not only from one plant to another, but also in different parts of the same aeration tank. Aeration rates are also a significant factor in the frothing that takes place. These factors of suspended solids concentration and aeration rates indicate the importance of the dual action of the two adsorptive surfaces, the biological floc and the air interface, in influencing frothing.

From the information obtained thus far, research on methods of froth control, based on modifications in the operation of treatment plants to control the character of the mixed liquor, are under study.

VII. ACKNOWLEDGEMENTS

The assistance provided by Assoc. Prof. Harlow W. Halvorson, Agriculture economics, and the personnel of the Numerical Analysis Laboratory of The University of Wisconsin for processing and programming the statistical computations are gratefully acknowledged. The authors are grateful to Prof. James H. Torrie, Agronomy, for his assistance with the statistical evaluation.

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APPENDIX A.

SAMPLE COMPUTATION FOR FOAM MEASUREMENT, Σ

$$\Sigma = \frac{V}{\frac{dV_a}{dt}}, \text{ seconds}$$

where:

V = volume of foam, cm^3

$\frac{dV_a}{dt}$ = rate of aeration, $cm^3/sec.$

$V = h \times A$, cm^3

where:

h = foam height, cm
A = cross-sectional area of foam column, cm^2

$$\frac{dV_a}{dt} = \frac{V \times k}{t} \times \frac{p_1 + p_2}{p_1}, \ cm^3/sec.$$

where:

V = total volume of air applied in a prescribed time interval, ft^3
k = 28,300 cm^3/ft^3
t = time interval, seconds
p_1 = barometric pressure, inches of Hg
p_2 = gage pressure, inches of Hg

Example:

At 2 minutes 00 seconds	$h = 2.2$ cm
At 5 minutes 00 seconds	$h = 2.4$ cm
Average	$h = 2.3$ cm

A – Foam meter No. 2 = 16.4 cm^2
V = 0.0139 cu. ft.
t = 180 seconds
p_1 = 29.34 inches Hg
p_2 = 3.1 inches Hg

$$\frac{dV_a}{dt} = \frac{0.0139 \times 28300}{180} \times \frac{29.34 + 3.1}{29.34} = 2.42 \ cm^3/sec.$$

$V = hA = 2.3 \times 16.4 = 37.7 \ cm^3$

$$\Sigma = \frac{V}{\frac{dV_a}{dt}} = \frac{37.7}{2.42} = 15.6 \text{ seconds}$$

SAMPLE COMPUTATIONS FOR FOAM MEASUREMENT, Σ_c

$$\Sigma_c = \frac{v}{\frac{dV_a}{dt} - \frac{dv}{dt}}, \text{ seconds}$$

where:

v = volume of foam after a prescribed period of aeration, cm^3 (computed in same manner as V)

$\frac{dV_a}{dt}$ = rate of aeration, $cm^3/sec.$ (computed as shown on preceding page)

$\frac{dv}{dt}$ = average rate of foam formation, $cm^3/sec.$ (volume of foam v divided by the aeration interval in seconds)

Example:

At 2 minutes 00 seconds h = 14.0 cm
At 5 minutes 00 seconds h = 35.8 cm
Height increase in 3 minutes = 21.8 cm
A = Foam meter No. 5 = 17.5 cm^2
V = 0.0134 cu. ft.
t = 180 sec.
p_1 = 29.13 inches Hg
p_2 = 3.7 inches Hg

$$\frac{dV_a}{dt} = \frac{0.0134 \times 28300}{180} \times \frac{29.13 + 3.7}{29.13} = 2.375 \text{ cm}^3/\text{sec.}$$

$$v = hA = 21.8 \times 17.5 = 381.5 \text{ cm}^3$$

$$\frac{dv}{dt} = \frac{381.5}{180} = 2.12 \text{ cm}^3/\text{sec.}$$

$$\Sigma_c = \frac{v}{\frac{dV_a}{dt} - \frac{dv}{dt}} = \frac{381.5}{2.375 - 2.12} = \frac{381.5}{0.255} = 1500 \text{ seconds}$$

APPENDIX B

Analysis: Alkylbenzenesulfonates
Date: March 7, 1956
Revised:

Method No.: A-24-56
By: J.D.F., F.R.S., R.A.A.
Approved by: E.M.H.

MONSANTO CHEMICAL CO., RESEARCH AND ENGINEERING DIVISION,
CHEMICAL RESEARCH DEPARTMENT, ANALYTICAL LABORATORIES

Alkylbenzenesulfonates, Spectrophotometrically, in Sewage and River Waters

I. Application

This procedure is applicable to the determination of alkylbenzenesulfonates (ABS) in sewage, river water and other materials, and recovers 99.5 ± 0.6% of the ABS present. All known interferences in sewage and river water are eliminated except quaternary surfactants. These can also be eliminated, but since it is believed that the interference is unimportant, the technique is not described. This method, designed to attain the highest possible accuracy, requires 3.5 ± 0.5 hours for one sample and an additional half hour for two samples. Appended (Section III) is an abridged version of slightly less accuracy requiring less than two hours for completion.

II. Procedure

Place in a separatory funnel of smallest suitable size a sample ($\leq$ 1.8 liters) containing 10-200 μg ABS; optimum 50-100 μg. (If desired, water samples >70 ml may be made alkaline (pH 8-9) with NaOH boiled down to <50 ml, transferred to funnel and neutralized with H_2SO_4.) Dilute with water to 70 ml or more. Add 5 ml pH 7.5 buffer plus 1 ml for every 100 ml of solution. Extract for 3 minutes with 25 ml MHA-$CHCl_3$ (plus 25 ml of $CHCl_3$ if aqueous volume >250 ml). Swirl or stir to break emulsion, and filter $CHCl_3$ extract through a $CHCl_3$ – wetted cotton plug into a 300 ml ₸ 24/40 Erlenmeyer flask. If persistent emulsions form, filter through $CHCl_3$ –wetted cotton into a 125 ml separatory funnel, using suction if required, then drain $CHCl_3$ into flask and return any aqueous phase to original funnel (See Figure 1). Rinse solution in funnel twice with 15-20 ml $CHCl_3$, and filter into flask. Repeat extraction and rinsing. Add to flask 35 ml water, 3 drops pH 7.5 buffer, and glass boiling beads. Attach short air condenser, boil off most of $CHCl_3$ and remove from heat. Repeat extraction and rinsing of sample two additional times, shaking for 2 minutes, and collect extract in flask. Replace condenser and boil off most of the $CHCl_3$. Rinse condenser and flask walls with 5-10 ml $CHCl_3$, then heat until all $CHCl_3$ has evaporated and aqueous solution has boiled one minute or more. Remove condenser, rinse in with 10-15 ml water, add 5 drops 25% NaOH, cover flask with special cover glass, and boil to 15-20 ml. Add water is necessary to require >5 minutes boiling.

Rinse cover into flask with 5 ml water, add 5 ml HCl and attach long air condenser. Reflux for 60 minutes, keeping the condensate below the middle of the condenser. Cool and rinse condenser into flask with 15 ml 3% NaOH. Remove condenser and rinse it into a 600 ml beaker with 15-20 ml MeOH–NH_4OH. Add 5 drops 25% NaOH to beaker and reserve for later use.

Add 1 drop phenophthalein to flask, make alkaline by dropwise addition of 25% NaOH, cool, acidify with 10% H_2SO_4, then make just alkaline with 3% NaOH. Transfer solution to a 125 ml separatory funnel containing 3-4 drops 1% H_2SO_4, and rinse in with water to a total volume of 60-75 ml. Adjust to pH 4-6 with 1% H_2SO_4 or NaOH, add 2 ml pH 4.8 buffer, and extract for 3 minutes with 25 ml MHA-hexane solution. Drain aqueous phase into a second 125 ml separatory funnel and the hexane into a 250 ml beaker. Rinse in with 15-20 ml hexane. Extract with 25 ml hexane, collect the aqueous phase in the first funnel, and the hexane in the beaker, rinsing in as before.

Decant the hexane from the 250 ml beaker into the 600 ml beaker into which the condenser was rinsed, taking care not to transfer any aqueous droplets. Rinse 250 ml beaker twice with 10-15 ml hexane and decant into large beaker. Rinse 250 ml beaker into first separatory funnel twice with 5 ml water, then into 600 ml beaker twice with 10 ml MeOH-NH_4OH and three times with 10 ml water. Stir solution in large beaker, add boiling beads, cover with a "Speedy-vap" and boil off hexane in a steam bath.

Repeat the extraction and rinsing of the solution in the separatory funnel two additional times using 25 ml MHA-hexane for the first and 25 ml hexane for the second extraction, and collect extracts in the 250 ml beaker previously used. After the last extraction discard the aqueous phase instead of collecting it in a separatory funnel. Decant the hexane from the 250 to the 600 ml beaker and rinse with hexane as before. Shake out and discard any aqueous droplets in the small beaker. Rinse 250 ml beaker into one of the separatory funnels with 15 ml MeOH–NH_4OH, swirl for a few seconds to wash sides, then drain into large beaker. Repeat once with 15 ml MeOH–NH_4OH then twice with 15 ml water. Repeat the four risings of small beaker using the other separatory funnel, adding all rinsings to the 600 ml beaker.

Stir solution in large beaker, cover, boil off the hexane, then boil down to 20-30 ml. Remove and rinse "speedy-vap" and stirring rod into beaker with 20-30 ml water, cover with a clean "speedy-vap" and boil down to 25-40 ml. Cool, add 1 drop phenolphthalein and 10% H_2SO_4 until acid, then make just alkaline by dropwise addition of 3% NaOH. Determine ABS by the following modified methylene blue method.

Transfer the solution to a 125 ml separatory funnel containing 2 ml 10% H_2SO_4, and rinse in with water to make a total volume of 85 ml. Add 1 ml methylene blue solution, swirl, and extract for 1 minute with 15 ml $CHCl_3$. Let stand 3 minutes, drain $CHCl_3$ into a second 125 ml separatory funnel and rinse in with 5 ml $CHCl_3$. Repeat the extraction two additional times. Add 55 ml 0.05% H_2SO_4 to second separatory funnel, shake 1 minute, let stand 1 minute, swirl, and let stand 2 minutes. Filter the $CHCl_3$ through a plug of $CHCl_3$–wetted cotton into a 100 ml volumetric flask. Rinse aqueous solution with 5 ml $CHCl_3$ and filter into flask. Add 10 ml $CHCl_3$ to second separatory funnel, shake 30 seconds, let stand 2 minutes, and filter $CHCl_3$ into flask. Rinse aqueous solution with 5 ml $CHCl_3$ and filter into flask, then rinse filter with 10-15 ml $CHCl_3$. Make solution in flask to volume with $CHCl_3$, mix well, and transfer to 23 mm round dry spectrophotometer cell. Do not rinse cell with sample. After 5-10 minutes, measure optical density at 650 mμ with a Beckman model B Spectrophotometer, using $CHCl_3$ as a reference solution.

Substract the optical density of the blank (obtained by analyzing a sample of distilled water by the above procedure) from that of the sample to obtain the net optical density. From a standard curve convert the net optical density to weight of ABS. The standard curve is prepared by analyzing known amounts of ABS from 0 to 200 μg by the methylene blue method described above and plotting the net optical density obtained against the weight of ABS.

III. Abridged Method

The time required for an analysis may be cut to 2 hours, with a slight decrease in accuracy by making the following changes. 1) Extract only twice with MHA-$CHCl_3$, 2) Reflux for 30 minutes with HCl, 3) Extract once with MHA-hexane and once with hexane, and 4) Extract the

ABS-methylene blue complex once using 30 ml of $CHCl_3$ and preparing the standard curve in the same way.

IV. Apparatus

1. **Separatory funnels,** glass stoppered, 125 ml and larger, with Teflon stopcocks. **All must be Desicoted.**
2. **Flask, Erlenmeyer,** 300 ml with ₸ 24/40 joint.
3. **Beakers,** low form 250 ml, **Desicoted,** 600 ml not Desicoted.
4. **Volumetric flask,** 100 ml, glass stoppered, **Desicoted.**
5. **Air condenser,** short, 110 x 18 mm with ₸ 24/40 joint
6. **Air condenser,** long 500 x 8 mm with ₸ 24/40 joint.
7. **Filter adapter,** Figure 2
8. **Wash bottles,** all glass, for solvents.
9. **Cover glasses,** 4 inch "Speedy-vap" and "Short & Good" Figure 3.
10. **Spectrophotometer cells,** 23 mm round, **Desicoted.**
11. **Spectrophotometer,** Beckman model B.

All Desicoted glassware must be cleaned after Desicoting by rinsing with 0.2% ABS solution then washing as described below before being used the first time, and must be re-Desicoted after every 50-75 analysis.

Glassware should be cleaned by washing with hot water, methanol, hot water, distilled water and acetone, and drying. Strong acids must never come into contact with glassware used for the methylene blue determination. Polyethylene apparatus may not be used at any time.

V. Reagents

1. **Chloroform** – reagent grade.
2. **Hexane** – commercial grade. Each lot must be tested for its blank and for its ability to extract ABS.
3. **1-methylheptylamine (MHA)** – DPI No. 2439. Store under refrigeration.
4. **MHA-$CHCl_3$ solution** – 0.10-0.15 ml MHA in 100 ml $CHCl_3$, make fresh daily.
5. **MHA-hexane solution** – 0.10-0.15 ml MHA in 100 ml hexane, make fresh daily.
6. **Methanol** – reagent grade. Each lot must be tested for blank. If high, redistill in all glass apparatus.
7. **MeOH-NH_4OH** – 1 ml reagent grade ammonium hydroxide in 100 ml methanol, make fresh daily.
8. **Buffer pH 7.5** – 27.2 g KH_2PO_4 in 800 ml H_2O, adjusted to pH 7.5 with 25% NaOH and made up to 1 liter with water. Add 10 ml $CHCl_3$ as preservative.
9. **Buffer pH 4.8** – 105 g citric acid, monohydrate, and 15 g NaOH in 800 ml H_2O, adjusted to pH 4.8 with 25% NaOH, and made up to 1 liter with water. Add 2 to 5 mm layer of hexane as preservative.
10. **Methylene blue solution** – 0.25 g methylene blue dissolved in 100 ml H_2O, heated on steam bath for 30 minutes, made up to 250 ml with water and filtered into brown glass bottle.
11. **Cotton** – Absorbent, U.S.P.
12. **Desicote** – green label.

None of the reagents or solvents may be stored in ployethylene ware.

VI. References

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2. J. D. Fairing, Research Notebooks; 21 to 54
3. F. R. Short, Research Notebooks; 16, 17, 44 to 53, 55, 56

John D. Fairing

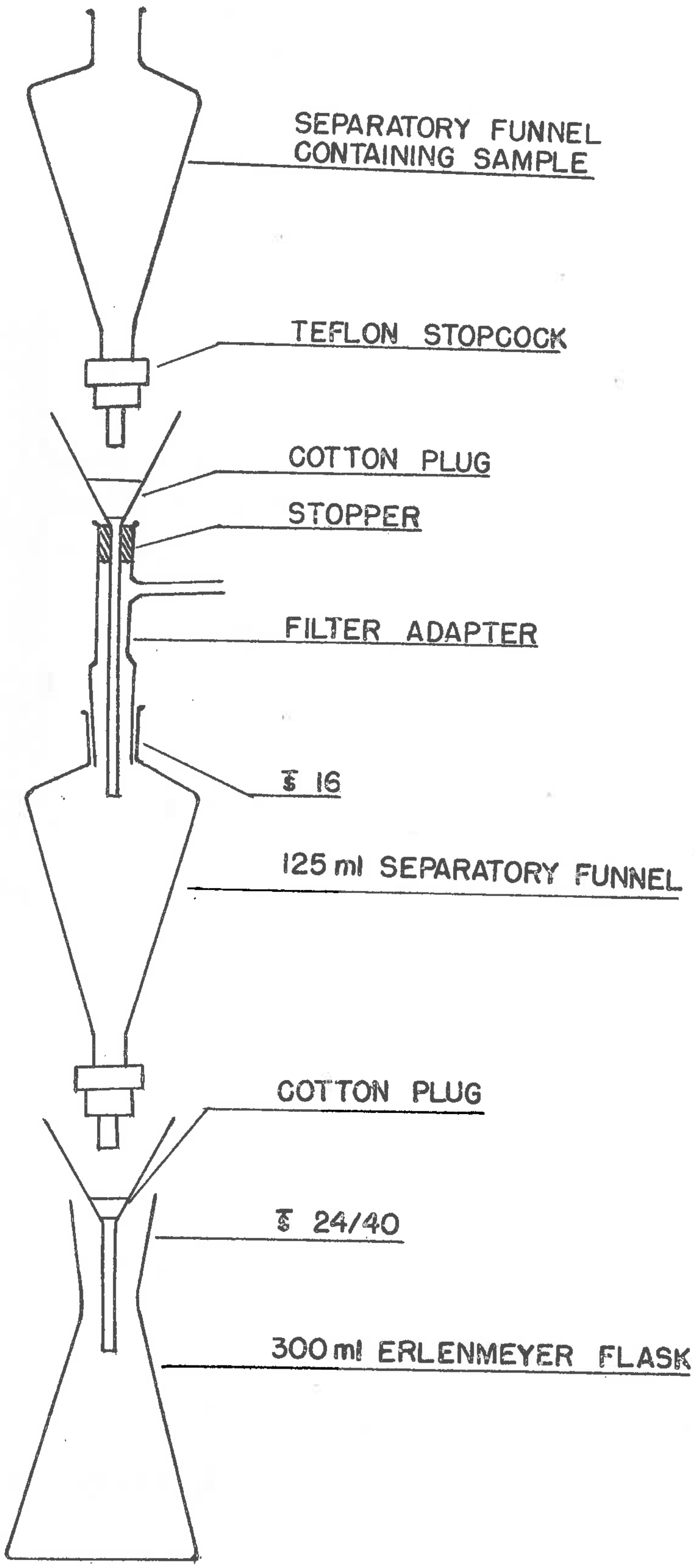
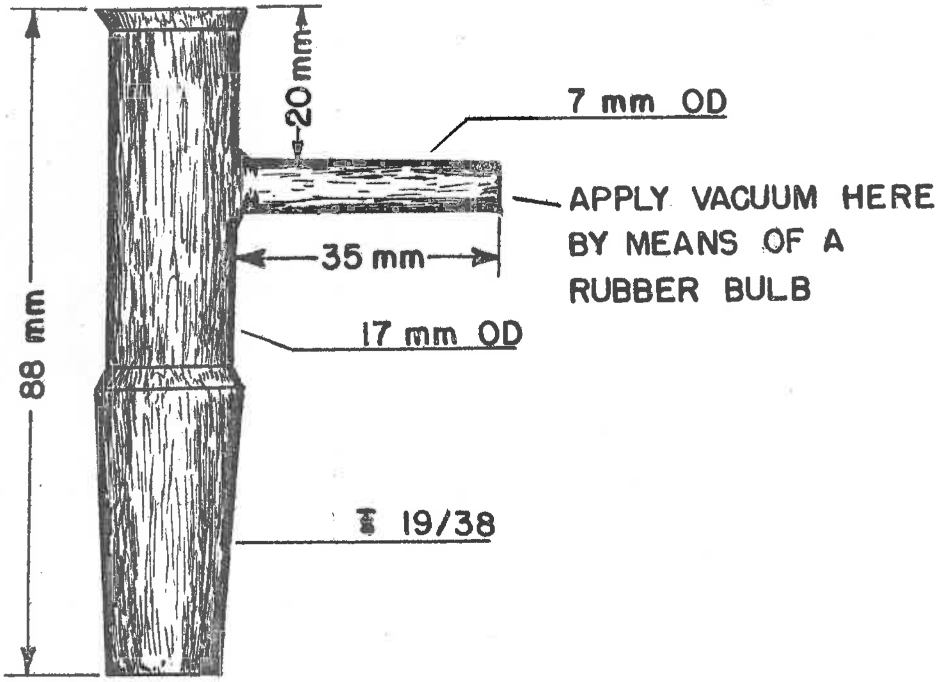
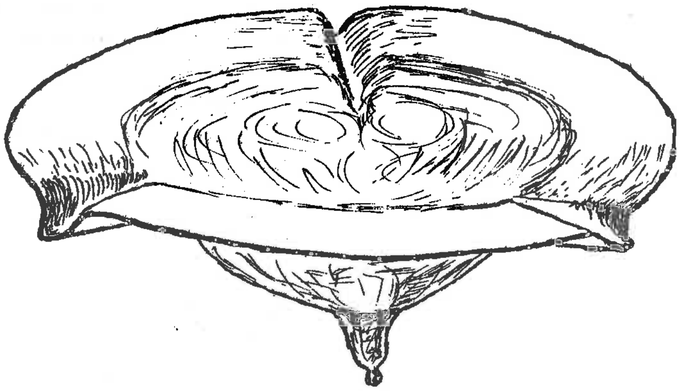

SEPARATORY FUNNEL CONTAINING SAMPLE
TEFLON STOPCOCK
COTTON PLUG
STOPPER
FILTER ADAPTER
$ 16
125 ml SEPARATORY FUNNEL
COTTON PLUG
$ 24/40
300 ml ERLENMEYER FLASK

Figure 1



APPLY VACUUM HERE BY MEANS OF A RUBBER BULB

Figure 2. FILTER ADAPTER



SPECIAL COVER GLASS

APPENDIX C

ANALYTICAL METHODS

1. pH – Laboratory studies – Model H–2 Beckman glass electrode pH meter
   Field studies – Model N Beckman portable pH meter.
2. Electrode Potential – For both laboratory and field studies measurements were made with the model N Beckman portable pH meter using an adapter and platinum electrode.
3. Ammonia nitrogen – The concentration of ammonia nitrogen was determined by Nesslerization of the distillate which has been distilled at pH 7.4. The concentrations were calculated from a standard % transmission curve using a Beckman photometer at 410 mμ according to **Standard Methods.**
4. Organic nitrogen – The Kjeldahl method as recommended in **Standard Methods** was used with slight modification. After acid digestion the sample was neutralized to pH 8.3 and distilled into ammonia free water for direct Nesslerization of the distillate. The Beckman photometer was used for optical density measurements similar to the ammonia nitrogen determination. This method was preferred because the concentration of organic nitrogen in the membrane filtered samples was low.
5. Biochemical Oxygen Demand (BOD) – The standard 5 day 20°C BOD dilution method according to **Standard Methods** was used. Three dilutions for each sample were made. The samples representing mixed liquor samples were made of the filtrate using Whatman #41 filter paper to remove the suspended solids. These resulting values were used in the statistical evaluation.
6. Suspended Solids – The method was used as recommended by **Standard Methods** with slight modification. The determination is identical except two glass fibre filter disks were used in place of the asbestos mat. The discs were made by the Hurlbut Paper Co., stock No. x-934-AH, 2.1 cm diameter.

   An evaluation of the asbestos mat and the glass fibre disc was made on 20 replicates for each of a single sample of mixed liquor.

   The mean value for the glass fibre filtered was 2528.5 mg/l with a standard deviation, s = ± 174.24 mg/l. The mean values for the asbestos filter was 2580.5 mg/l with a standard deviation of ± 153.09 mg/l. Although the asbestos filter mat yields better results, as evidenced by the comparison of the standard deviations, the glass fibre disc method did not yield a significant difference at the 95% confidence level.
7. Surface Tension – These measurements were made with a Cenco No. 70545 Du Nouy platinum ring tensiometer. The results represent an average of three readings for each sample tested.
8. Alkybenzene Sulfonate – A detailed method, developed by the research laboratories of the Monsanto Chemical Co., is presented in appendix B. A discussion of detergent determinations is presented in the section "Detergent Determinations."
9. Foam Measurement – Two methods for foam measurement are used and a discussion of the methods is presented in the section "Foam Measurements."

College of Engineering

University of Wisconsin

ENGINEERING EXPERIMENT STATION

Report No. 9

Final Report
on

FROTHING IN SEWAGE TREATMENT

by
Gerard A. Rohlich, and Lawrence B. Polkowski,
Laboratories of Hydraulic and Sanitary Engineering

Sponsored by
Association of American Soap and Glycerine Producers, Inc.

Madison, Wisconsin

Period Ending June 30, 1957

TABLES

AND

FIGURES

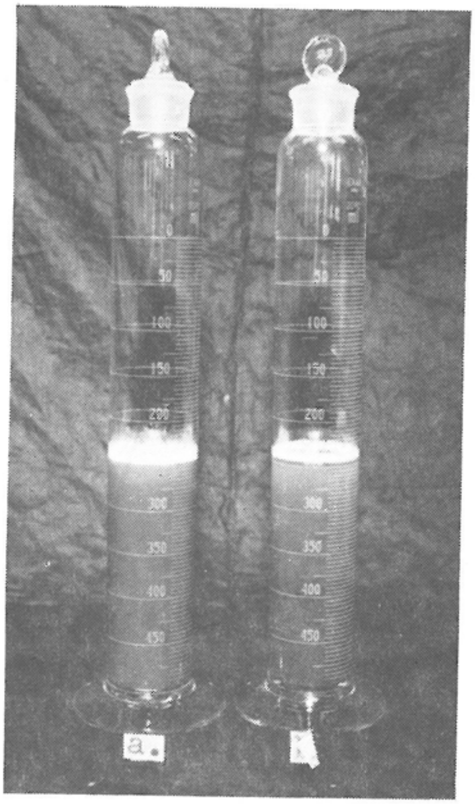


FIG. 1 FOAM PERSISTENCY MEASUREMENT

a. CYLINDER AFTER SHAKING

b. CYLINDER AFTER BREAK AT THE SURFACE (TERMINATION OF PERSISTENCY TIME INTERVAL)

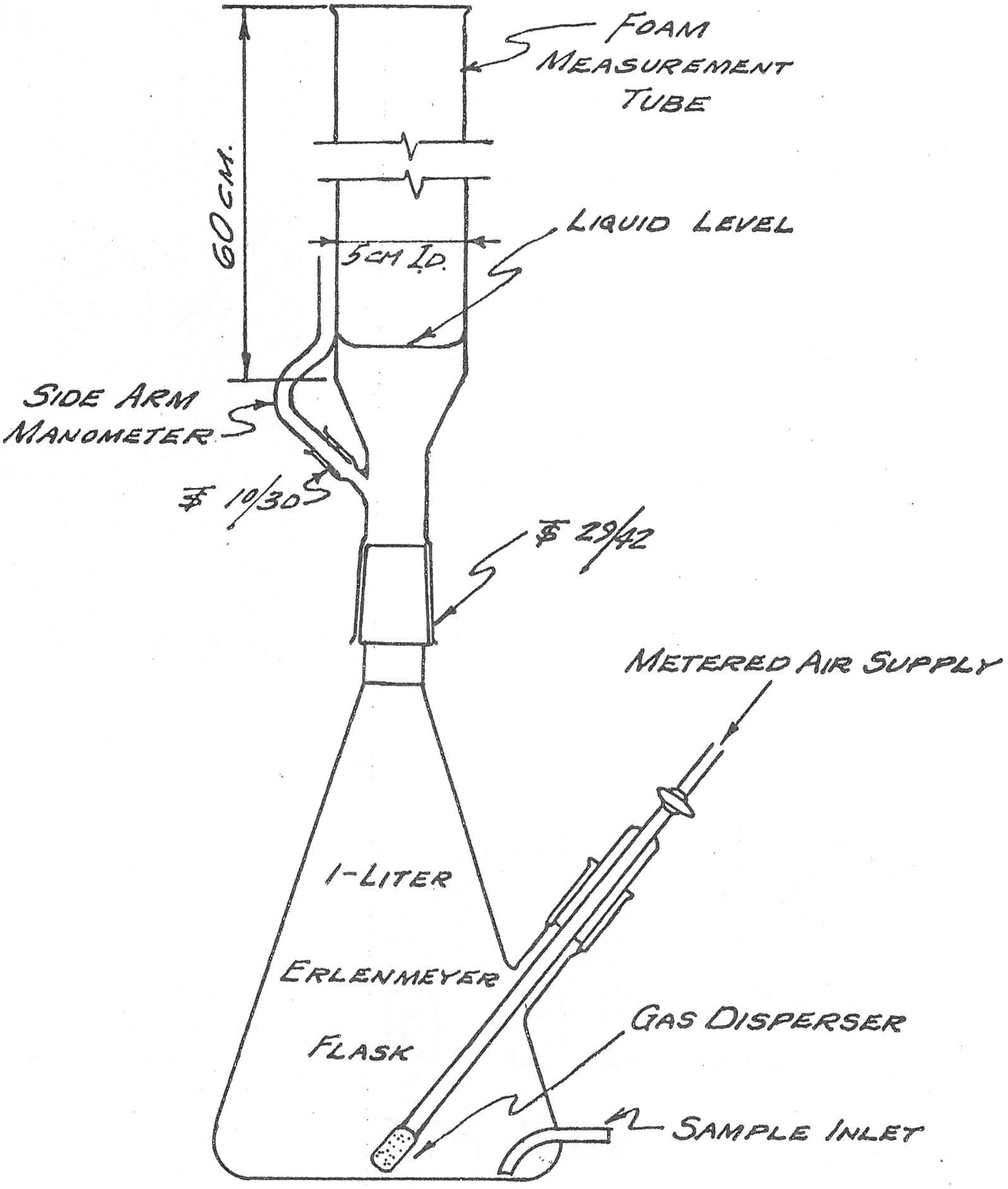


Fig. 2 FOAM METER FOR MEASUREMENT OF Σ

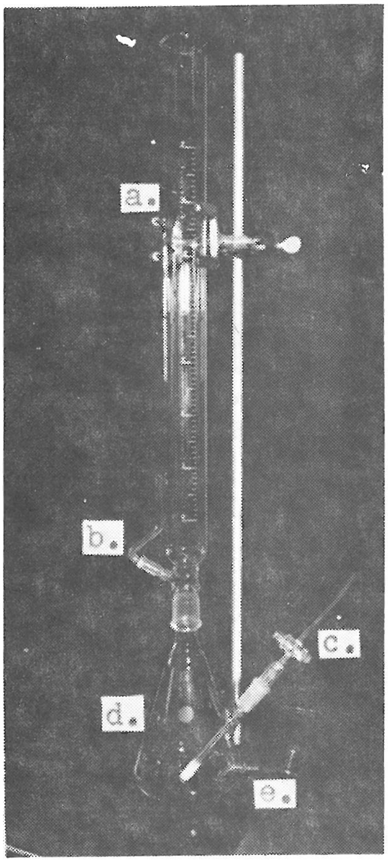


Fig.3 ASSEMBLED FOAM METER

a. FOAM MEASUREMENT COLUMN
b. SIDE MANOMETER FOR FOAM DENSITY MEASUREMENT
c. AIR SUPPLY WITH GAS DISPERSER
d. SAMPLE FLASK
e. SAMPLE INLET & DRAIN

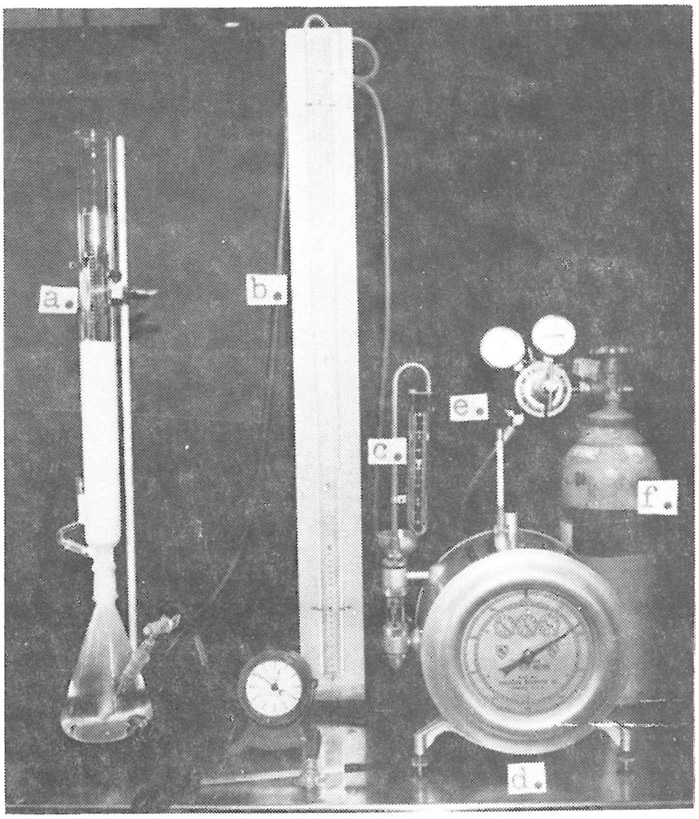
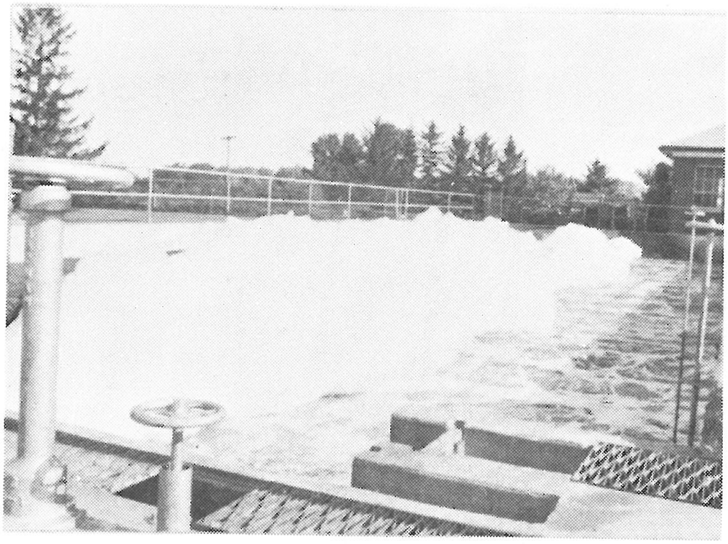


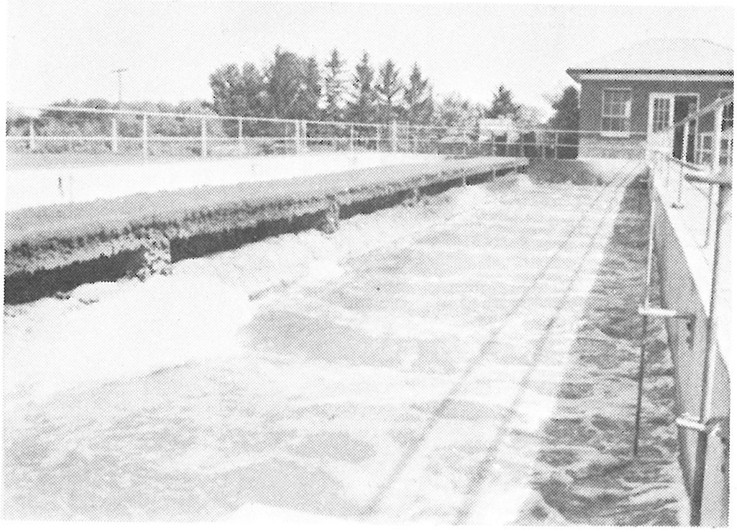
Fig.4 COMPLETE FOAM MEASUREMENT UNIT

a. FOAM METER
b. FLOW RATE MANOMETER
c. GAGE PRESSURE MANOMETER
d. GAS TOTALIZER - WET TEST METER
e. AIR REGULATORY VALVE
f. AIR CYLINDER

FIG. 5 FROTHING CONDITIONS CORRESPONDING TO FOAM MEASUREMENTS AT CITY A



TIME	8:30 a.m.
Σ	11.3 secs.
PERSISTENCY	20 secs.
SUSP'D SOLIDS	380 ppm

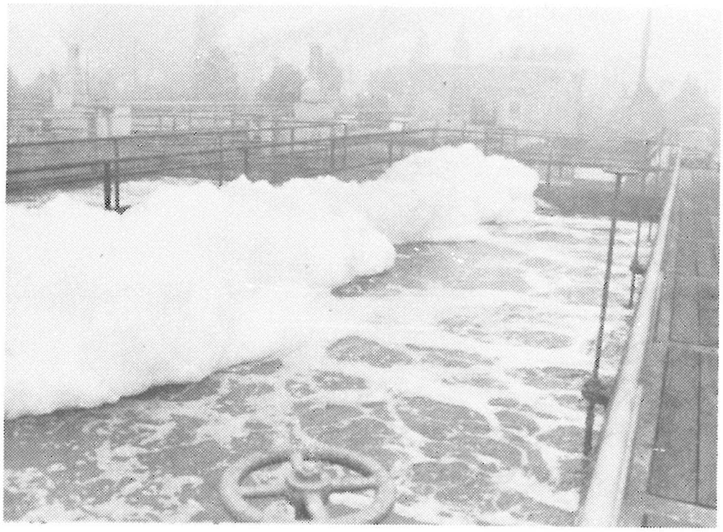


TIME	9:45 a.m.
Σ	0 secs.
PERSISTENCY	2 secs
SUSP'D SOLIDS	310 ppm

FIG.6 FROTHING CONDITIONS CORRESPONDING TO FOAM MEASUREMENTS AT CITY C

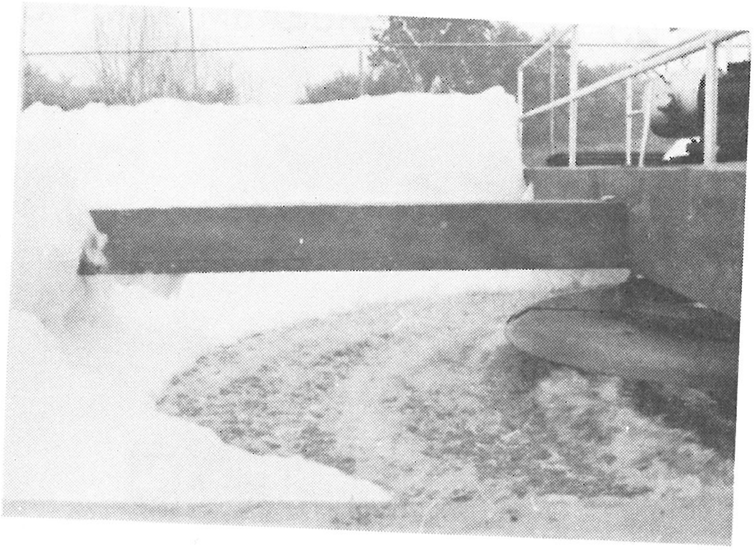
TIME 4:00 p.m.
Σ 10 secs.
PERSISTENCY 15 secs.
SUSP'D SOLIDS 1160 ppm

TIME 5:40 p.m.
Σ 14.3 secs.
PERSISTENCY 22 secs.
SUSP'D. SOLIDS 1230 ppm

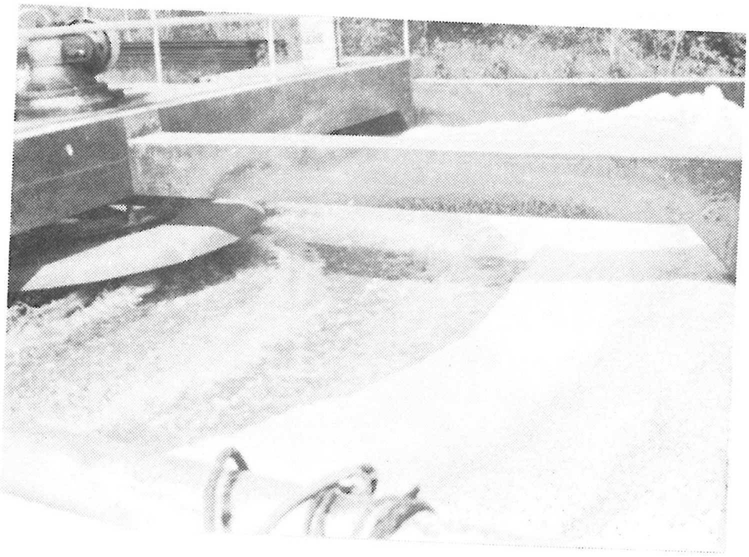


TIME 7:00 p.m.
Σ 15.1 secs.
PERSISTENCY 36 secs.
SUSP'D SOLIDS 940 ppm

FIG. 7 FROTHING CONDITIONS CORRESPONDING TO FOAM MEASUREMENTS AT CITY G

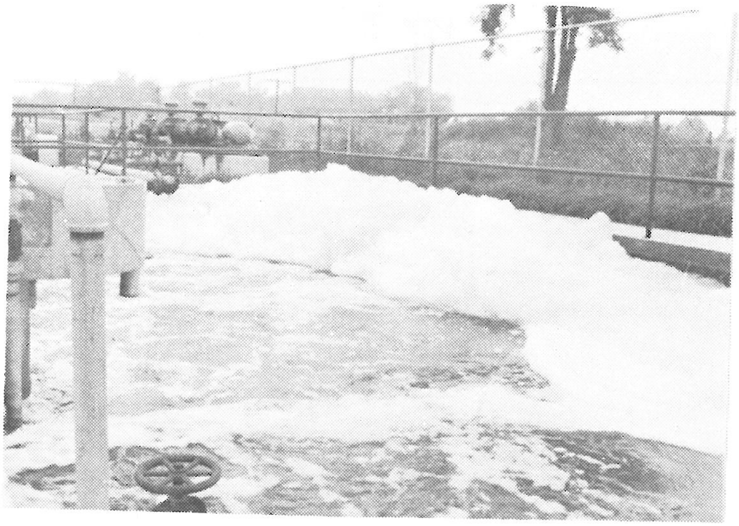


TIME 8:45 a.m.
Σ_c 1900 To ∞ secs.
PERSISTENCY 1805 secs.
SUSP'D SOLIDS 650 ppm



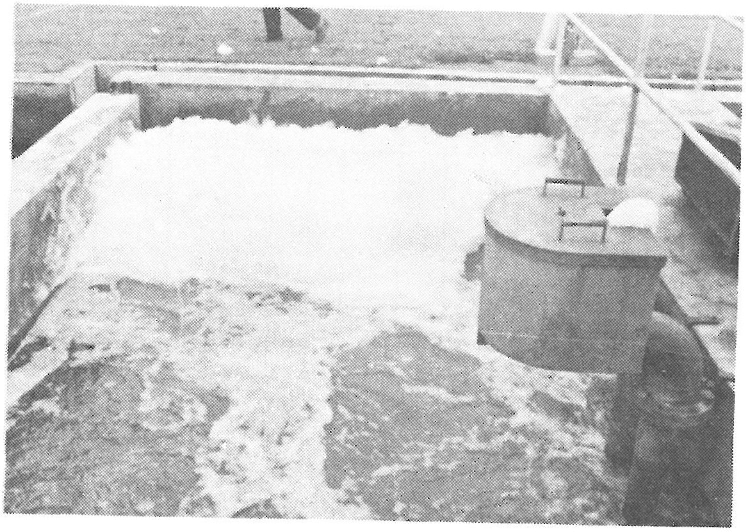
TIME 10:05 a.m.
Σ_c 270 To 1200 secs.
PERSISTENCY 2847 secs.
SUSP'D SOLIDS 1160 ppm

FIG. 8 FROTHING CONDITIONS CORRESPONDING TO FOAM MEASUREMENTS AT CITY I



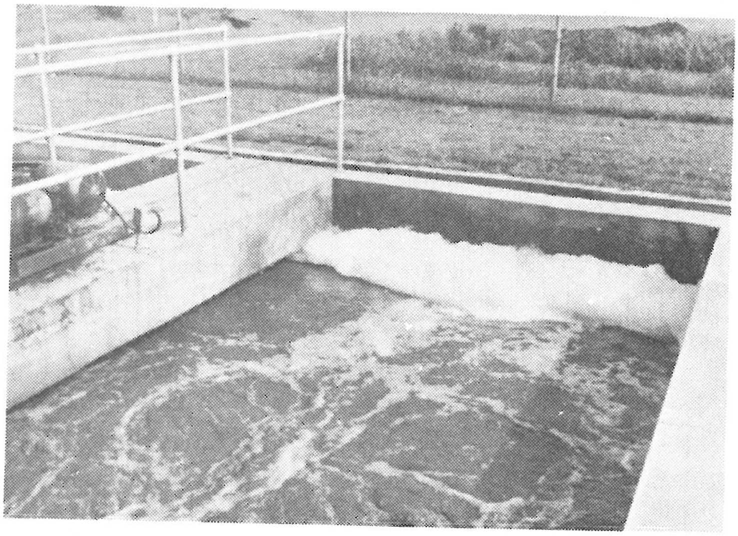
TIME	11:00 a.m.
Σ	10.8 secs.
PERSISTENCY	13 secs
SUSP'D SOLIDS	2480 ppm

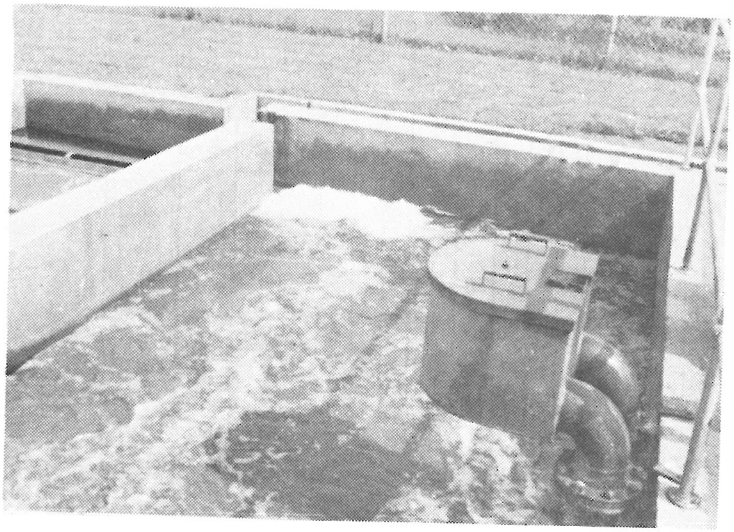
FIG. 9 FROTHING CONDITIONS CORRESPONDING TO FOAM MEASUREMENTS AT CITY J



TIME 8:20 a.m.
Σ 12.6 secs.
PERSISTENCY 13 secs.
SUSP'D SOLIDS 1590 ppm

TIME 9:05 a.m.
Σ 7.3 secs.
PERSISTENCY 7 secs.
SUSP'D SOLIDS 1570 ppm





TIME 9:50 a.m.
Σ 1.6 secs.
PERSISTENCY 3 secs.
SUSP'D SOLIDS 1460 ppm

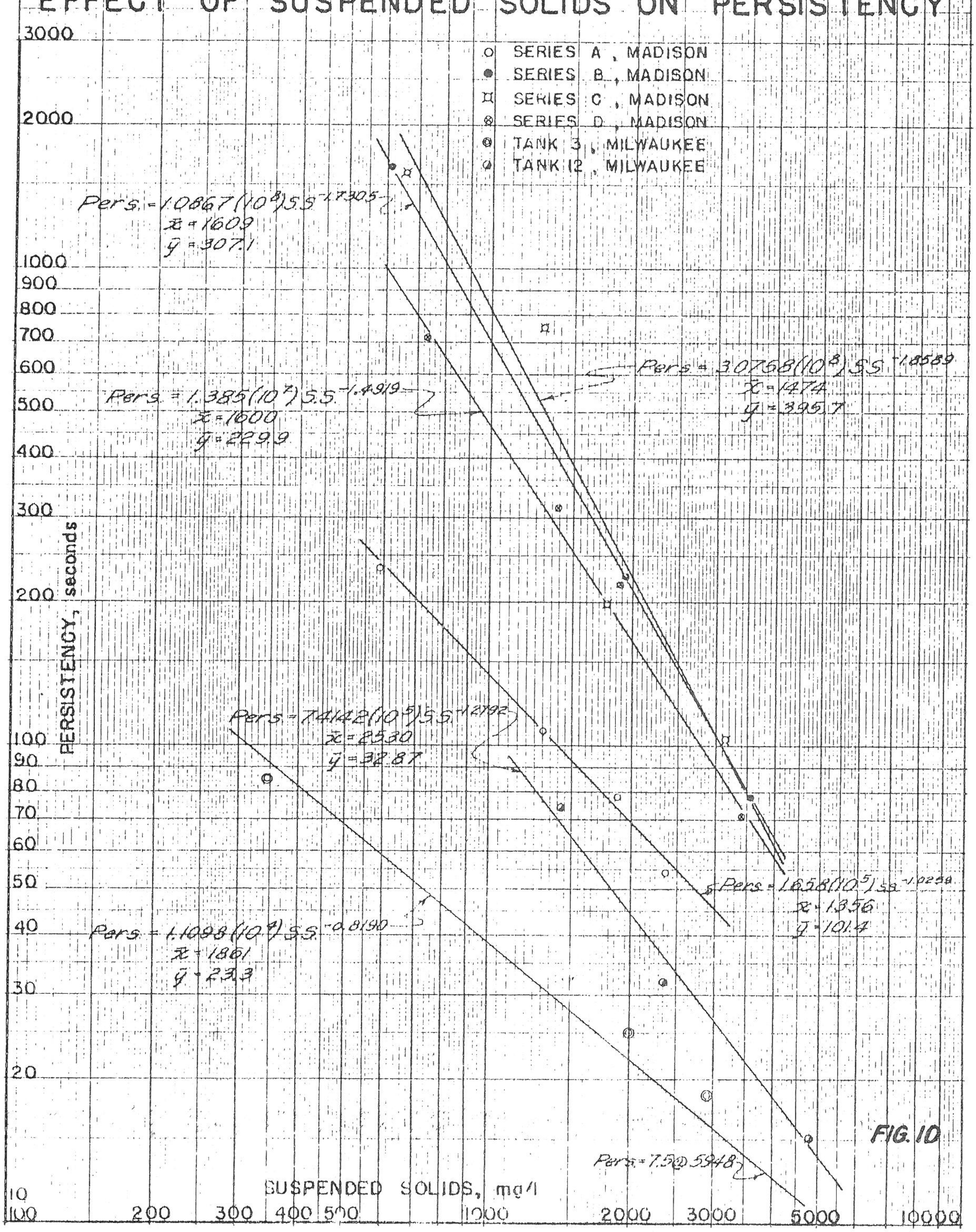

EFFECT OF SUSPENDED SOLIDS ON PERSISTENCY
○ SERIES A, MADISON
● SERIES B, MADISON
⌑ SERIES C, MADISON
⊗ SERIES D, MADISON
⊚ TANK 3, MILWAUKEE
⊘ TANK 12, MILWAUKEE
Pers. = 1.0867(10⁸) S.S.^-1.7305
x̄ = 1609
ȳ = 307.1
Pers. = 3.0758(10⁸) S.S.^-1.8589
x̄ = 1474
ȳ = 395.7
Pers. = 1.385(10⁷) S.S.^-1.4919
x̄ = 1600
ȳ = 229.9
Pers. = 7.4142(10⁵) S.S.^-1.2792
x̄ = 2530
ȳ = 32.87
Pers. = 1.658(10⁵) S.S.^-1.0259
x̄ = 1356
ȳ = 101.4
Pers. = 1.1098(10⁴) S.S.^-0.8190
x̄ = 1861
ȳ = 23.3
Pers. = 7.5@ 5948
PERSISTENCY, seconds
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
SUSPENDED SOLIDS, mg/l
100
200
300
400
500
1000
2000
3000
5000
10000

FIG. 10

EFFECT OF SUSPENDED SOLIDS ON Σ

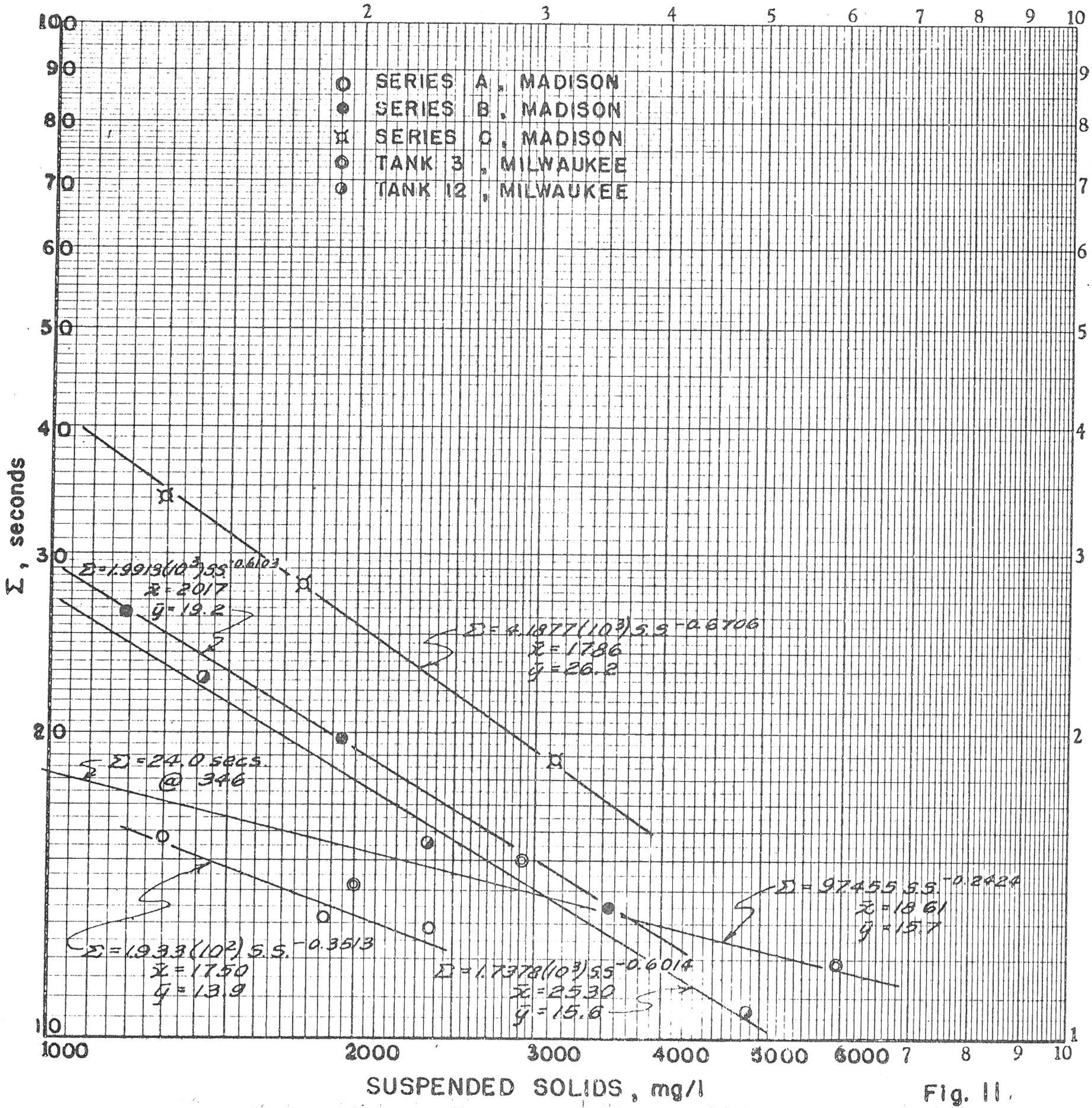


Fig. 11.

TABLE I

EFFECT OF VARYING SUSPENDED SOLIDS CONCENTRATION OF MIXED LIQUOR ON FOAM MEASUREMENT

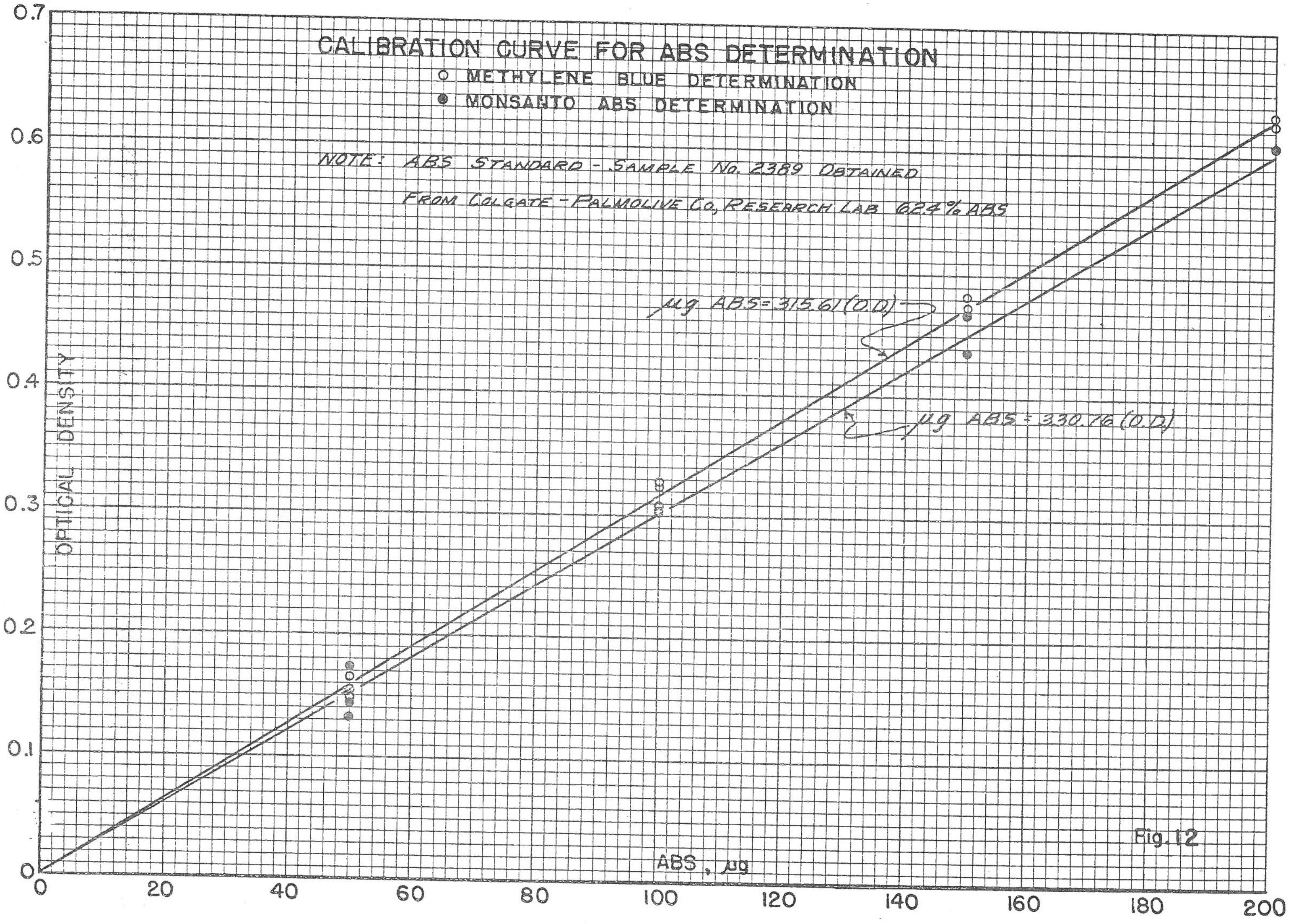
Sample	Date	Suspended Solids mg/1	Persistency Sec.	Σ, Sec.
1. Madison	5/1/57	589	235	—
		1300	107	15.8
		1865	78	13.2
		2367	54	12.9
2. Madison	5/1/57	612	1643	Σ_c = 1680
		1190	—	26.3
		1940	226	19.8
		3555	78	13.5
3. Madison	5/1/57	660	1585	Σ_c = 1410
		1297	755	34.1
		1765	199	28.0
		3135	103	18.9
4. Madison	5/1/57	732	719	30.3
		1393	316	29.0
		1887	218	27.0
		3403	71	18.0
5. Milwaukee	2/18/57	1418	74	22.6
		2352	32	15.6
		4856	15	10.7
6. Milwaukee	2/18/57	346	85	24.0
		2000	25	14.2
		2915	18.5	15.0
		5948	7.5	11.9

TABLE II

EFFECT OF INCREASING AND DECREASING SUSPENDED SOLIDS CONCENTRATION OF SEWAGE TREATMENT PLANT MIXED LIQUOR SAMPLES ON FREE ABS, NH_3-N, AND ORGANIC NITROGEN

Date	Treatment Plant	Sample	ABS mg/l	NH_3-N mg/l	Organic-N mg/l	Suspended Solids mg/l
6/6/57	City G	3-1	5.49	34.27	2.29	650*
		3-1 (Incr. S.S.)	5.14	38.44	2.63	1660
6/10/57	City C	5-1	4.30	21.12	2.93	1160*
		5-1 (Incr. S.S.)	4.10	21.26	3.04	2280
		5-1 (Decr. S.S.)	4.57	20.86	2.86	120
6/13/57	City I	6-2	—	9.34	4.79	2140*
		6-2 (Incr. S.S.)	1.42	18.64	5.69	4870

NOTE: *Indicates concentration of suspended solids of the mixed liquor used in the aeration tanks.

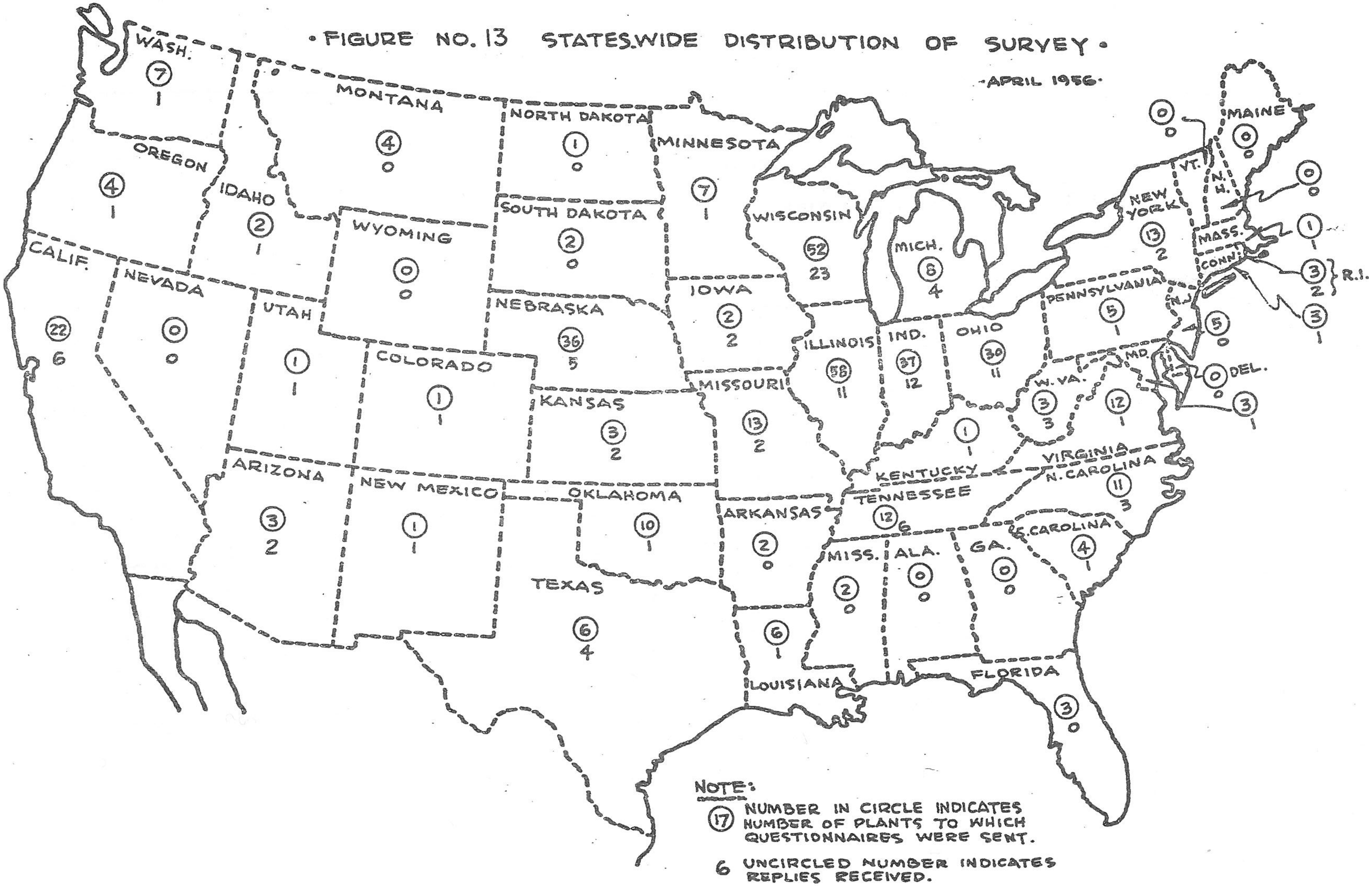


CALIBRATION CURVE FOR ABS DETERMINATION
○ METHYLENE BLUE DETERMINATION
● MONSANTO ABS DETERMINATION
NOTE: ABS STANDARD - SAMPLE No. 2389 OBTAINED
FROM COLGATE - PALMOLIVE Co, RESEARCH LAB 62.4% ABS
μg ABS = 315.61 (O.D.)
μg ABS = 330.76 (O.D.)
OPTICAL DENSITY
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
ABS, μg
0
20
40
60
80
100
120
140
160
180
200

Fig. 12

·FIGURE NO. 13 STATES-WIDE DISTRIBUTION OF SURVEY·

·APRIL 1956·



NOTE:

⑰ NUMBER IN CIRCLE INDICATES NUMBER OF PLANTS TO WHICH QUESTIONNAIRES WERE SENT.

6 UNCIRCLED NUMBER INDICATES REPLIES RECEIVED.

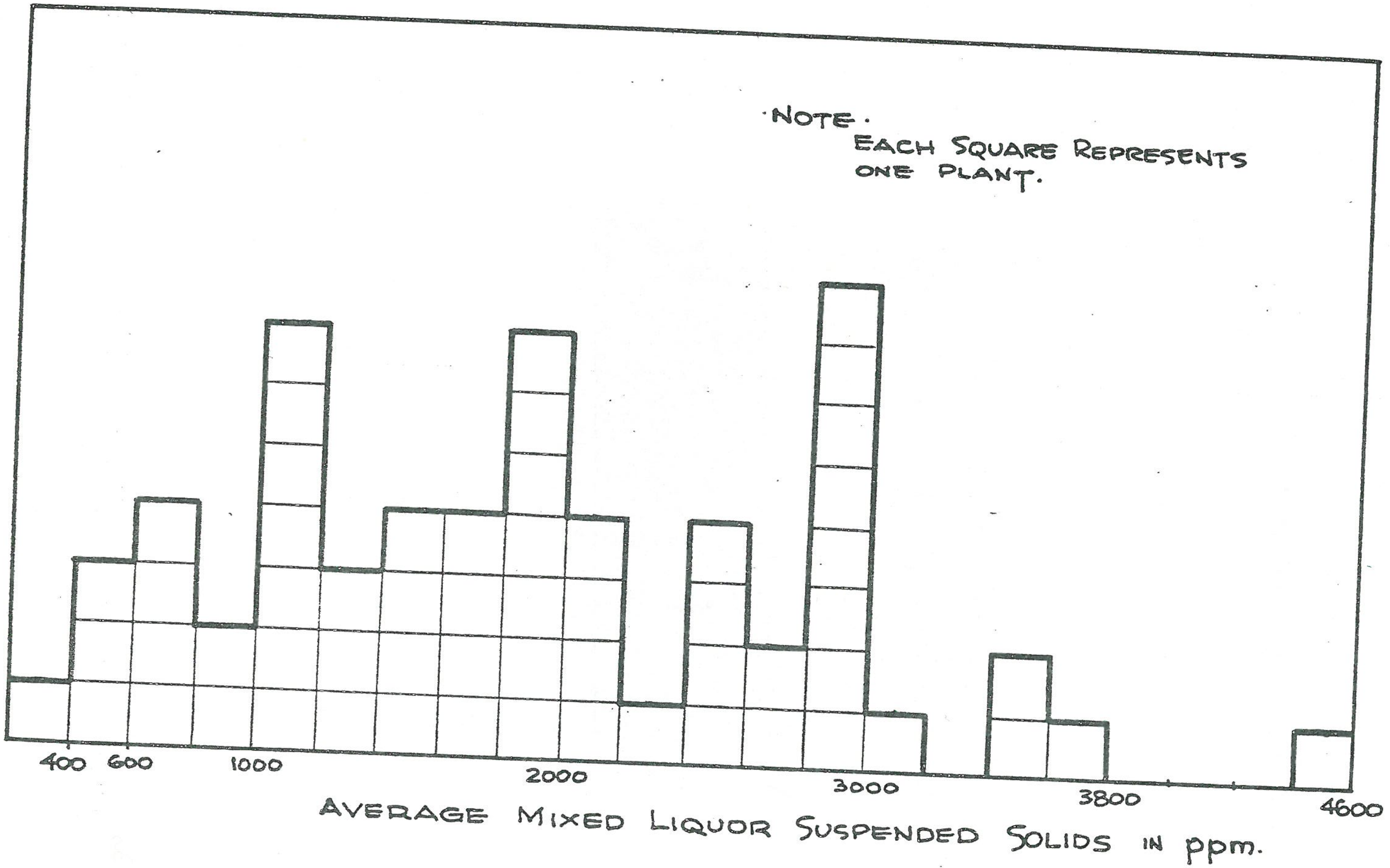


FIGURE 14 - SUSPENDED SOLIDS DATA.

FIG. 15 FROTH FORMATION ON EXPERIMENTAL AERATION TANK FOR RUN No. 6 (VARY RATE OF AERATION)

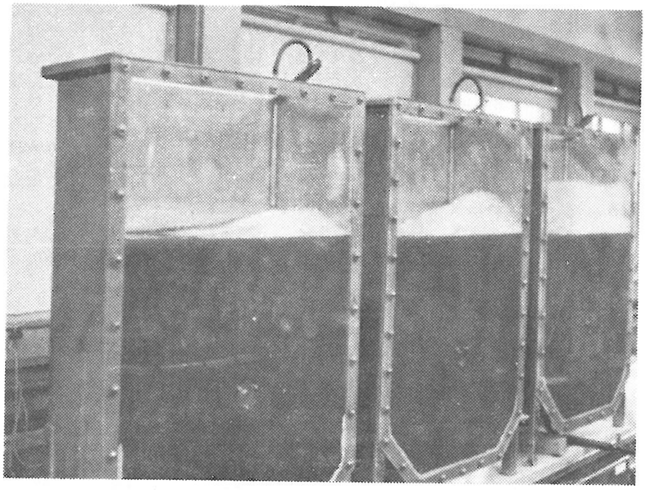


FIG. 16 AERATION COLUMNS FOR FROTH FORMATION STUDIES OF ORGANIC SOLUTIONS WITH AND WITHOUT ABS

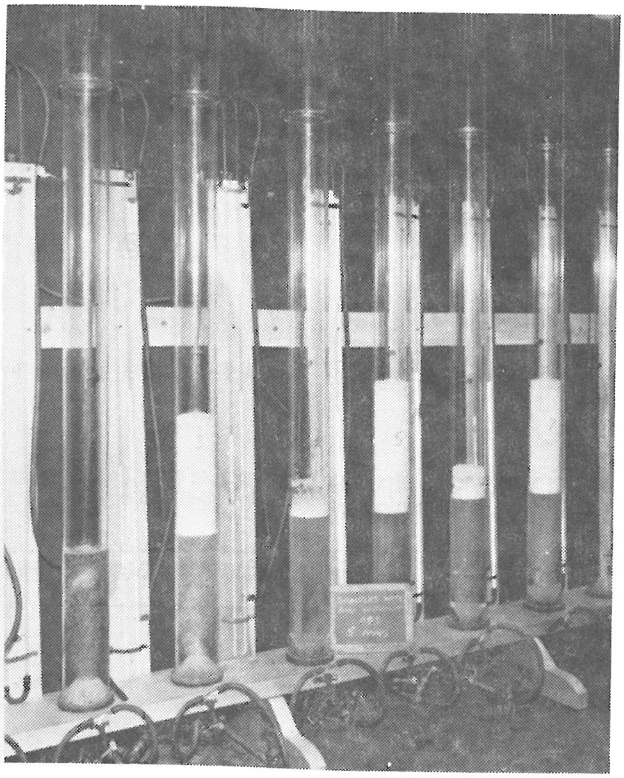


TABLE IV- Results from Full-Strength Organic Solutions

	Compounds Added					With 10 mg/1 A.B.S.						Without A.B.S.					
Sample No. 1	Beef Extract mg/1 2	Bacto-Peptone mg/1 3	Urea, mg/1 4	Dextrose mg/1 5	Inorg. Salts 6	Surface Tension Dynes/cm 7	pH 8	W, sec. 9	W_c, sec. 10	Max. Ht., cm 11	Max. Ht. End, cm 12	Surface Tension Dynes/cm 13	pH 14	W, sec. 15	W_c, sec. 16	Max. Ht., cm 17	Max. Ht. End, cm 18
1	200	300	50	300	x	42.4	7.45	-	∞	-	75	58.4	7.3	-	42	-	5
2	200	300	50	300	-	40.7	7.4	-	∞	-	97	59.8	7.25	-	30	-	4
3	200	300	50	-	x	45.2	7.35	-	∞	-	88	58.7	7.5	-	-	-	-
4	200	300	50	-	-	45.7	7.6	-	∞	-	66	61.3	7.6	-	-	-	-
5	200	300	-	300	x	45.0	7.5	-	∞	-	100	56.9	7.5	-	-	-	-
6	200	300	-	300	-	42.6	7.45	-	∞	-	76	62.8	7.6	12.5	-	1	-
7	200	-	50	300	x	46.4	7.95	-	∞	-	90	61.2	7.55	-	-	-	-
8	200	-	50	300	-	42.7	7.45	-	∞	-	76	63.3	7.65	12.5	-	1	-
9	-	300	50	300	x	48.8	7.55	-	∞	-	67	67.7	7.7	55	-	6	-
10	-	300	50	300	-	44.6	7.75	-	∞	-	69	67.5	7.8	37	-	4	-
11	200	300	-	-	x	45.0	7.55	-	∞	-	65	60.7	7.35	18.5	-	2	-
12	200	300	-	-	-	42.6	7.45	-	6140	-	67	58.4	7.35	12.5	-	1	-
13	200	-	50	-	x	44.6	7.65	-	3560	-	57	65.4	7.6	-	-	-	-
14	200	-	50	-	-	Sample Lost.						59.5	7.45	12.5	-	1	-
15	-	300	50	-	x	46.1	7.75	-	∞	-	63	69.3	7.75	46	-	5	-
16	-	300	50	-	-	49.1	7.75	-	23,800	-	61	66.1	7.7	65	-	7	-
17	200	-	-	300	x	43.4	7.55	-	1,000	-	51	66.2	7.6	12.5	-	1	-
18	200	-	-	300	-	45.9	7.45	-	2,460	-	62	59.0	7.45	12.5	-	1	-
19	-	300	-	300	x	46.3	7.75	-	∞	-	39	67.1	7.75	46	-	5	-
20	-	300	-	300	-	48.1	7.75	-	1850	-	54	69.8	7.75	75	-	11	-
21	-	-	50	300	x	48.8	7.75	-	∞	-	34	71.3	7.85	-	-	-	-
22	-	-	50	300	-	52.3	7.75	-	6070	-	31	74.4	7.75	-	-	-	-
23	200	-	-	-	x	44.0	7.45	-	19,000	-	61	61.8	7.45	12.5	-	1	-
24	200	-	-	-	-	42.2	7.4	-	1470	-	59	61.1	7.5	28	-	3	-
25	-	300	-	-	x	51.2	7.75	-	6150	-	60	69.0	7.8	-	54	-	9
26	-	300	-	-	-	48.6	7.7	-	1850	-	61	65.8	7.7	-	-	-	-
27	-	-	50	-	x	51.8	7.75	-	1200	-	50	74.2	7.8	-	-	-	-
28	-	-	50	-	-	50.9	7.75	-	1810	-	28	74.4	7.75	-	54	-	7
29	-	-	-	300	x	52.0	7.8	-	1470	-	27	74.4	7.8	-	-	-	-
30	-	-	-	300	-	50.4	7.8	-	735	-	43	74.3	7.85	-	-	-	-
31	-	-	-	-	x	50.9	7.75	-	720	-	23	74.3	7.75	-	-	-	-
32	-	-	-	-	-	50.6	7.6	-	25	-	2	Not Run.					

Cols. 11 and 17 - Maximum height is synonymous with V
Cols. 12 and 18 - Maximum height at end of froth formation.

x - Salts present

TABLE V - Results from One-Tenth Strength Organic Solutions

	Compounds Added					With 10 mg/l A.B.S.						Without A.B.S.					
Sample No. 1	Beef Extract mg/l 2	Bacto-Peptone mg/l 3	Urea, mg/l 4	Dextrose mg/l 5	Inorg. Salts 6	Surface Tension Dynes/cm 7	pH 8	W, sec. 9	W_c, sec. 10	Max. Ht., cm 11	Max. Ht, End, cm 12	Surface Tension Dynes/cm 13	pH 14	W, sec. 15	W_c, sec. 16	Max. Ht., cm 17	Max. Ht, End, cm 18
1	20	30	5	30	x	51.5	7.45	-	∞	-	65	71.2	7.75	-	-	-	-
2	20	30	5	30	-	51.0	7.55	-	∞	-	68	73.5	7.45	-	-	-	-
3	20	30	5	-	x	49.4	7.8	-	1330	-	50	73.4	7.5	-	-	-	-
4	20	30	5	-	-	50.5	7.6	-	∞	-	80	72.6	7.45	-	-	-	-
5	20	30	-	30	x	52.1	7.85	-	1850	-	50	73.2	7.5	-	-	-	-
6	20	30	-	30	-	49.1	7.6	-	∞	-	75	70.4	7.35	-	-	-	-
7	20	-	5	30	x	51.0	7.8	-	1000	-	25	73.1	7.55	-	-	-	-
8	20	-	5	30	-	52.1	7.7	-	∞	-	35	72.6	7.6	-	-	-	-
9	-	30	5	30	x	51.4	7.8	-	19,000	-	56	73.3	7.55	-	-	-	-
10	-	30	5	30	-	49.2	7.6	-	∞	-	70	72.8	7.5	-	-	-	-
11	20	30	-	-	x	50.2	7.5	-	∞	-	80	72.3	7.85	-	-	-	-
12	20	30	-	-	-	50.7	7.7	-	∞	-	35	72.3	7.7	-	-	-	-
13	20	-	5	-	x	52.9	7.55	-	∞	-	37	73.2	7.6	-	-	-	-
14	20	-	5	-	-	50.7	7.7	-	1850	-	28	73.7	7.7	-	-	-	-
15	-	30	5	-	x	51.4	7.6	-	∞	-	40	72.6	7.5	-	-	-	-
16	-	30	5	-	-	50.7	7.6	-	6140	-	31	73.4	7.7	9.5	-	1	-
17	20	-	-	30	x	49.8	7.6	-	3560	-	30	72.7	7.55	-	-	-	-
18	20	-	-	30	-	51.6	7.7	-	19,000	-	32	73.6	7.7	-	-	-	-
19	-	30	-	30	x	51.8	7.7	-	∞	-	51	72.6	7.5	-	-	-	-
20	-	30	-	30	-	49.7	7.7	-	6140	-	31	73.6	7.7	9.5	-	1	-
21	-	-	5	30	x	51.5	7.7	-	∞	-	52	73.1	7.55	-	-	-	-
22	-	-	5	30	-	51.2	7.7	-	3560	-	30	73.5	7.7	-	-	-	-
23	20	-	-	-	x	50.3	7.7	- No computation-			5	73.8	7.6	-	-	-	-
24	20	-	-	-	-	49.1	7.75	-	∞	-	36	71.0	7.6	-	-	-	-
25	-	30	-	-	x	48.8	7.7	-	19,000	-	33	71.0	7.65	-	-	-	-
26	-	30	-	-	-	51.8	7.75	-	3400	-	30	70.5	7.7	-	-	-	-
27	-	-	5	-	x	56.5	7.7	-	3560	-	30	73.6	7.7	-	-	-	-
28	-	-	5	-	-	50.1	7.75	-	∞	-	37	70.2	7.65	-	-	-	-
29	-	-	-	30	x	50.7	7.7	-	6140	-	31	73.3	7.7	-	-	-	-
30	-	-	-	30	-	50.2	7.75	-	∞	-	35	71.6	7.7	-	-	-	-

Note: In column 17 and 18 where no value is shown no froth was formed.

x - Salts present

EFFECT OF ALKYLBENZENE SULFONATE ON FROTH FORMATION IN TAP WATER WITH 300 mg/l BACTO-PEPTONE

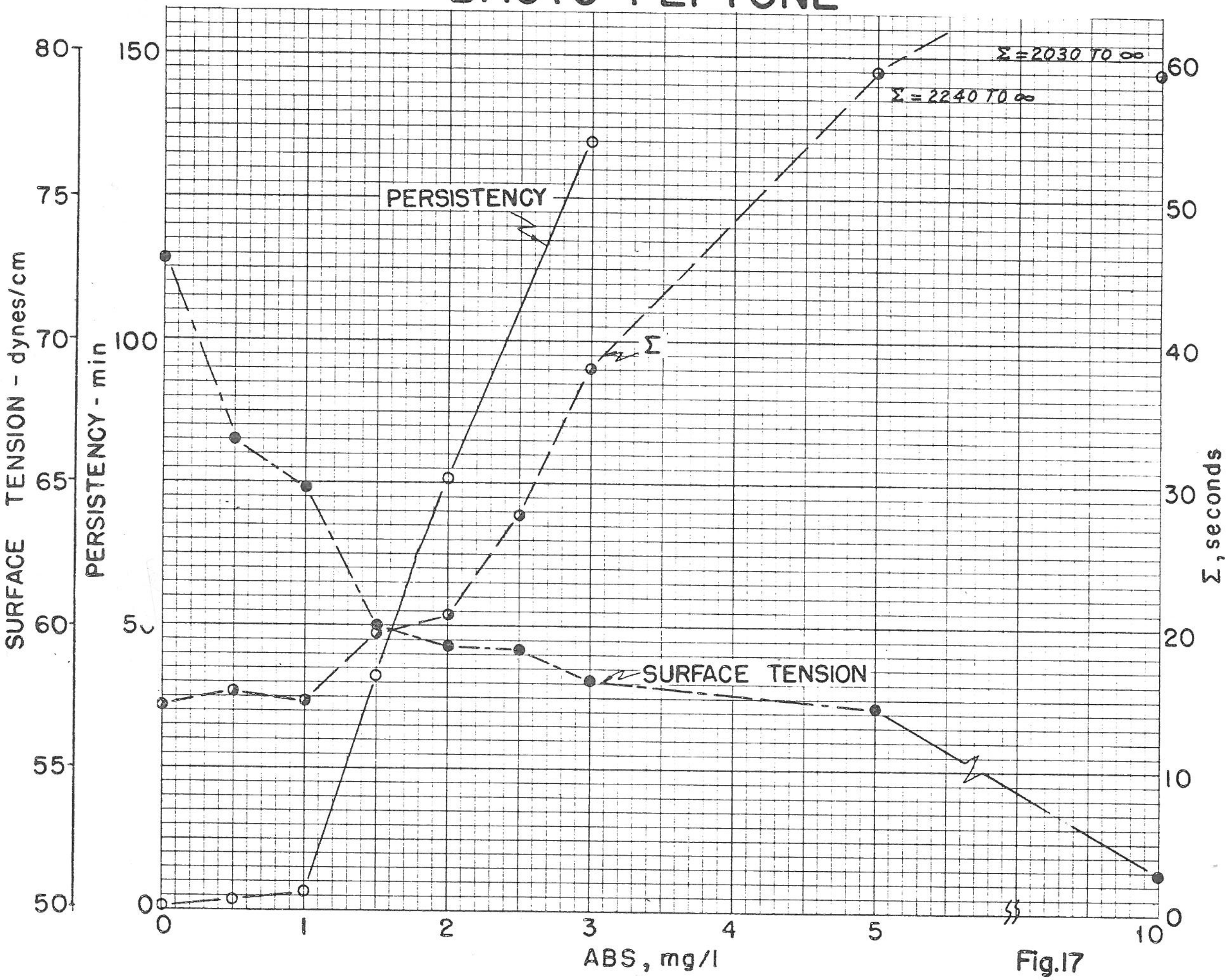


Fig.17

TABLE VI

EFFECT OF ALKYLBENZENE SULFONATE (ABS) ON FROTH FORMATION IN TAP WATER WITH 300 mg/l BACTO-PEPTONE (DIFCO GRADE)

Date	ABS mg/l	Σ, Sec.	Persistency Min.-Sec.	Surface Tension dynes/cm
Dec. 12, 1956	0.0	12.8	0-27	73.6
		12.6	0-24	74.2
		14.2	0-22	71.1
		16.0	0-19	72.5
		16.0	0-24	72.4
Dec. 12, 1956	0.5	15.7	1-17	63.9
		15.2	1-39	67.2
		15.0	1-44	67.6
		14.7	1-27	69.3
		16.3	1-35	64.5
Dec. 12, 1956	1.0	13.8	2-48	67.8
		15.5	3-42	65.5
		15.1	4-22	63.5
		14.6	3-23	61.7
		15.0	2-17	65.6
Dec. 13, 1956	1.5	20.0	34-56	62.0
		20.9	30-11	62.2
		21.0	48-34	61.3
		18.5	54-05	55.9
		19.3	39-07	58.8
Dec. 13, 1956	2.0	20.2	80-45	55.6
		20.2	70-55	62.0
		21.4	113-00	61.4
		20.8	—	59.8
		21.8	—	57.5
Dec. 13, 1956	2.5	29.6	75-00	60.7
		26.8	75-00	60.0
		28.8	—	58.5
		26.3	—	59.5
		27.9	—	57.5
Dec. 14, 1956	3.0	39.3	155-00	57.4
		39.8	115-00	57.3
		42.4	—	61.2
		35.2	—	57.7
		33.9	—	56.9

TABLE VI (cont.)

Date	ABS mg/l	Σ, Sec.	Persistency Min.-Sec.	Surface Tension dynes/cm
Dec. 14, 1956	5.0	Σ_c = 8,130	—	53.6
		Σ_c = ∞	—	59.3
		Σ_c = 24,400	—	59.2
		Σ_c = 25,800	—	57.2
		Σ_c = 2,240	—	56.9
Dec. 14, 1956	10.0	Σ_c = 8,730	—	52.4
		Σ_c = 8,400	—	53.1
		Σ_c = 2,500	—	49.7
		Σ_c = 2,030	—	49.9
		Σ_c = ∞	—	51.7

TABLE VII

EFFECT OF BACTO-PEPTONE (DIFCO GRADE) ON FROTH FORMATION IN TAP WATER WITH 3.0 mg/1 ALKYLBENZENE SULFONATE

Date - December 17, 1956

Bacto-Peptone mg/1	Σ, sec.	Persistency Min.-Sec.	Surface Tension dynes/cm
0	10.2	0-30	59.8
3	8.5	0-29	57.5
5	10.9	0-28	55.8
10	15.4	0-56	56.3
13	—	1-34	—
15	Σ_c = 832	20-10	56.7
30	Σ_c = 874	84-00	56.5
50	Σ_c = 1400	105-00	56.9
80	Σ_c = 1125	118-00	56.7
100	Σ_c = 1690	—	54.4

EFFECT OF BACTO-PEPTONE ON FROTH FORMATION IN TAP WATER WITH 3.0 mg/l ALKYLBENZENE SULFONATE

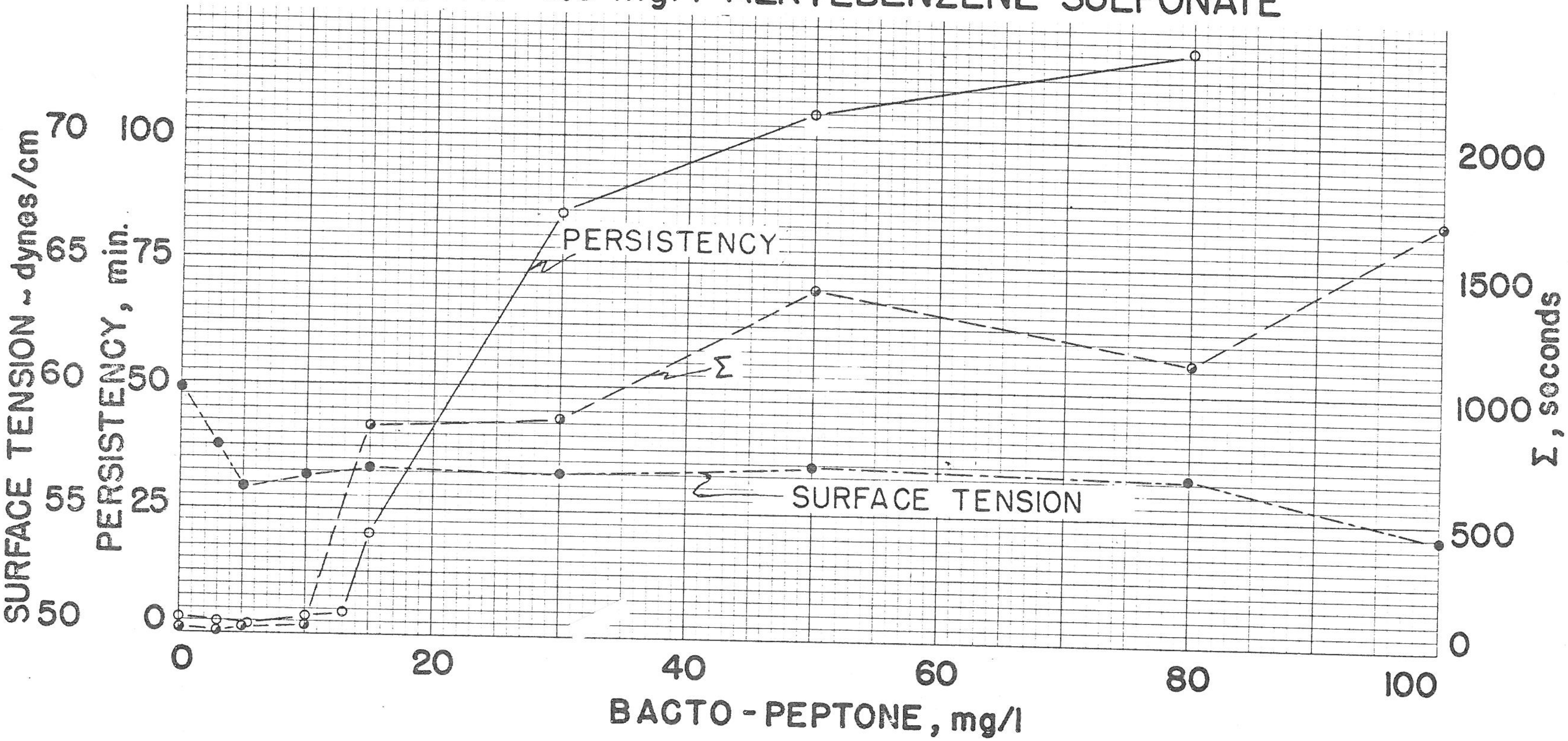


Fig.18

EFFECT OF VARYING CONCENTRATIONS OF ALKYLBENZENE SULFONATE ON FROTH FORMATION IN AERATION TANK MIXED LIQUOR

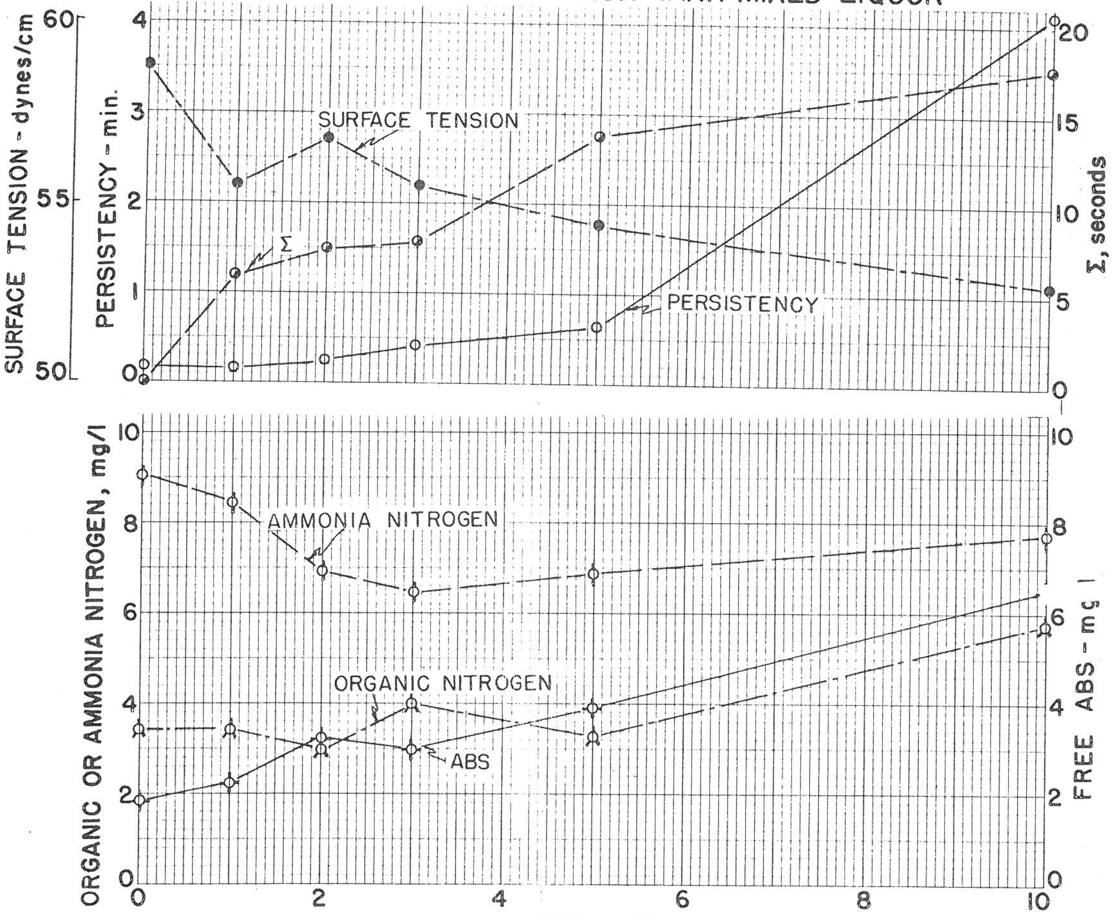


Fig. 19

TABLE VIII

EFFECT OF VARYING CONCENTRATIONS OF ALKYLBENZENE SULFONATE ON FROTH FORMATION IN AERATION TANK MIXED LIQUOR

Date - December 24, 1956

Added ABS mg/1	HA Milipore Membrane Filtrate Ammonia Nitrogen mg/1	HA Milipore Membrane Filtrate Organic Nitrogen mg/1	HA Milipore Membrane Filtrate ABS mg/1	Σ, Sec.	Persistency Min.-Sec.	Surface Tension dynes/cm
0	9.09	3.42	1.85	0	0-10	58.8
1	8.46	3.41	2.25	6	0-10	55.5
2	6.97	3.02	3.22	7.5	0-15	56.8
3	6.48	4.01	3.0	7.9	0-25	55.5
5	6.86	3.28	3.9	13.8	0-40	54.4
10	7.75	5.75	6.5	17.6	4-07	52.8

NOTE: Suspended Solids Concentration = 1440 mg/1

EFFECT OF VARYING pH ON FROTH FORMATION IN AERATION TANK MIXED LIQUORS

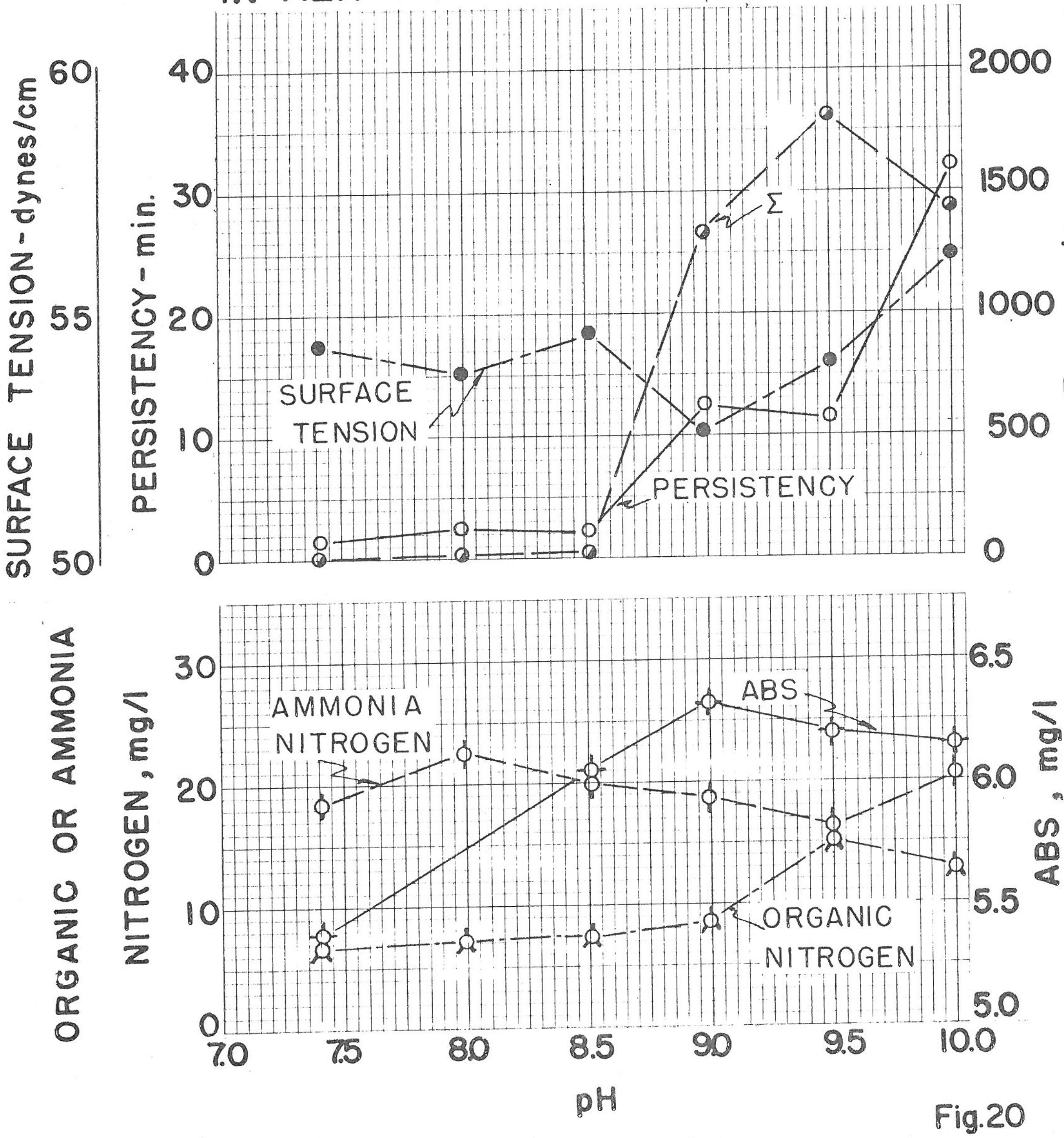


Fig.20

TABLE IX

EFFECT OF VARYING pH ON FROTH FORMATION IN AERATION TANK MIXED LIQUORS

Date - January 15, 1957

pH	HA Milipore Membrane Filtrate			Σ, Seconds	Persistency Min.-Sec.	Surface Tension dynes/cm
	Ammonia Nitrogen mg/l	Organic Nitrogen mg/l	ABS mg/l			
7.4	18.3	6.56	5.35	13	1-29	54.3
8.0	22.6	7.08	—	16	2-50	53.8
8.5	20.4	7.41	6.05	18.7	2-05	54.7
9.0	18.8	8.40	6.32	$\Sigma_c = 1330$	12-54	52.6
9.5	16.2	15.07	6.20	$\Sigma_c = 1810$	11-45	54.0
10.0	20.5	12.76	6.15	$\Sigma_c = 1430$	32-05	56.2

NOTE: pH increased by NAOH addition
Suspended solids concentration = 1610 mg/l

TABLE XI

Samples 200 mg/l Beef extract 300 " Peptone 50 " Urea 10 " ABS Madison tap water	Surface Tension dynes/cm	pH	TON mg/l Bulk	TON mg/l Froth	% Incr. TON in Froth over Bulk	$\Sigma_{c'}$ sec.	Σ sec.	Density[1] $[\rho]$ g/cc
0 Time, Tube 1	45.8	7.7	81.5			∞		0.0133
0 Time, Tube 2	46.1	7.75	82.5			12,700		0.0127
0 Time, Tube 3	41.1	7.75	87			∞		0.0146
0 Time, Tube 4	47.3	7.75	85.2			∞		0.0112
5 Min.	47.5	7.80	90.3	143	58	18,200		0.0103
10 Min.	49.7	7.75	87.0	138	57	5,060		0.00565
15 Min.	50.0	7.8	84.0	153	82	8,000		0.00757
25 Min.	54.9	7.9	85.2	127	49	∞		0.00483
35 Min.	56.5	7.95	82.8	148	78	*		0.0022
45 Min.	60.8	8.02	82.8	174	111		36	+
55 Min.	64.7	8.07	81.6	196	140		22	+
70 Min.	66.1	8.1	79.2	254	221		14	+

\+ Unable to determine

* Error in measurement

(1) Density of foam $[\rho] = \frac{\rho v_1}{v}$ where ρ is the density of the liquid; v_1 is the volume of liquid in a volume of foam v

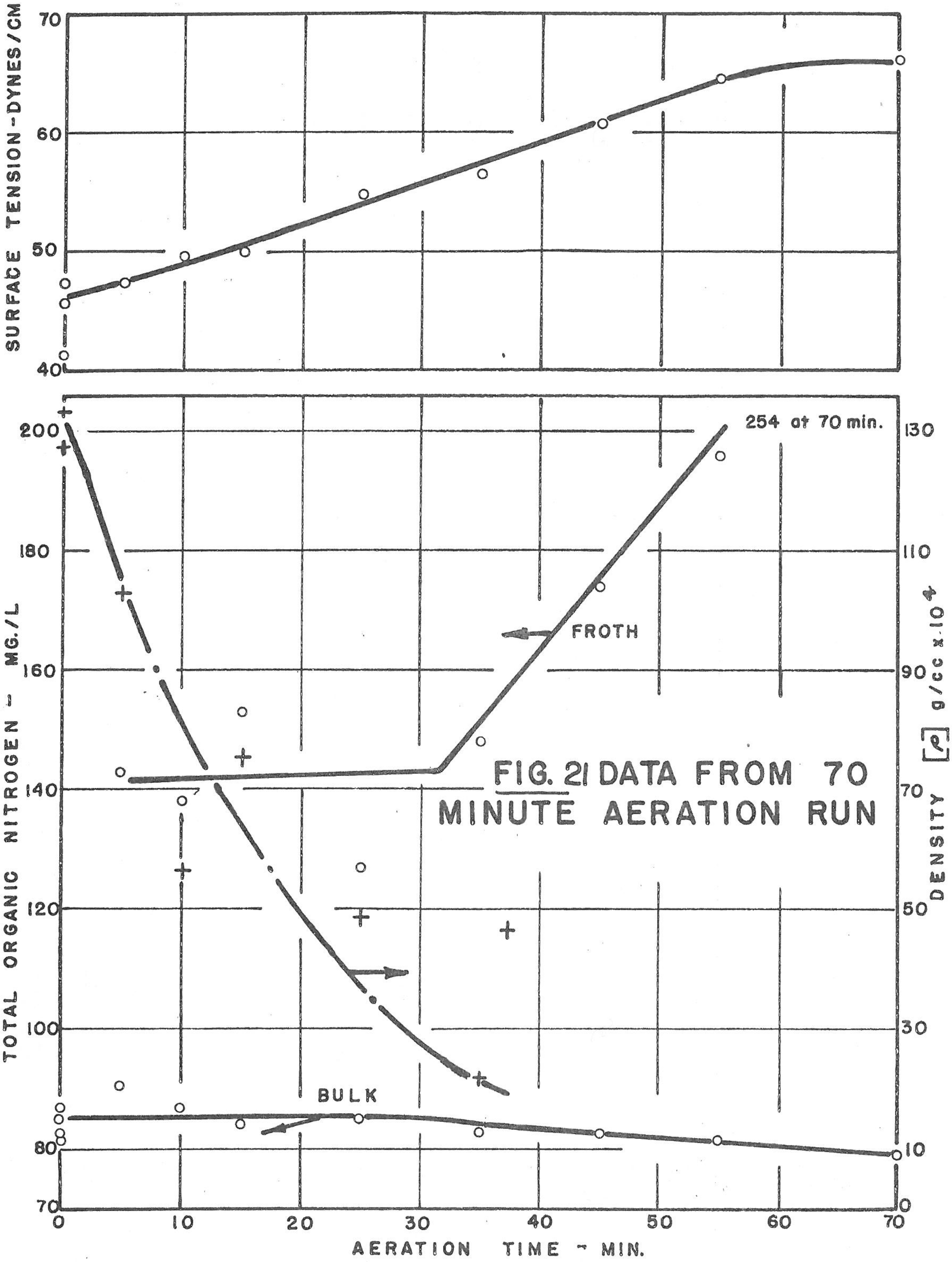
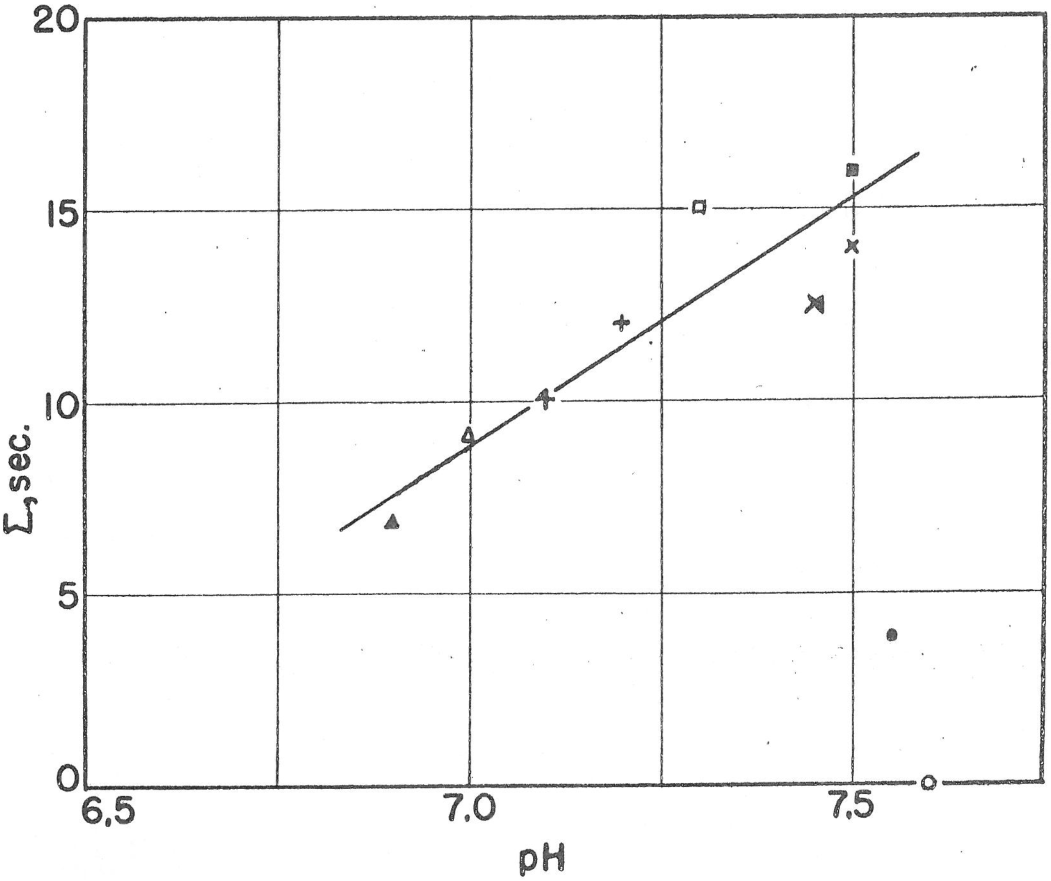


FIG. 21 DATA FROM 70 MINUTE AERATION RUN

KEY

CITY	HIGH FLOW	LOW FLOW
A	○	●
B	△	▲
C	□	■
D	×	✖
E	+	✚

FIG. 22 FINAL EFFLUENTS



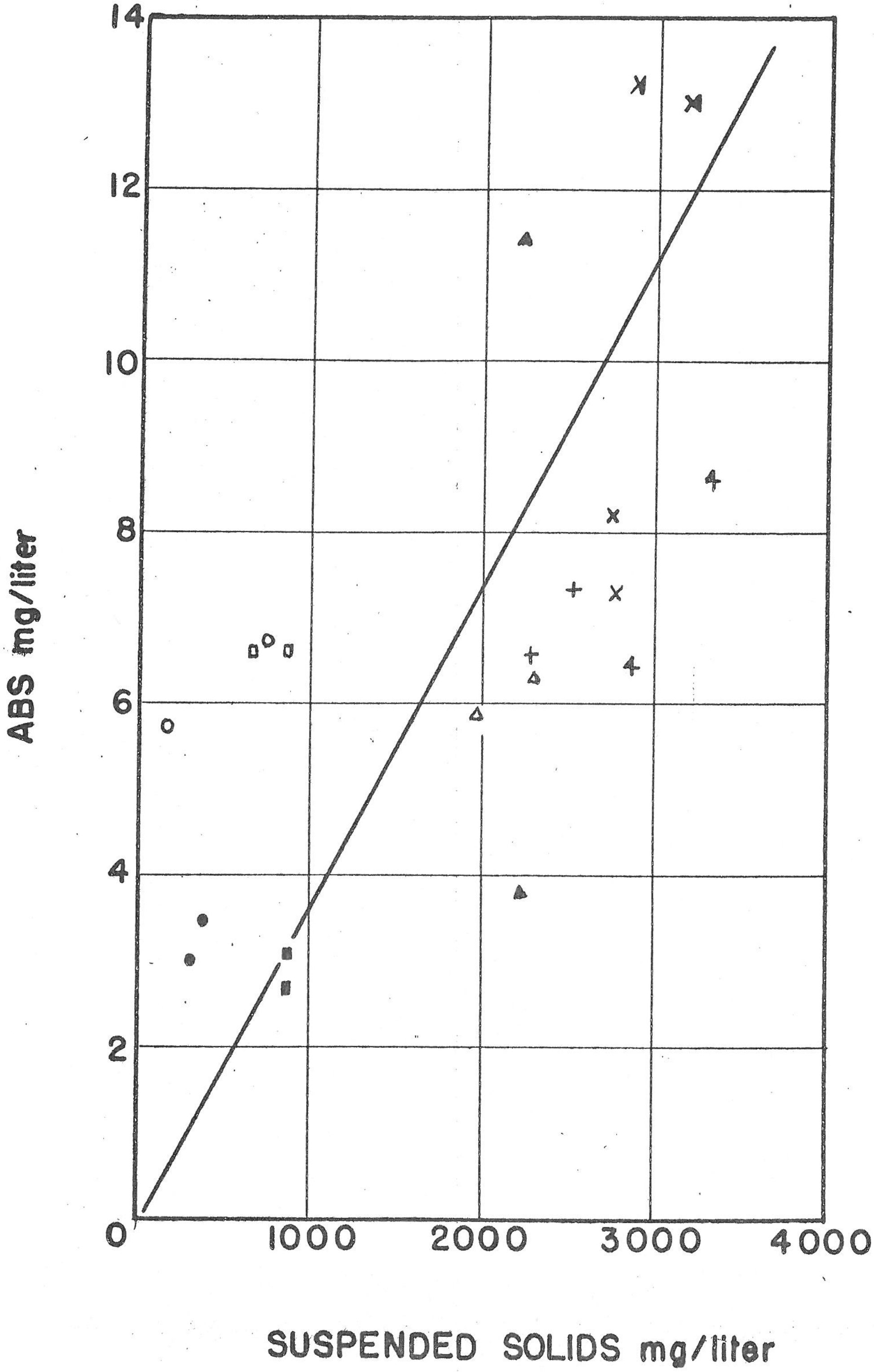


FIG. 23

AERATION EFFLUENT and INFLUENT

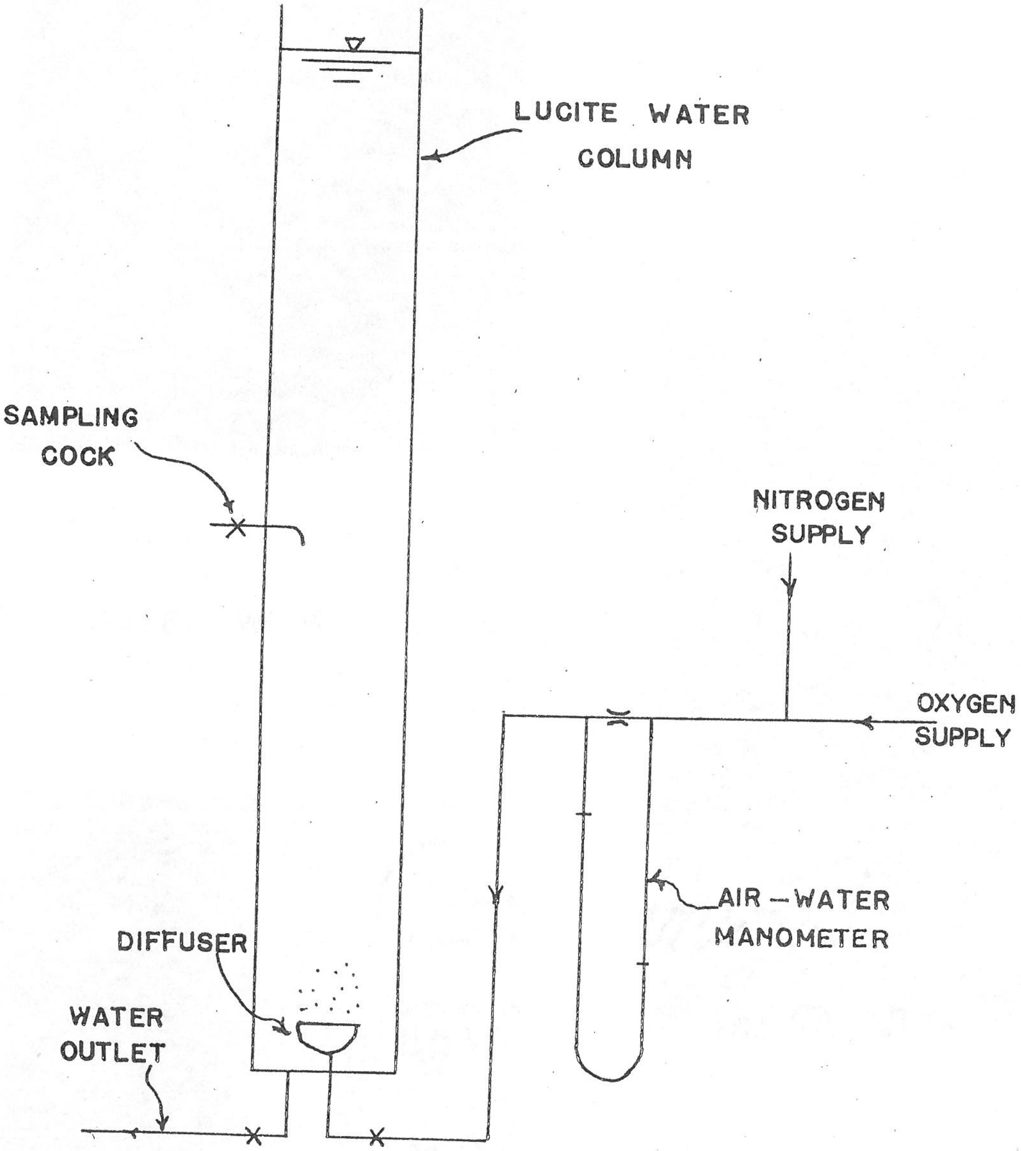
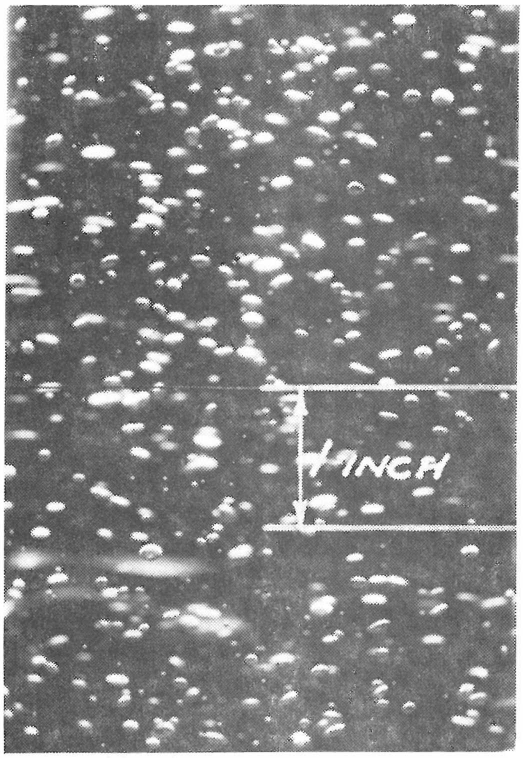
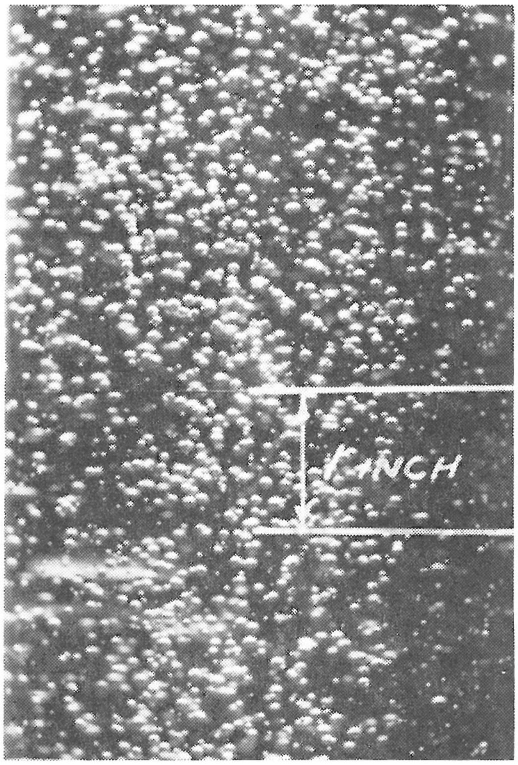


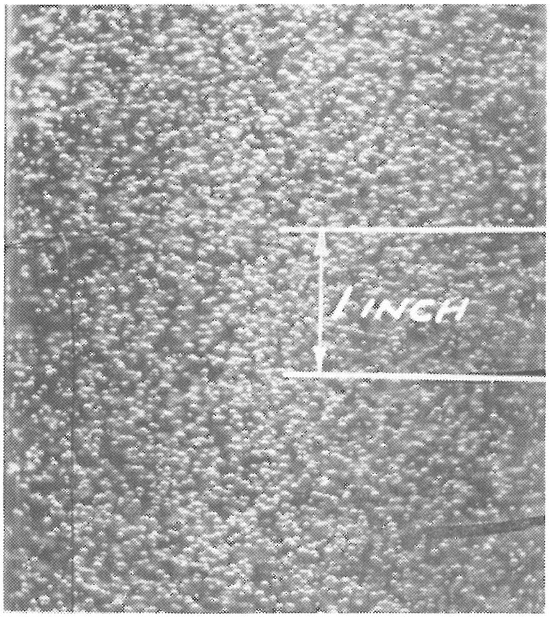
FIG 24 SCHEMATIC DIAGRAM OF AERATION COLUMN



TAP WATER WITH 0ppm ABS

TAP WATER WITH 3 ppm ABS





TAP WATER WITH 6 ppm ABS

Fig.25 EFFECT OF ABS ON BUBBLE SIZE FOR EQUAL RATES OF AERATION.

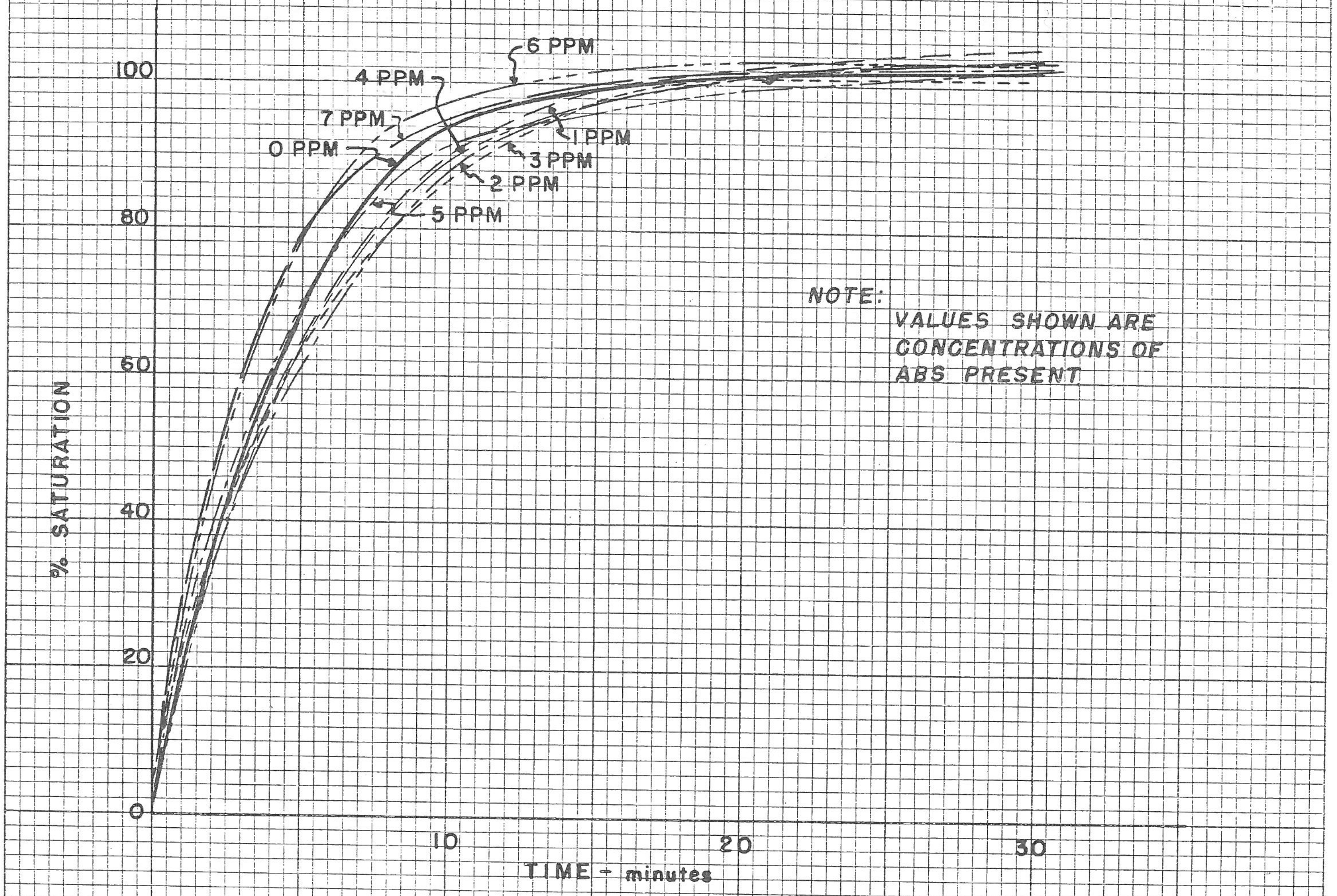


FIG. 26 SUMMARY GRAPH

EXPERIMENTAL AERATION TANK

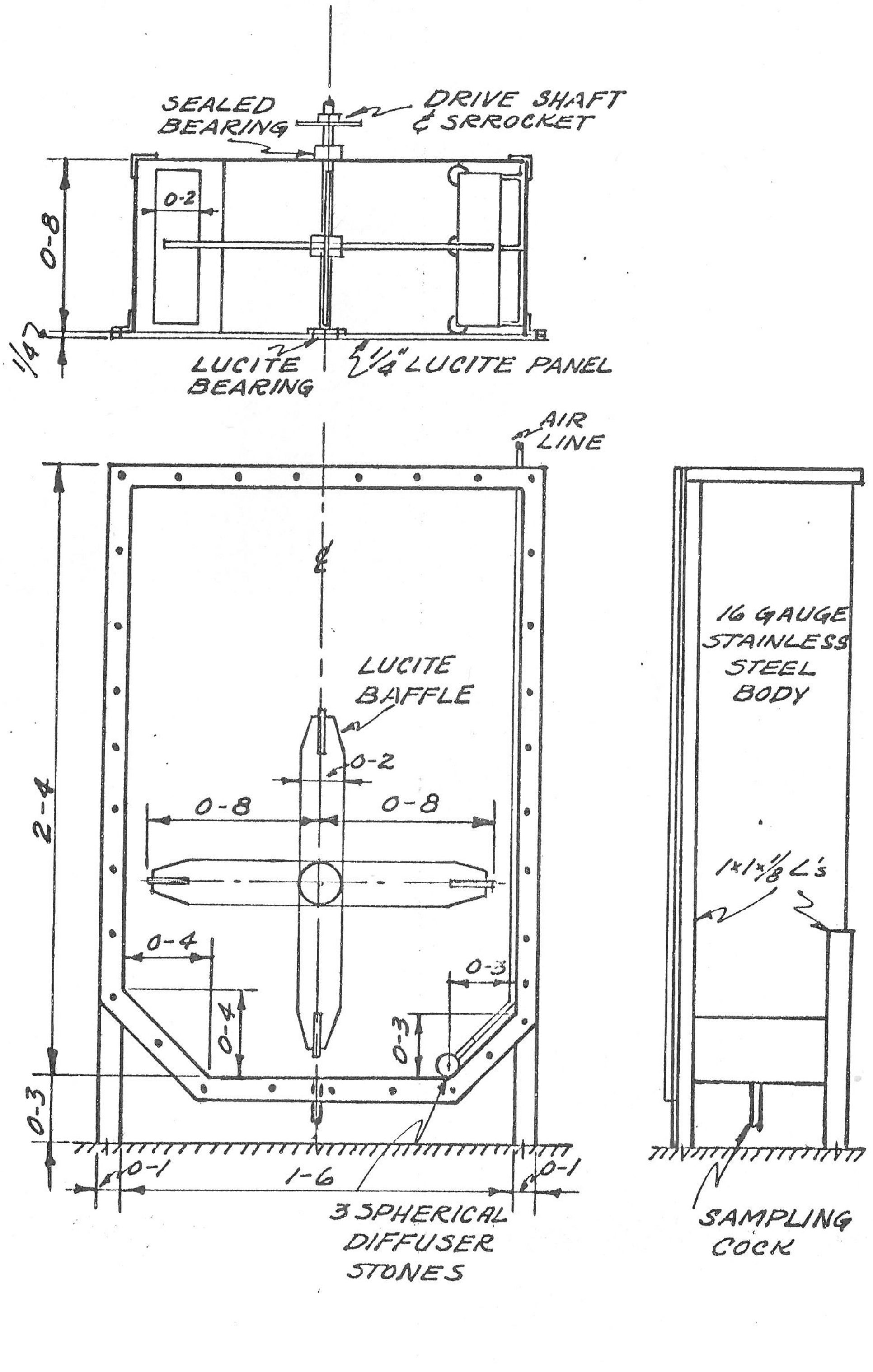


FIG. 27

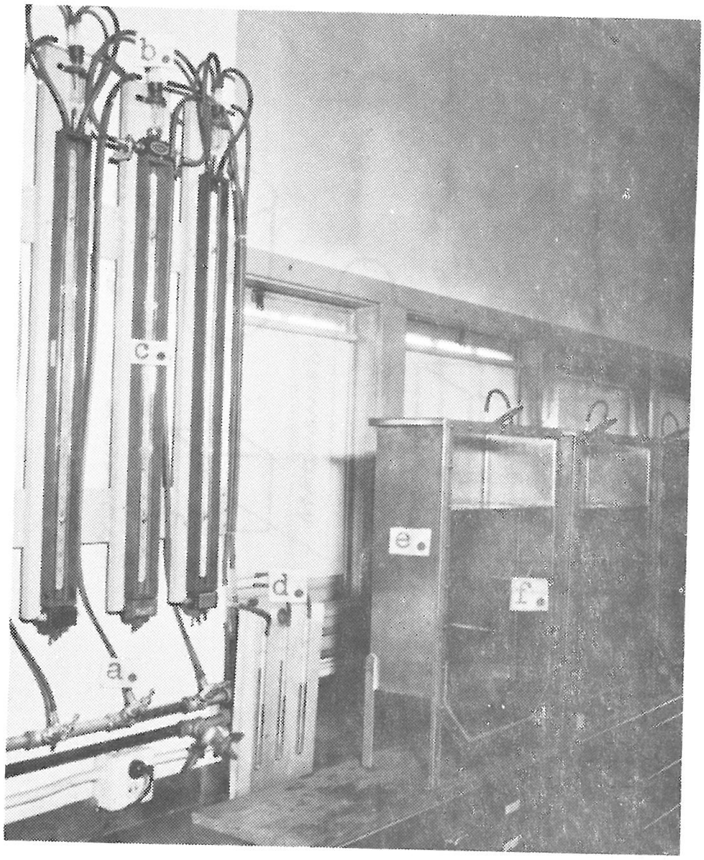
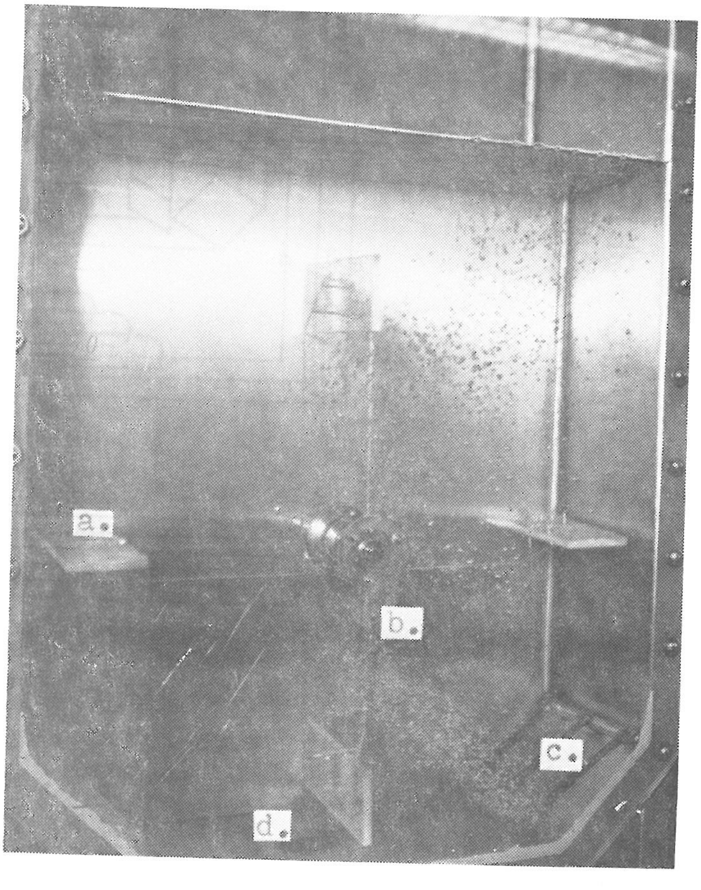


Fig.28 COMPLETE AERATION TANK ASSEMBLY.

a. AIR REGULATORY VALVES
b. ORIFICE CONTAINER
c. AIR-WATER MANOMETER
d. GAGE PRESSURE MERCURY MANOMETER
e. AERATION TANK
f. ROTATING BAFFLE

Fig.29 AERATION TANK FOR ACTIVATED SLUDGE STUDIES.

a. ROTATING BAFFLE
b. AIR BUBBLE PATTERN
c. SPHERICAL DIFFUSER STONES
d. SAMPLE OPENING & DRAIN



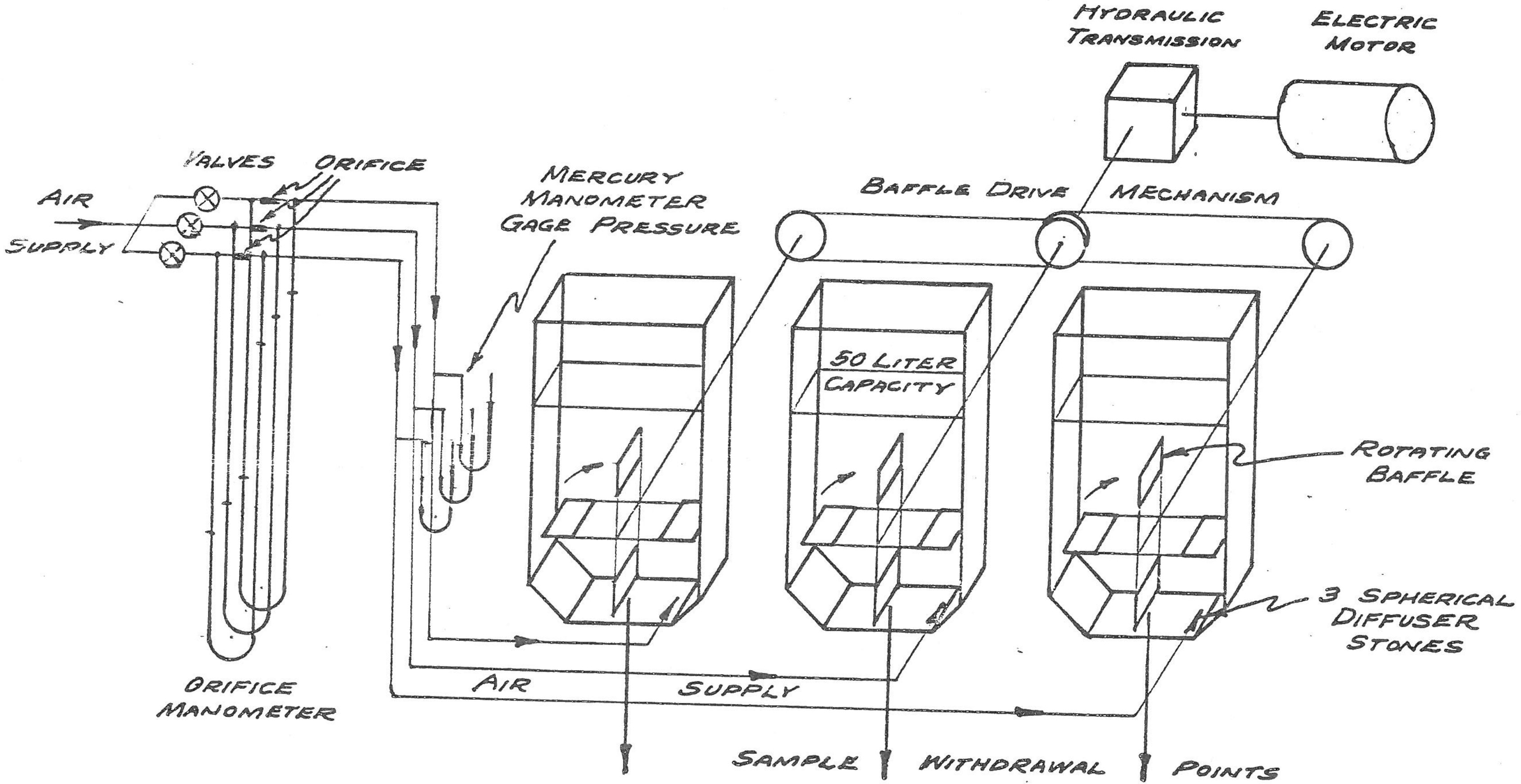


Fig. 30 SCHEMATIC SKETCH OF EXPERIMENTAL AERATION UNITS

TABLE XV

SUMMARY DATA SHEET

Run No. 1 Control (Incomplete)

Date 3/30/57

Sample and Unit	Aeration Time, Hours	Persistency, seconds	Persistency, seconds (3000)	Persistency, seconds (2000)	Σ, seconds	Σ, seconds (3000)	Σ, seconds (2000)	ABS, mg/1	Ammonia Nitrogen, mg/1	Organic Nitrogen, mg/1	p^H	BOD, mg/1	Electrode E_h Potential, m.v.	Temp. °C	Suspended Solids, mg/1	Surface Tension Dynes/cm	Data used in Correlation Studies	Correlation Identification No.
PE								5.26	32.2	26.6		304						
PEF								3.23	27.9	5.0		94						
RSF								2.94	49.3	9.6		86						
I-O	0	19	—	—	16.0	—	—	—	—	—	7.0	—	+213	15.0	—	54.0		
II-O	0	17	—	—	16.2	—	—	—	—	—	7.3	205	+207	15.0	4160	53.1		
III-O	0	18	—	—	7.9	—	—	—	—	—	7.4	—	+195	15.0	4210	53.4		
I-I	1	31	43*	64*	20.3	25.9*	34.5*	2.83	35.8	5.0	7.4	45	+219	15.5	4210*	53.9	0	1
II-I	1	34	46*	69*	17.7	21.7*	29.0*	3.01	35.5	3.9	7.3	44	+189	16.0	4020*	54.5	0	2
III-I	1	36	52*	80*	15.7	19.8*	26.2*	2.64	35.3	4.7	7.5	44	+171	16.0	4210*	55.1	0	3
I-2	2	50	78*	132*	17.7	22.5*	29.9*	2.78	35.8	4.7	7.3	40	+207	16.5	4210*	55.1	0	4
II-2	2	47	63*	103*	17.7	21.2*	28.3*	2.98	36.5	4.7	7.4	39	+189	16.5	3870*		0	5
III-2	2	49	75*	127*	14.3	17.8*	23.3*	2.90	35.0	3.3	—	37	+189	—	4210*			
I-3	3	69	126*	260*	16.7	21.2*	28.3*	—	35.3	4.0	7.4	38	+219	17.0	4210			
II-3	3	59	78*	133*	—	—	—	2.92	34.0	3.1	7.4	34	+237	17.0	3730			
II-4	4	75	115*	240*	15.8	18.7*	24.6*	2.87	34.6	3.1	7.4	36	+225	18.0	3870*		0	6

Note: * Interpolated values

PE - Primary Effluent

PEF - AA milipore membrane filtrate of primary effluent

RSF - AA milipore membrane filtrate of return sludge

TABLE XVI

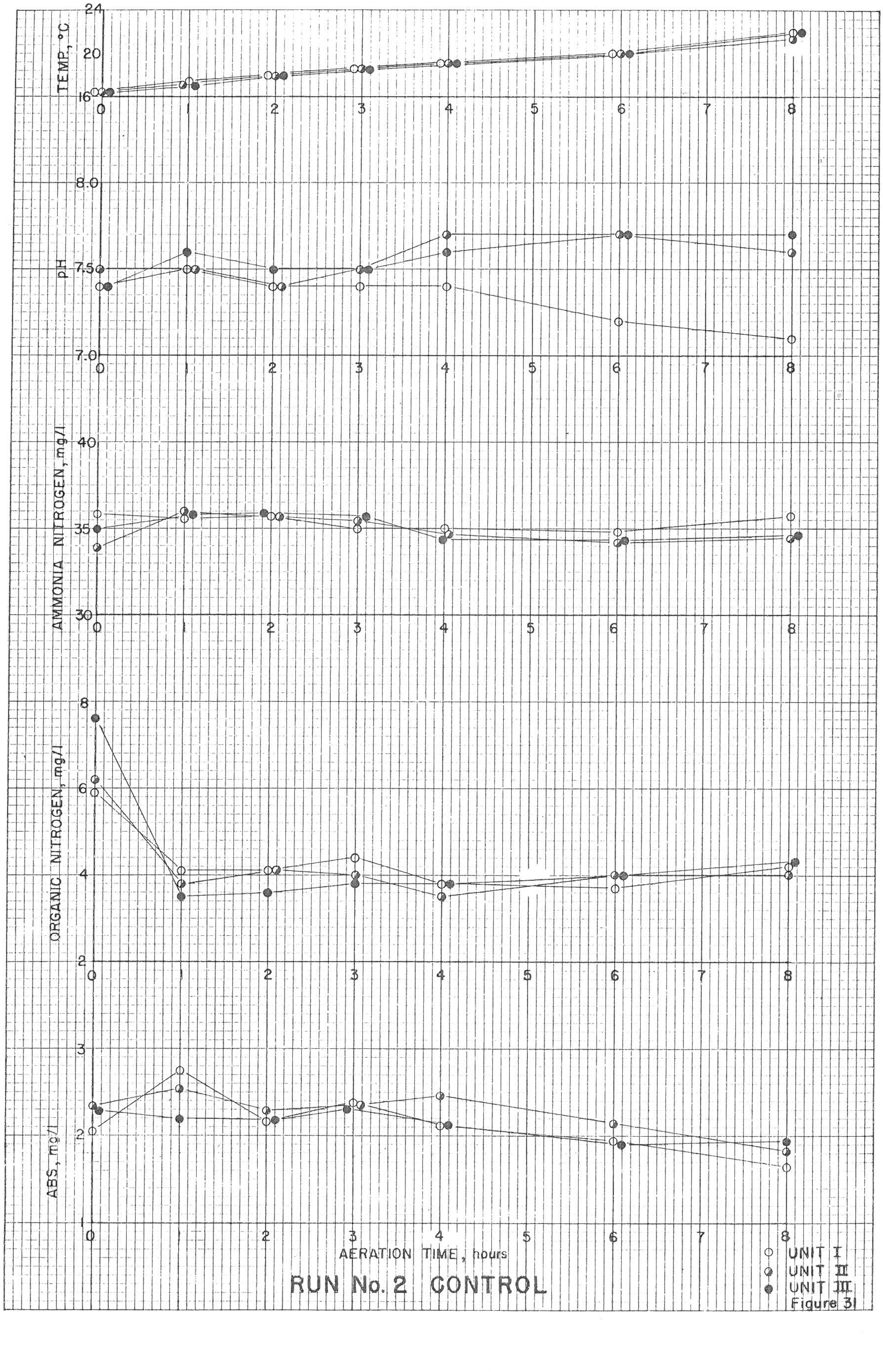
SUMMARY DATA SHEET

Run No. 2 Control

Date 4/6/57

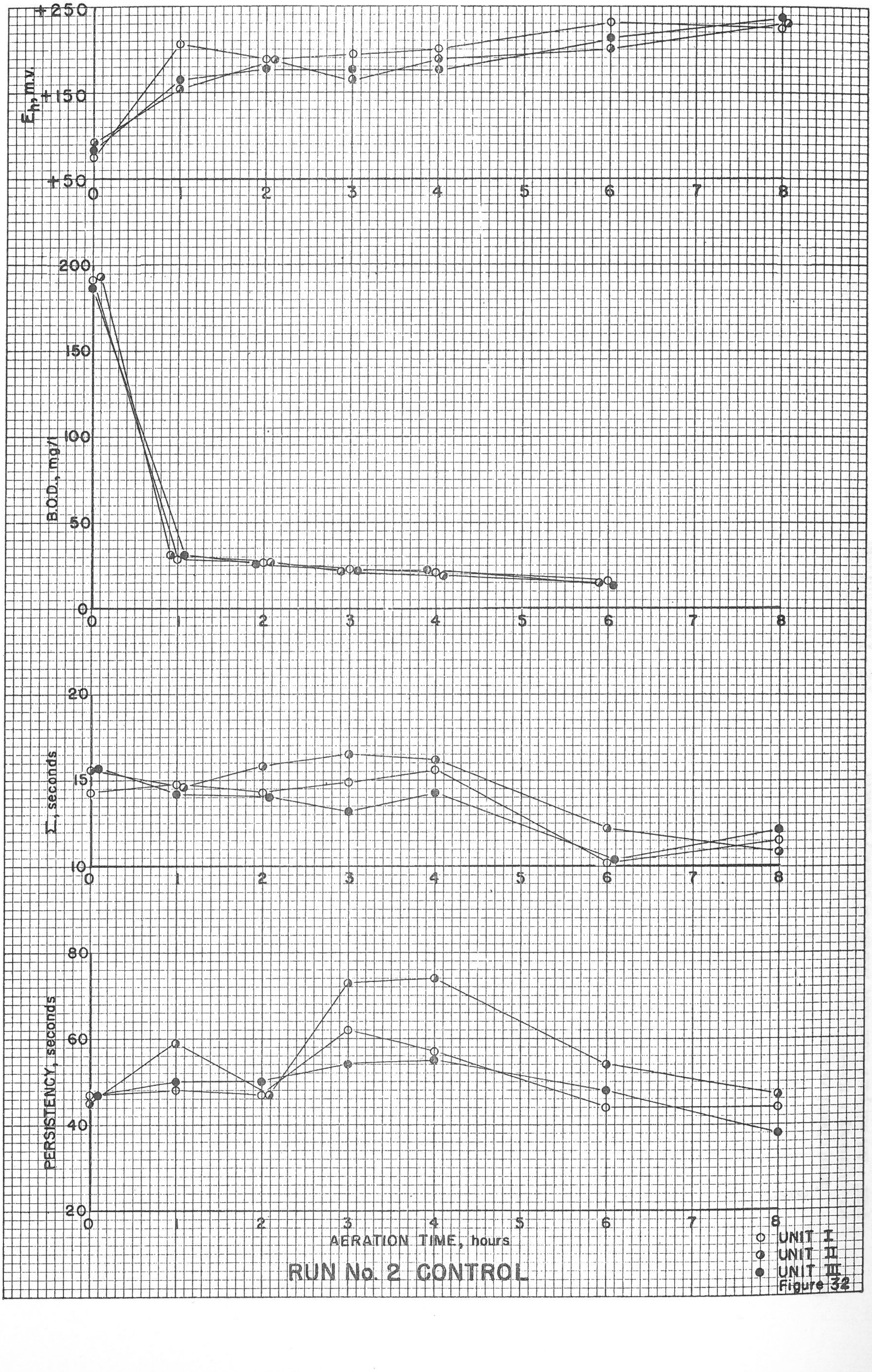
Sample and Unit	Aeration Time, Hours	Persistency, seconds	Persistency, seconds (3000)	Persistency, seconds (2000)	Σ, seconds	Σ, seconds (3000)	Σ, seconds (2000)	ABS, mg/1	Ammonia Nitrogen, mg/1	Organic Nitrogen, mg/1	pH	BOD mg/1	Electrode E_h Potencial, m.v.	Temp. °C	Suspended Solids, mg/1	Data used in Correlation Studies	Correlation Identification No.
PE								3.40	32.8	18.8		269			131		
PEF								2.70	31.9	4.6		108			—		
RS								—	—	—		—			8820		
RSF								2.27	41.3	4.6		27			—		
I-0	0	47	48*	74*	14.3	14.4*	18.0*	2.05	35.8	5.9	7.4	192	+ 75	16.5	3040	0	7
II-0	0	45	45*	69*	15.6	15.6*	20.2*	2.33	33.9	6.2	7.5	194	+ 93	16.5	3020	0	8
III-0	0	47	49*	76*	15.7	15.2*	19.5*	2.29	35.0	7.6	7.4	187	+ 87	16.5	2860	0	9
I-1	1	48	48*	74*	14.8	14.8*	19.0*	2.75	35.6	4.1	7.5	29	+207	17.5	3010*	0	10
II-1	1	59	59*	95*	14.6	14.6*	18.6*	2.53	36.0	3.8	7.5	31	+153	17.0	3010*	0	11
III-1	1	50	49*	75*	14.2	14.0*	17.3*	2.19	35.8	3.5	7.6	31	+165	17.0	2930*	0	12
I-2	2	47	46*	71*	14.3	14.2*	17.6*	2.16	35.7	4.1	7.4	27	+189	18.0	2980*	0	13
II-2	2	47	47*	72*	15.8	15.8*	20.3*	2.29	35.7	4.1	7.4	27	+189	18.0	3000*	0	14
III-2	2	50	50*	77*	14.0	14.0*	17.2*	2.18	35.8	3.6	7.5	26	+177	18.0	3000*	0	15
I-3	3	62	60*	97*	14.9	14.7*	18.6*	2.38	35.0	4.4	7.4	23	+195	18.5	2950	0	16
II-3	3	73	73*	121*	16.5	16.5*	21.2*	2.35	35.4	4.0	7.5	22	+165	18.5	2990	0	17
III-3	3	54	55*	87*	13.2	13.3*	16.0*	2.30	35.7	3.8	7.5	22	+177	18.5	3070	0	18
I-4	4	57	57*	90*	15.6	15.6*	20.0*	2.11	35.0	3.8	7.4	21	+201	19.0	3000*	0	19
II-4	4	74	74*	124*	16.2	16.2*	20.8*	2.46	34.7	3.5	7.7	19	+189	19.0	3000*	0	20
III-4	4	55	55*	86*	14.3	14.3*	17.8*	2.12	34.4	3.8	7.6	22	+177	19.0	3000*	0	21
I-6	6	44	44*	65*	10.2	10.2*	11.0*	1.94	34.8	3.7	7.2	16	+231	20.0	3000*	0	22
II-6	6	54	54*	84*	12.2	12.2*	14.0*	2.14	34.2	4.0	7.7	15	+201	20.0	3000*	0	23
III-6	6	48	48*	73*	10.4	10.4*	11.3*	1.90	34.3	4.0	7.7	13	+213	20.0	3000*	0	24
I-8	8	44	44*	65*	11.5	11.5*	13.7*	1.65	35.7	4.2	7.1	—	+225	22.0	3000*		
II-8	8	47	47*	72*	10.8	10.8*	11.9*	1.82	34.4	4.0	7.6	—	+231	21.5	3000*		
III-8	8	38	38*	56*	12.2	12.2*	14.0*	1.94	34.6	4.3	7.7	—	+237	22.0	3000*		
I-FE	6							2.51	34.6	9.8		34			31		
II-FE	6							2.54	34.3	9.3		32			25		
III-FE	6							2.21	34.5	10.0		34			22		
Total																	
I-0								13.98									
II-0								14.56									
I-3								13.31									
II-3								18.70									
III-3								14.01									

Note: * Interpolated values
PE - Primary effluent
PEF - AA milipore membrane filtrate of primary effluent
RS - Return Sludge
RSF - AA milipore membrane filtrate of return sludge
FE - Final effluent



RUN No. 2 CONTROL

Figure 31



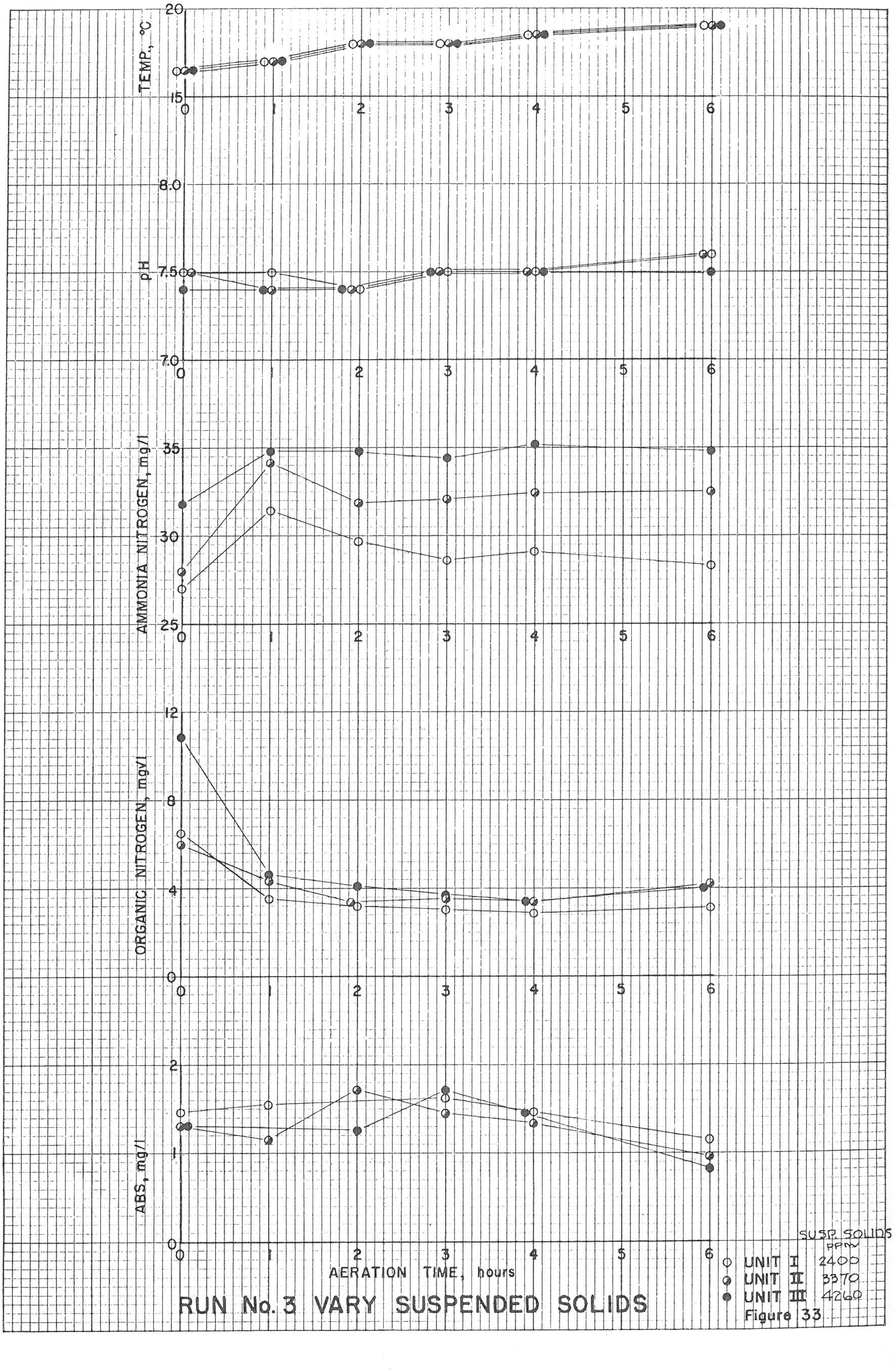
RUN No. 2 CONTROL

Figure 32

TABLE XVII
SUMMARY DATA SHEET
Run No. 3
Vary Suspended Solids
Date 4/13/57

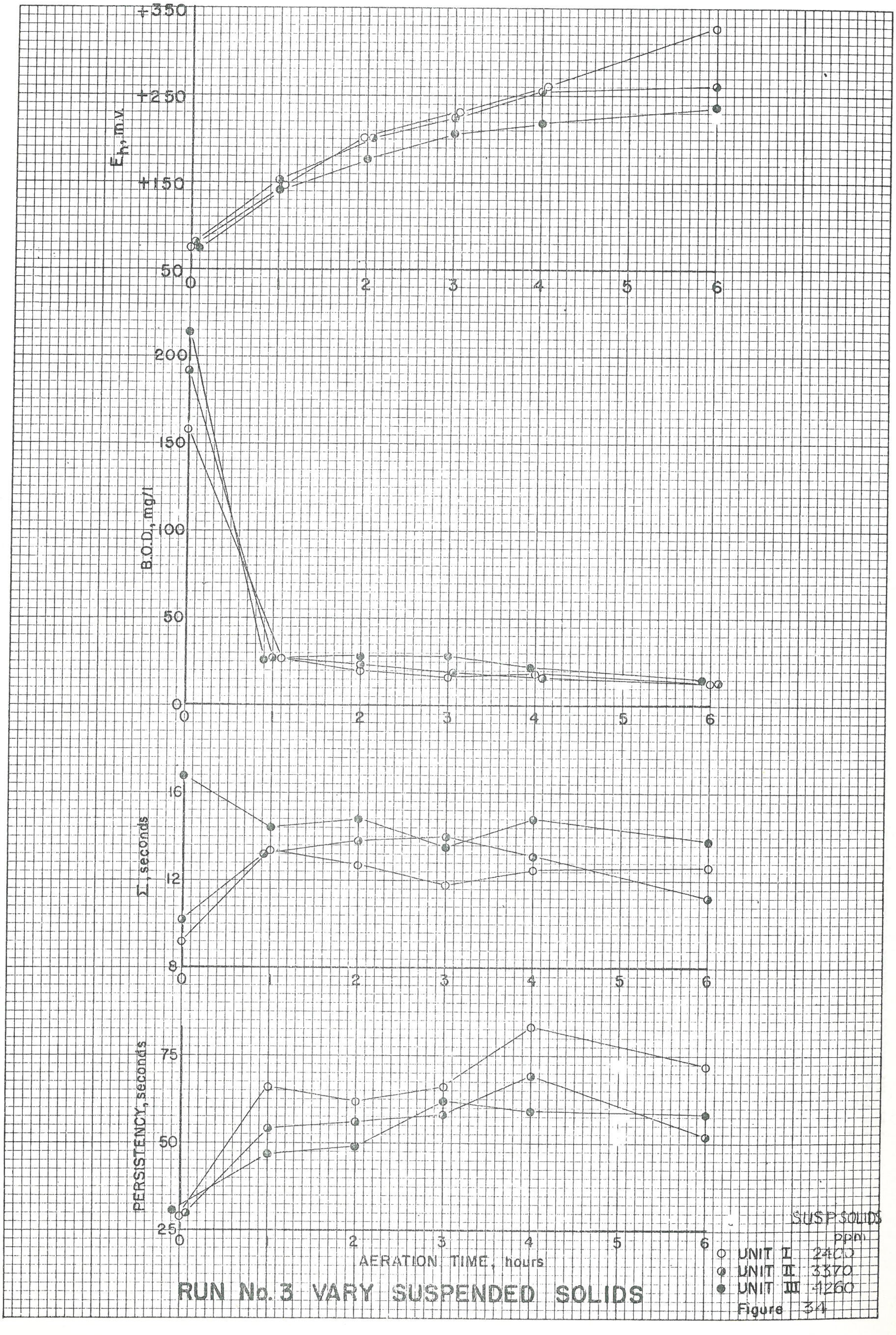
Sample and Unit	Aeration Time, Hours	Persistency, seconds	Persistency, seconds (3000)	Persistency, seconds (2000)	Σ, seconds	Σ, seconds (3000)	Σ, seconds (2000)	ABS mg/1	Ammonia Nitrogen, mg/1	Organic Nitrogen mg/1	pH	BOD, mg/1	Electrode E_h Potential, m.v.	Temp. °C	Suspended Solids, mg/1	Data used in Correlation Studies	Correlation Identification No.
PE								3.97				219			142		
PEF								2.83				142			—		
RS-1								—				—			10590		
RSF								0.90				38			—		
RS-2								—				—			1400		
RSF								0.95				6			—		
I-0	0	29	24*	34*	9.2	8.9*	9.6*	1.47	27.0	5.5	7.5	158	+ 75	16.5	2400	0	25
II-0	0	30	33*	48*	10.2	10.5*	11.5*	1.31	28.0	6.0	7.5	192	+ 81	16.5	3370	0	26
III-0	0	31	44*	66*	16.8	21.3*	28.5*	1.31	31.8	10.9	7.4	214	+ 75	16.5	4260	0	27
I-1	1	66	52*	81*	13.4	12.3*	14.2*	1.54	31.4	3.5	7.5	27	+147	17.0	2405*	0	28
II-1	1	54	61*	98*	13.2	14.0*	17.3*	1.15	34.2	4.3	7.4	27	+153	17.0	3350*	0	29
III-1	1	47	71*	117*	14.4	17.9*	23.3*	—	34.8	4.6	7.4	26	+141	17.0	4180*		
I-2	2	62	49*	76*	12.7	11.8*	13.4*	—	29.7	3.2	7.4	20	+201	18.0	2410*		
II-2	2	56	63*	102*	13.8	14.6*	18.5*	1.71	31.9	3.4	7.4	23	+201	18.0	3325*	0	30
III-2	2	49	50*	121*	14.8	18.2*	24.0*	1.26	34.8	4.1	7.4	28	+177	18.0	4105*	0	31
I-3	3	66	52*	81*	11.8	11.2*	12.5*	1.62	28.6	3.0	7.5	16	+231	18.0	2415*	0	32
II-3	3	58	65*	106*	14.0	14.7*	18.7*	1.45	32.1	3.5	7.5	19	+225	18.0	3300*	0	33
III-3	3	62	98*	190*	13.5	16.2*	21.0*	1.71	34.4	3.7	7.5	28	+207	18.0	4030*	0	34
I-4	4	83	64*	104*	12.5	11.7*	13.2*	1.47	29.1	2.9	7.5	18	+261	18.5	2420	0	35
II-4	4	69	77*	131*	13.1	13.6*	16.6*	1.33	32.4	3.4	7.5	16	+255	18.5	3280	0	36
III-4	4	59	84*	148*	14.8	17.6*	23.0*	1.46	35.2	3.6	7.5	22	+219	18.5	3950	0	37
I-6	6	72	54*	84*	12.6	11.6*	13.2*	1.15	28.3	3.1	7.6	13	+327	19.0	2310	0	38
II-6	6	52	54*	84*	11.2	11.3*	12.6*	0.96	32.5	4.2	7.6	13	+261	19.0	3100	0	39
III-6	6	58	78*	135*	13.8	16.0*	20.6*	0.82	34.8	4.0	7.5	15	+237	19.0	3790	0	40
I-FE	6											12					
II-FE	6											19					
III-FE	6											21					

Note: * Interpolated values
PE - Primary Effluent
PEF - AA milipore membrane filtrate of primary effluent
RS - 1,2 - Return Sludge
RSF - AA milipore membrane filtrate of return sludge
FE - Final effluent



RUN No. 3 VARY SUSPENDED SOLIDS

Figure 33



RUN No. 3 VARY SUSPENDED SOLIDS

Figure 34

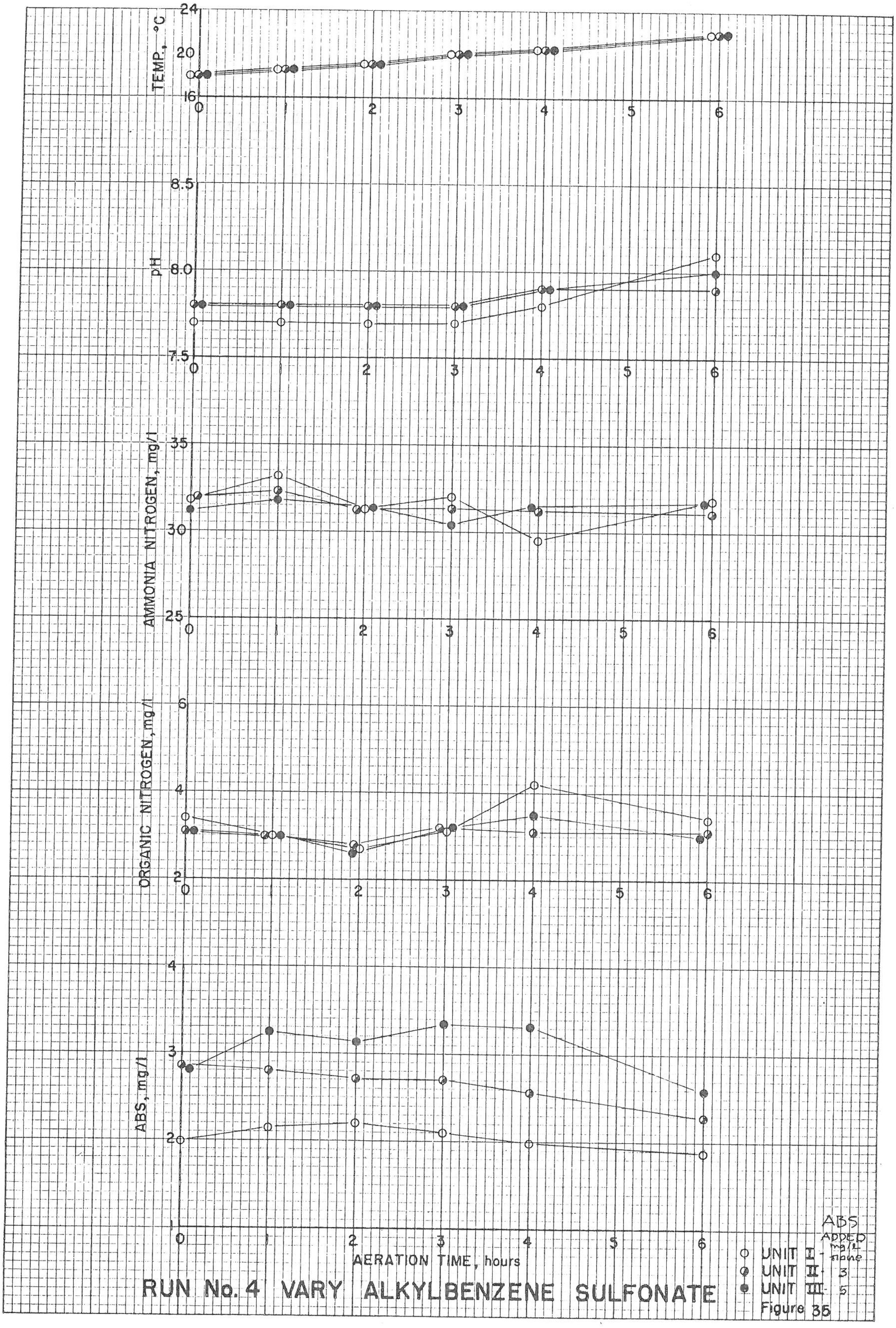
TABLE XVIII
SUMMARY DATA SHEET
Run No. 4
Vary ABS
Date 5/4/57

Sample and Unit	Aeration Time, Hours	Persistency, seconds	Persistency, seconds (3000)	Persistency, seconds (2000)	Σ, seconds	Σ, seconds (3000)	Σ, seconds (2000)	ABS, mg/l	Ammonia Nitrogen, mg/l	Organic Nitrogen, mg/l	pH	BOD, mg/l	Electrode E_h Potential, m.v.	Temp. °C	Suspended solids, mg/l	Data used in Correlation Studies	Correlation Identification No.
PE								3.41	32.4	13.8		202			176		
PEF								2.69	30.6	3.4		107			–		
RS								15.46	–	–		–			5660		
RSF								1.91	36.2	3.5		22			–		
I-0	0	43	30*	41*	14.7	12.4*	14.5*	1.99	31.8	3.4	7.7	112	+ 93	18.0	1920	0	41
II-0	0	70	45*	68*	21.5	16.2*	21.0*	2.86	32.0	3.1	7.8	119	+105	18.0	1940	0	42
III-0	0	111	65*	106*	22.4	16.8*	21.7*	2.81	31.2	3.1	7.8	106	+ 81	18.0	1930	0	43
I-1	1	88	53*	84*	14.8	12.5*	14.5*	2.15	33.2	3.0	7.7	23	+177	18.5	1920*	0	44
II-1	1	109	63*	103*	15.1	12.6*	14.8*	2.80	32.3	3.0	7.8	17	+171	18.5	1915*	0	45
III-1	1	204	100*	191*	17.0	13.7*	16.7*	3.25	31.8	3.0	7.8	21	+177	18.5	1935*	0	46
I-2	2	74	46*	70*	13.3	11.6*	13.1*	2.20	31.3	2.7	7.7	16	+243	19.0	1920*	0	47
II-2	2	129	71*	118*	15.9	13.0*	15.4*	2.71	31.2	2.8	7.8	20	+237	19.0	1885*	0	48
III-2	2	166	90*	158*	17.2	13.8*	16.9*	3.14	31.4	2.6	7.8	22	+237	19.0	1945*	0	49
I-3	3	91	55*	87*	14.3	12.2*	14.0*	2.10	32.0	3.1	7.7	16	+255	20.0	1920	0	50
II-3	3	127	70*	116*	16.1	13.1*	15.6*	2.71	31.3	3.2	7.8	20	+249	20.0	1860	0	51
III-3	3	171	92*	165*	16.8	13.6*	16.5*	3.35	30.4	3.2	7.8	17	+255	20.0	1950	0	52
I-4	4	70	44*	66*	16.3	13.2*	15.8*	1.98	29.5	4.2	7.8	17	+273	20.5	1890*	0	53
II-4	4	128	70*	116*	15.5	13.0*	15.4*	2.57	31.2	3.1	7.9	20	+267	20.5	1865*	0	54
III-4	4	205	101*	197*	18.4	14.4*	18.1*	3.32	31.5	3.5	7.9	21	+261	20.5	1960*	0	55
I-6	6	76	46*	70*	12.9	11.2*	12.5*	1.87	31.8	3.4	8.1	16	+285	22.0	1860	0	56
II-6	6	113	64*	104*	16.9	13.5*	16.3*	2.28	31.1	3.1	7.9	17	+273	22.0	1870	0	57
III-6	6	195	100*	190*	15.1	12.7*	15.0*	2.58	31.7	3.0	8.0	18	+267	22.0	1970	0	58
I-FE	6								32.5	7.0		36			69		
II-FE	6								32.6	7.8		38			91		
III-FE	6								31.2	7.8		38			78		
Total																	
I-0								8.96									
II-0								9.53									
III-0								12.29									
I-6								6.08									
II-6								7.10									
III-6								9.80									

Note: Unit I Control - PE
Unit II PE + 3 mg/l ABS
Unit III PE + 5 mg/l ABS

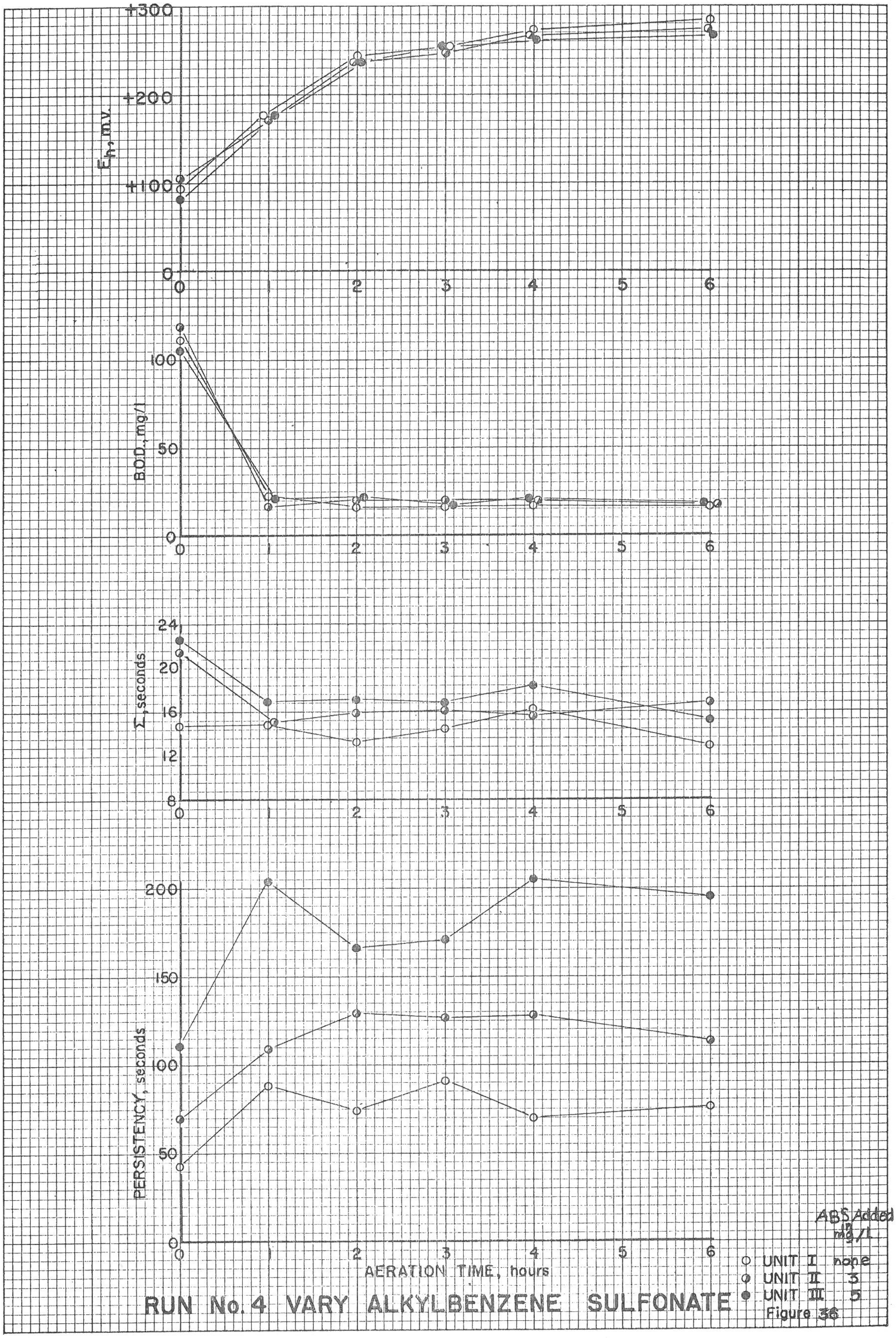
* Interpolated values
PE Primary Effluent
PEF AA milipore membrane filtrate of primary effluent

RS Return Sludge
RSF AA milipore membrane filtrate of return sludge
FE Final Effluent



RUN No. 4 VARY ALKYLBENZENE SULFONATE

Figure 35



RUN No. 4 VARY ALKYLBENZENE SULFONATE

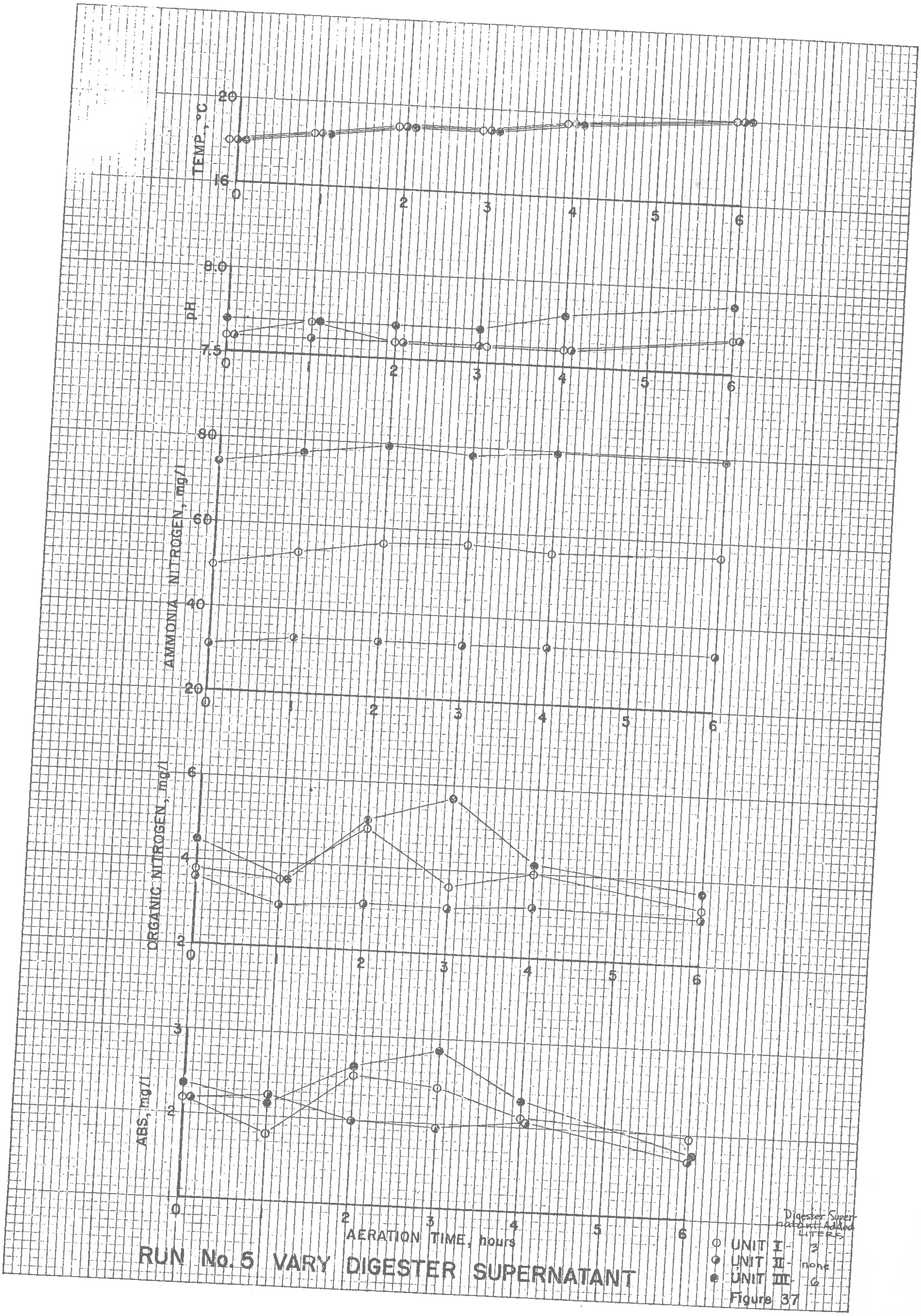
Figure 36

TABLE XIX
SUMMARY DATA SHEET
Run No. 5
Vary Digester Supernatant
Date 5/11/57

Sample and Unit	Aeration Time, Hours	Persistency, seconds	Persistency, seconds (3000)	Persistency, seconds (2000)	Σ, seconds	Σ, seconds (3000)	Σ, seconds (2000)	ABS mg/l	Ammonia Nitrogen, mg/l	Organic Nitrogen mg/l	pH	B.O.D., mg/l	Electrode E_h Potential, m.v.	Temp., °C	Suspended Solids, mg/l	Surface Tension, Dynes/cm	Data used in Correlation Studies	Correlation Identification No.
PE		3800						3.63	34.2	16.6		182			130			
PEF		–						2.93	30.7	3.8		130			–			
RS		14						–	–	–		–			8450			
RSF		–						1.78	40.1	4.3		36			–			
DS		72						–	387	5.9		527			840			
DSF		–						2.95	313	7.8		218			–			
I-0	0	44	44*	65*	16.1	16.0*	20.6*	2.18	49.9	3.8	7.6	185	+ 93	18.0	2980	55.7	+	93
II-0	0	57	54*	84*	16.3	15.8*	20.3*	2.19	31.2	3.6	7.6	140	+111	18.0	2860	56.4	0	59
III-0	0	49	54*	84*	16.0	16.8*	21.5*	2.36	74.3	4.5	7.7	197	+123	18.0	3260	55.7	+	94
I-1	1	60	59*	94*	15.4	15.3*	19.6*	1.79	53.4	3.6	7.7	34	+201	18.5	2985*	59.0	+	95
II-1	1	56	53*	83*	15.9	15.5*	19.8*	2.25	33.2	3.0	7.6	25	+ 95	18.5	2870*	55.7	0	60
III-1	1	54	57*	90*	11.4	11.6*	13.0*	2.17	77.0	3.6	7.7	46	+207	18.5	3170*	55.4	+	96
I-2	2	45	45*	67*	13.6	13.5*	16.3*	2.52	56.3	4.9	7.6	36	+267	19.0	2985*	55.6	+	97
II-2	2	47	45*	68*	12.7	12.5*	14.5*	1.99	33.2	3.1	7.6	23	+237	19.0	2880*	56.6	0	61
III-2	2	46	47*	72*	12.9	13.0*	15.4*	2.63	79.6	5.1	7.7	42	+249	19.0	3080*	56.0	+	98
I-3	3	50	50*	77*	11.5	11.5*	12.8*	2.42	57.1	3.6	7.6	31	+285	19.0	2990	57.4	+	99
II-3	3	57	55*	86*	10.3	10.2*	11.2*	1.95	33.2	3.1	7.6	19	+255	19.0	2900	56.6	0	62
III-3	3	44	44*	66*	10.5	10.5*	11.6*	2.87	78.0	5.7	7.7	40	+261	19.0	2990	56.1	+	100
I-4	4	49	47*	72*	11.8	11.7*	13.2*	2.11	55.8	4.0	7.6	26	+249	19.5	2915*	57.9	+	101
II-4	4	59	56*	89*	11.5	11.0*	12.3*	2.07	33.7	3.2	7.6	16	+237	19.5	2880*	58.0	0	63
III-4	4	43	42*	62*	12.0	11.8*	13.5*	2.31	79.5	4.2	7.8	37	+255	19.5	2935*	57.6	+	102
I-6	6	49	46*	70*	9.2	9.1*	9.8*	1.95	56.4	3.3	7.7	22	+249	20.0	2840	58.5	+	103
II-6	6	50	47*	73*	10.1	10.0*	10.9*	1.68	33.3	3.1	7.7	18	+261	20.0	2860	61.1	0	64
III-6	6	43	41*	61*	9.7	9.6*	10.5*	1.75	79.2	3.7	7.9	33	+261	20.0	2880	59.9	+	104
I-FE	6								57.5	10.0		45			71			
II-FE	6								34.4	7.1		33			49			
III-FE	6								78.4	11.9		61			65			

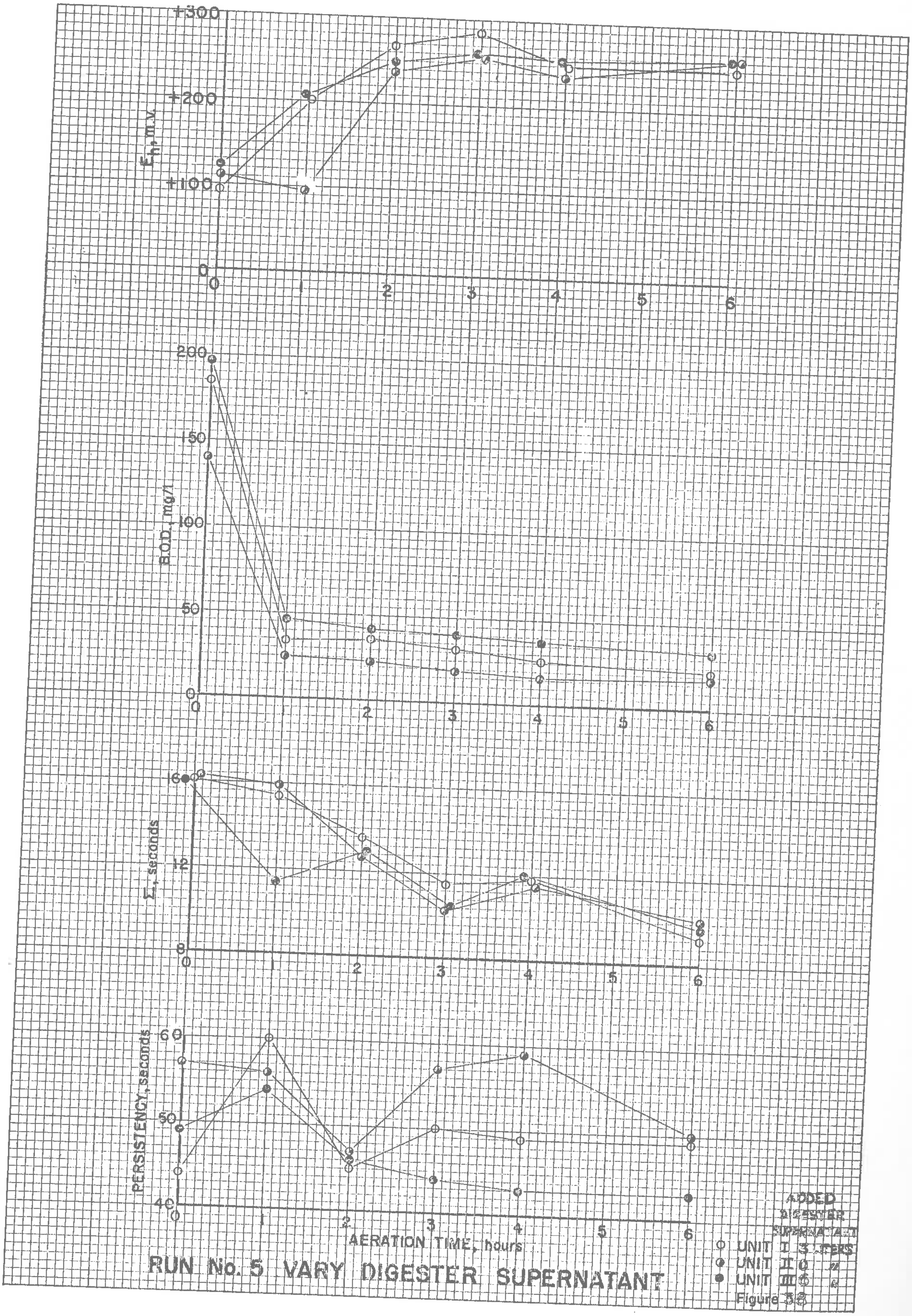
Note: 1 Unit I 27 liters of PE + 3 liters of DS
Unit II Control 30 liters of PE
Unit III 24 liters of PE + 6 liters of DS

2 * Interpolated values
PE Primary effluent
PEF AA milipore membrane filtrate of primary effluent
RS Return sludge
RSF AA milipore membrane filtrate of return sludge
DS Digester supernatant
DSF AA milipore membrane filtrate of digester supernatant



RUN No. 5 VARY DIGESTER SUPERNATANT

Figure 37



RUN No. 5 VARY DIGESTER SUPERNATANT

Figure 38

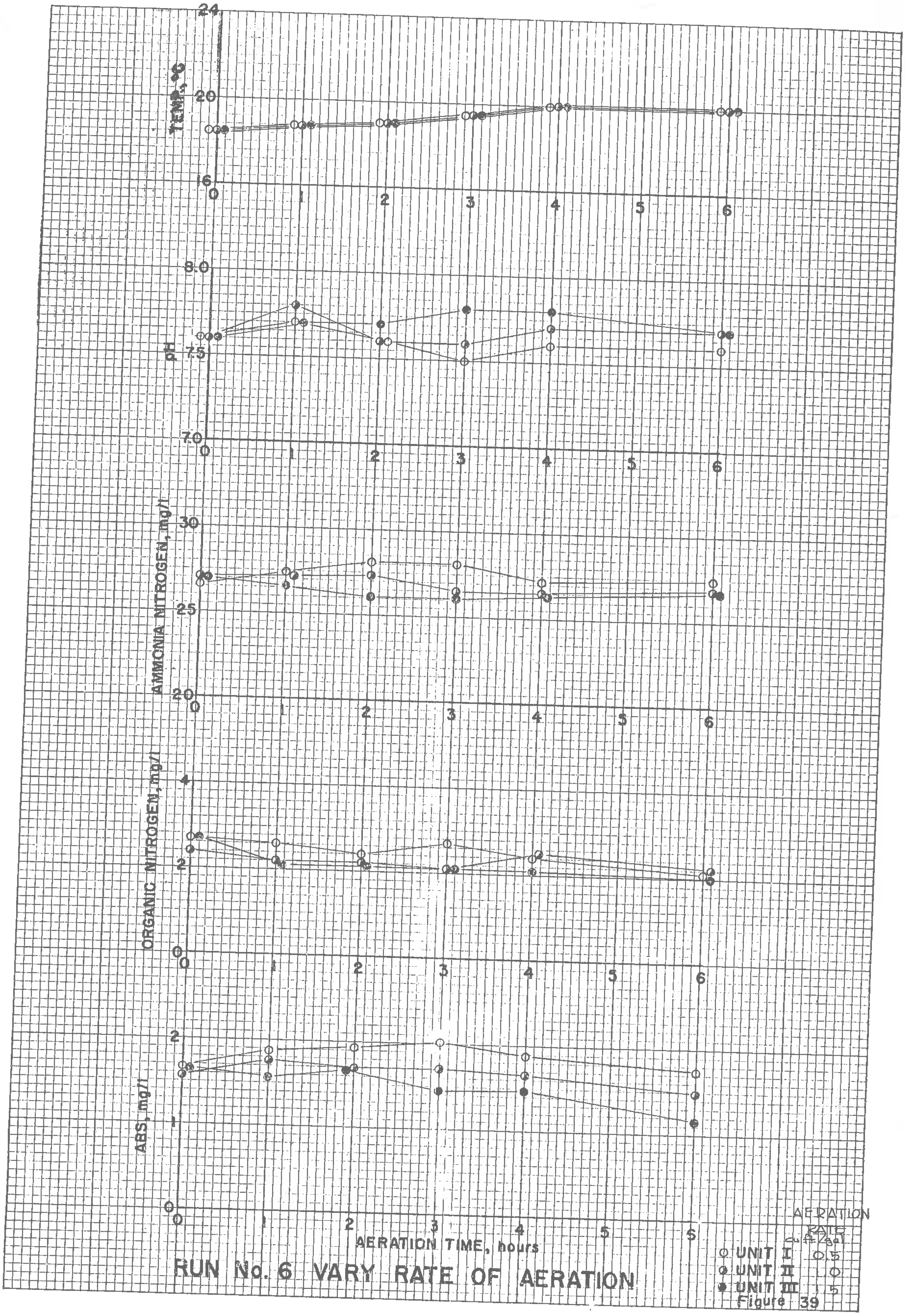
TABLE XX
SUMMARY DATA SHEET
Run No. 6
Vary Rate of Aeration
Date 5/18/57

Sample and Unit	Aeration time, Hours	Persistency, seconds	Persistency, seconds (3000)	Persistency, seconds (2000)	Σ, seconds	Σ, seconds (3000)	Σ, seconds (2000)	ABS mg/l	Ammonia Nitrogen, mg/l	Organic Nitrogern, mg/l	pH	B.O.D., mg/l	Electrode E_h, Potential, m.v.	Temp. °C	Suspended Solids, mg/l	Surface Tension, Dynes/cm	Data used in Correlation Studies	Correlation Identification No.
PE								4.04	28.0	13.8		178			204			
PEF								3.16	27.4	3.0		106			–			
RS		29						21.81	–	–		–			8270			
RSF								1.48	26.4	3.6		12			–			
I-0	0	47	44*	67*	18.4	17.6*	23.0*	1.67	26.6	2.7	7.6	70	+213	18.5	2850	57.7	0	65
II-0	0	53	48*	74*	13.3	12.8*	15.1*	1.58	27.1	2.4	7.6	76	+207	18.5	2750	57.8	0	66
III-0	0	57	51*	78*	16.2	15.1*	19.4*	1.66	27.0	2.7	7.6	68	+207	18.5	2700	59.1	0	67
I-1	1	60	56*	89*	14.3	13.9*	17.1*	1.87	27.4	2.6	7.7	20	+219	18.8	2845*	59.6	0	68
II-1	1	46	43*	63*	16.4	15.6*	20.0*	1.76	27.2	2.2	7.8	15	+231	18.8	2780*	59.9	0	69
III-1	1	37	34*	49*	12.6	12.2*	14.0*	1.56	26.6	2.1	7.7	20	+249	18.8	2725*	62.1	0	70
I-2	2	54	50*	78*	14.6	14.1*	17.6*	1.93	28.1	2.4	7.6	18	+267	19.0	2845*	59.2	0	71
II-2	2	52	48*	74*	11.2	11.0*	12.2*	1.69	27.3	2.2	7.6	13	+261	19.0	2810*	60.2	0	72
III-2	2	50	46*	69*	10.0	9.8*	10.7*	1.67	26.1	2.1	7.7	14	+249	19.0	2750*	58.8	0	73
I-3	3	55	51*	80*	13.7	13.3*	16.0*	2.01	28.1	2.7	7.5	19	+279	19.5	2840	59.8	0	74
II-3	3	56	52*	81*	14.5	14.0*	17.4*	1.71	26.5	2.1	7.6	9	+267	19.5	2840	62.2	0	75
III-3	3	47	43*	65*	12.2	11.9*	13.5*	1.45	26.1	2.1	7.8	10	+267	19.5	2770	60.1	0	76
I-4	4	52	50*	78*	11.1	11.0*	12.3*	1.88	27.2	2.4	7.6	13	+267	20.0	2945*	59.4	0	77
II-4	4	60	61*	98*	10.7	10.8*	11.8*	1.66	26.5	2.5	7.7	8	+261	20.0	3050*	61.2	0	78
III-4	4	39	38*	56*	10.8	10.7*	11.8*	1.47	26.3	2.1	7.8	7	+267	20.0	2960*	60.5	0	79
I-6	6	63	64*	105*	10.4	10.5*	11.5*	1.73	27.4	2.1	7.6	10	+333	20.0	3050	58.0	0	80
II-6	6	52	57*	90*	11.4	11.6*	13.1*	1.48	26.8	2.2	7.7-	11	+303	20.0	3260	60.9	0	81
III-6	6	45	47*	71*	12.0	12.2*	14.0*	1.16	26.7	2.0	7.7	7	+321	20.0	3150	59.6	0	82
I-FE	6							1.82				17			77			
II-FE	6							1.51				14			73			
III-FE	6							1.42				16			79			
Total																		
I-0								9.62										
III-0								9.70										
I-6								9.39										
II-6								7.34										
III-6								6.80										

Note: Unit I- Aeration rate 0.5 cu. ft./gal./6 hr.
Unit II - Aeration rate 1.0 cu. ft./gal./6 hr.
Unit III - Aeration rate 1.5 cu. ft./gal./6 hr.

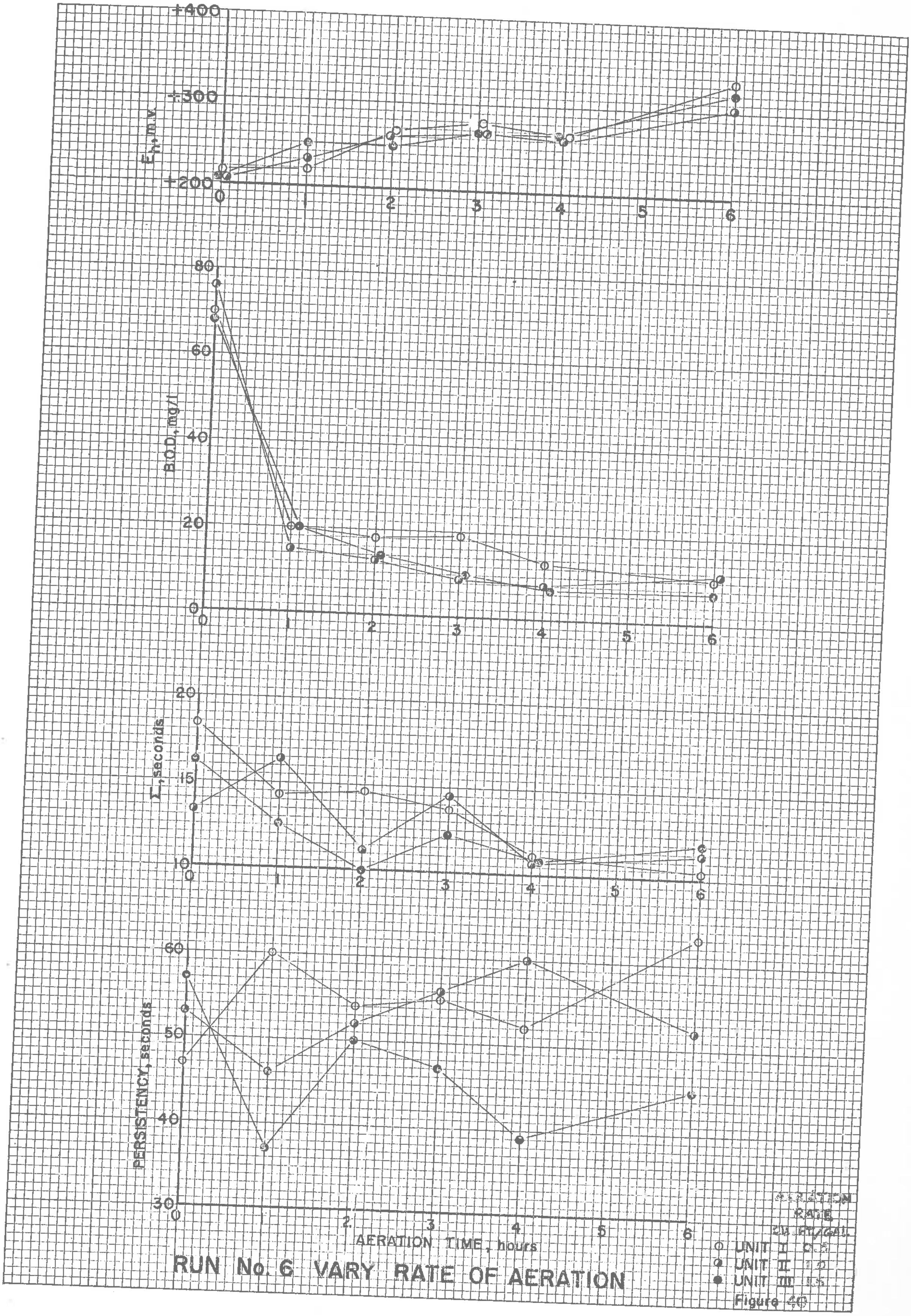
* Interpolated values
PE Primary effluent
PEF AA milipore membrane filtrate of primary effluent

RS Return sludge
RSF AA milipore membrane filtrate of return sludge



RUN No. 6 VARY RATE OF AERATION

Figure 39



RUN No. 6 VARY RATE OF AERATION

Figure 40

TABLE XXI

Treatment Plant Survey

Date	Sample	City, Wisconsin	Persistency, seconds	Persistency, seconds (3000)	Persistency, seconds (2000)	Σ, seconds	Σ, seconds (3000)	Σ, seconds (2000)	ABS mg/1	Ammonia Nitrogen, mg/1	Organic Nitrogen, mg/1	pH	BOD, mg/1	Electrode E_h Potential, m.v.	Temp. °C	Suspended Solids, mg/1	Surface Tension, Dynes/cm	Data used in Correlation Studies	Correlation Identification No.
6/3/57	1-1	F	2	2*	3*	0	0*	0*	0.41	3.9	4.7	7.6	96	+393	21	4200	60.9		
	1-2		3	4*	4*	0	0*	0*	0.57	3.5	3.8	7.5	–	+351	21	4150	61.6	0	83
	1-3		2	2*	3*	0	0*	0*	0.43	1.0	2.8	7.3	9	+351	21	4000	60.7	0	84
6/4/57	2-1	A	31	10*	12*	11.1	7.9*	8.4*	2.57	10.3	10.7	7.5	48	+327	18	360	53.1	0	85
	2-2		20	6*	8*	11.3	8.1*	8.7*	2.48	9.4	2.0	7.6	8	+297	18	380	55.3	0	86
	2-3		2	–	–	0	0*	0*	2.28	9.6	2.2	7.6	–	+291	18	310	55.7		
6/6/57	3-1	G	1805	115*	235*	$\sum c$ = 1930 to ∞			5.49	34.3	2.3	7.7	5	+261	16	650	51.8		
	3-2		2847	275*	740*	$\sum c$ = 270 to 1220			6.15	33.9	3.2	7.6	6	+297	18	1160	53.4		
	3-3		239	50*	77*	$\sum c$ = 730 to 1500			6.32	37.4	2.2	7.6	9	+267	17	700	53.5		
6/10/57	4-1	H	4	2*	2*	4.5	3.4*	3.7*	1.41	12.8	1.5	7.8	1	+237	12	620	64.6	0	87
	4-2		6	3*	4*	4.7	3.7*	4.0*	1.36	13.4	2.0	7.6	5	+309	13	890	63.6	0	88
	4-3		5	2*	3*	3.9	3.0*	3.2*	1.40	12.3	2.1	7.6	4	+333	14	640	64.3	0	89
6/10/57	5-1	C	15	9*	11*	10.0	–	–	4.30	21.1	2.9	7.3	24	+243	15	1160	52.8		
	5-2		22	13*	16*	14.3	–	–	4.96	22.4	3.0	7.2	40	+237	15	1230	53.3		
	5-3		36	15*	20*	15.1	–	–	5.38	20.2	3.0	7.2	29	+243	15	940	52.6		
6/13/57	6-1	I	13	11*	15*	10.8	10.3*	11.3*	1.33	8.5	3.7	–	3	+333	17	2480	67.4		
	6-2		17	13*	18*	11.1	10.2*	11.1*	1.33	9.3	4.8	–	3	+381	17	2140	67.1		
6/14/57	7-1	J	13	9*	11*	12.6	10.8*	11.9*	1.81	28.8	5.8	7.4	2	+333	15	1590	61.2	0	90
	7-2		7	5*	6*	7.3	6.4*	7.0*	1.94	31.9	3.5	7.4	2	+387	15	1570	–	0	91
	7-3		3	2*	3*	1.6	1.5*	1.6*	1.88	19.0	4.2	7.3	4	+315	15	1460	–	0	92

Note: Deformant was used in City C

* Interpolated values

TABLE XXII

Summary of Simple Correlation Coefficients (r)

	No. of Observations	ABS	Ammonia Nitrogen	Organic Nitrogen	pH	BOD	Electrode Potential E_h	Temperature	Suspended Solids	Σ	Σ (3000)	Σ (2000)
Persistency	92	0.568**	0.347**	-0.179	0.568**	-0.131	-0.166	0.481**	-0.198	0.529**		
Persistency	104	0.529**	0.062	-0.191	0.521**	-0.137	-0.163	0.454**	-0.208*	0.524**		
Persistency (3000)	92	0.444**	0.641**	-0.117	0.219*	-0.097	-0.287**	0.412**			0.602**	
Persistency (3000)	104	0.419**	0.250*	-0.124	0.196*	-0.091	-0.284**	0.390**			0.597**	
Persistency (2000)	92	0.434**	0.570**	-0.114	0.201	-0.114	-0.244*	0.372**				0.529**
Persistency (2000)	104	0.404**	0.191	-0.126	0.173	-0.112	-0.241*	0.348**				0.524**
Persistency (Rectified)	92	0.517**	0.684**	-0.093	0.406**	-0.034	-0.354**	0.490**	0.043	0.776**		
Persistency (Rectified)	104	0.499**	0.317**	-0.094	0.390**	-0.033	-0.341**	0.481**	0.044	0.759**		
Persistency (3000) (Rectified)	92	0.392**	0.805**	-0.029	0.183	0.034	-0.418**	0.445**			0.739**	
Persistency (3000) (Rectified)	104	0.386**	0.421**	-0.023	0.185	0.041	-0.403**	0.441**			0.724**	
Persistency (2000) (Rectified)	92	0.388**	0.794**	-0.039	0.177	0.023	-0.409**	0.458**				0.675**
Persistency (2000) (Rectified)	104	0.381**	0.405**	-0.035	0.176	0.029	-0.395**	0.452**				0.658**
Σ	92	0.642**	0.699**	0.124	0.161	0.209*	-0.533**	0.128	0.162			
Σ	104	0.601**	0.238*	0.112	0.124	0.232*	-0.544**	0.093	0.154			
Σ (3000)	92	0.472**	0.749**	0.233*	-0.145	0.228*	-0.517**	-0.020				
Σ (3000)	104	0.447**	0.298**	0.222*	-0.158	0.255**	-0.530**	-0.045				
Σ (2000)	92	0.463**	0.705**	0.253*	-0.190	0.250*	-0.521**	-0.072				
Σ (2000)	104	0.432**	0.256**	0.237*	-0.203*	0.278**	-0.536**	-0.099				
ABS	92		0.430**	0.077	0.184	0.013	-0.332**	0.016	-0.210*			
ABS	104		0.330**	0.117	0.188	0.038	-0.298**	-0.004	-0.184			
Ammonia Nitrogen	92			0.125	-0.082	0.097	-0.506**	0.070	0.387**			
Ammonia Nitrogen	104			0.185	0.158	0.158	-0.191	0.137	0.280**			
Organic Nitrogen	92				-0.417**	0.607**	-0.341**	-0.258*	0.179			
Organic Nitrogen	104				-0.371**	0.559**	-0.310**	-0.236*	0.191			
pH	92					-0.189	0.105	0.483**	-0.468**			
pH	104					-0.149	0.111	0.492**	-0.428**			
BOD	92						-0.650**	-0.252*	0.196			
BOD	104						-0.661**	-0.244*	0.204*			
Electrode Potential	92							0.208*	-0.238*			
Electrode Potential	104							0.227*	-0.231*			

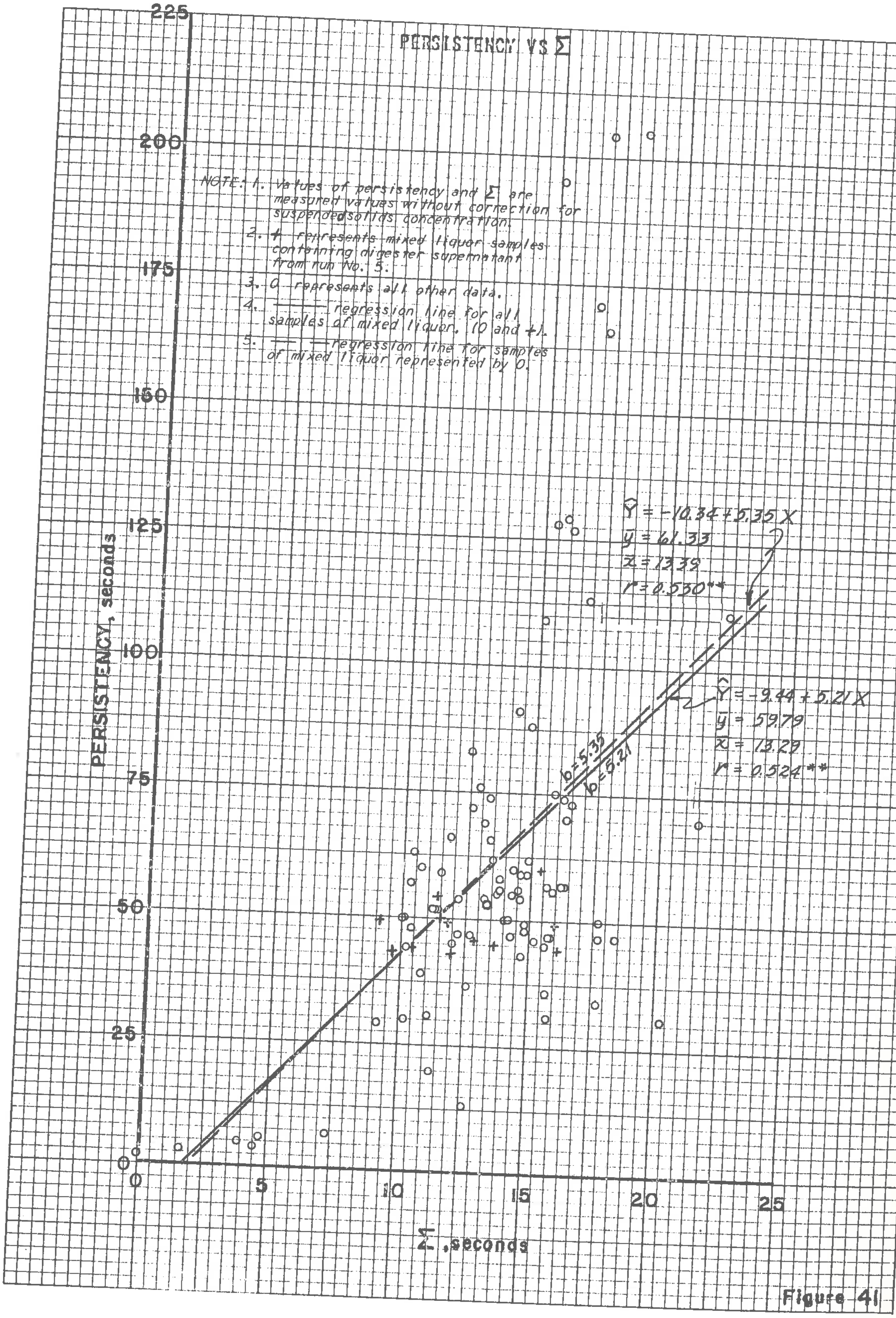
Note: 104 Observations includes all samples of mixed liquor, degrees of freedom = n-2=102

a. Highly significant if r exceeds 0.252 at 99% confidence level**
b. Significant if r exceeds 0.194 at 95% confidence level*

92 Observations includes all samples of mixed liquor excepting samples containing digester supernatant from run No. 5, degrees of freedom = n-2=90

a. Highly significant if r exceeds 0.267 at 99% confidence level**
b. Significant if r exceeds 0.205 at 95% confidence level*

(Rectified) indicates logs of the persistency values were used.



NOTE: 1. Values of persistency and Σ are measured values without correction for suspendedsolids concentration.

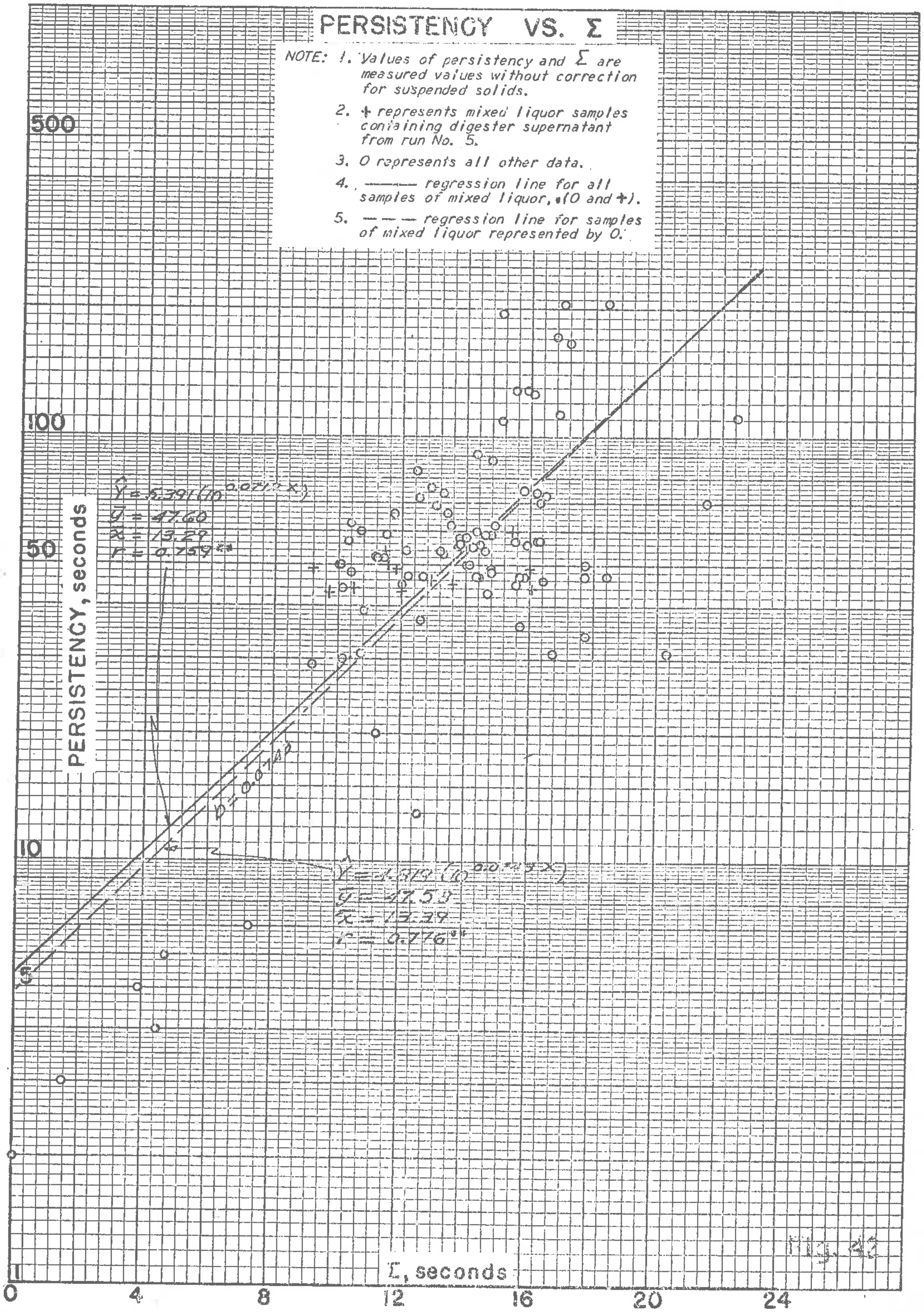
2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ——— regression line for all samples of mixed liquor. (O and +).

5. — — regression line for samples of mixed liquor represented by O.

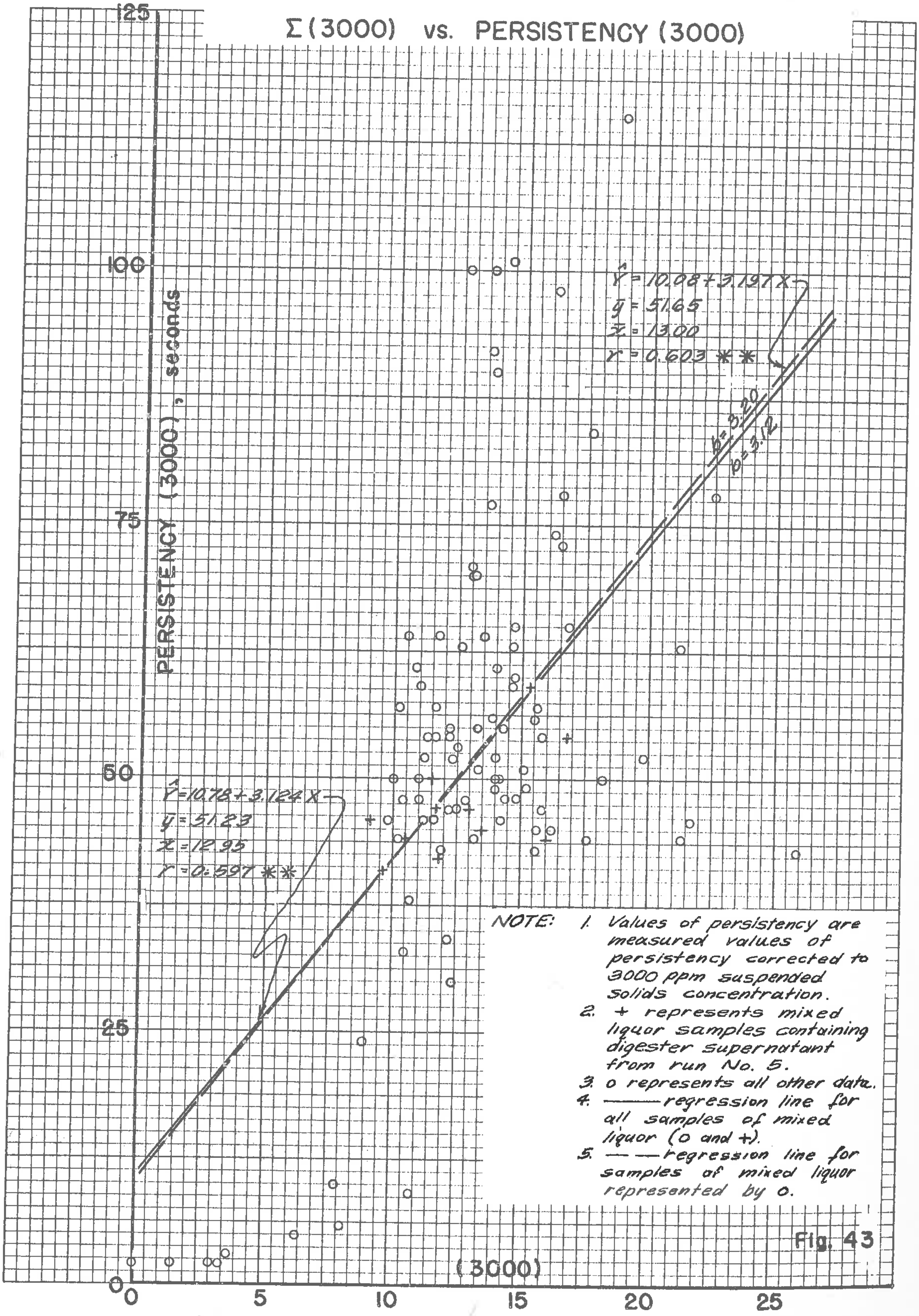
Figure 41



PERSISTENCY VS. Σ

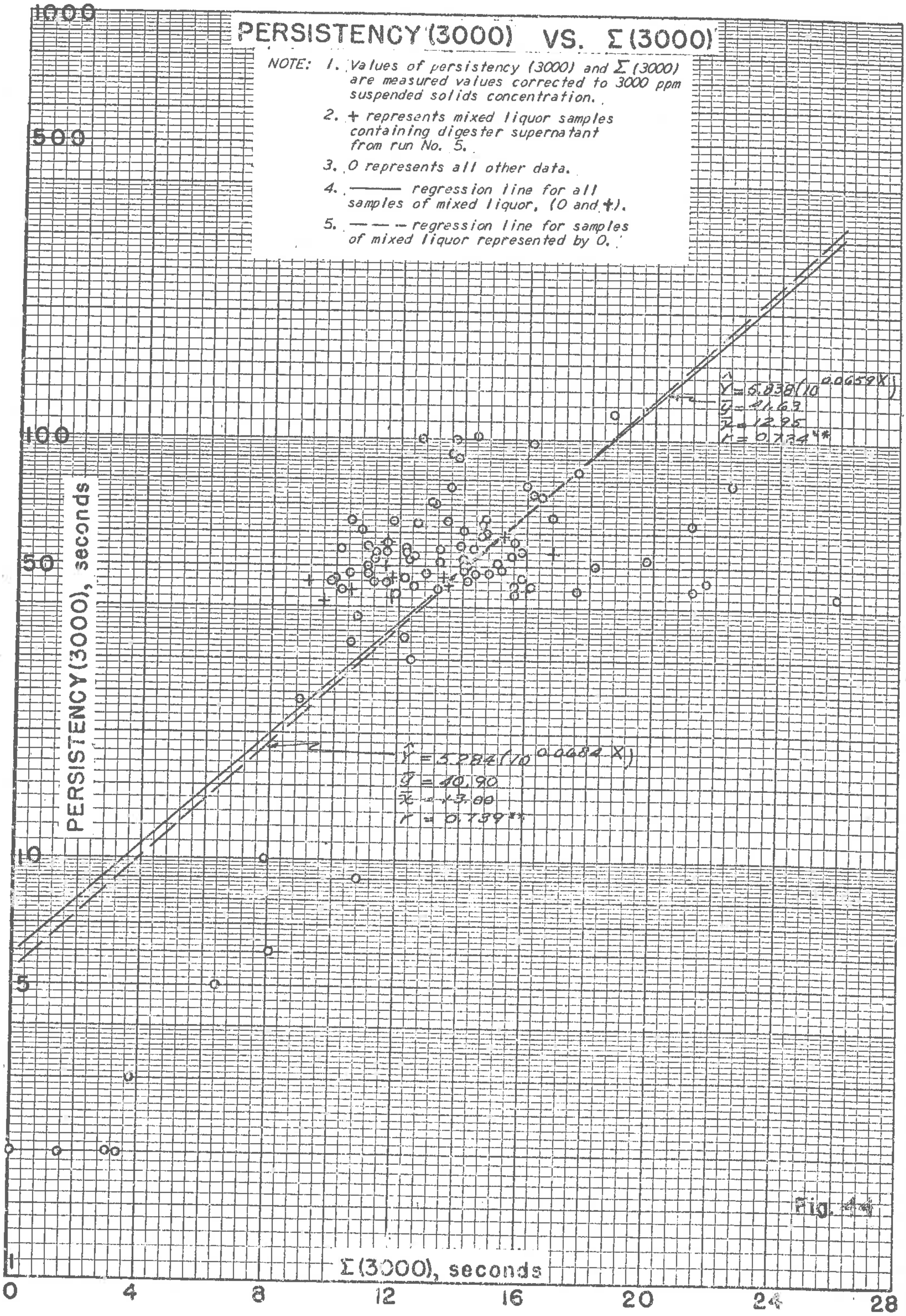
NOTE:
1. Values of persistency and Σ are measured values without correction for suspended solids.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data.
4. ——— regression line for all samples of mixed liquor, (O and +).
5. — — — regression line for samples of mixed liquor represented by O.

Fig. 42



NOTE:
1. Values of persistency are measured values of persistency corrected to 3000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. o represents all other data.
4. ——— regression line for all samples of mixed liquor (o and +).
5. — — — regression line for samples of mixed liquor represented by o.

Fig. 43



PERSISTENCY (3000) VS. Σ(3000)

NOTE: 1. Values of persistency (3000) and Σ (3000) are measured values corrected to 3000 ppm suspended solids concentration.

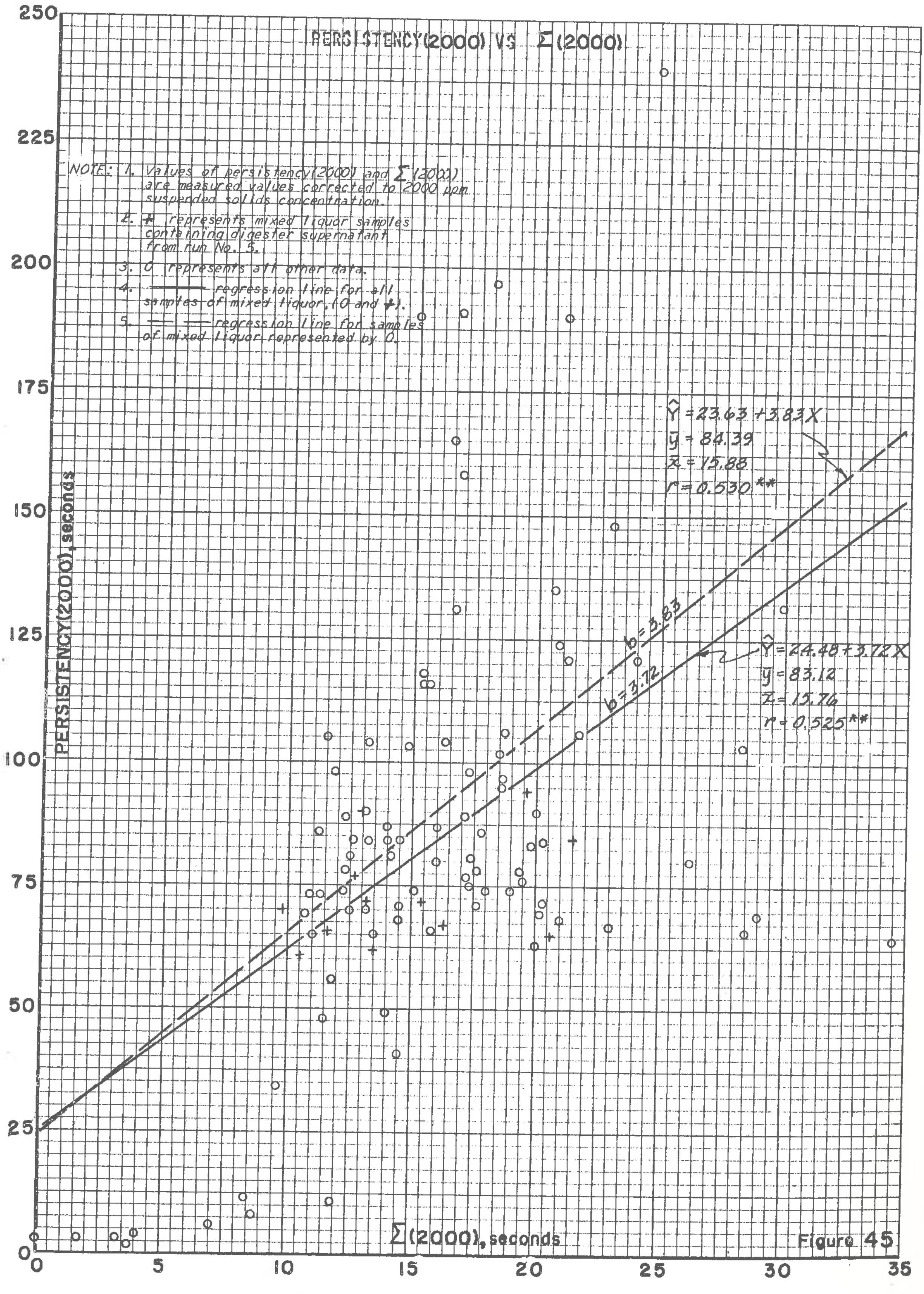
2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ——— regression line for all samples of mixed liquor, (O and +).

5. — — — regression line for samples of mixed liquor represented by O.

Fig. 44



NOTE: 1. Values of persistency(2000) and Σ(2000) are measured values corrected to 2000 ppm suspended solids concentration.

2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

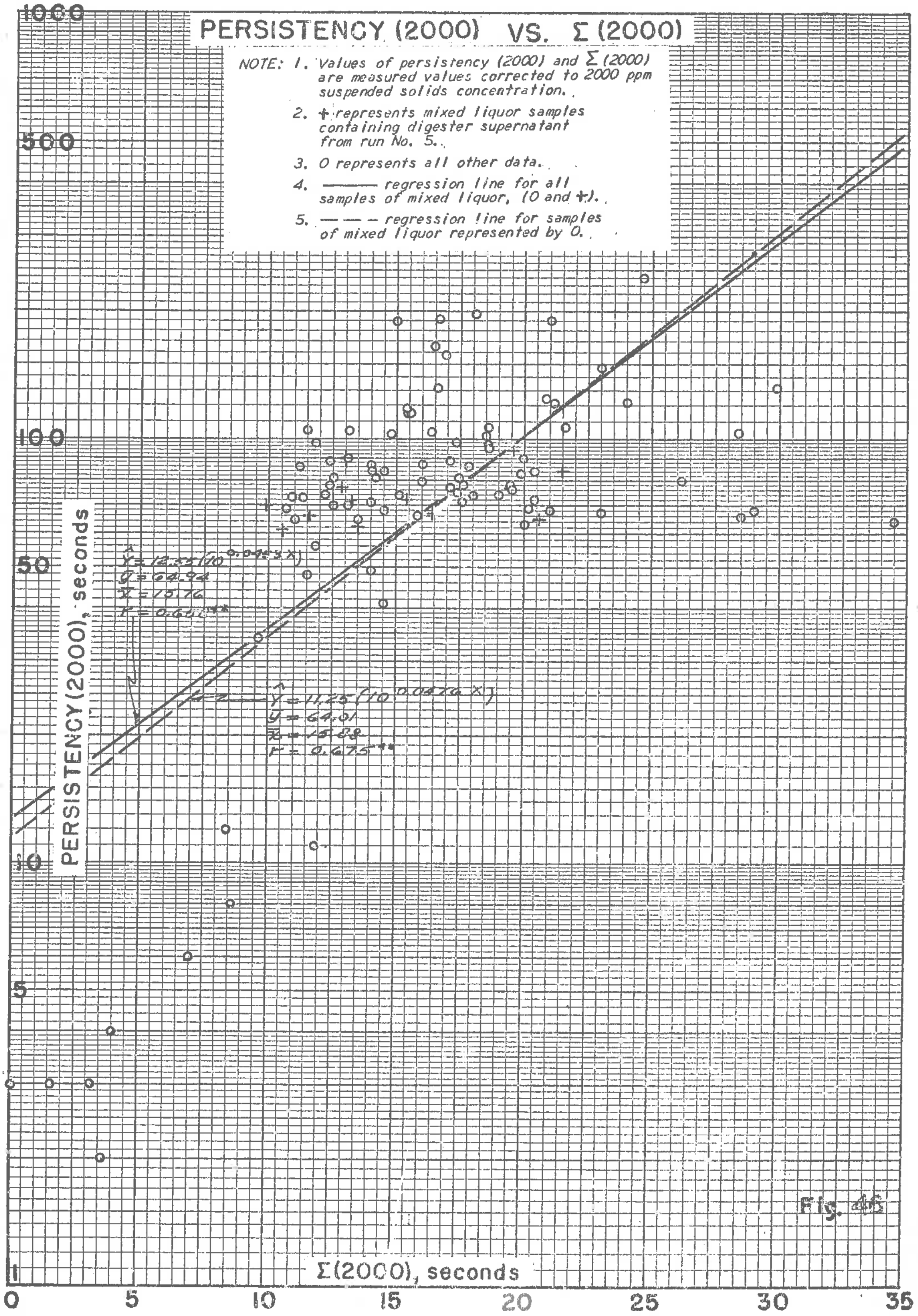
4. ——— regression line for all samples of mixed liquor. (O and +).

5. — — regression line for samples of mixed liquor represented by O.

$\hat{Y} = 23.63 + 3.83X$
$\bar{y} = 84.39$
$\bar{x} = 15.88$
$r = 0.530^{**}$

$\hat{Y} = 24.48 + 3.72X$
$\bar{y} = 83.12$
$\bar{x} = 15.76$
$r = 0.525^{**}$

Figure 45



PERSISTENCY (2000) VS. Σ (2000)

NOTE: 1. Values of persistency (2000) and Σ (2000) are measured values corrected to 2000 ppm suspended solids concentration.

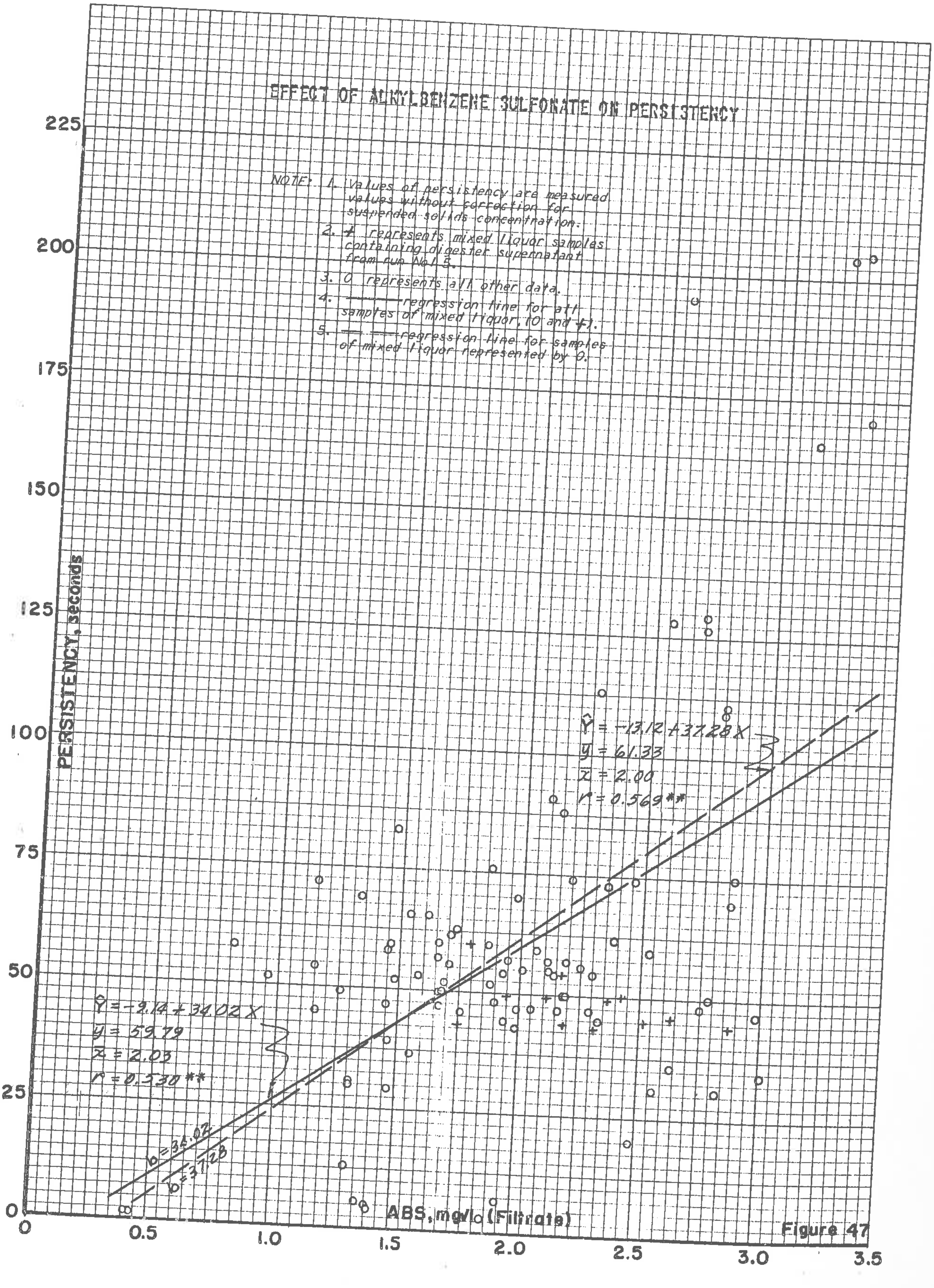
2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ——— regression line for all samples of mixed liquor, (O and +).

5. — — — regression line for samples of mixed liquor represented by O.

Fig. 46


EFFECT OF ALKYLBENZENE SULFONATE ON PERSISTENCY

NOTE: 1. Values of persistency are measured values without correction for suspended solids concentration.

2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ———— regression line for all samples of mixed liquor, (O and +).

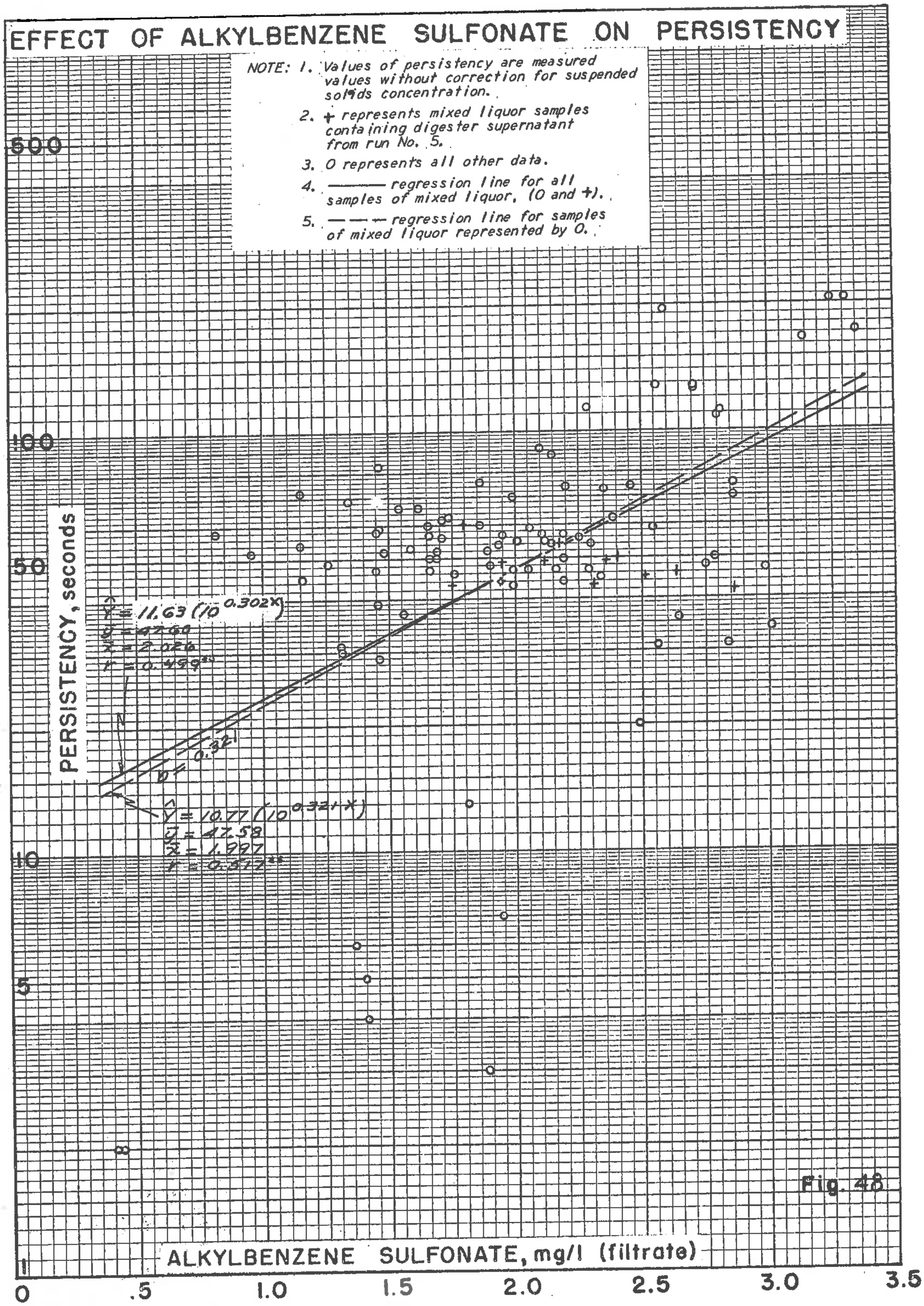
5. — — — regression line for samples of mixed liquor represented by O.

$\hat{Y} = -13.12 + 37.28X$
$\bar{y} = 61.33$
$\bar{x} = 2.00$
$r = 0.569^{**}$

$\hat{Y} = -9.14 + 34.02X$
$\bar{y} = 59.79$
$\bar{x} = 2.03$
$r = 0.530^{**}$

$b = 34.02$
$b = 37.28$

Figure 47



EFFECT OF ALKYLBENZENE SULFONATE ON PERSISTENCY

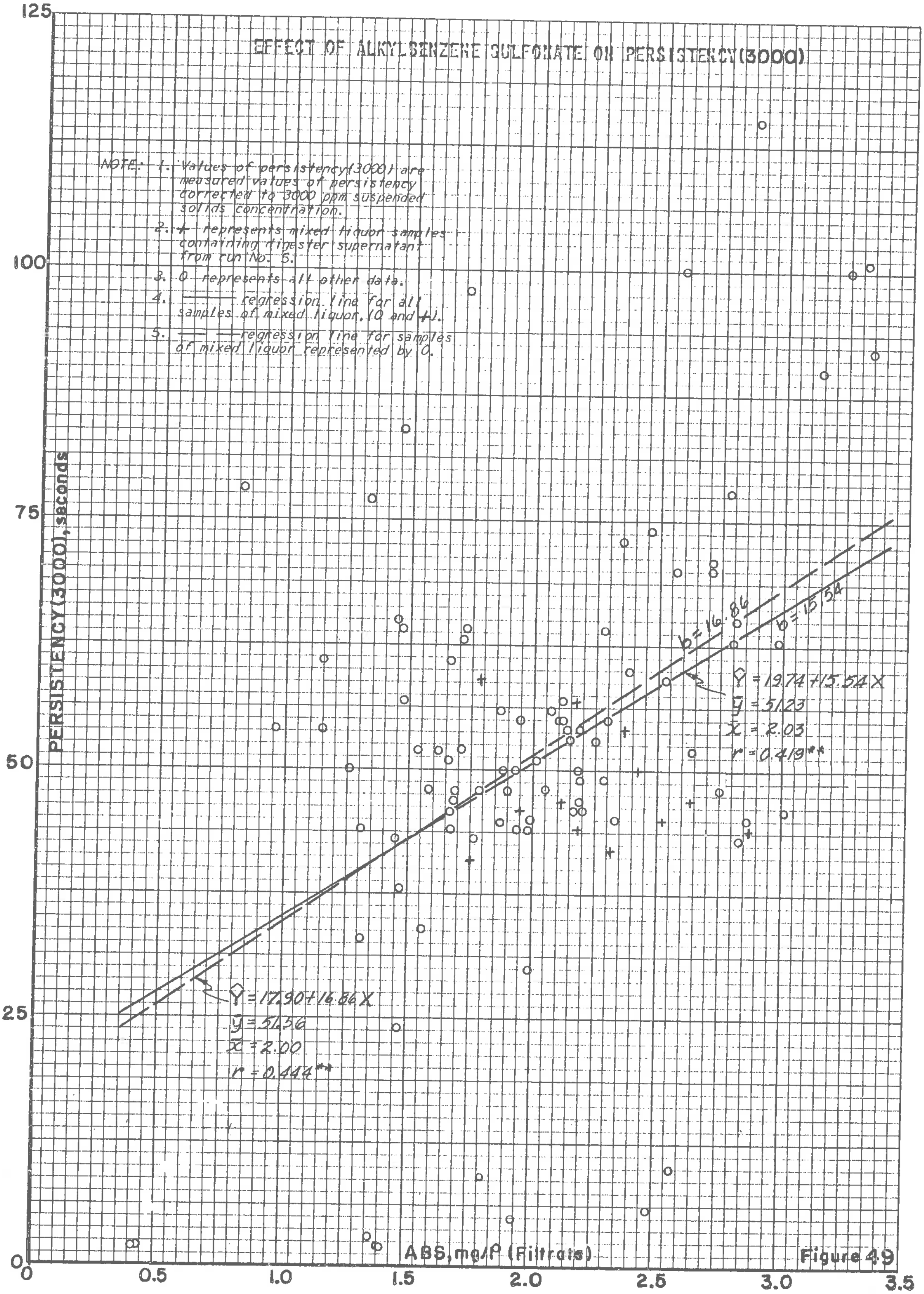
NOTE:
1. Values of persistency are measured values without correction for suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data.
4. ——— regression line for all samples of mixed liquor. (O and +).
5. — — — regression line for samples of mixed liquor represented by O.

$\hat{Y} = 11.63\,(10^{0.302X})$
$\bar{y} = 47.60$
$\bar{x} = 2.026$
$r = 0.499^{**}$

$b = 0.321$

$\hat{Y} = 10.77\,(10^{0.321X})$
$\bar{y} = 47.58$
$\bar{x} = 1.997$
$r = 0.512^{**}$

Fig. 48

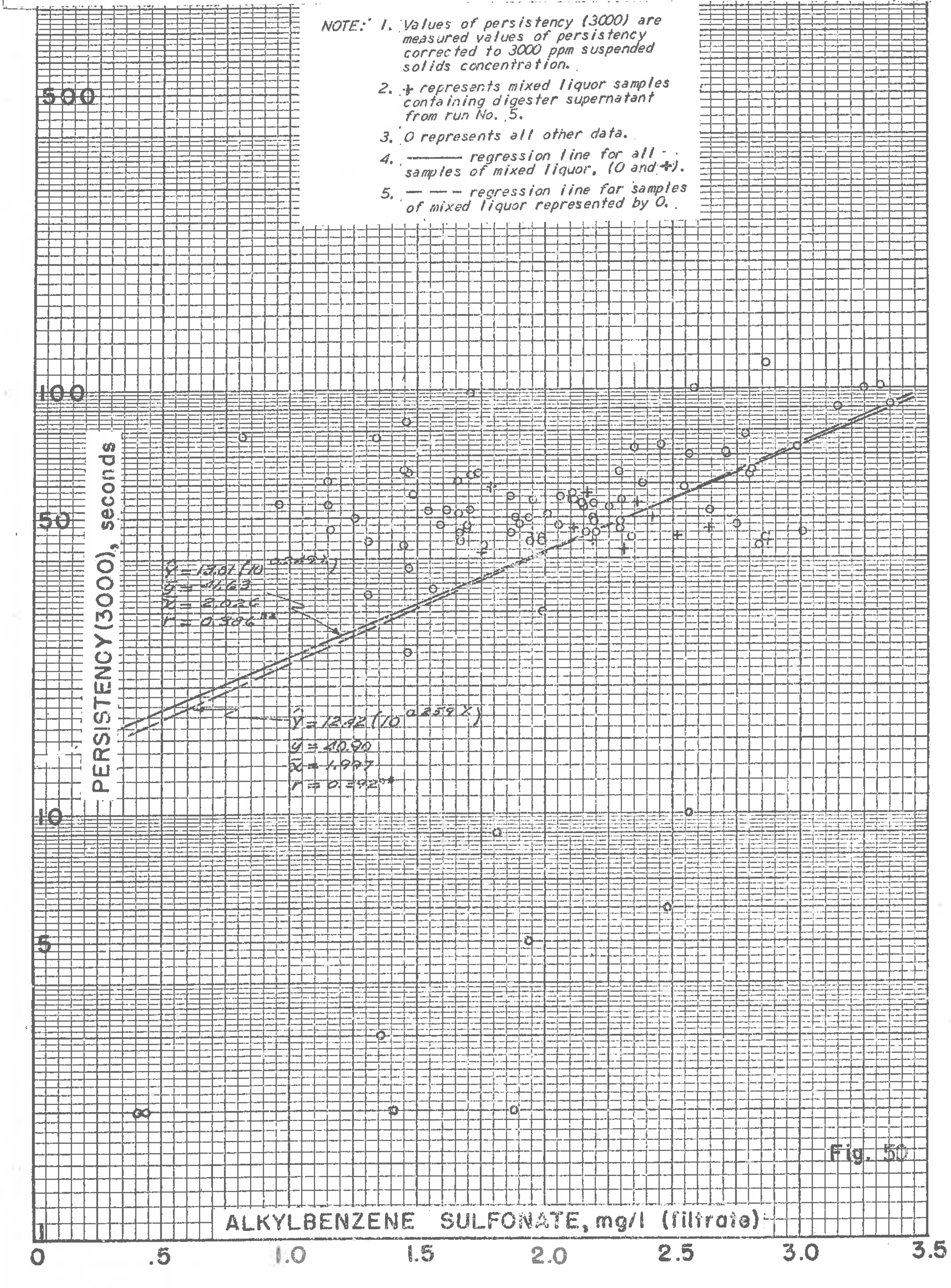


EFFECT OF ALKYLBENZENE SULFONATE ON PERSISTENCY(3000)

NOTE:
1. Values of persistency(3000) are measured values of persistency corrected to 3000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data.
4. ——— regression line for all samples of mixed liquor. (O and +).
5. — — regression line for samples of mixed liquor represented by O.

Figure 49

EFFECT OF ALKYLBENZENE SULFONATE ON PERSISTENCY (3000)



NOTE: 1. Values of persistency (3000) are measured values of persistency corrected to 3000 ppm suspended solids concentration.

2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

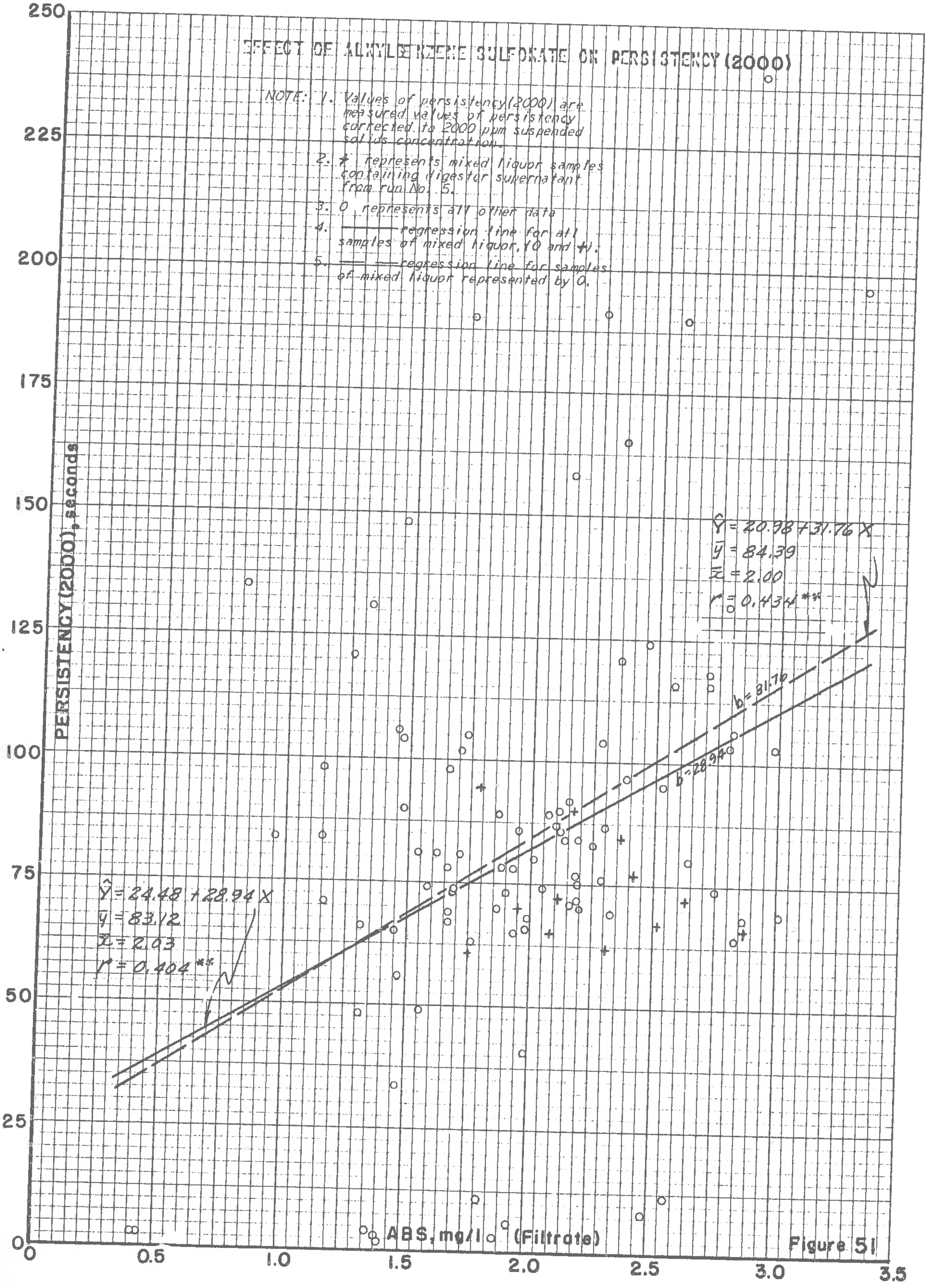
4. ——— regression line for all samples of mixed liquor, (O and +).

5. — — — regression line for samples of mixed liquor represented by O.

$\hat{Y} = 13.01 (10^{0.2492X})$
$\bar{y} = 41.63$
$\bar{x} = 2.026$
$r = 0.506^{**}$

$\hat{Y} = 12.42 (10^{0.259X})$
$\bar{y} = 40.90$
$\bar{x} = 1.977$
$r = 0.392^{**}$

Fig. 50



EFFECT OF ALKYLBENZENE SULFONATE ON PERSISTENCY (2000)

NOTE:
1. Values of persistency (2000) are measured values of persistency corrected to 2000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data
4. ——— regression line for all samples of mixed liquor, (O and +).
5. — — regression line for samples of mixed liquor represented by O.

Figure 51

EFFECT OF ALKYLBENZENE SULFONATE ON PERSISTENCY(2000)

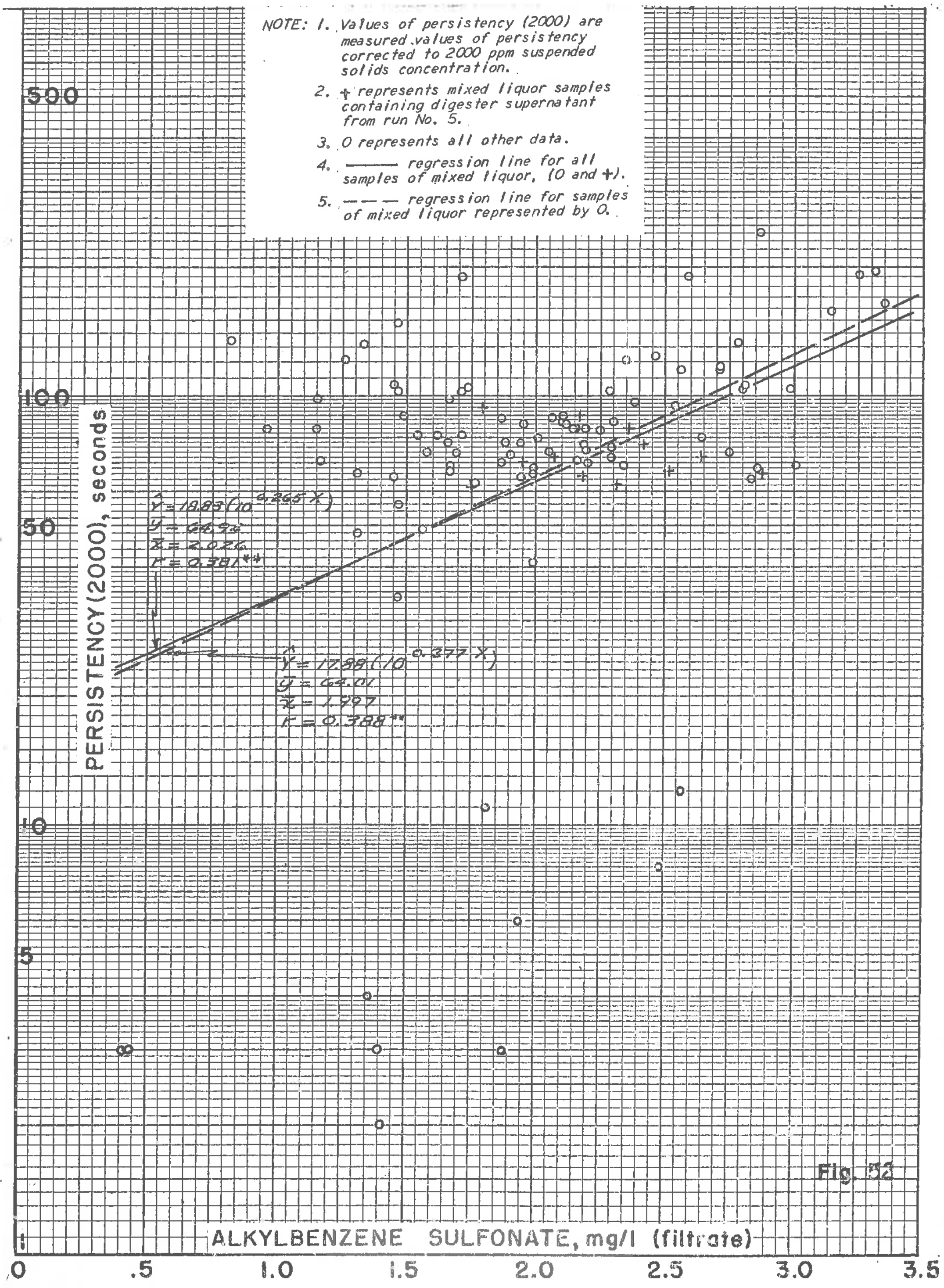
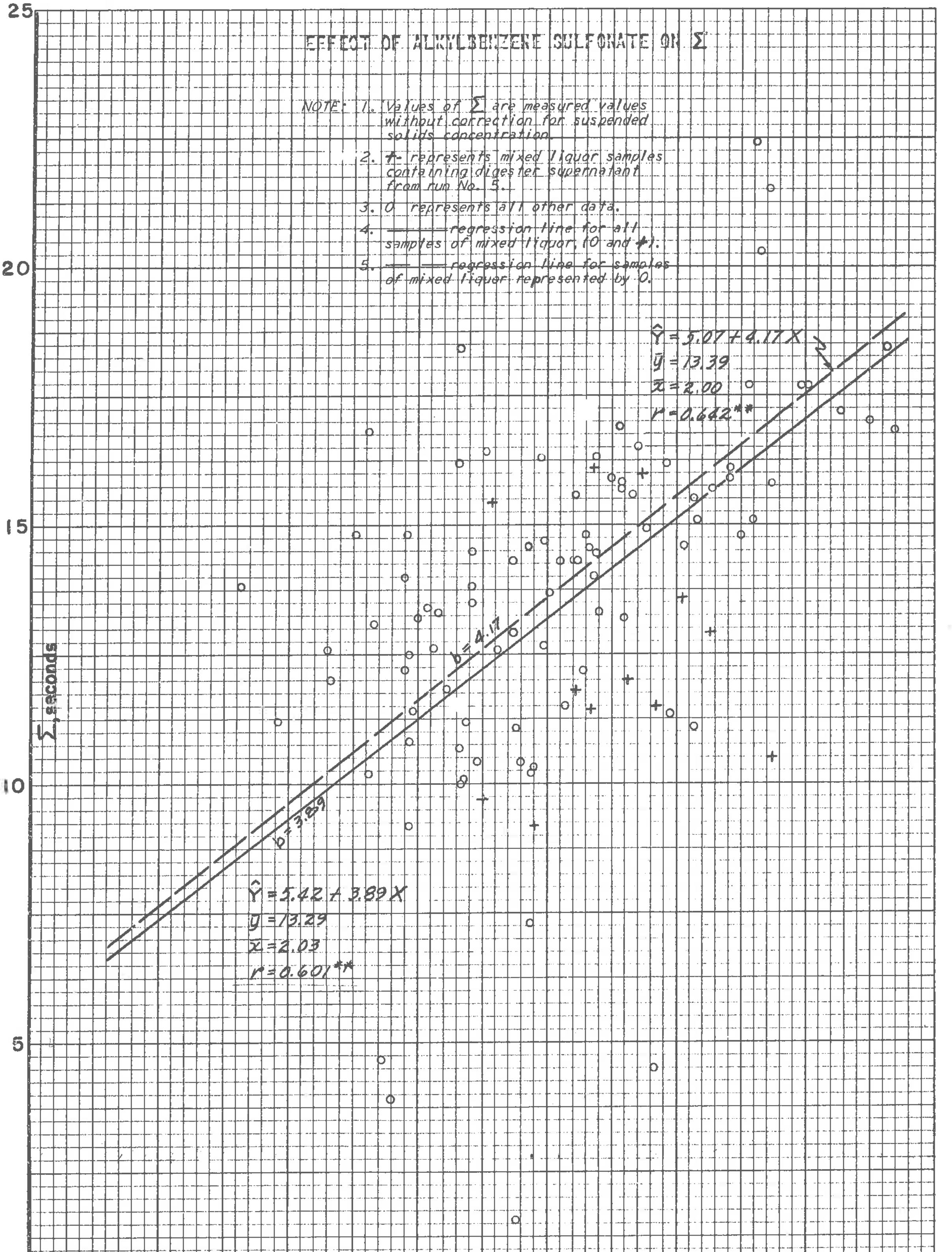


Fig. 52



EFFECT OF ALKYLBENZENE SULFONATE ON Σ

NOTE: 1. Values of Σ are measured values without correction for suspended solids concentration.

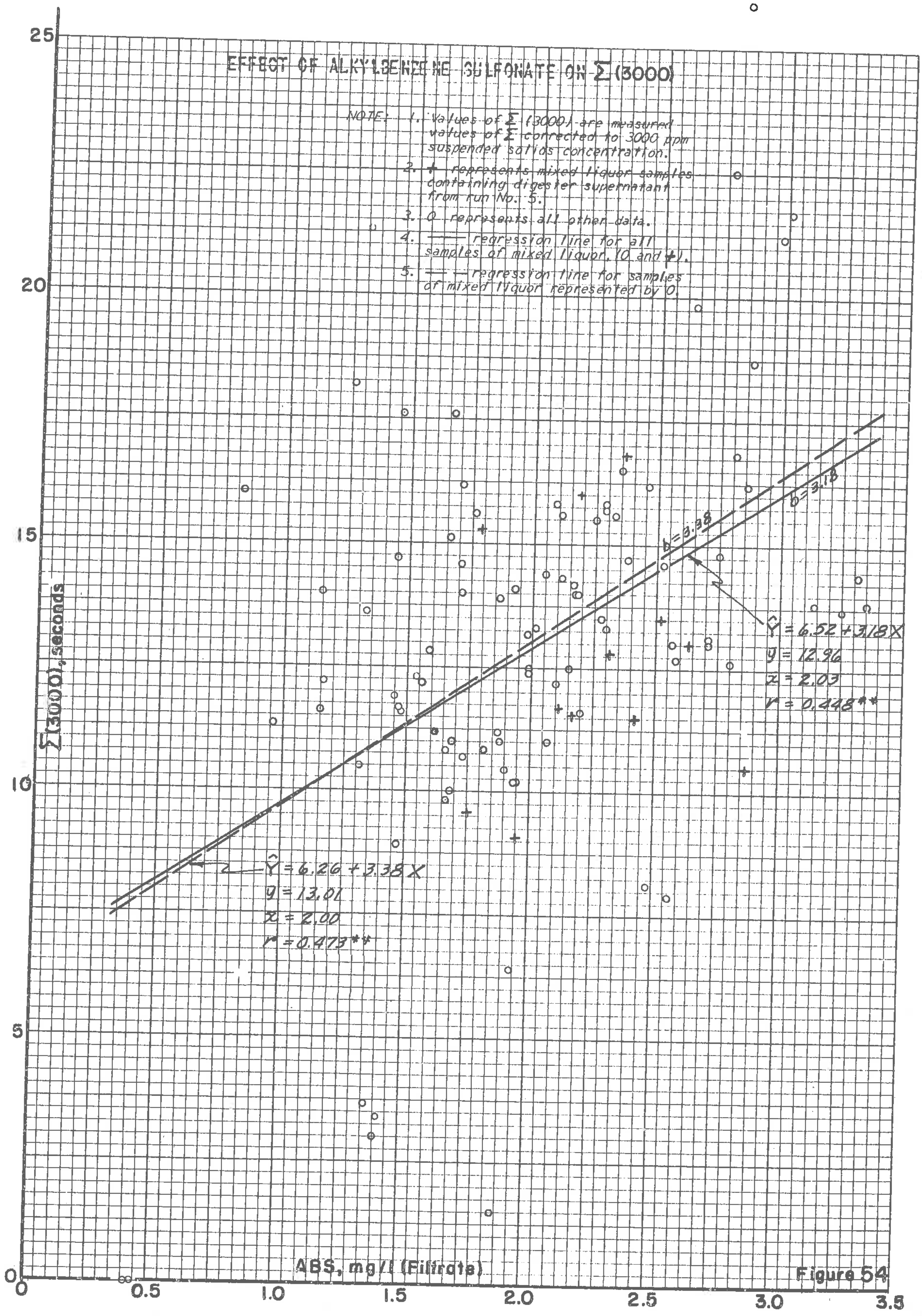
2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ———— regression line for all samples of mixed liquor, (O and +).

5. — — regression line for samples of mixed liquor represented by O.

Figure 53



EFFECT OF ALKYLBENZENE SULFONATE ON Σ(3000)

NOTE: 1. Values of Σ (3000) are measured values of Σ corrected to 3000 ppm suspended solids concentration.

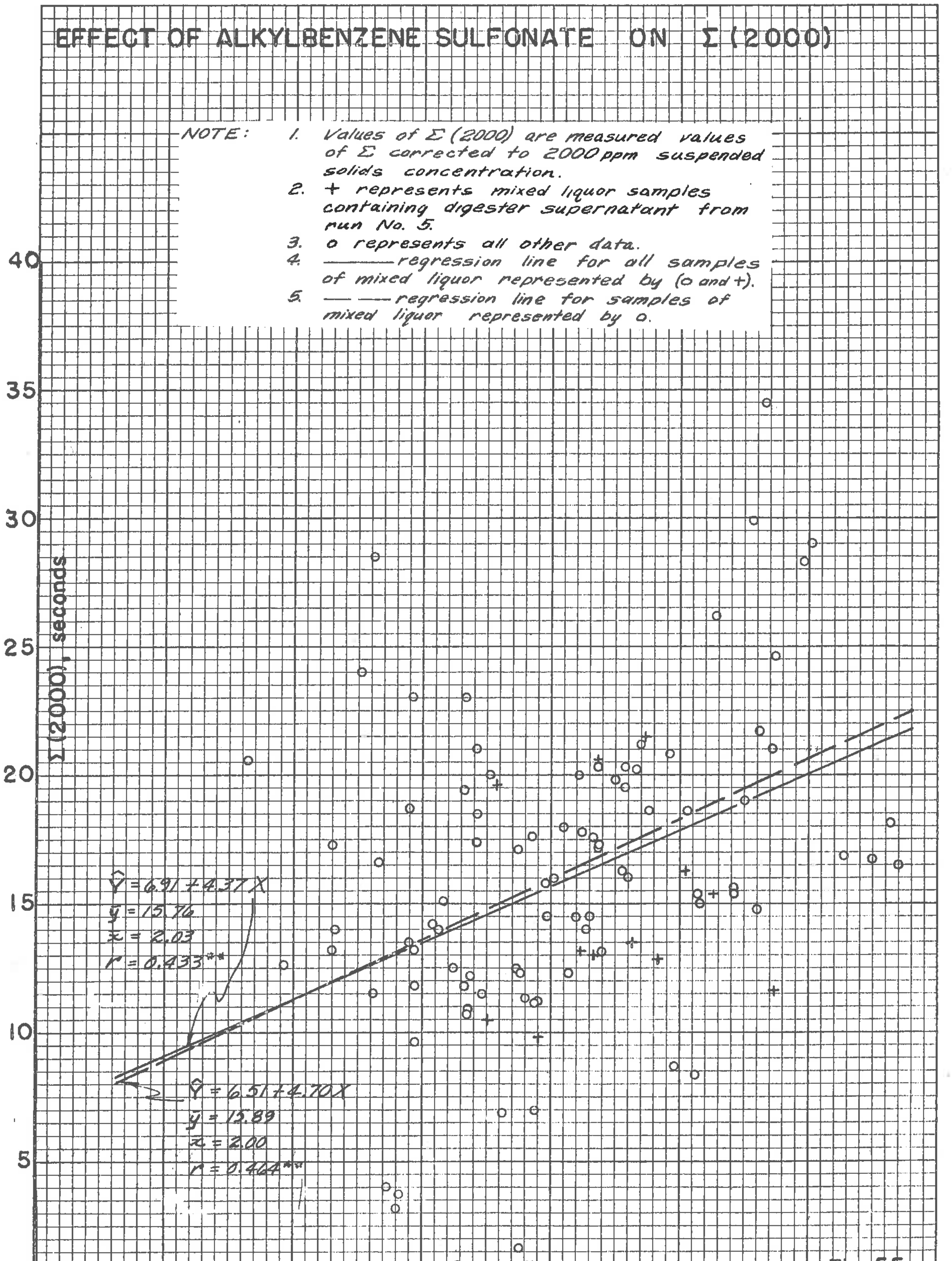
2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ——— regression line for all samples of mixed liquor, (O and +).

5. — — regression line for samples of mixed liquor represented by O.

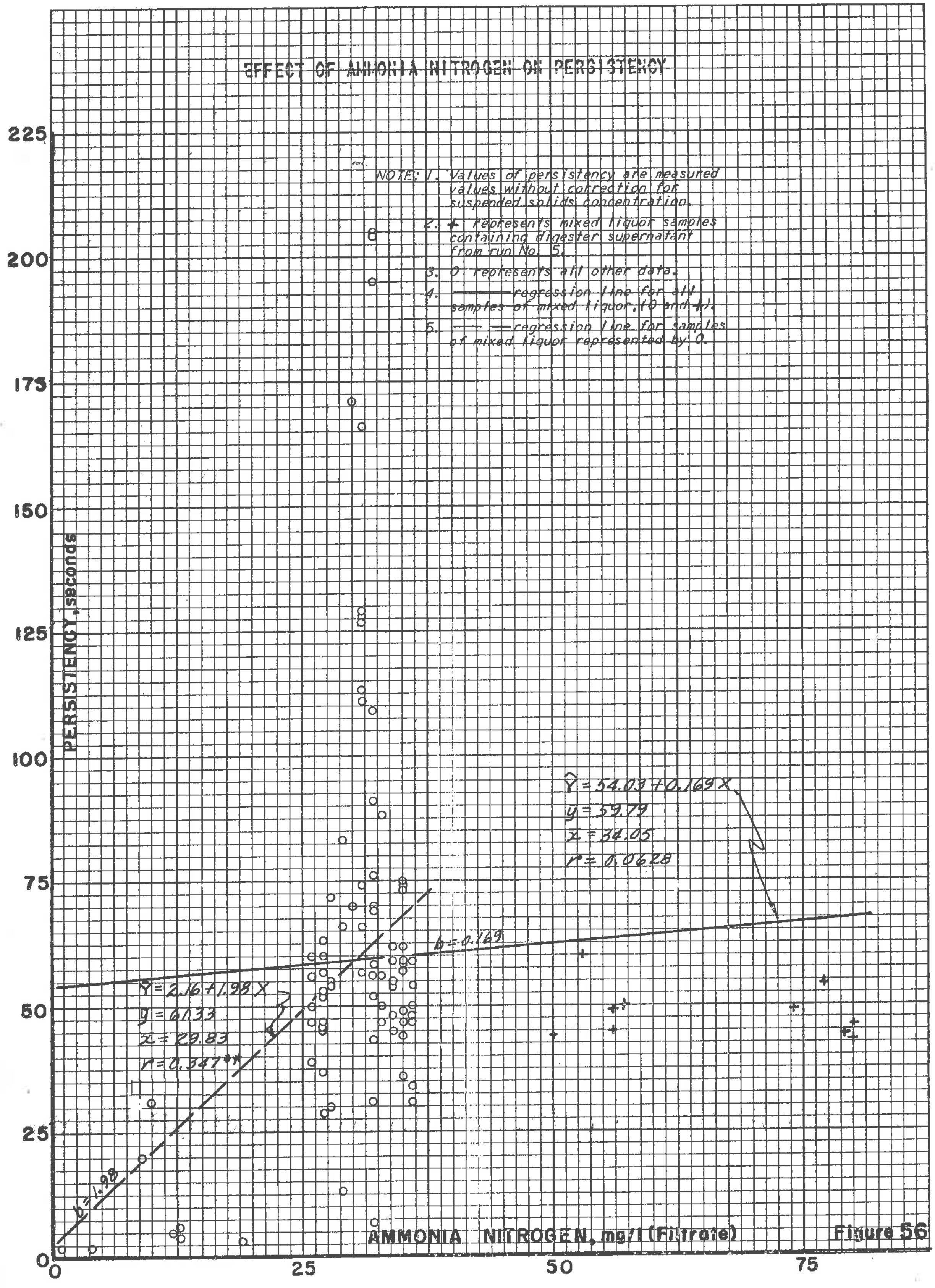
Figure 54



EFFECT OF ALKYLBENZENE SULFONATE ON Σ (2000)

NOTE:
1. Values of Σ (2000) are measured values of Σ corrected to 2000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. o represents all other data.
4. ——— regression line for all samples of mixed liquor represented by (o and +).
5. — — — regression line for samples of mixed liquor represented by o.

Fig. 55



NOTE: 1. Values of persistency are measured values without correction for suspended solids concentration.

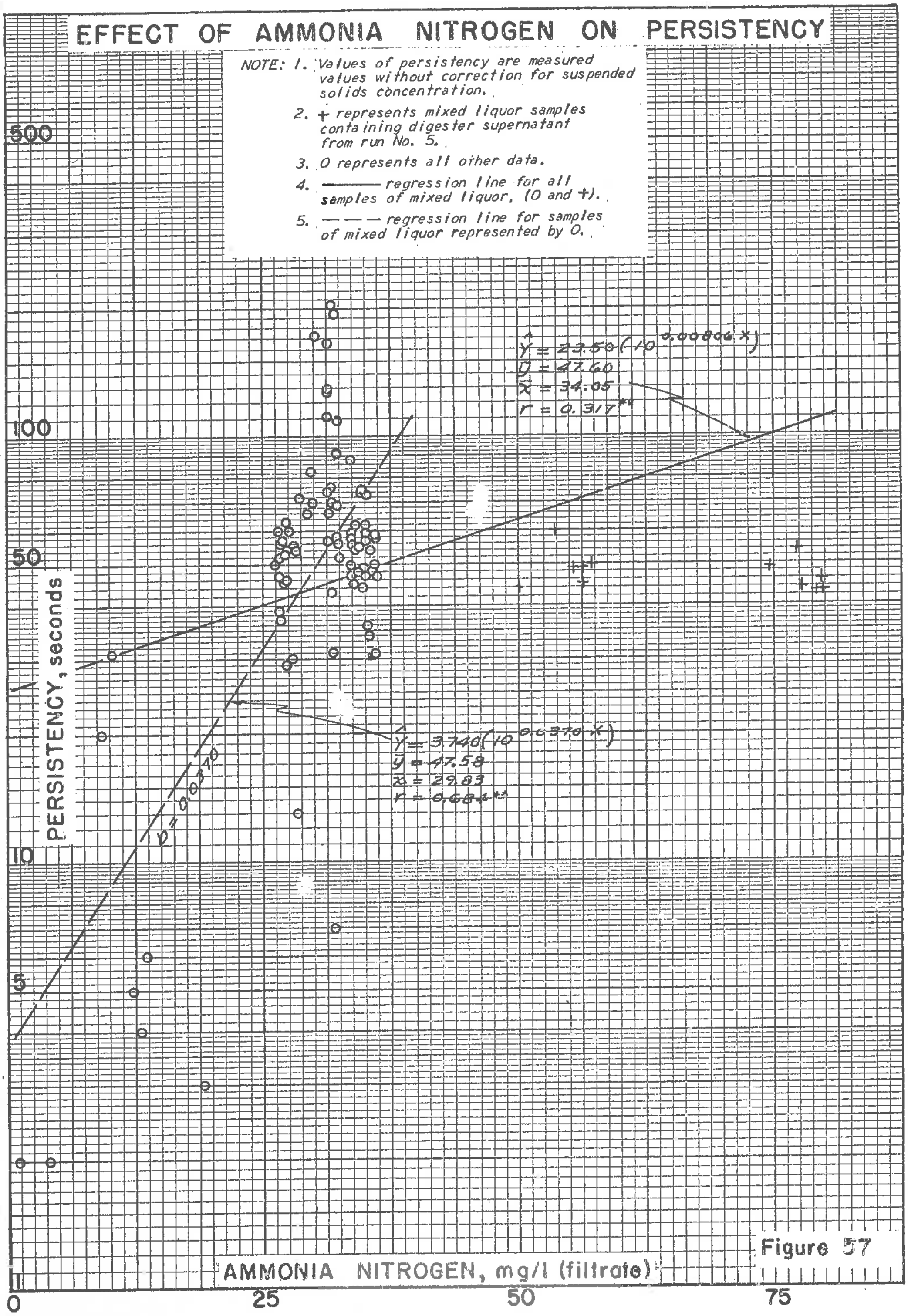
2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ——— regression line for all samples of mixed liquor. (O and +).

5. — — regression line for samples of mixed liquor represented by O.

Figure 56



EFFECT OF AMMONIA NITROGEN ON PERSISTENCY

NOTE: 1. Values of persistency are measured values without correction for suspended solids concentration.

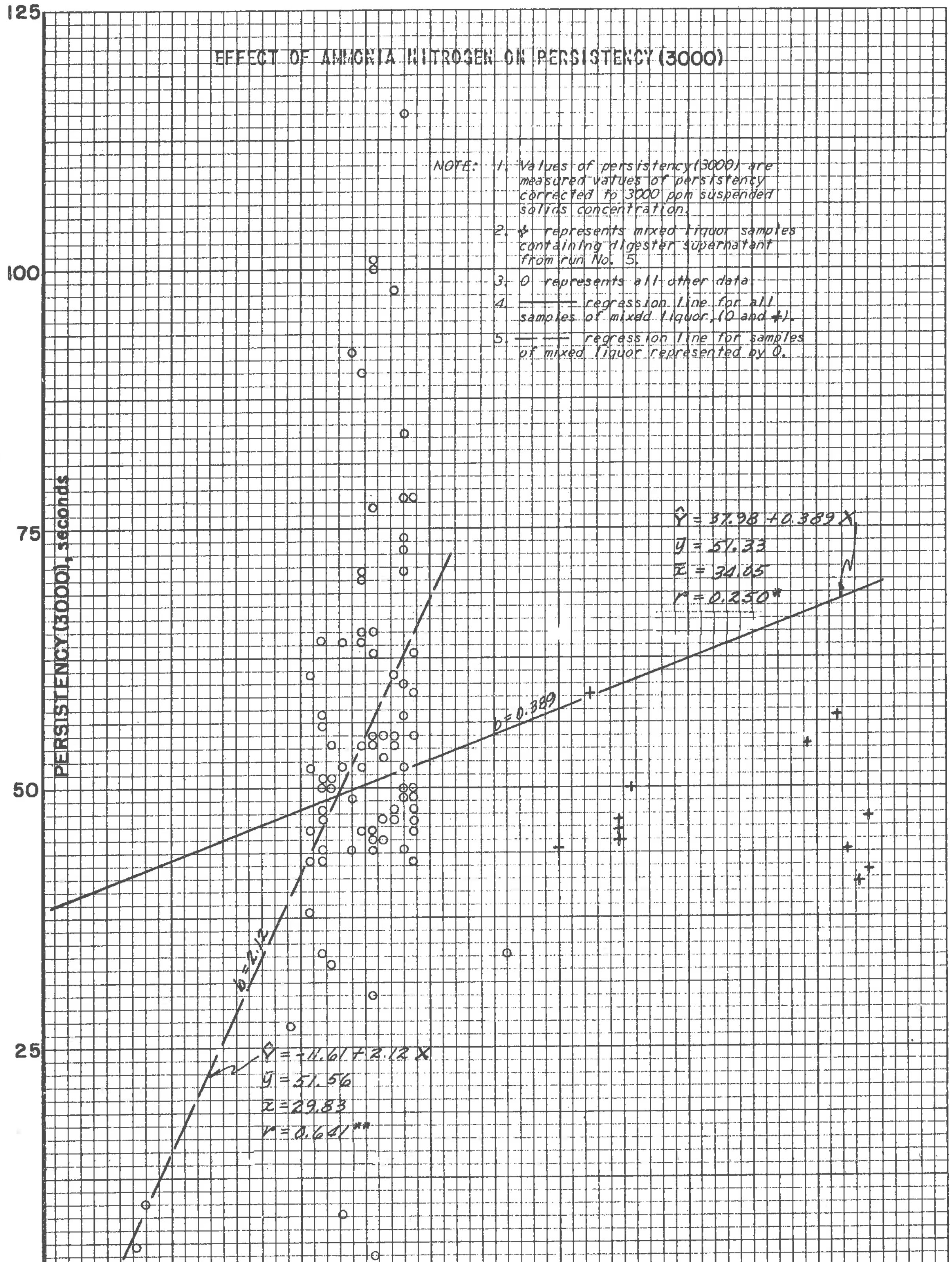
2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ——— regression line for all samples of mixed liquor, (O and +).

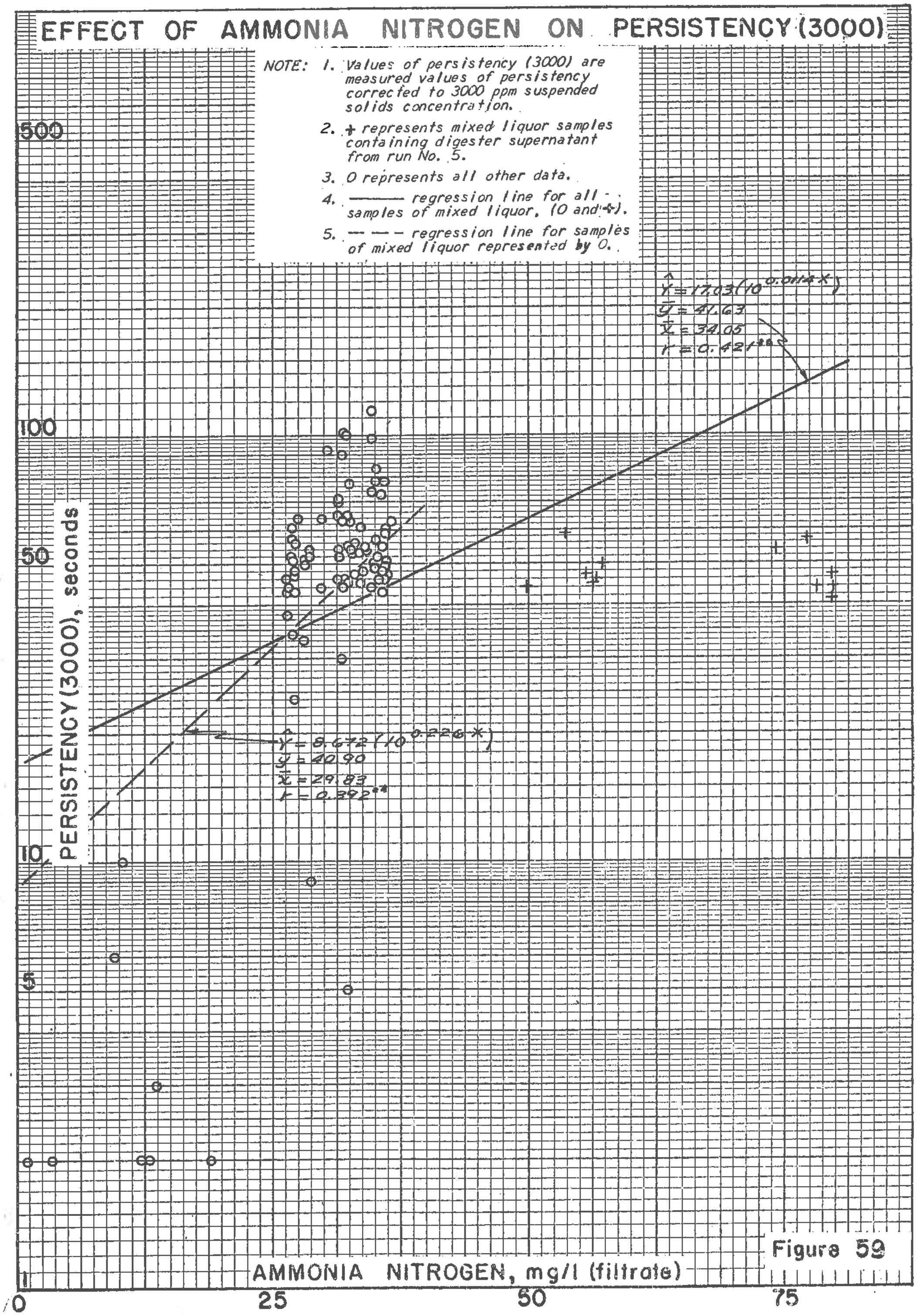
5. — — — regression line for samples of mixed liquor represented by O.

Figure 57



NOTE:
1. Values of persistency (3000) are measured values of persistency corrected to 3000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. 0 represents all other data.
4. ——— regression line for all samples of mixed liquor, (0 and +).
5. — — regression line for samples of mixed liquor represented by 0.

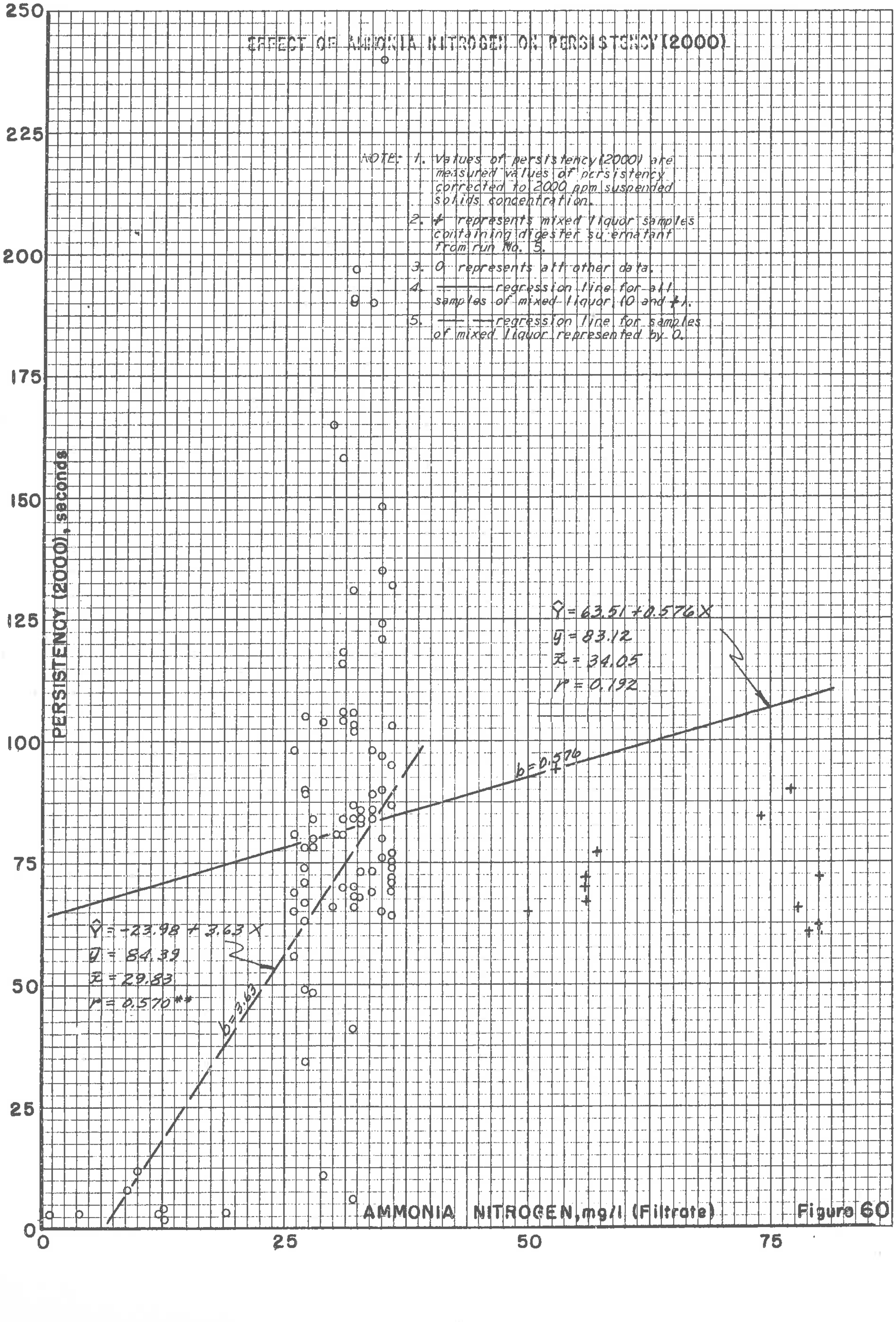
Figure 58



EFFECT OF AMMONIA NITROGEN ON PERSISTENCY (3000)

NOTE:
1. Values of persistency (3000) are measured values of persistency corrected to 3000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data.
4. ——— regression line for all samples of mixed liquor. (O and +).
5. — — — regression line for samples of mixed liquor represented by O.

Figure 59



EFFECT OF AMMONIA NITROGEN ON PERSISTENCY (2000)

NOTE: 1. Values of persistency (2000) are measured values of persistency corrected to 2000 ppm suspended solids concentration.

2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ——— regression line for all samples of mixed liquor (O and +).

5. — — regression line for samples of mixed liquor represented by O.

Figure 60

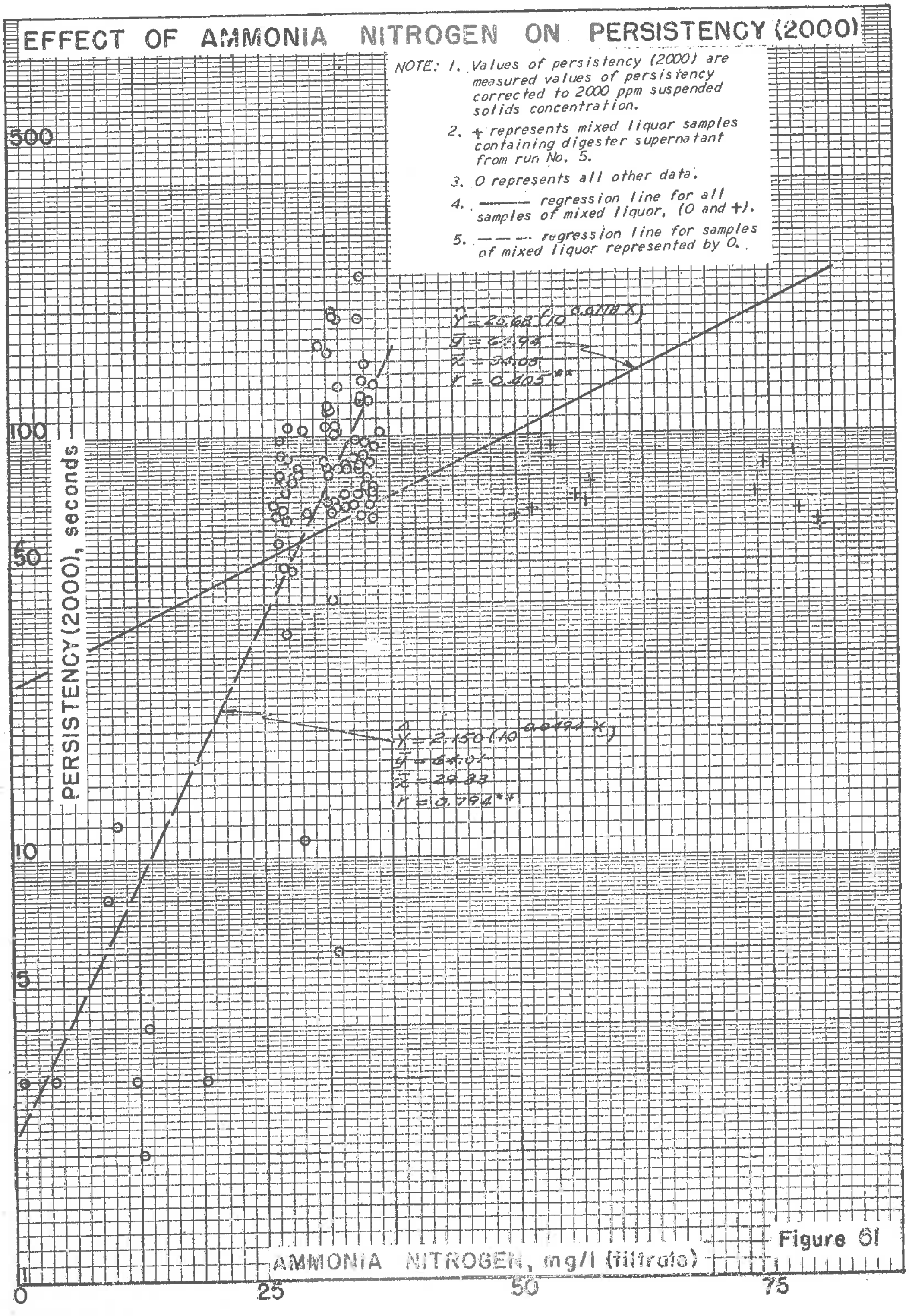

EFFECT OF AMMONIA NITROGEN ON PERSISTENCY (2000)
NOTE: 1. Values of persistency (2000) are measured values of persistency corrected to 2000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data.
4. ——— regression line for all samples of mixed liquor, (O and +).
5. — — — regression line for samples of mixed liquor represented by O.
$\hat{Y} = 25.68 (10^{0.0118 X})$
$\bar{y} = 64.94$
$\bar{x} = 34.03$
$r = 0.405^{**}$
$\hat{Y} = 2.150 (10^{0.0494 X})$
$\bar{y} = 64.01$
$\bar{x} = 29.33$
$r = 0.794^{**}$
PERSISTENCY (2000), seconds
500
100
50
10
5
1
AMMONIA NITROGEN, mg/l (filtrate)
0
25
50
75

Figure 61

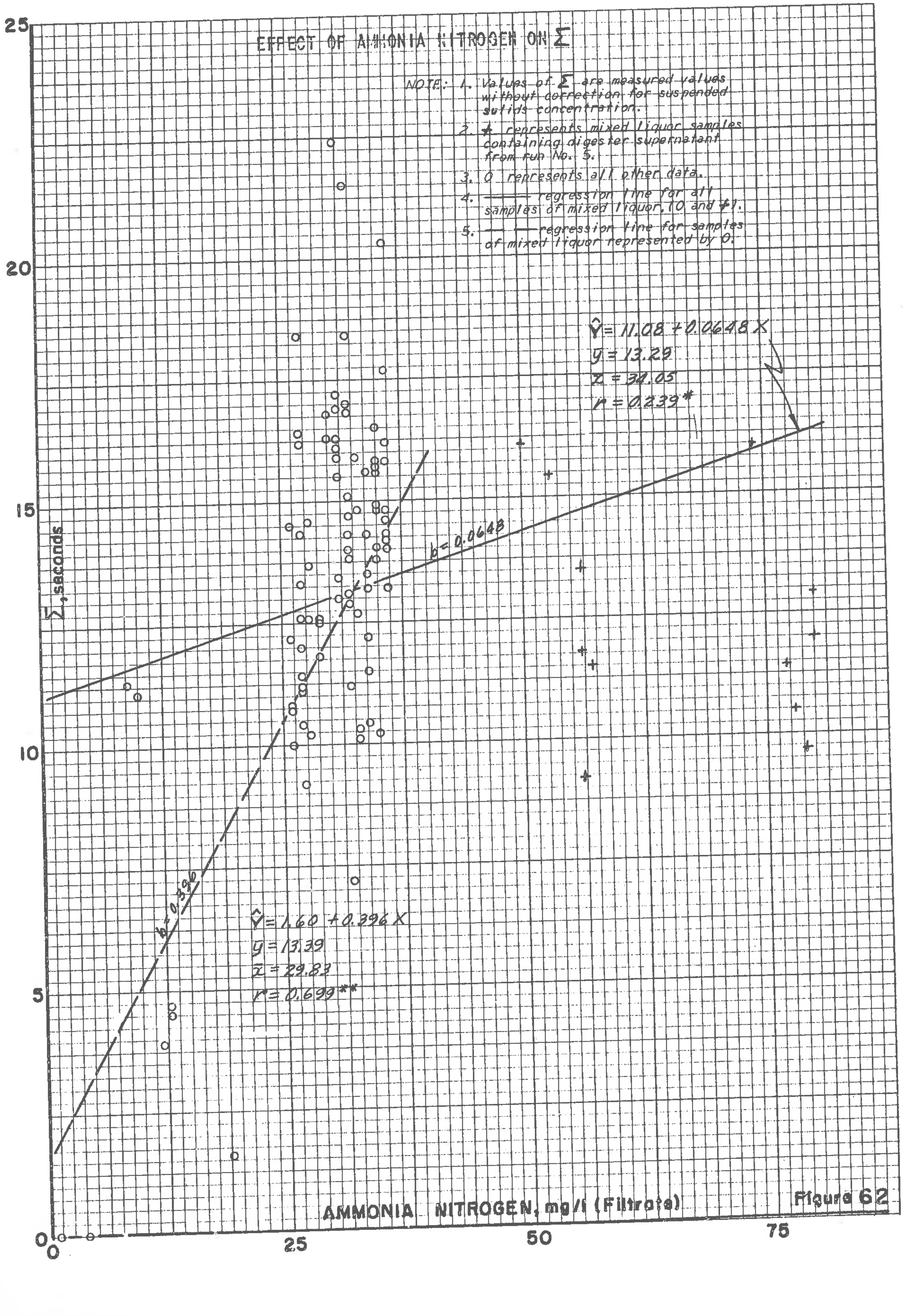
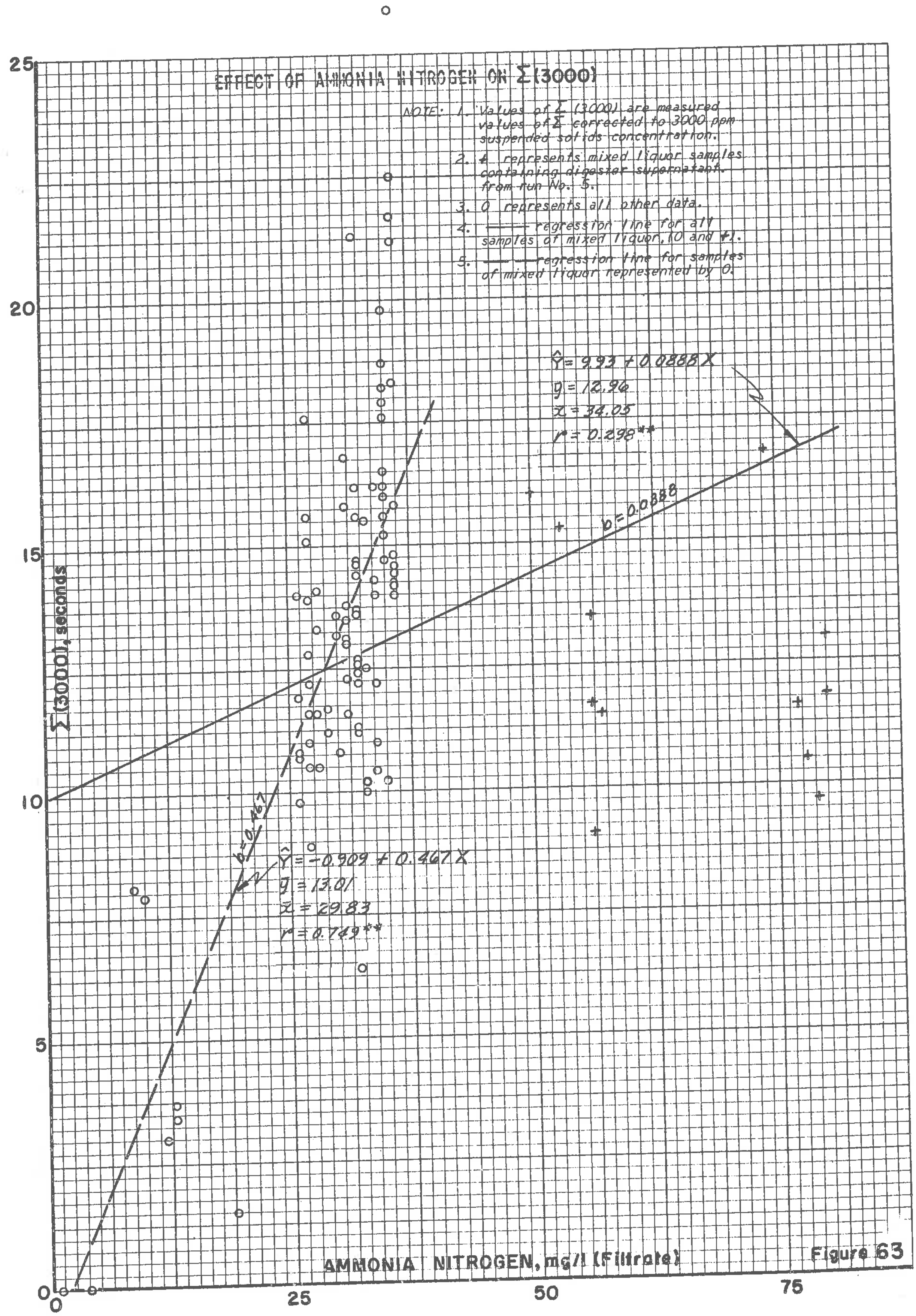

EFFECT OF AMMONIA NITROGEN ON Σ
NOTE: 1. Values of Σ are measured values without correction for suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data.
4. ——— regression line for all samples of mixed liquor, (O and +).
5. — — regression line for samples of mixed liquor represented by O.
Ŷ = 11.08 + 0.0648 X
ȳ = 13.29
x̄ = 34.05
r = 0.239*
b = 0.0648
b = 0.396
Ŷ = 1.60 + 0.396 X
ȳ = 13.39
x̄ = 29.83
r = 0.699**
Σ, seconds
AMMONIA NITROGEN, mg/l (Filtrate)
0
5
10
15
20
25
0
25
50
75

Figure 62



EFFECT OF AMMONIA NITROGEN ON Σ(3000)

NOTE: 1. Values of Σ (3000) are measured values of Σ corrected to 3000 ppm suspended solids concentration.

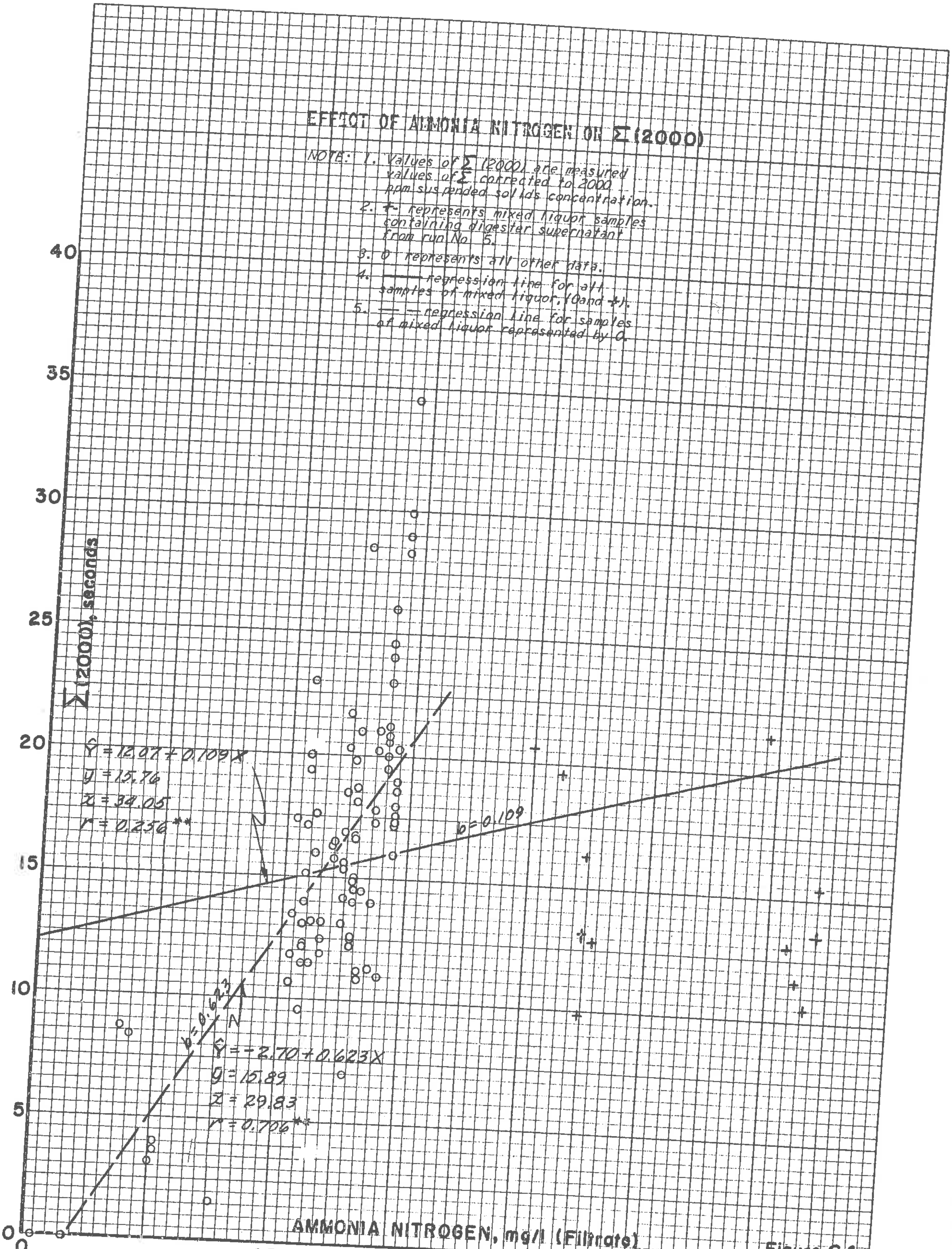
2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ——— regression line for all samples of mixed liquor, (O and +).

5. — — regression line for samples of mixed liquor represented by O.

Figure 63



EFFECT OF AMMONIA NITROGEN ON Σ(2000)

NOTE: 1. Values of Σ (2000) are measured values of Σ corrected to 2000 ppm suspended solids concentration.

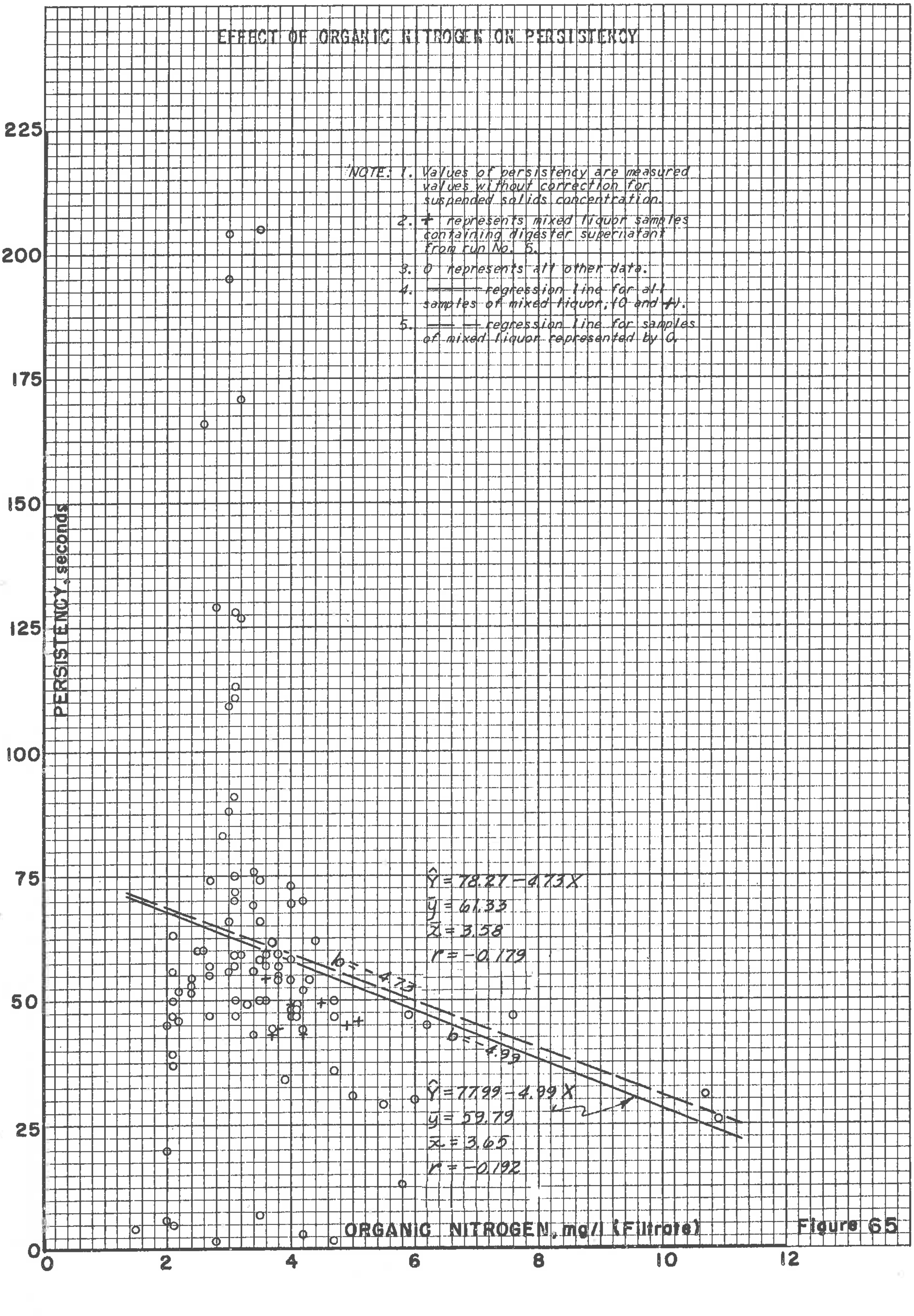
2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ——— regression line for all samples of mixed liquor, (O and +).

5. — — regression line for samples of mixed liquor represented by O.

Figure 64



EFFECT OF ORGANIC NITROGEN ON PERSISTENCY

NOTE: 1. Values of persistency are measured values without correction for suspended solids concentration.

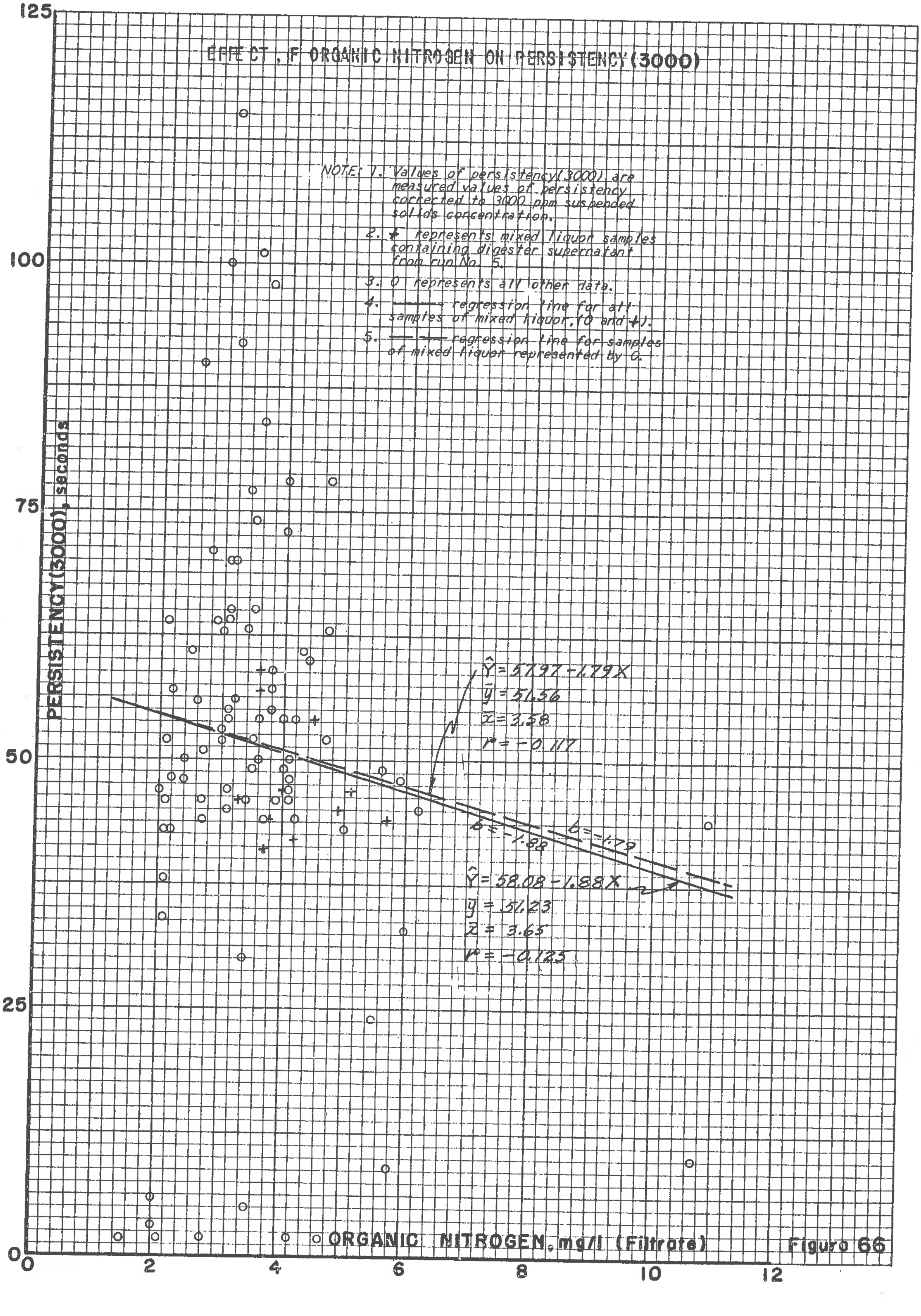
2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ——— regression line for all samples of mixed liquor, (O and +).

5. —— — regression line for samples of mixed liquor represented by O.

Figure 65



EFFECT OF ORGANIC NITROGEN ON PERSISTENCY(3000)

NOTE: 1. Values of persistency(3000) are measured values of persistency corrected to 3000 ppm suspended solids concentration.

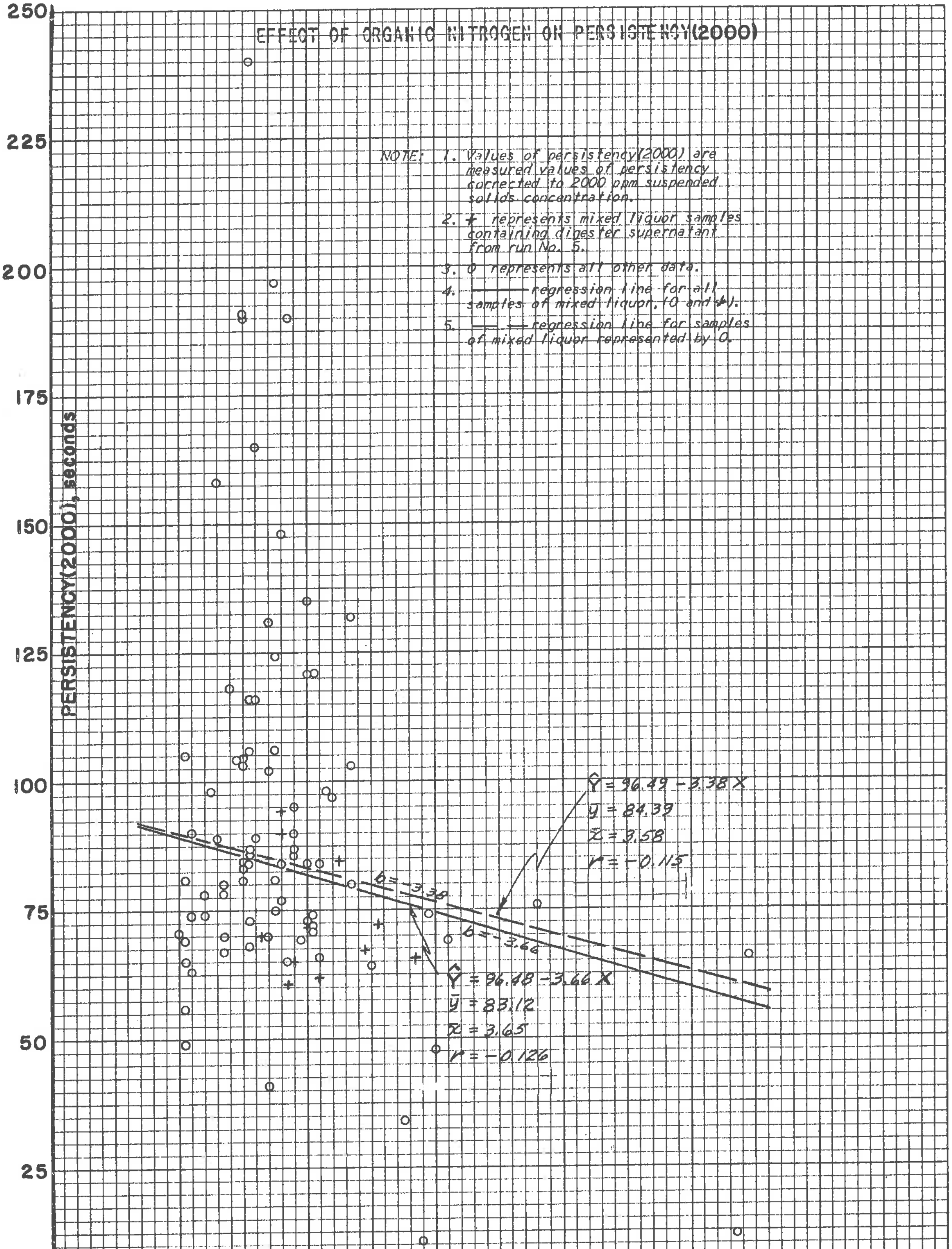
2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ——— regression line for all samples of mixed liquor, (O and +).

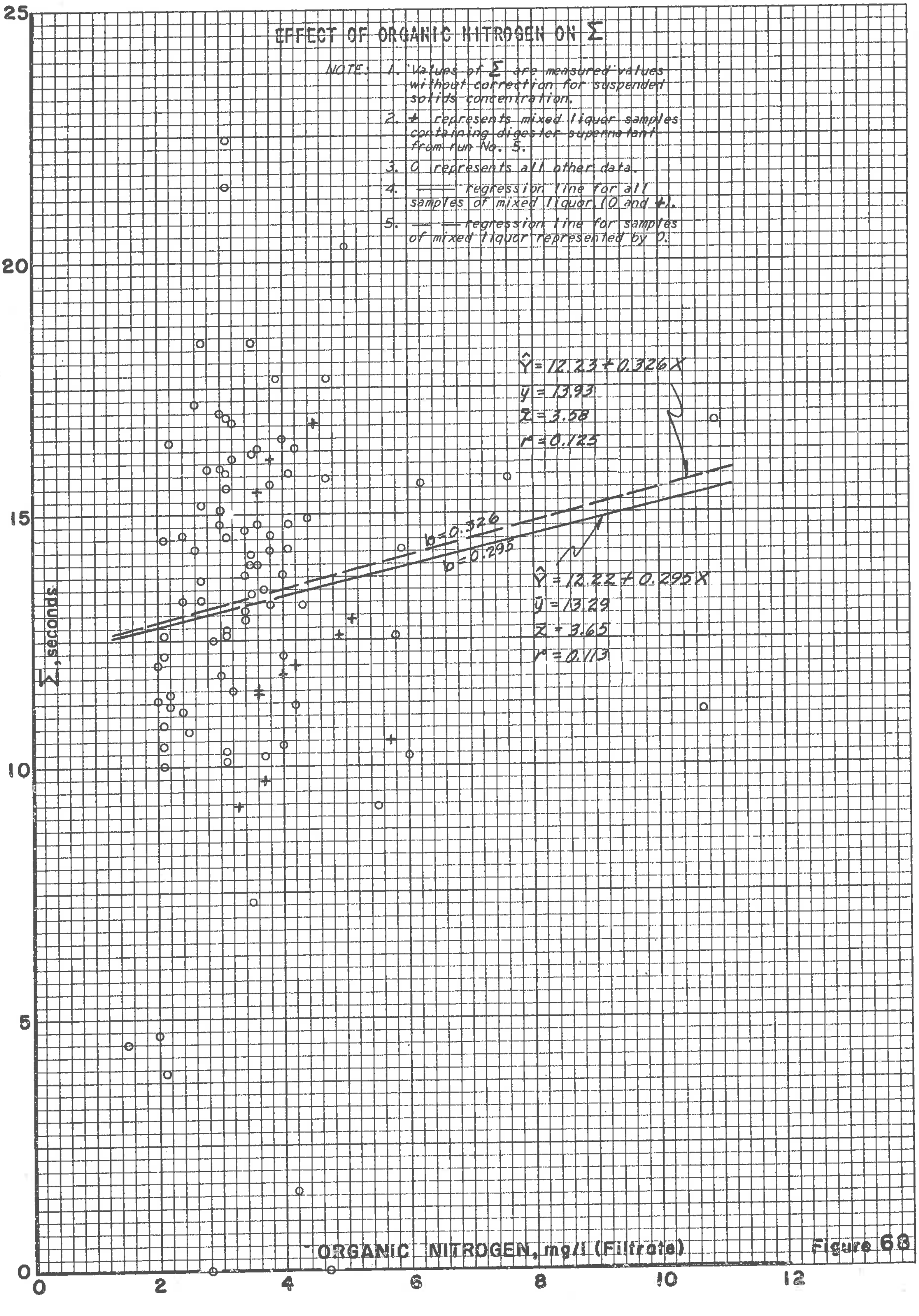
5. — — regression line for samples of mixed liquor represented by O.

Figure 66



EFFECT OF ORGANIC NITROGEN ON PERSISTENCY(2000)
NOTE: 1. Values of persistency(2000) are measured values of persistency corrected to 2000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data.
4. ——— regression line for all samples of mixed liquor. (O and +).
5. — — regression line for samples of mixed liquor represented by O.
Ŷ = 96.49 − 3.38 X
ȳ = 84.39
x̄ = 3.58
r = −0.115
b = −3.38
b = −3.66
Ŷ = 96.48 − 3.66 X
ȳ = 83.12
x̄ = 3.65
r = −0.126
PERSISTENCY(2000), seconds
250
225
200
175
150
125
100
75
50
25
0
ORGANIC NITROGEN, mg/l (Filtrate)
0
2
4
6
8
10
12

Figure 67



EFFECT OF ORGANIC NITROGEN ON Σ

NOTE: 1. Values of Σ are measured values without correction for suspended solids concentration.

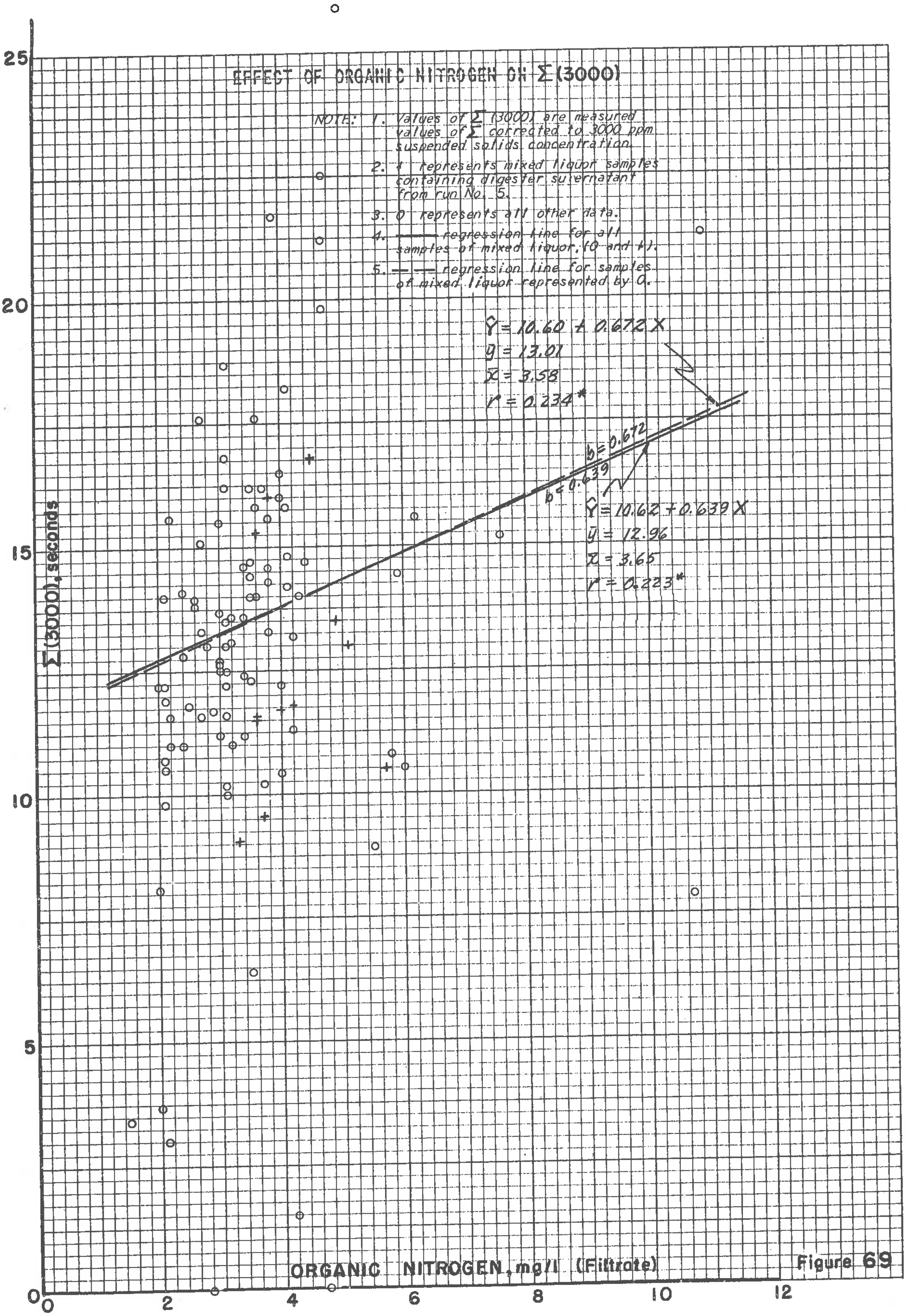
2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ——— regression line for all samples of mixed liquor (O and +).

5. — — regression line for samples of mixed liquor represented by O.

Figure 68



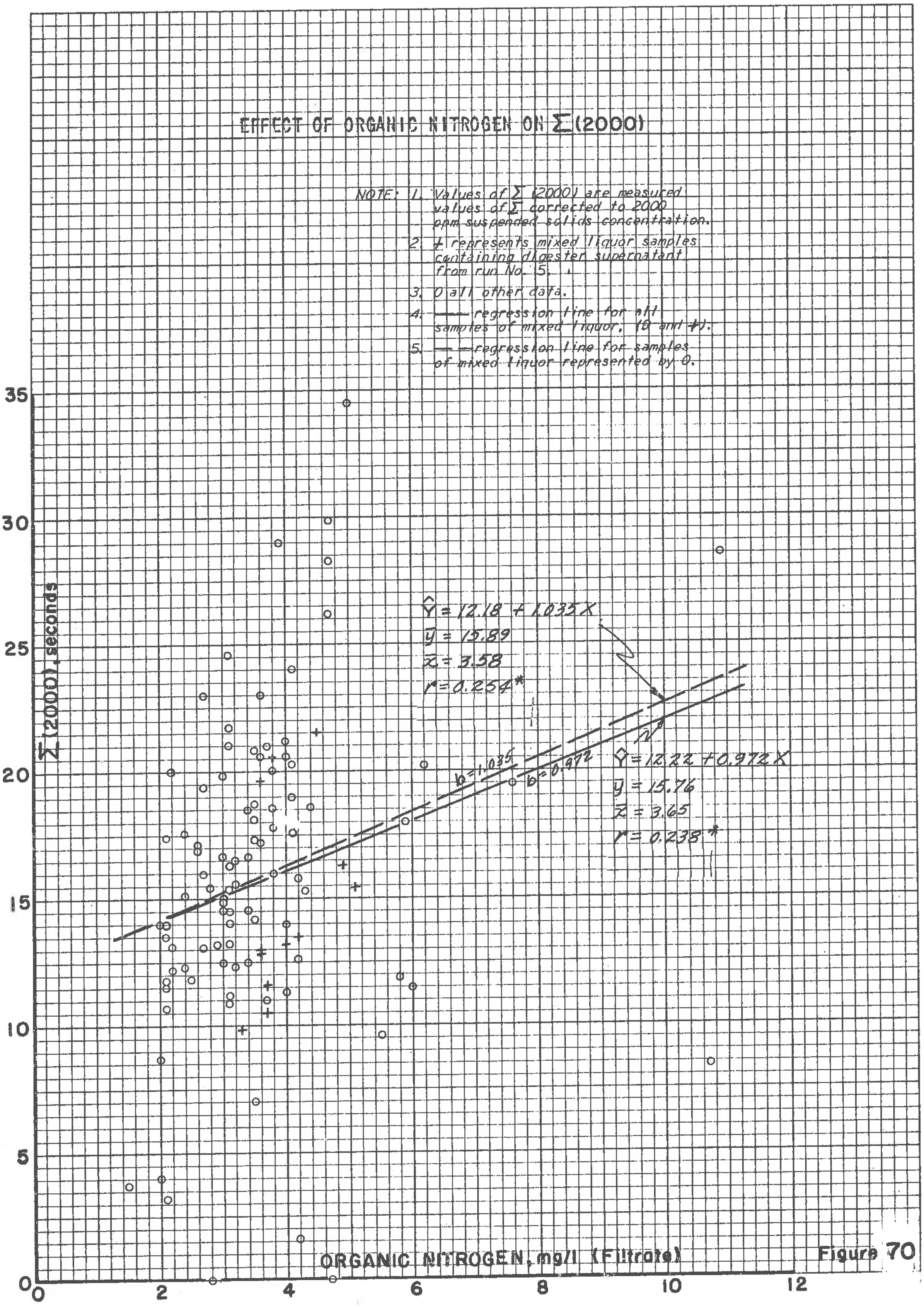
EFFECT OF ORGANIC NITROGEN ON $\Sigma(3000)$

NOTE:
1. Values of $\Sigma(3000)$ are measured values of Σ corrected to 3000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data.
4. ——— regression line for all samples of mixed liquor. (O and +).
5. — — regression line for samples of mixed liquor represented by O.

$\hat{Y} = 10.60 + 0.672X$
$\bar{y} = 13.01$
$\bar{x} = 3.58$
$r = 0.234^*$

$\hat{Y} = 10.62 + 0.639X$
$\bar{y} = 12.96$
$\bar{x} = 3.65$
$r = 0.223^*$

Figure 69



EFFECT OF ORGANIC NITROGEN ON Σ(2000)

NOTE:
1. Values of Σ (2000) are measured values of Σ corrected to 2000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O all other data.
4. —— regression line for all samples of mixed liquor. (O and +).
5. — — regression line for samples of mixed liquor represented by O.

Figure 70

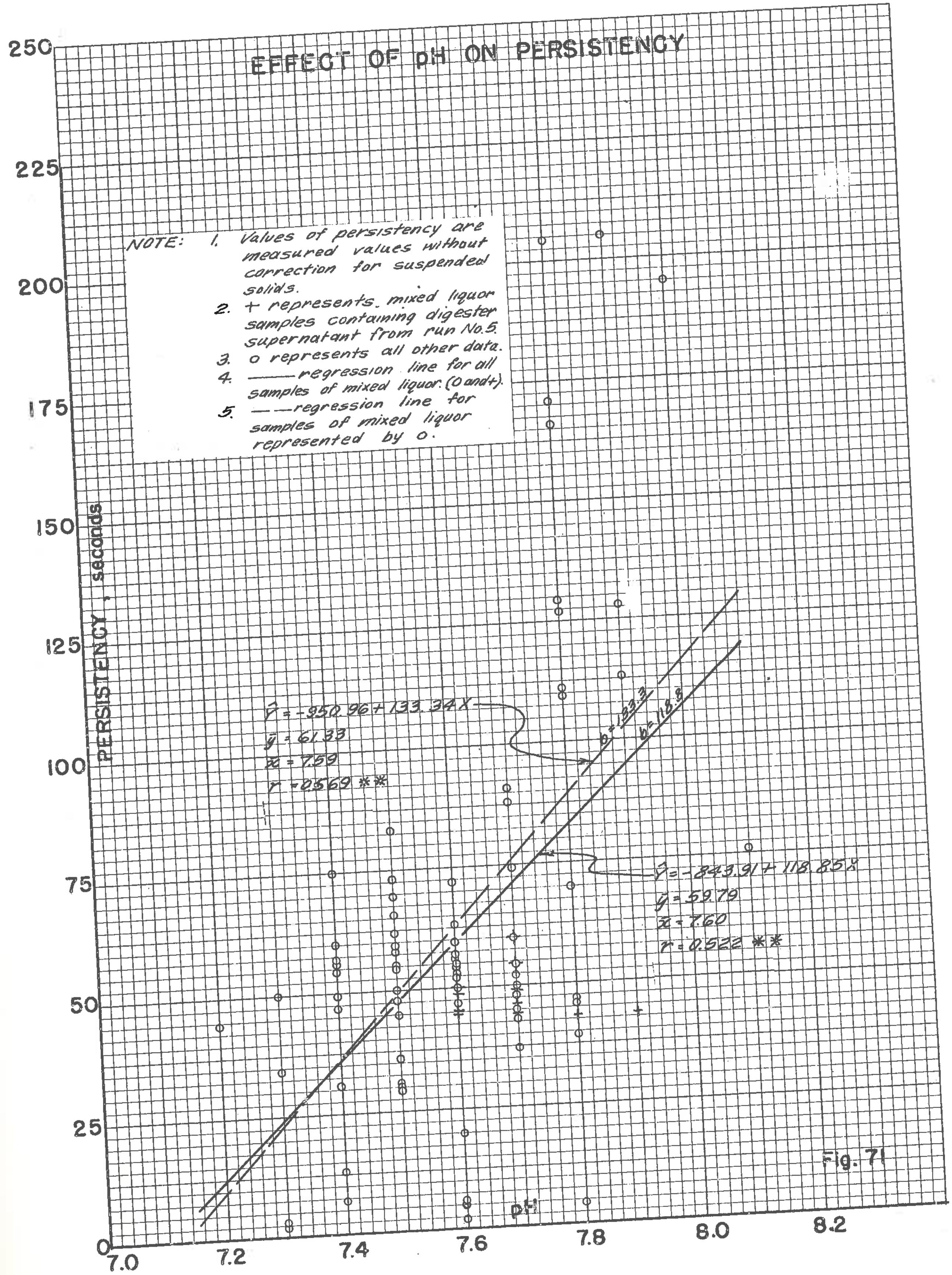
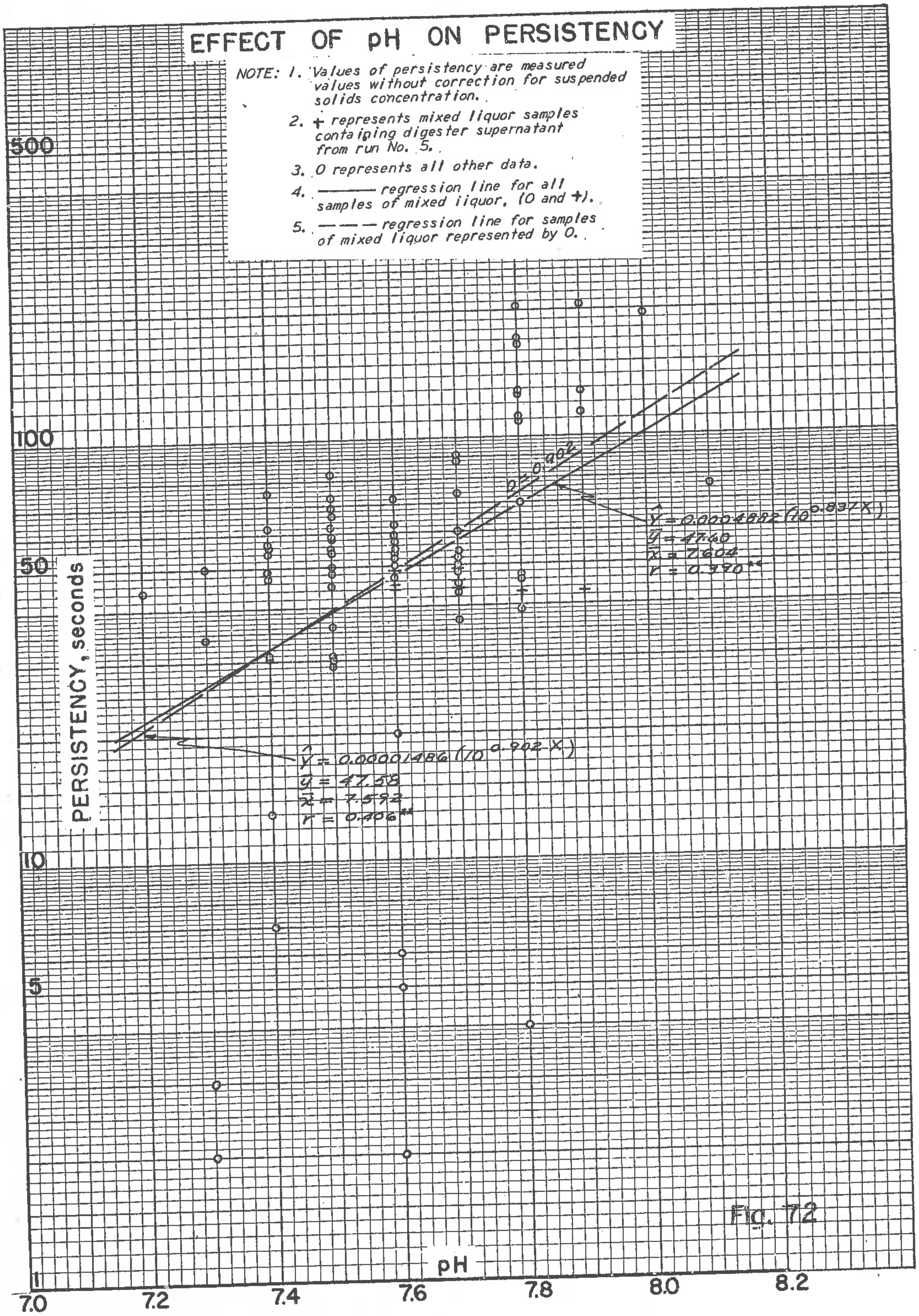

EFFECT OF pH ON PERSISTENCY
NOTE: 1. Values of persistency are measured values without correction for suspended solids.
2. + represents mixed liquor samples containing digester supernatant from run No.5.
3. o represents all other data.
4. ——— regression line for all samples of mixed liquor. (0 and+).
5. — — regression line for samples of mixed liquor represented by o.
$\hat{Y} = -950.96 + 133.34X$
$\bar{y} = 61.33$
$\bar{x} = 7.59$
$r = 0.569$ **
$b = 133.3$
$b = 118.8$
$\hat{Y} = -843.91 + 118.85X$
$\bar{y} = 59.79$
$\bar{x} = 7.60$
$r = 0.522$ **
PERSISTENCY, seconds
250
225
200
175
150
125
100
75
50
25
0
pH
7.0
7.2
7.4
7.6
7.8
8.0
8.2

Fig. 71



EFFECT OF pH ON PERSISTENCY

NOTE: 1. Values of persistency are measured values without correction for suspended solids concentration.

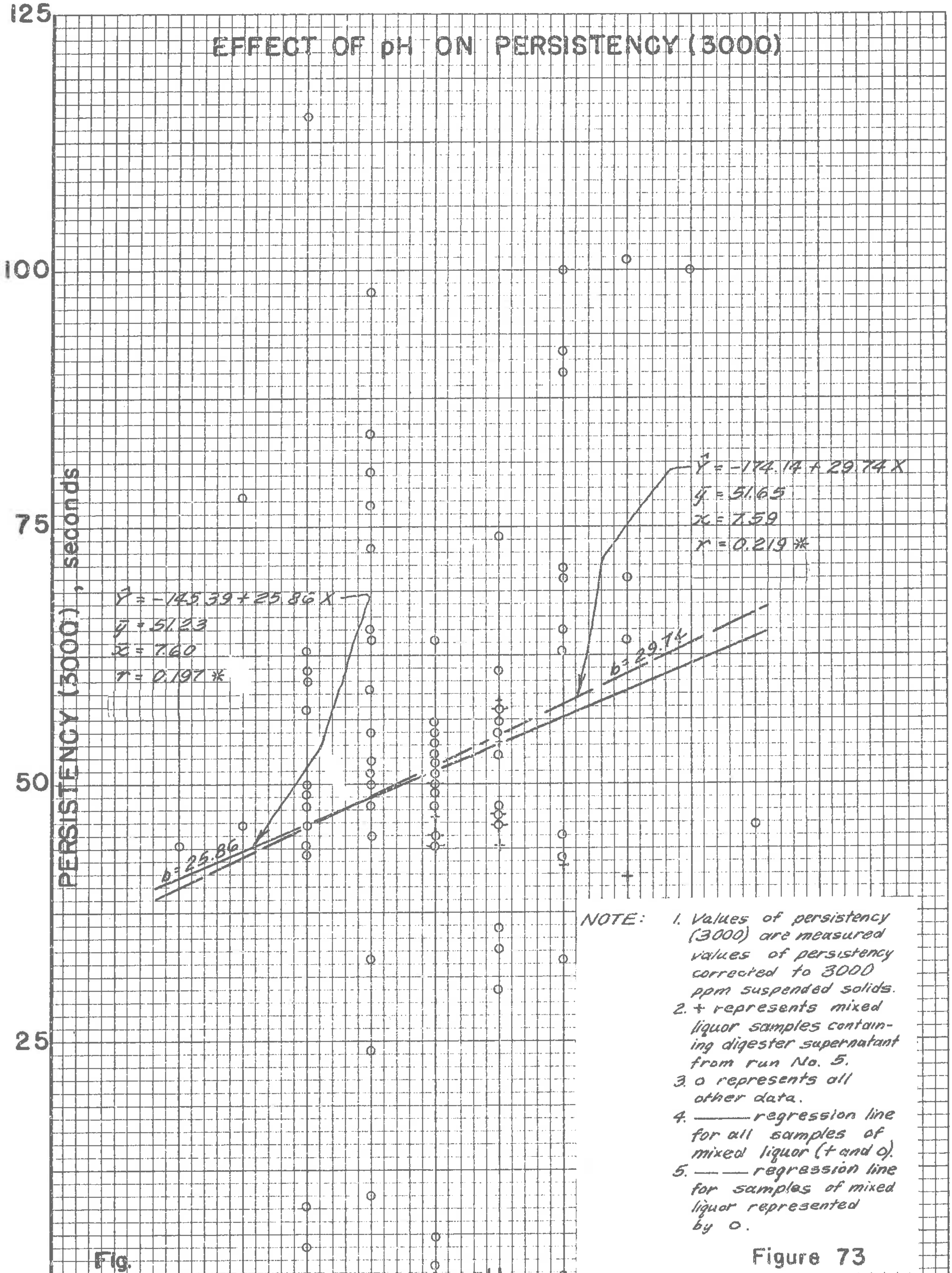
2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ——— regression line for all samples of mixed liquor, (O and +).

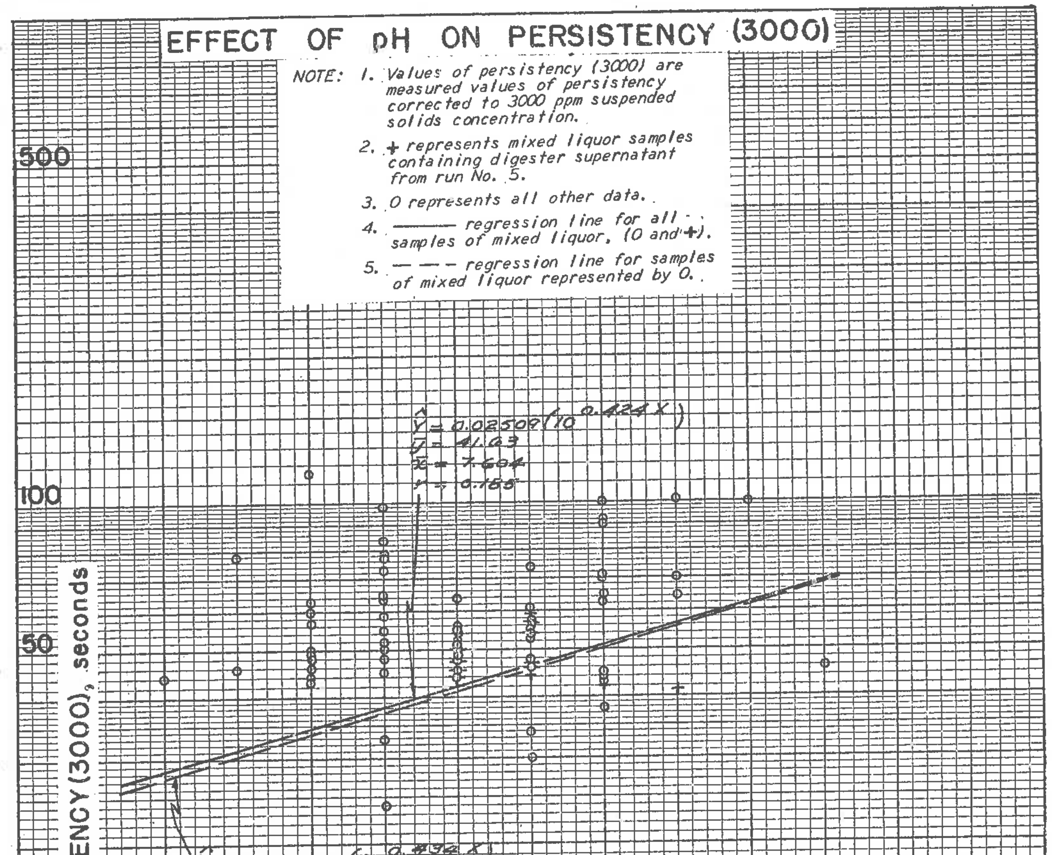
5. — — — regression line for samples of mixed liquor represented by O.

Fig. 72


EFFECT OF pH ON PERSISTENCY (3000)

NOTE:
1. Values of persistency (3000) are measured values of persistency corrected to 3000 ppm suspended solids.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. o represents all other data.
4. ——— regression line for all samples of mixed liquor (+ and o).
5. — — — regression line for samples of mixed liquor represented by o.

Figure 73

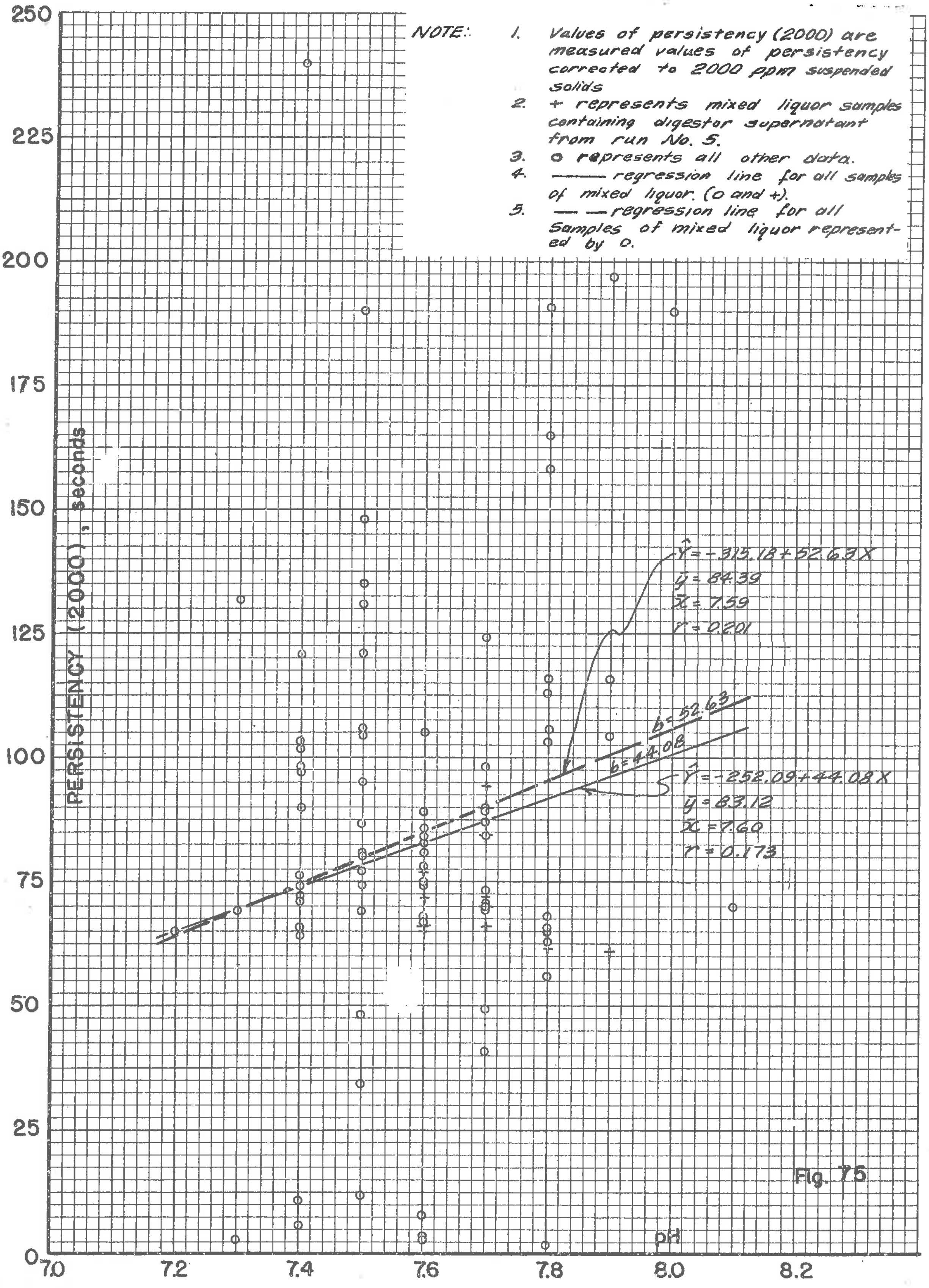


EFFECT OF pH ON PERSISTENCY (3000)

NOTE:
1. Values of persistency (3000) are measured values of persistency corrected to 3000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data.
4. ——— regression line for all samples of mixed liquor, (O and +).
5. — — — regression line for samples of mixed liquor represented by O.

Figure 74

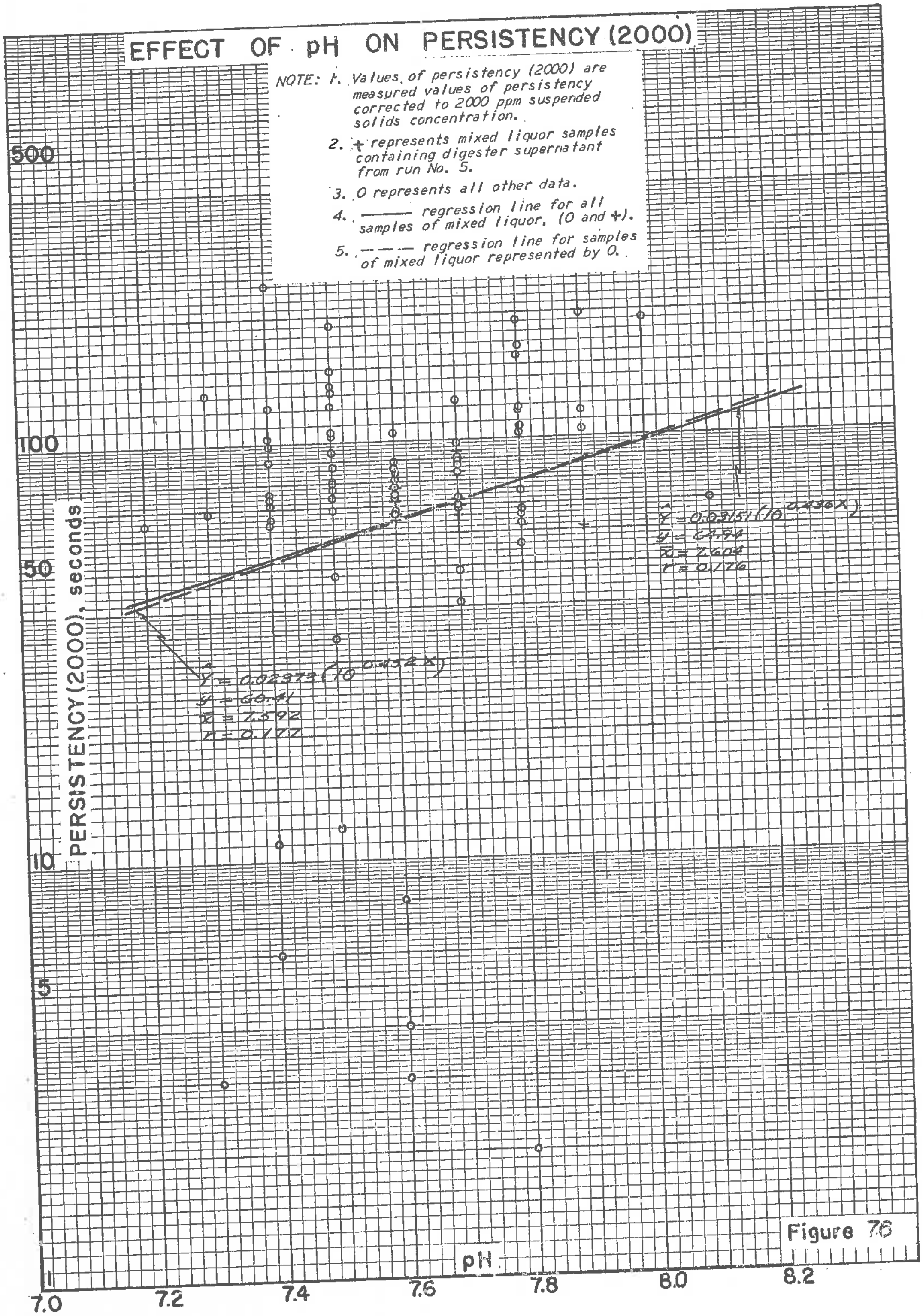
EFFECT OF pH ON PERSISTENCY (2000)



NOTE:

1. Values of persistency (2000) are measured values of persistency corrected to 2000 ppm suspended solids
2. + represents mixed liquor samples containing digestor supernatant from run No. 5.
3. o represents all other data.
4. ——— regression line for all samples of mixed liquor. (o and +).
5. — — regression line for all Samples of mixed liquor represented by o.

Fig. 75



EFFECT OF pH ON PERSISTENCY (2000)

NOTE: 1. Values of persistency (2000) are measured values of persistency corrected to 2000 ppm suspended solids concentration.

2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

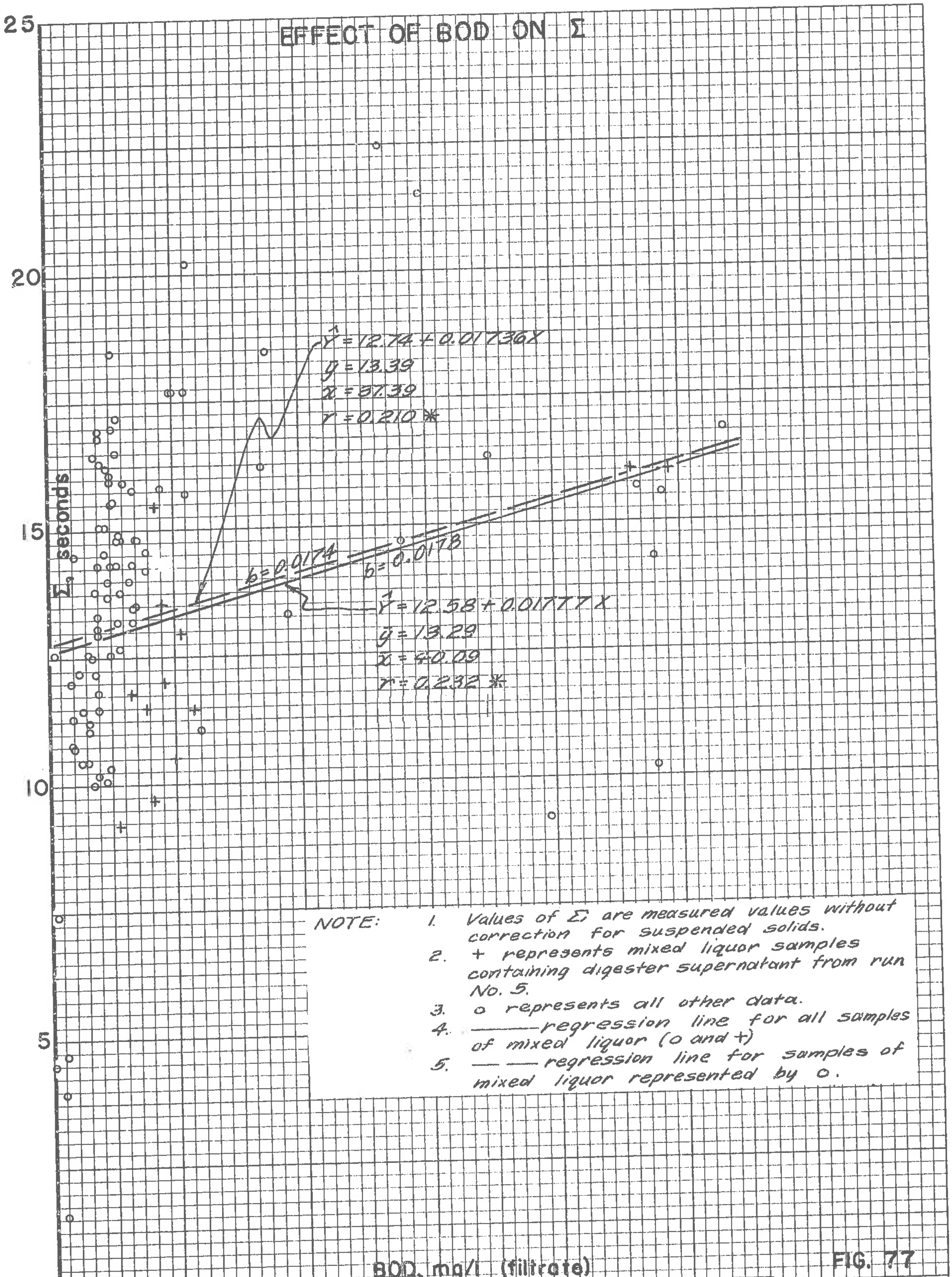
4. ——— regression line for all samples of mixed liquor, (O and +).

5. — — — regression line for samples of mixed liquor represented by O.

$\hat{Y} = 0.03151(10^{0.436X})$
$y = 64.94$
$\bar{x} = 7.604$
$r = 0.176$

$\hat{Y} = 0.02373(10^{0.452X})$
$y = 60.41$
$\bar{x} = 7.592$
$r = 0.177$

Figure 76



EFFECT OF BOD ON Σ

NOTE:
1. Values of Σ are measured values without correction for suspended solids.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. o represents all other data.
4. ——— regression line for all samples of mixed liquor (o and +)
5. — — regression line for samples of mixed liquor represented by o.

FIG. 77

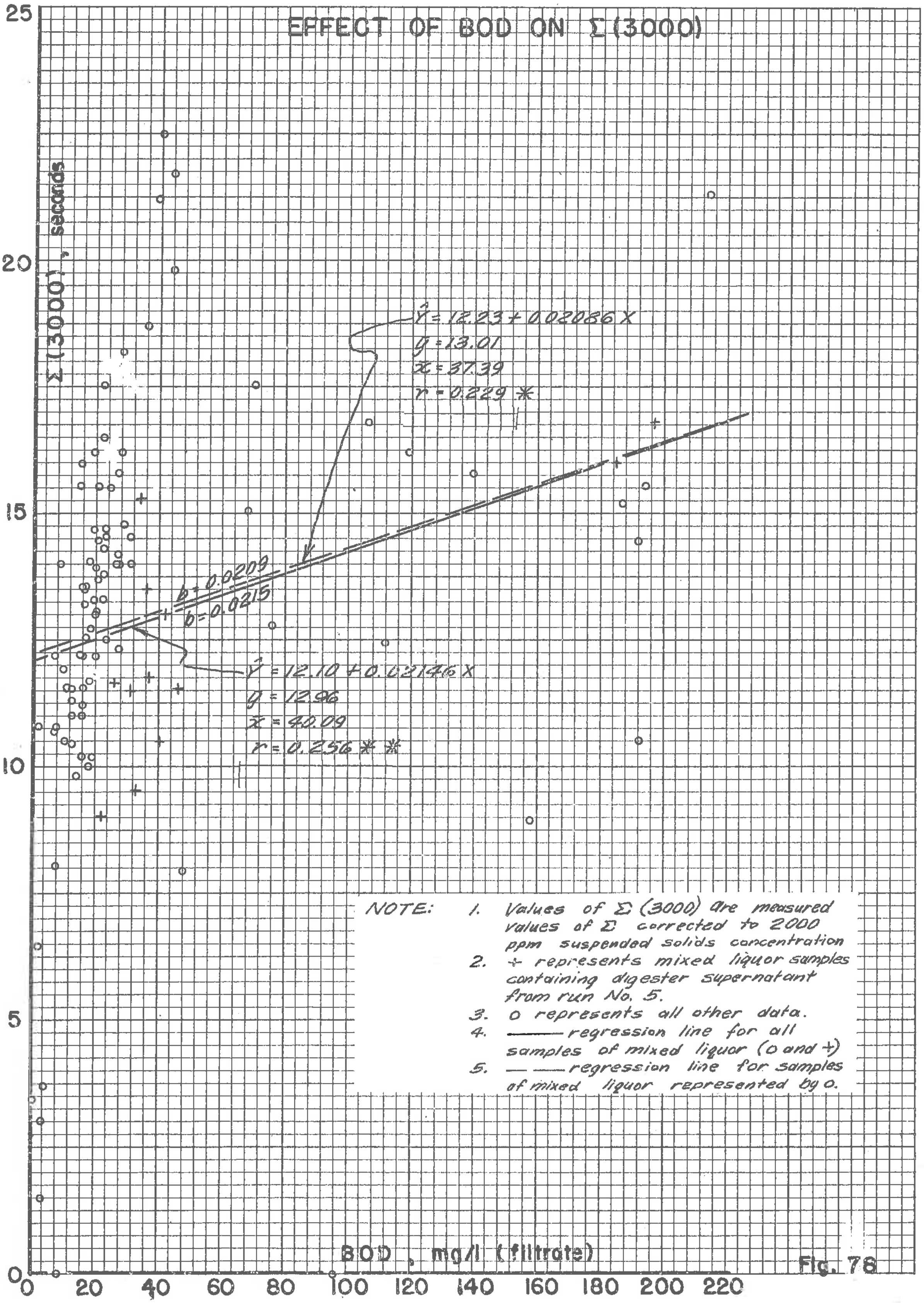

EFFECT OF BOD ON Σ(3000)
Σ (3000), seconds
BOD, mg/l (filtrate)
0
5
10
15
20
25
0
20
40
60
80
100
120
140
160
180
200
220
Ŷ = 12.23 + 0.02086 X
ȳ = 13.01
x̄ = 37.39
r = 0.229 *
b = 0.0209
b = 0.0215
Ŷ = 12.10 + 0.02146 X
ȳ = 12.96
x̄ = 40.09
r = 0.256 * *
NOTE: 1. Values of Σ (3000) are measured values of Σ corrected to 2000 ppm suspended solids concentration
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. o represents all other data.
4. ——— regression line for all samples of mixed liquor (o and +)
5. — — — regression line for samples of mixed liquor represented by o.

Fig. 78

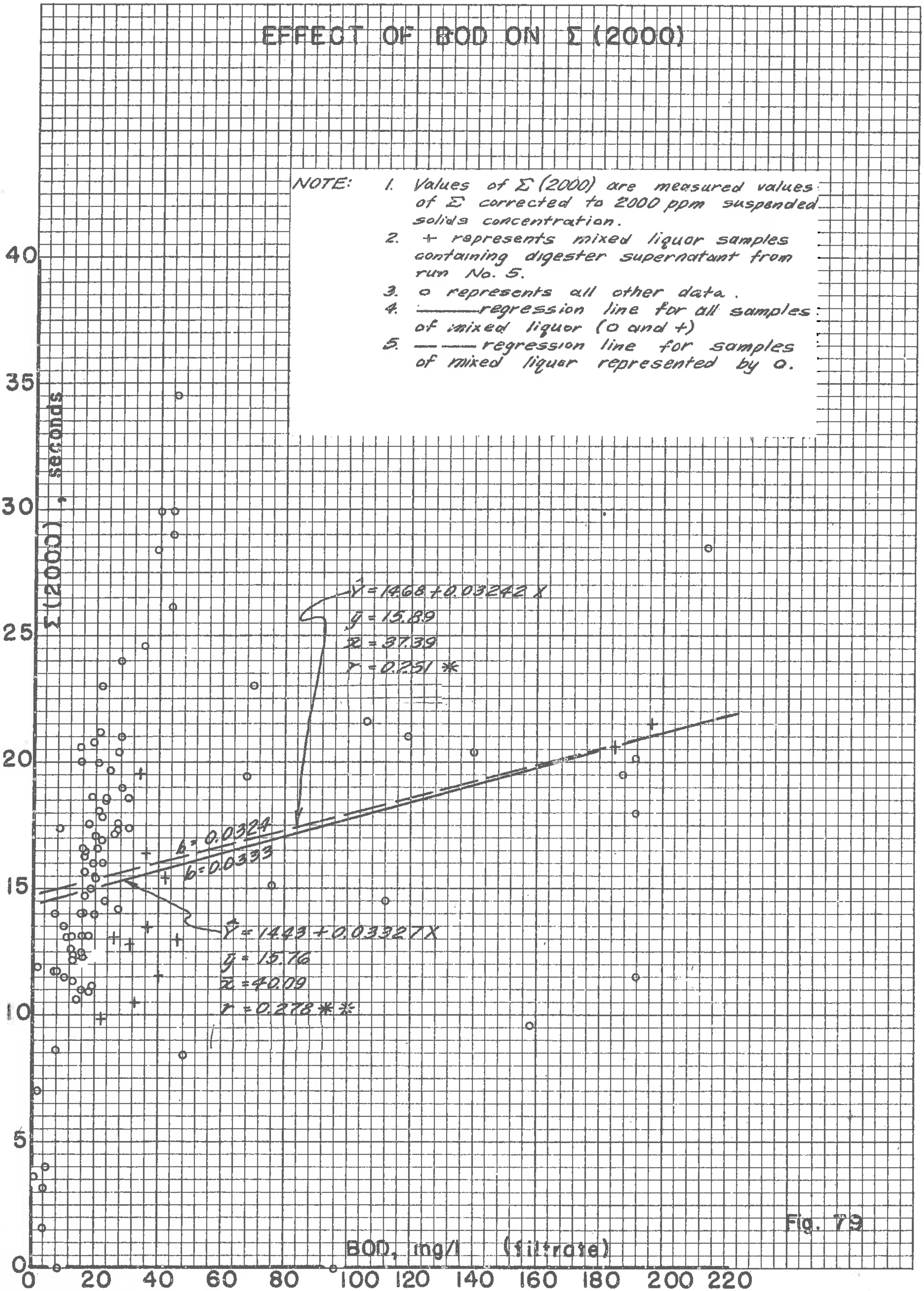
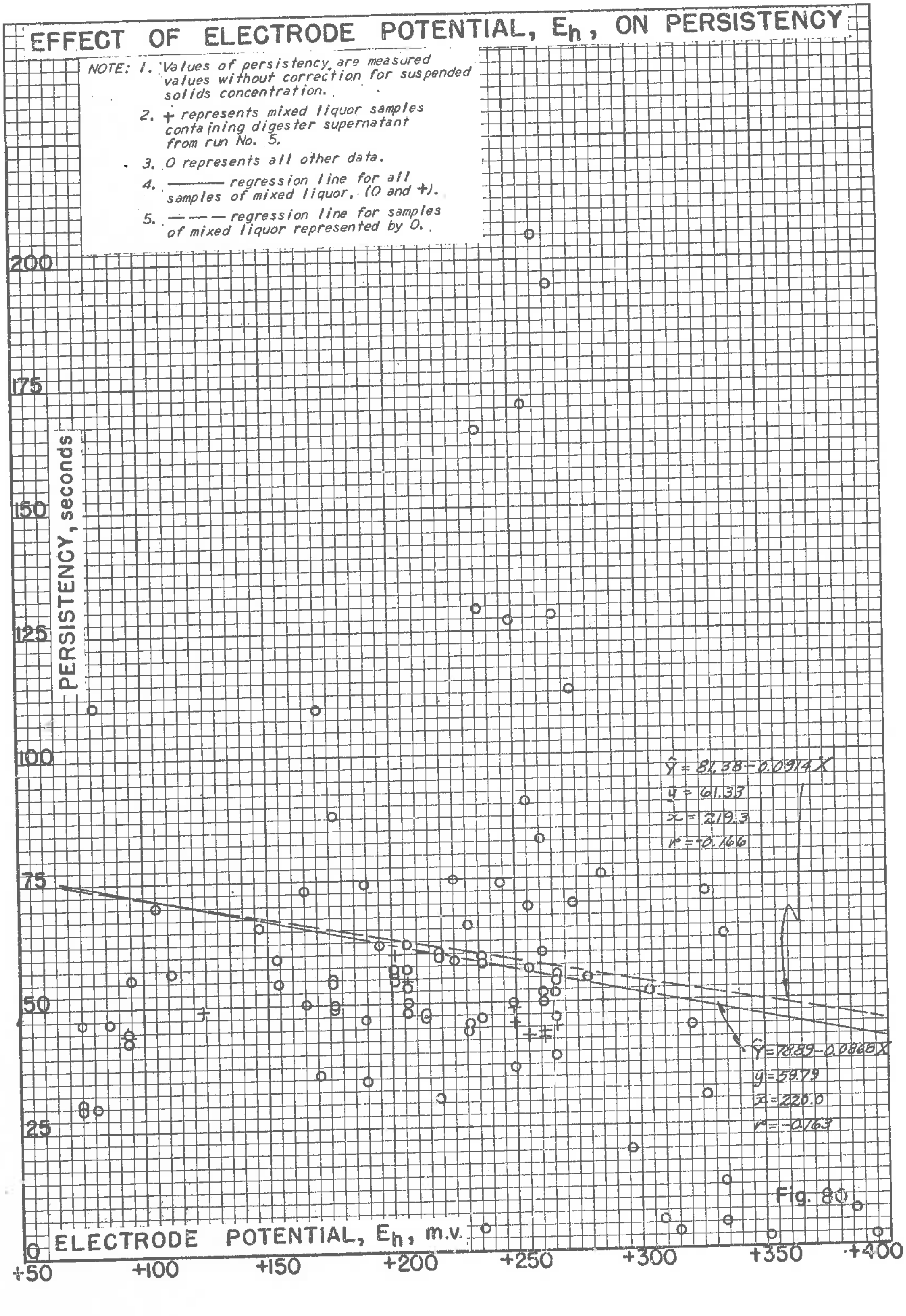

EFFECT OF BOD ON Σ (2000)
NOTE: 1. Values of Σ (2000) are measured values of Σ corrected to 2000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. o represents all other data.
4. ——— regression line for all samples of mixed liquor (o and +)
5. — — — regression line for samples of mixed liquor represented by o.
Ŷ = 14.68 + 0.03242 X
ȳ = 15.89
x̄ = 37.39
r = 0.251 *
b = 0.0324
b = 0.0333
Ŷ = 14.43 + 0.03327 X
ȳ = 15.76
x̄ = 40.09
r = 0.278 **
Σ (2000), seconds
BOD, mg/l (filtrate)
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100
120
140
160
180
200
220

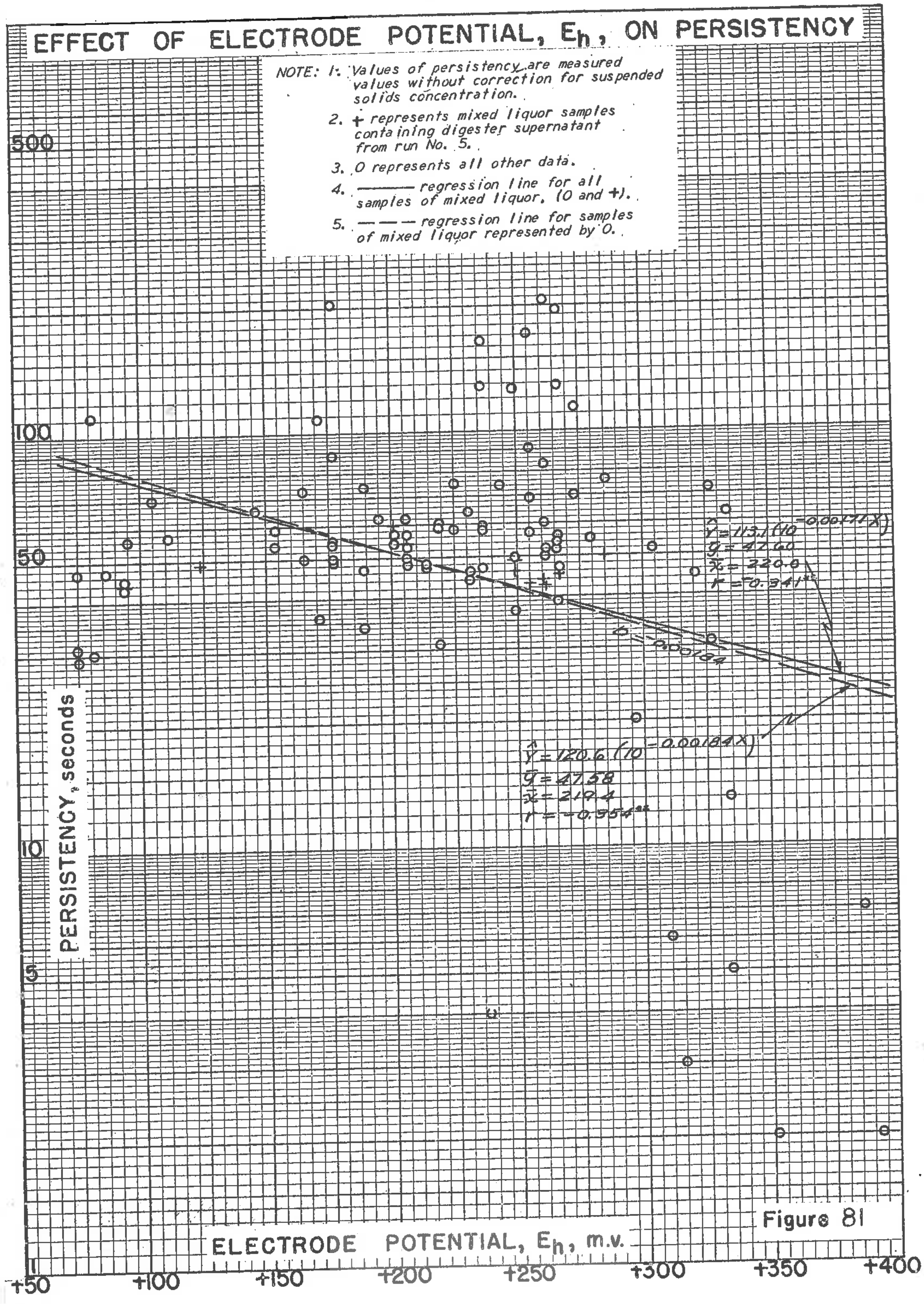
Fig. 79



EFFECT OF ELECTRODE POTENTIAL, E_h, ON PERSISTENCY

NOTE:
1. Values of persistency are measured values without correction for suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data.
4. ——— regression line for all samples of mixed liquor, (O and +).
5. — — — regression line for samples of mixed liquor represented by O.

Fig. 80



NOTE: 1. Values of persistency are measured values without correction for suspended solids concentration.

2. + represents mixed liquor samples containing digester supernatant from run No. 5.

3. O represents all other data.

4. ——— regression line for all samples of mixed liquor. (O and +).

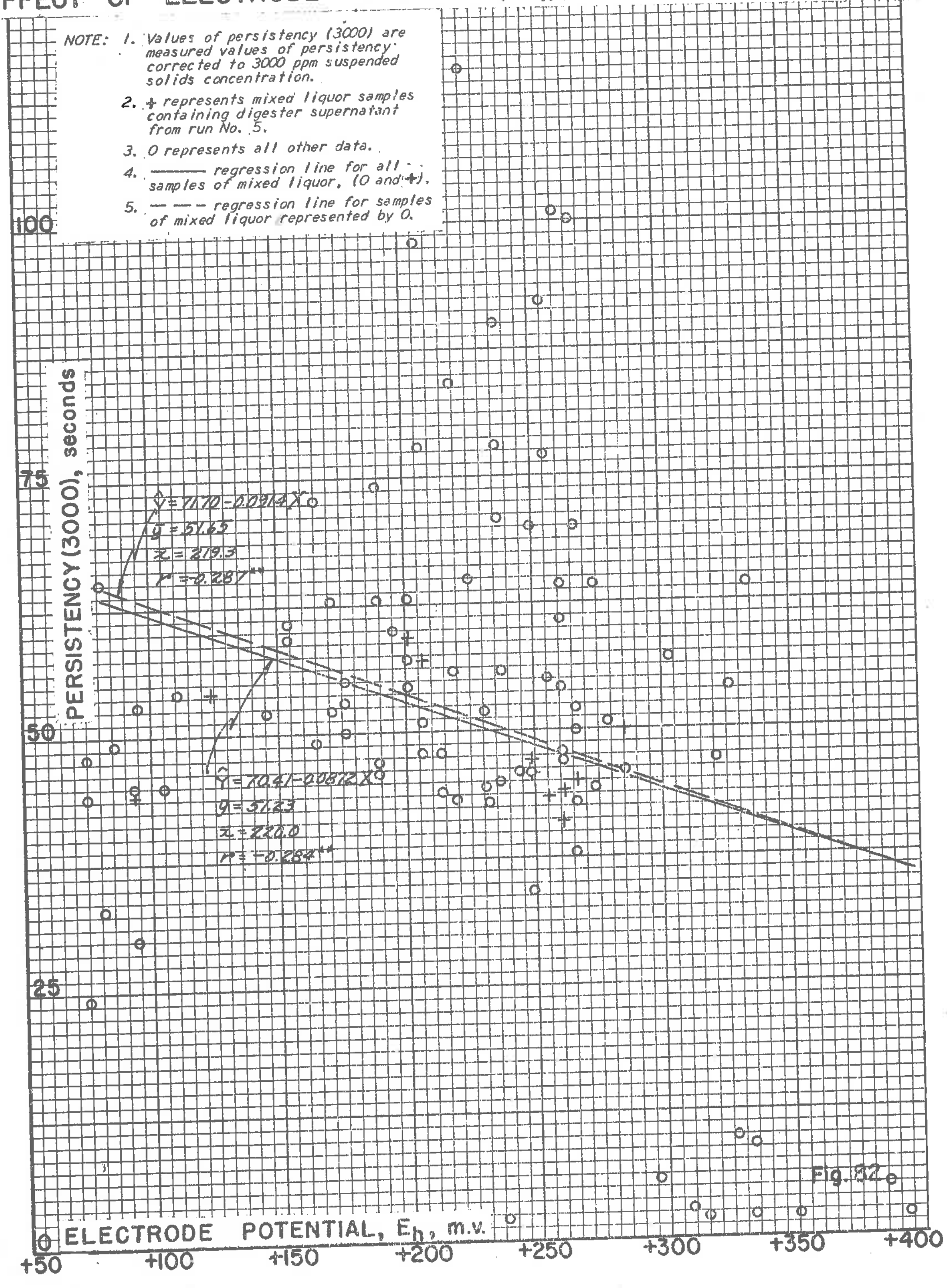
5. — — — regression line for samples of mixed liquor represented by O.

$\hat{Y} = 113.1(10^{-0.00171X})$
$\bar{y} = 47.60$
$\bar{x} = 220.0$
$r = -0.341^{**}$

$\hat{Y} = 120.6(10^{-0.00184X})$
$\bar{y} = 47.58$
$\bar{x} = 219.4$
$r = -0.354^{**}$

Figure 81

EFFECT OF ELECTRODE POTENTIAL, E_h, ON PERSISTENCY (3000)



NOTE:
1. Values of persistency (3000) are measured values of persistency corrected to 3000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data.
4. ——— regression line for all samples of mixed liquor, (O and +).
5. — — — regression line for samples of mixed liquor represented by O.

Fig. 32

EFFECT OF ELECTRODE POTENTIAL, E_h, ON PERSISTENCY (3000)

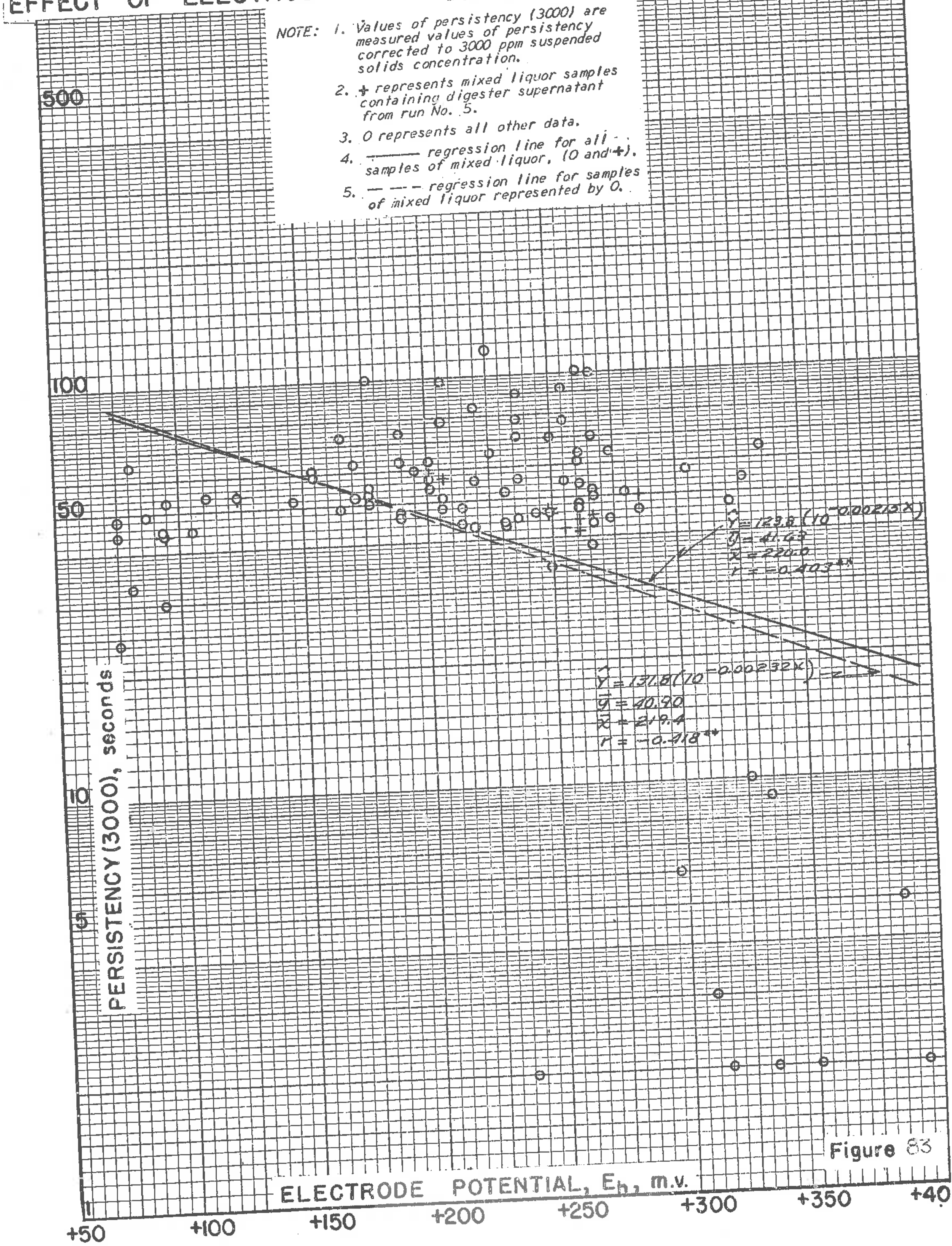


Figure 83

EFFECT OF ELECTRODE POTENTIAL, E_h, ON PERSISTENCY (2000)

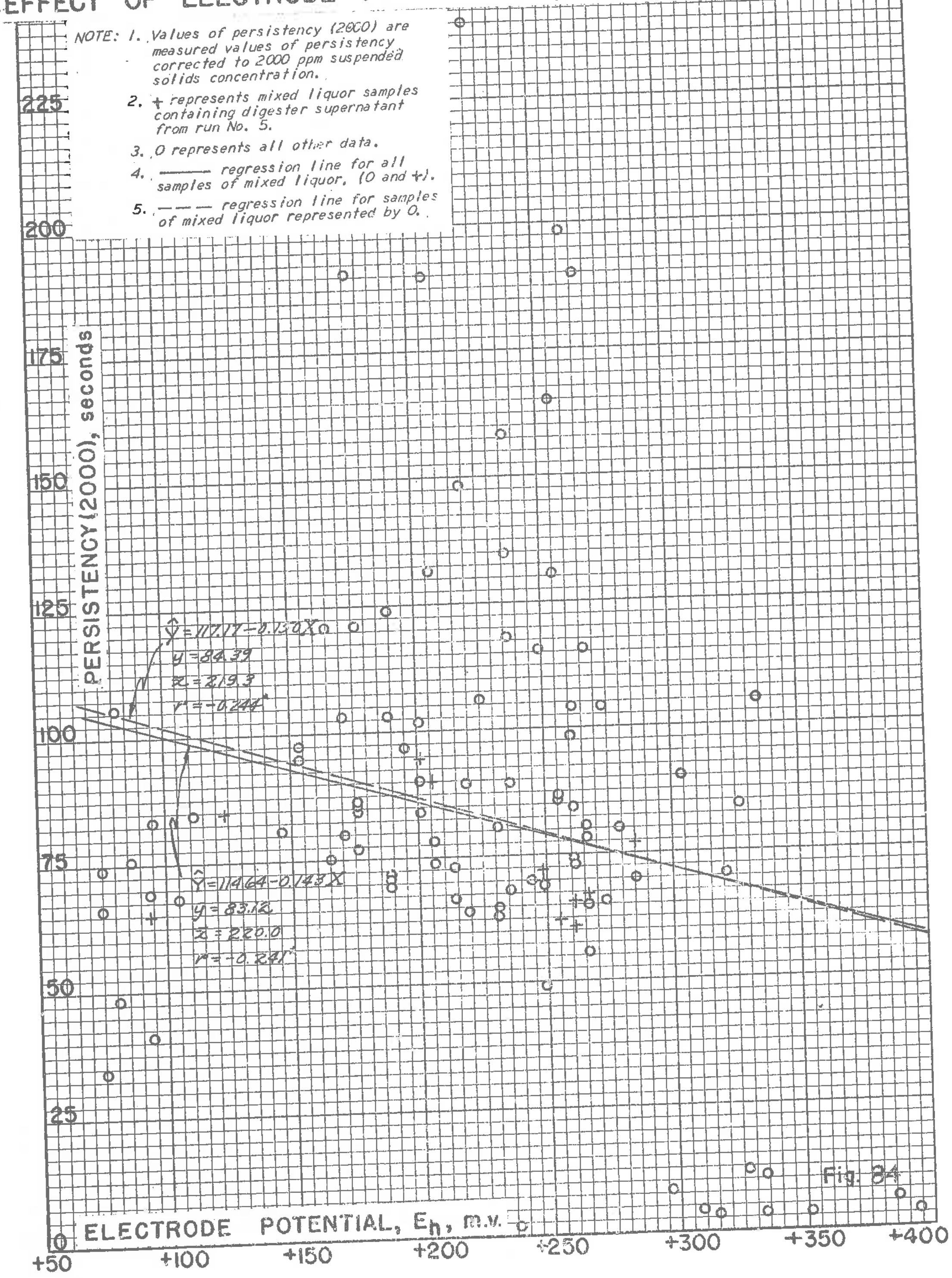


Fig. 34

EFFECT OF ELECTRODE POTENTIAL, E_h, ON PERSISTENCY (2000)

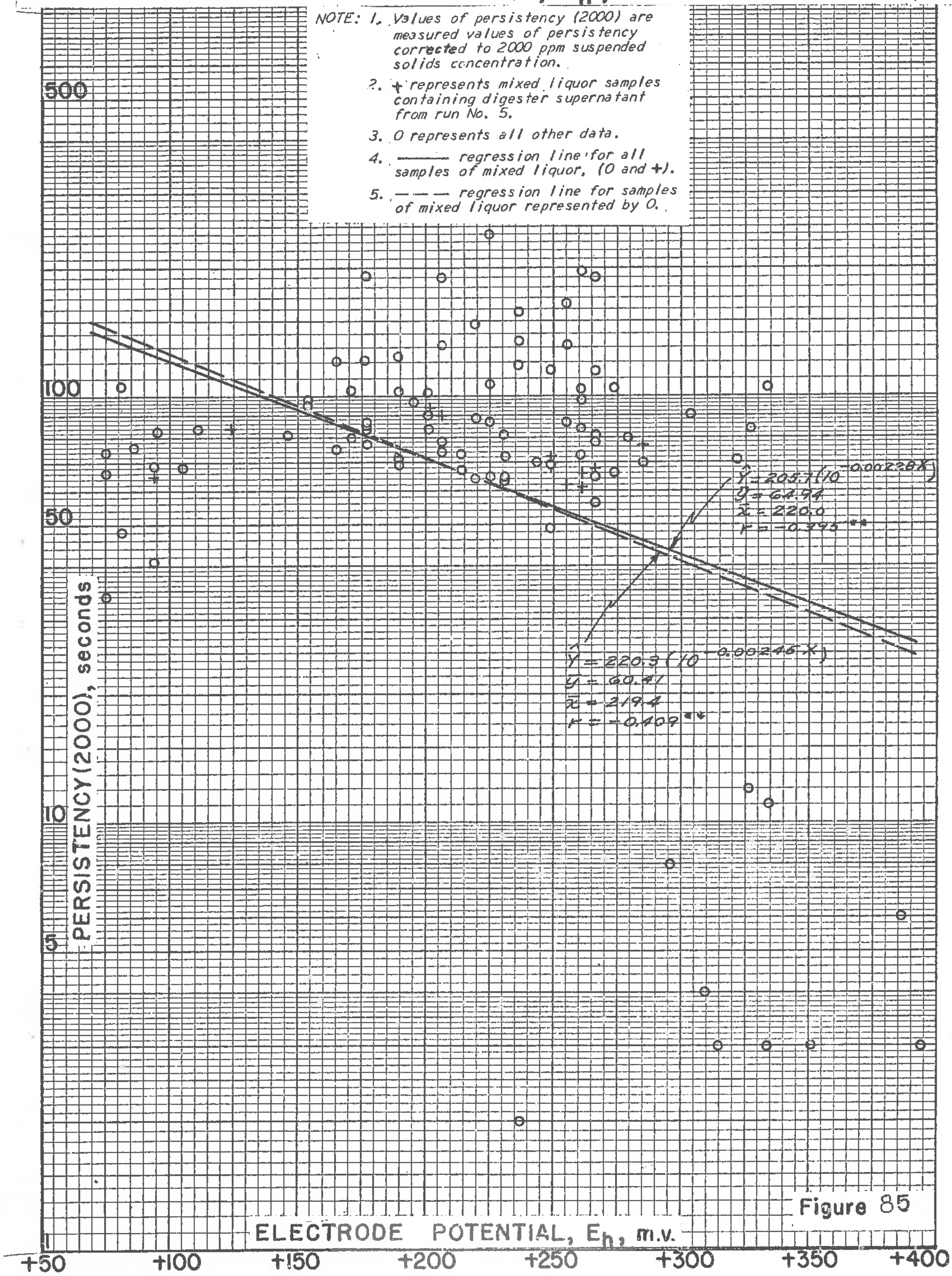


Figure 85

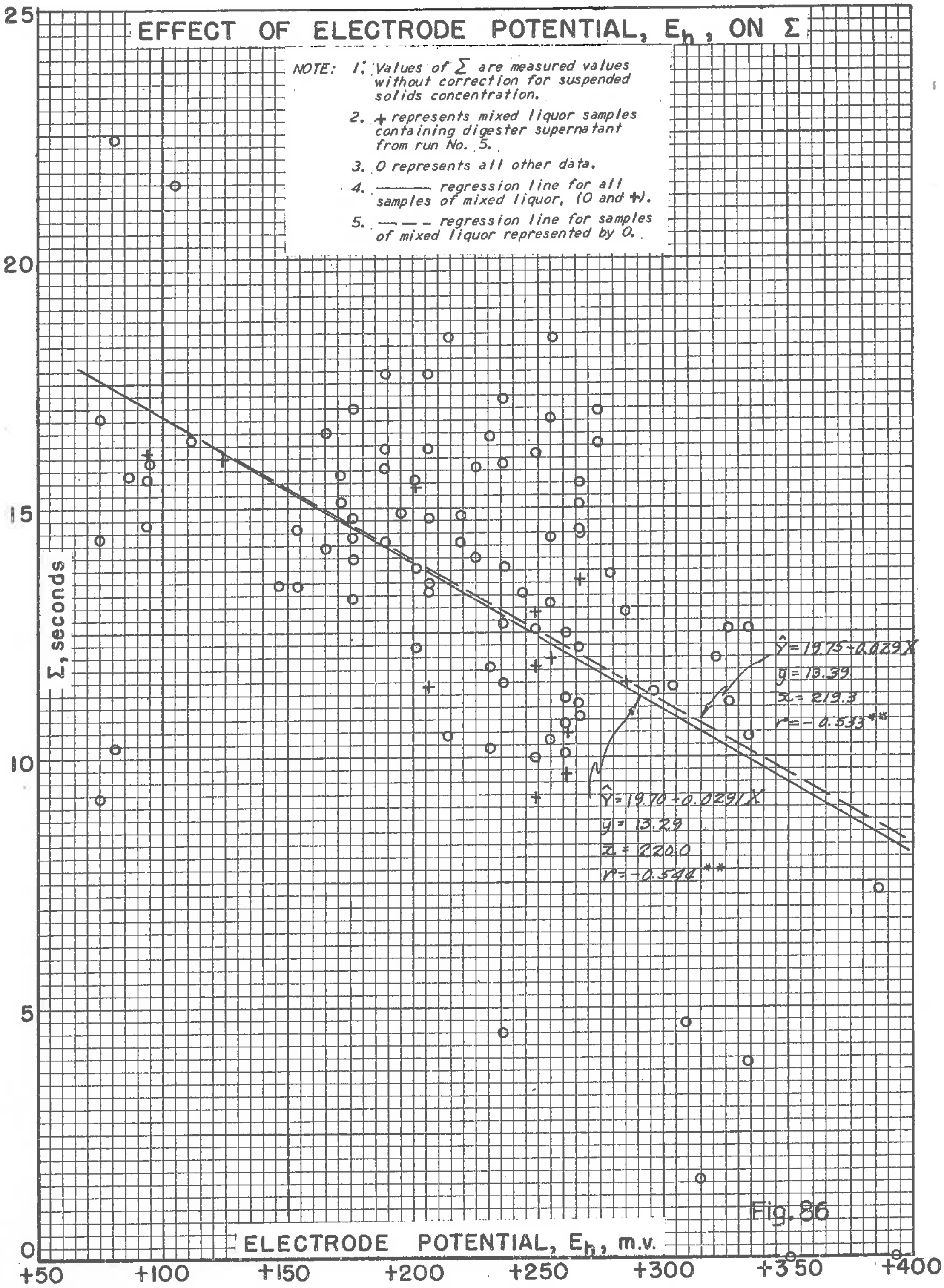
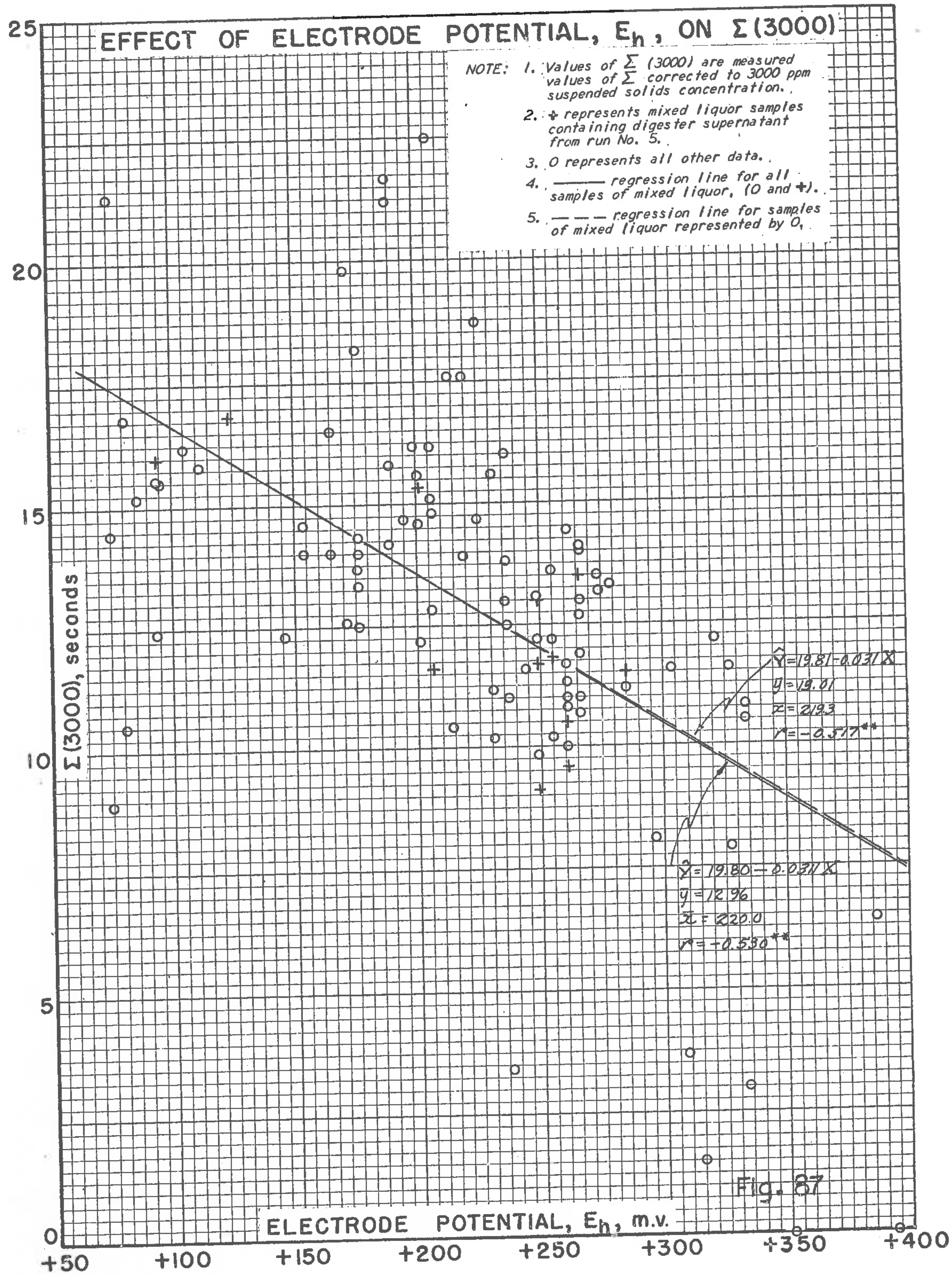

EFFECT OF ELECTRODE POTENTIAL, E_h, ON Σ
NOTE: 1. Values of Σ are measured values without correction for suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data.
4. ——— regression line for all samples of mixed liquor, (O and +).
5. — — — regression line for samples of mixed liquor represented by O.
$\hat{Y}=19.75-0.029X$
$\bar{y}=13.39$
$\bar{x}=219.3$
$r=-0.533^{**}$
$\hat{Y}=19.70-0.0291X$
$\bar{y}=13.29$
$\bar{x}=220.0$
$r=-0.544^{**}$
Σ, seconds
25
20
15
10
5
0
ELECTRODE POTENTIAL, E_h, m.v.
+50
+100
+150
+200
+250
+300
+350
+400

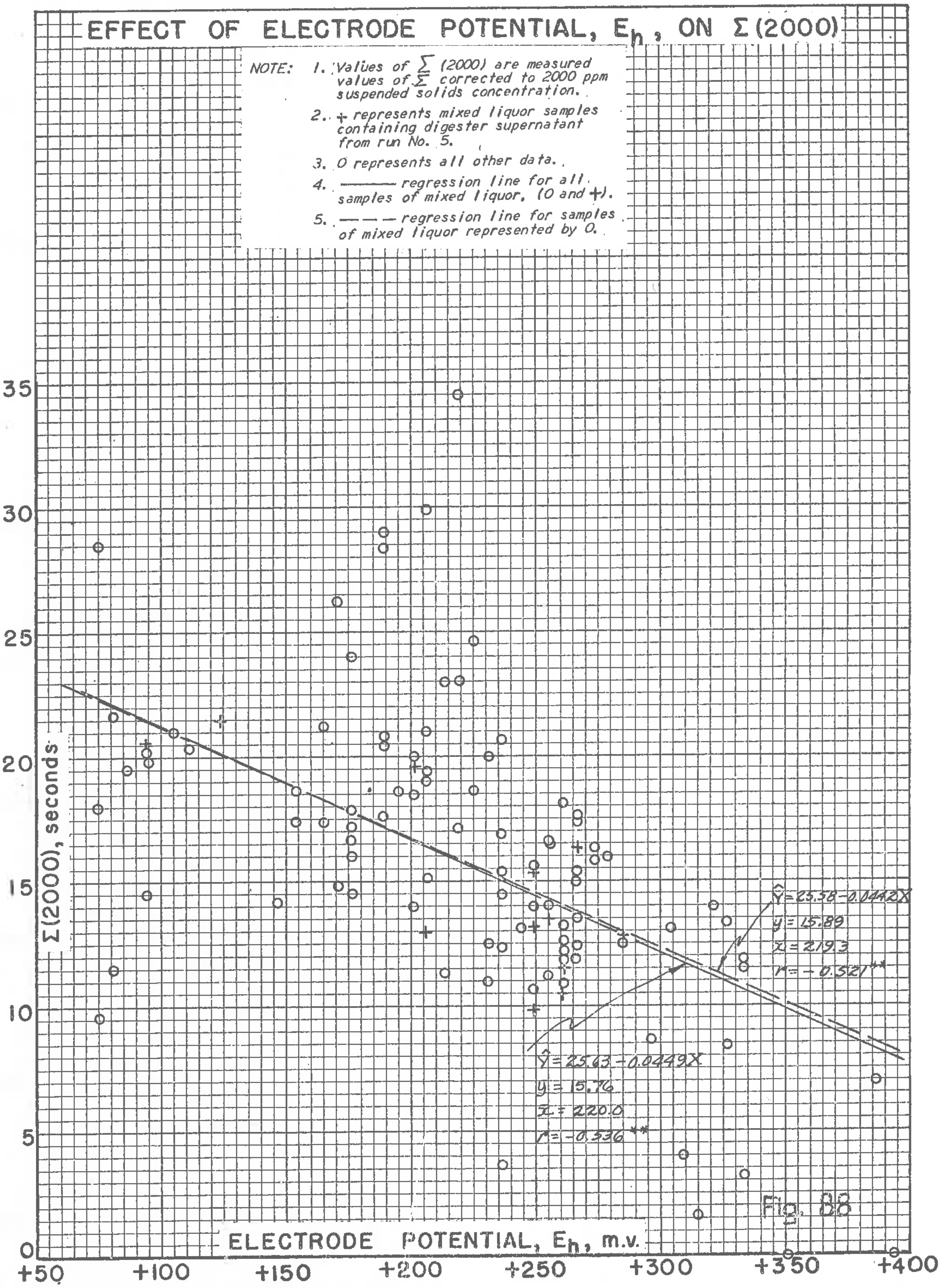
Fig. 86



EFFECT OF ELECTRODE POTENTIAL, E_h, ON $\Sigma(3000)$

NOTE:
1. Values of Σ (3000) are measured values of Σ corrected to 3000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data.
4. ——— regression line for all samples of mixed liquor, (O and +).
5. — — — regression line for samples of mixed liquor represented by O.

Fig. 87



EFFECT OF ELECTRODE POTENTIAL, E_h, ON $\Sigma(2000)$

NOTE:
1. Values of $\sum(2000)$ are measured values of $\sum$ corrected to 2000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data.
4. ——— regression line for all samples of mixed liquor, (O and +).
5. — — — regression line for samples of mixed liquor represented by O.

Fig. 88

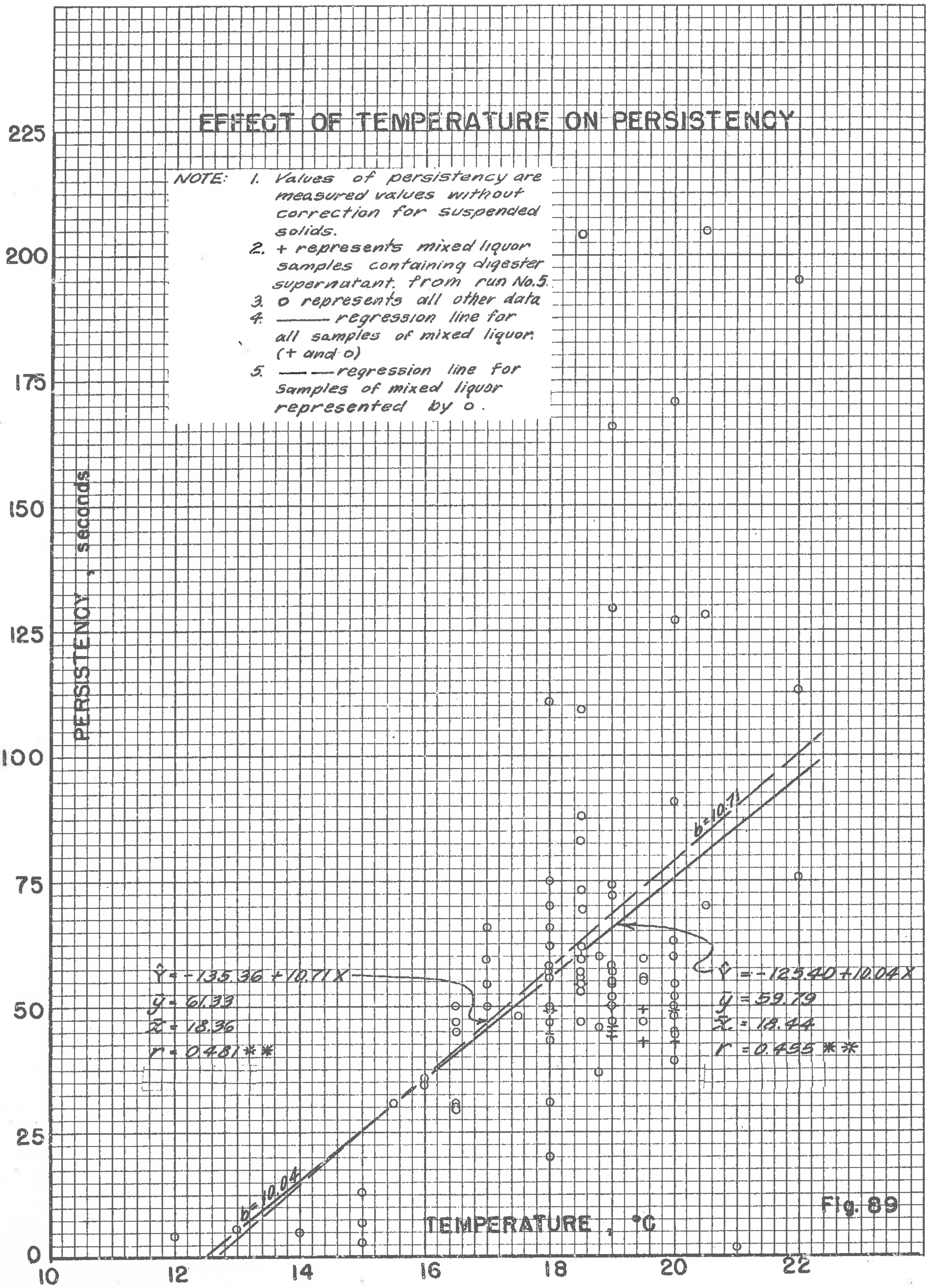
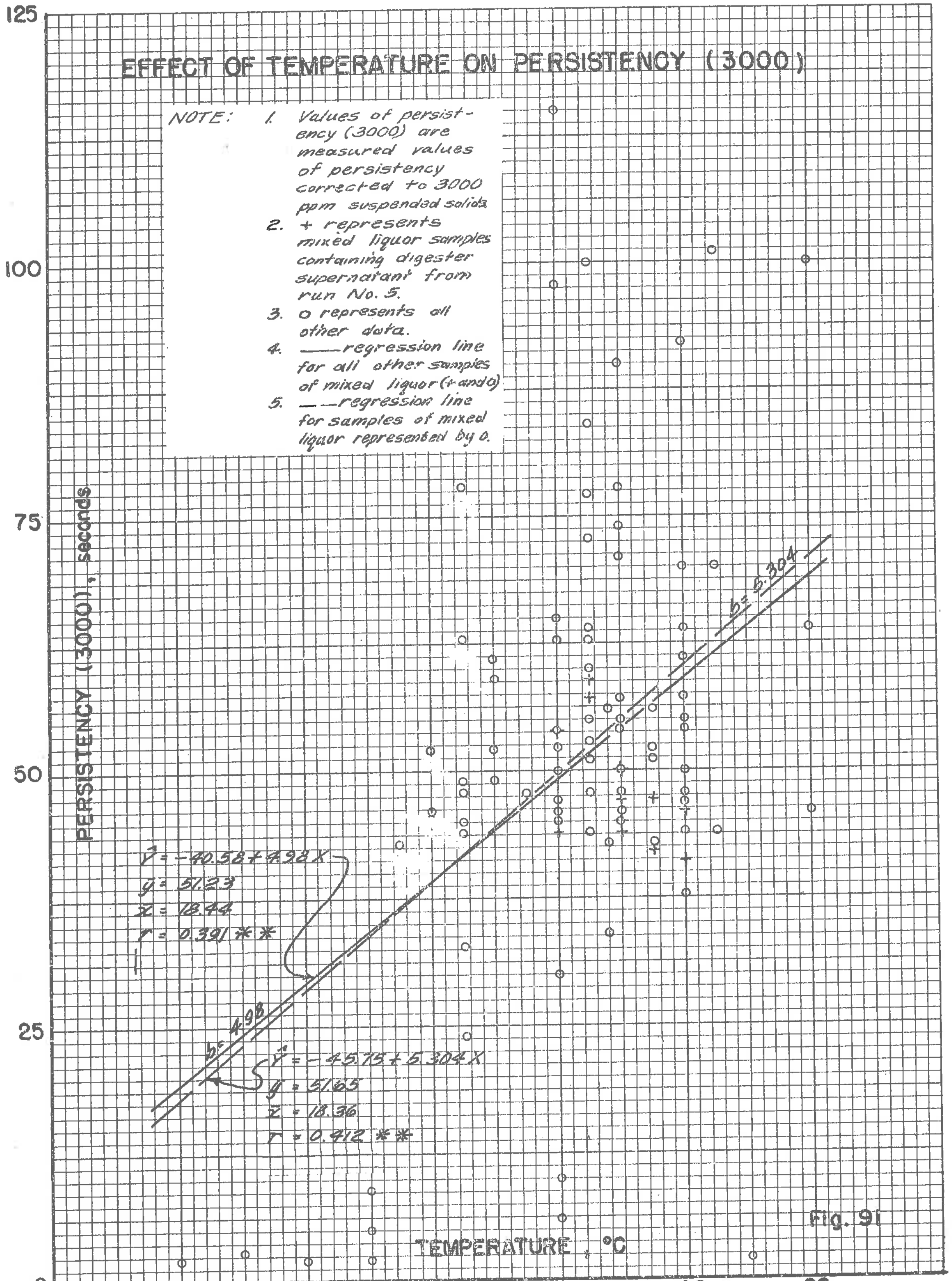


Fig. 89

EFFECT OF TEMPERATURE ON PERSISTENCY

NOTE:
1. Values of persistency are measured values without correction for suspended solids.
2. + represents mixed liquor samples containing digester supernatant from run No.5.
3. o represents all other data
4. ——— regression line for all samples of mixed liquor. (+ and o)
5. — — —regression line for samples of mixed liquor represented by o.



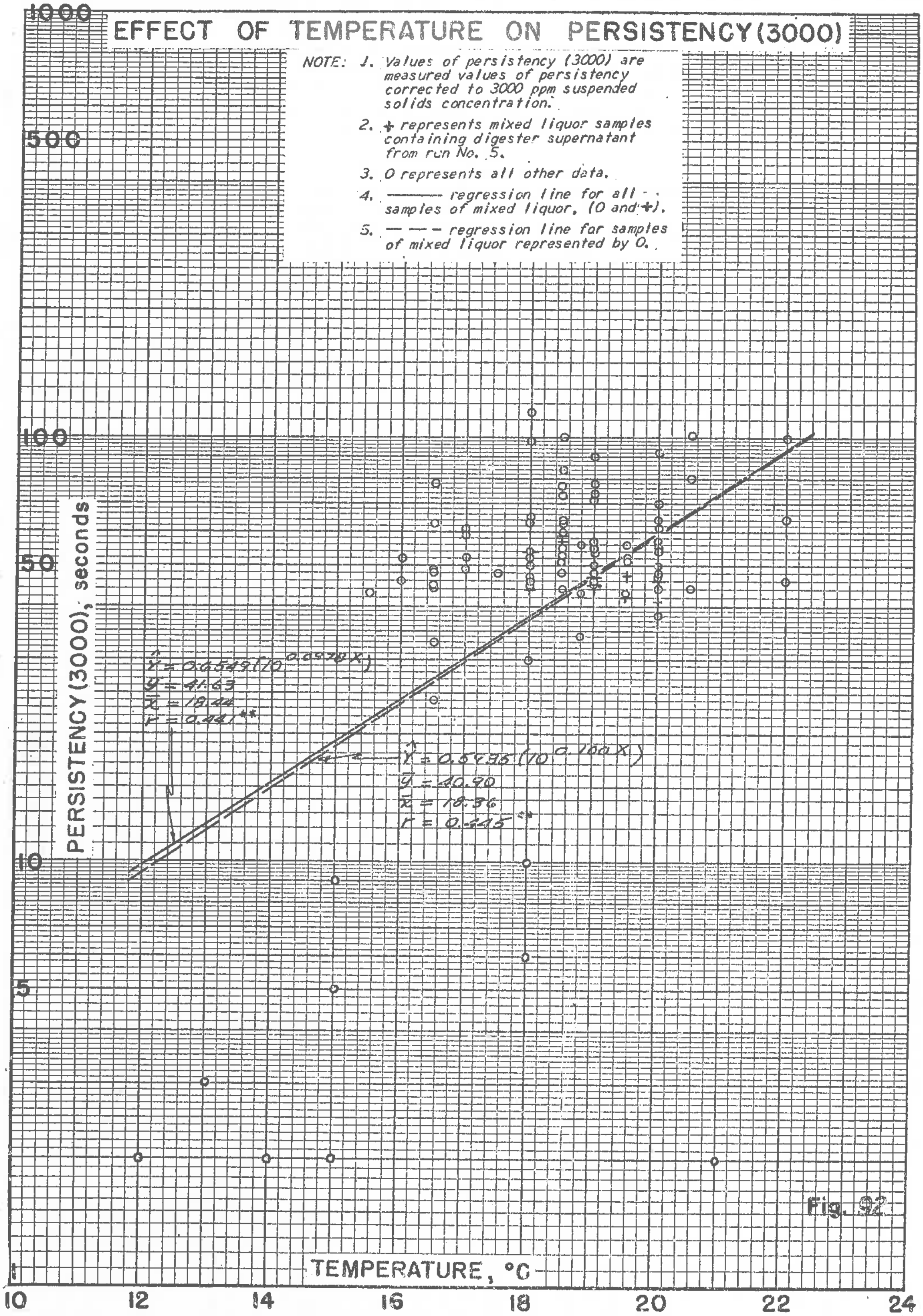
EFFECT OF TEMPERATURE ON PERSISTENCY (3000)

NOTE:
1. Values of persistency (3000) are measured values of persistency corrected to 3000 ppm suspended solids
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. o represents all other data.
4. ——regression line for all other samples of mixed liquor (+ and o)
5. — —regression line for samples of mixed liquor represented by o.

$\hat{Y} = -40.58 + 4.98X$
$\bar{y} = 51.23$
$\bar{x} = 18.44$
$r = 0.391$ **

$\hat{Y} = -45.75 + 5.304X$
$\bar{y} = 51.65$
$\bar{x} = 18.36$
$r = 0.412$ **

Fig. 91



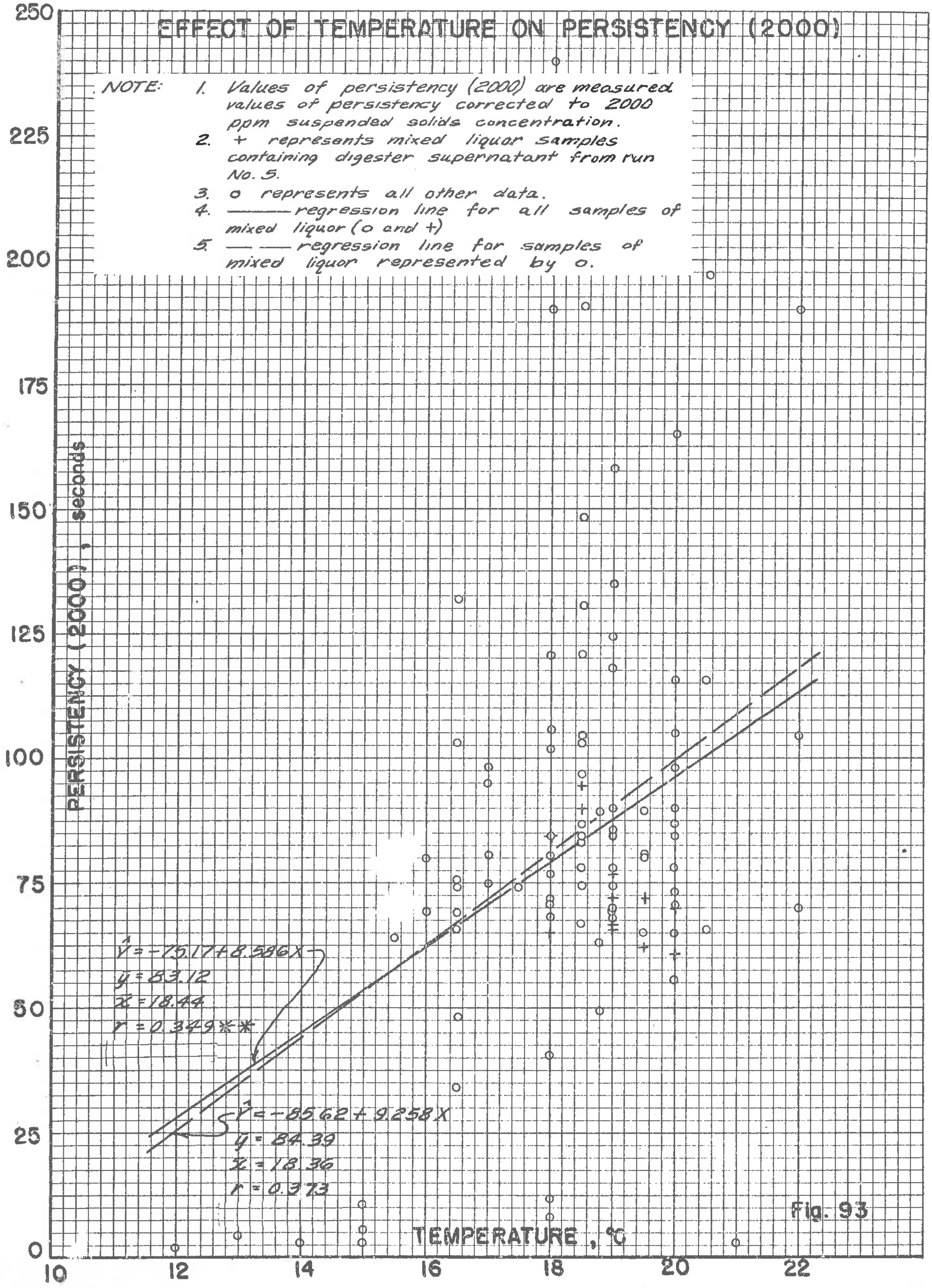
EFFECT OF TEMPERATURE ON PERSISTENCY(3000)

NOTE:
1. Values of persistency (3000) are measured values of persistency corrected to 3000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. O represents all other data.
4. ——— regression line for all samples of mixed liquor, (O and +).
5. — — — regression line for samples of mixed liquor represented by O.

$\hat{Y} = 0.6549(10^{0.0978X})$
$\bar{y} = 41.63$
$\bar{x} = 19.44$
$r = 0.441^{**}$

$\hat{Y} = 0.5935(10^{0.100X})$
$\bar{y} = 40.90$
$\bar{x} = 18.36$
$r = 0.445^{**}$

Fig. 92

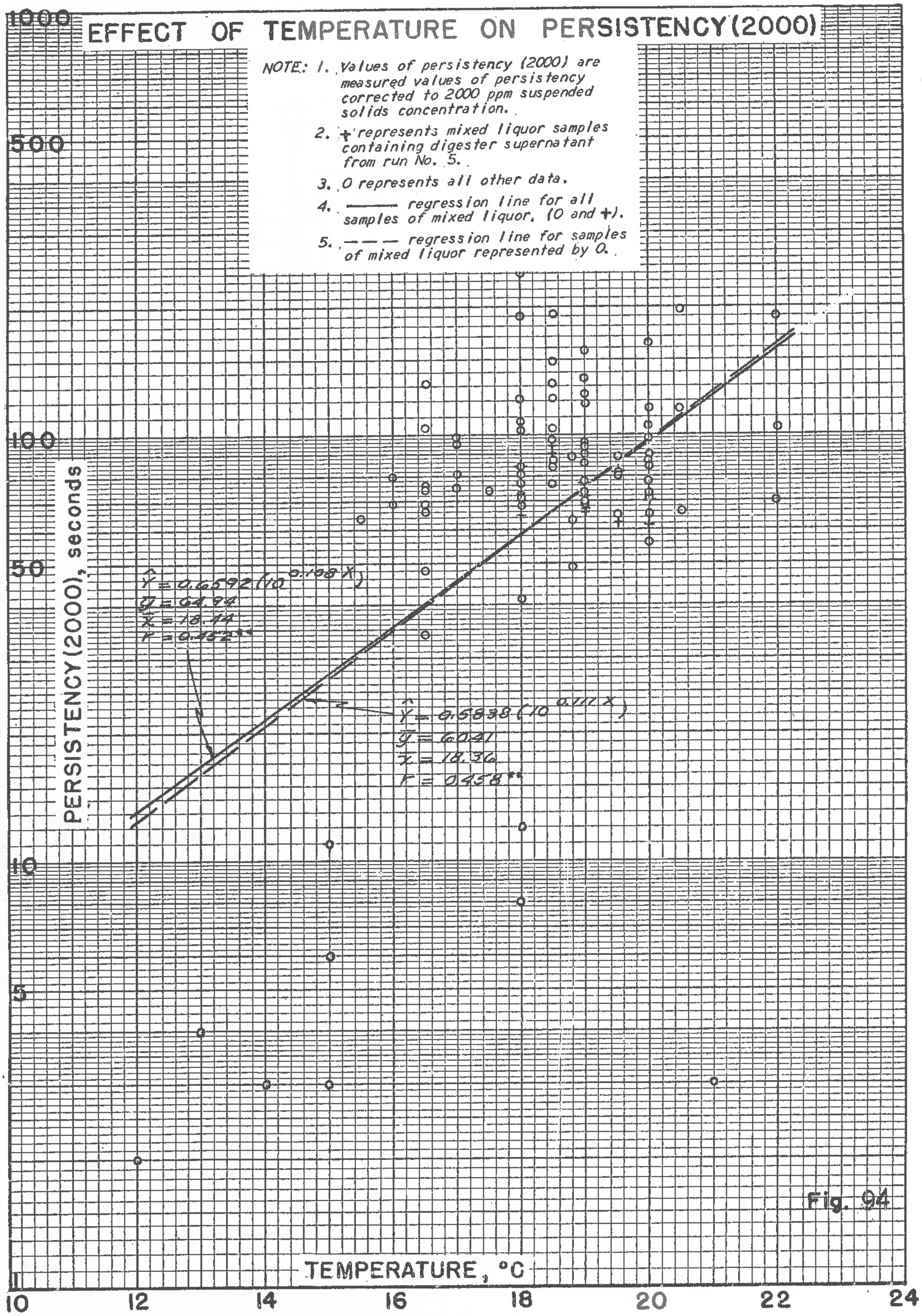


NOTE:
1. Values of persistency (2000) are measured values of persistency corrected to 2000 ppm suspended solids concentration.
2. + represents mixed liquor samples containing digester supernatant from run No. 5.
3. o represents all other data.
4. ——— regression line for all samples of mixed liquor (o and +)
5. — — regression line for samples of mixed liquor represented by o.

$\hat{Y} = -75.17 + 8.586X$
$\bar{y} = 83.12$
$\bar{x} = 18.44$
$r = 0.349^{**}$

$\hat{Y} = -85.62 + 9.258X$
$\bar{y} = 84.39$
$\bar{x} = 18.36$
$r = 0.373$

Fig. 93



EFFECT OF TEMPERATURE ON PERSISTENCY(2000)

NOTE: 1. Values of persistency (2000) are measured values of persistency corrected to 2000 ppm suspended solids concentration.

2. + represents mixed liquor samples containing digester supernatant from run No. 5.

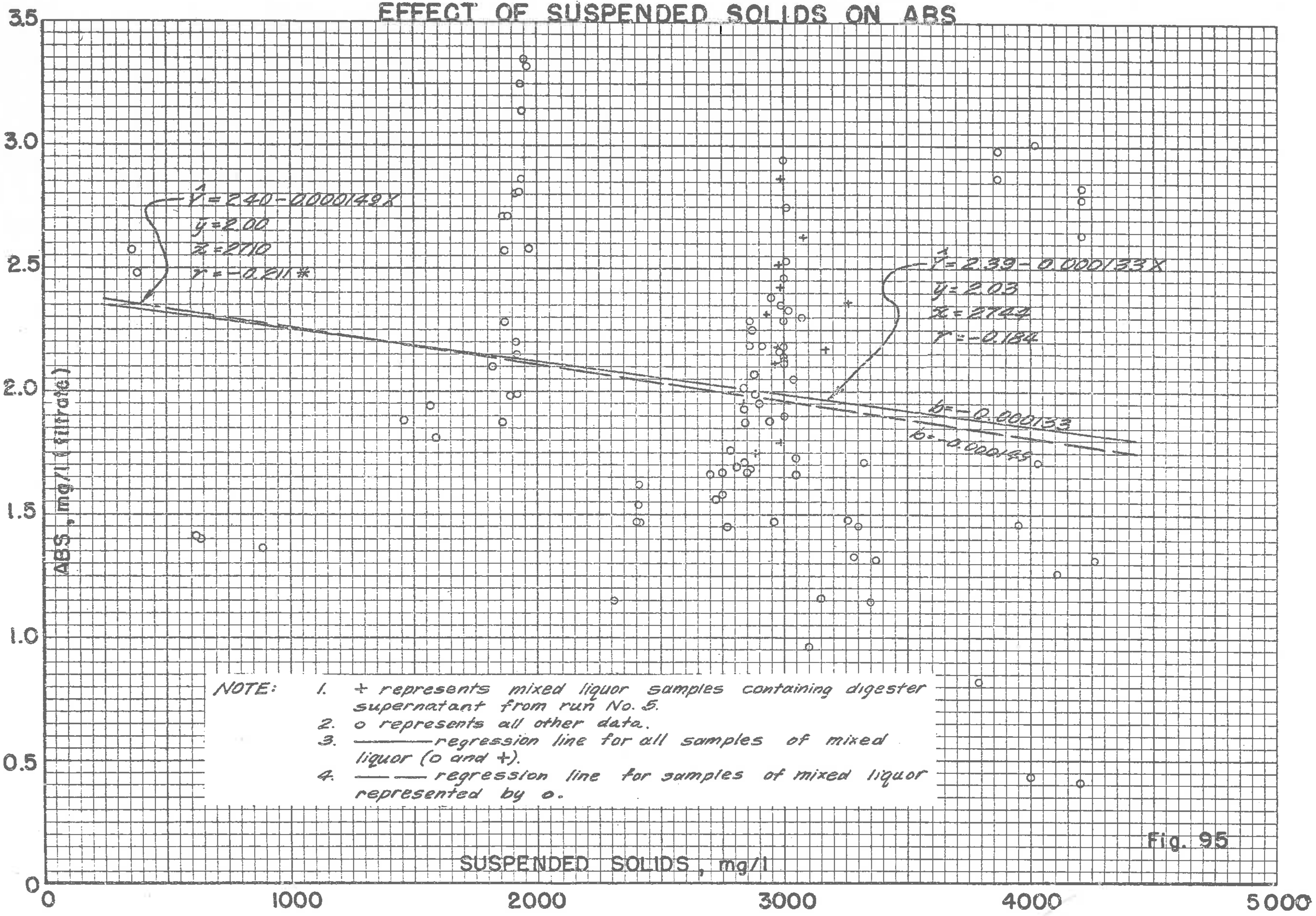
3. O represents all other data.

4. ——— regression line for all samples of mixed liquor. (O and +).

5. — — — regression line for samples of mixed liquor represented by O.

Fig. 94

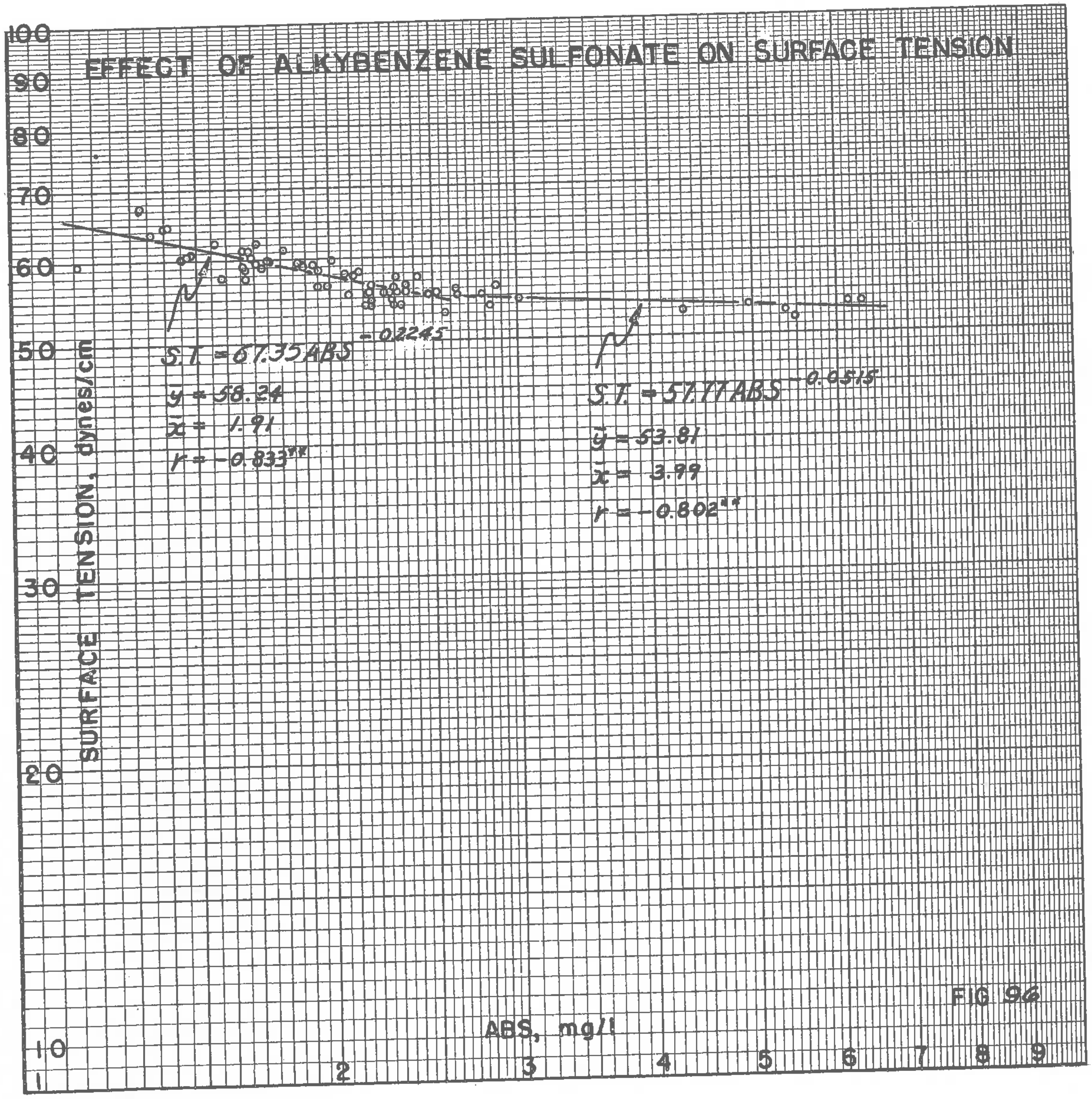
EFFECT OF SUSPENDED SOLIDS ON ABS



NOTE:

1. + represents mixed liquor samples containing digester supernatant from run No. 5.
2. o represents all other data.
3. ———— regression line for all samples of mixed liquor (o and +).
4. —— —— regression line for samples of mixed liquor represented by o.

Fig. 95



EFFECT OF ALKYBENZENE SULFONATE ON SURFACE TENSION

FIG 94

TABLE XXIII

SUMMARY TABLE OF MULTIPLE CORRELATIONS

Multiple Correlation	Item	Dependent Variable	No. of Variables m	No. of Observations n	$\bar{R}^2_{1,2\text{--}n}$	X_1 ABS	X_2 Ammonia Nitrogen	X_3 Organic Nitrogen	X_4 pH	X_5 BOD	X_6 Electrode Potential	X_7 Temperature	X_8 Suspended Solids
A	I	Persistency	9	104	0.597	0.515**	0.026	−0.001	0.264**	−0.188	−0.323**	0.413**	−0.037
	II			$\hat{y}_1$ = −559		+ 29.2 X_1	− 0.549 X_2	− 0.0408 X_3	+ 61.9 X_4	− 0.146 X_5	− 0.169 X_6	+ 8.39 X_7	− 0.00157 X_8
	III					4.97	0.208	2.22	23.13	0.0779	0.0507	1.90	0.00431
B	I	Persistency	9	92	0.633	0.459**	0.181	0.003	0.295**	−0.074	−0.133	0.412**	−0.117
	II			$\hat{y}_1$ = −643.		+ 25.4 X_1	+ 0.901 X_2	+ 0.0819 X_3	+ 67.4 X_4	− 0.0640 X_5	− 0.0746 X_6	+ 8.01 X_7	− 0.00488 X_8
	III					5.39	0.535	2.40	23.9	0.0940	0.0606	1.94	0.00452
C	I	Log Persistency	9	104	0.613	0.380**	0.104	−0.002	0.108	−0.277**	−0.512**	0.500**	−0.005
	II			Log $\hat{y}_3$ = −1.624		+ 0.184 X_1	+ 0.00196 X_2	− 0.000497 X_3	+ 0.228 X_4	− 0.00202 X_5	− 0.00272 X_6	+ 0.0986 X_7	− 0.00000213 X_8
	III					0.0459	0.00192	0.0205	0.213	0.000718	0.000468	0.0175	0.0000398
D	I	Log Persistency	9	92	0.788	0.265*	0.665**	−0.026	0.216*	−0.037	−0.222*	0.572**	−0.228*
	II			Log $\hat{y}_3$ = −3.320		+ 0.0972 X_1	+ 0.0313 X_2	− 0.00422 X_3	+ 0.349 X_4	− 0.000232 X_5	− 0.000909 X_6	+ 0.0888 X_7	− 0.0000695 X_8
	III					0.0388	0.00385	0.0173	0.172	0.000677	0.000437	0.0140	0.0000325
E	I	Σ	9	104	0.540	0.551**	−0.139	−0.003	0.129	−0.053	−0.393**	0.103	0.245*
	II			$\hat{y}_2$ = − 18.5		+ 3.45 X_1	− 0.0306 X_2	− 0.00789 X_3	+ 3.17 X_4	− 0.00435 X_5	− 0.0277 X_6	+ 0.206 X_7	+ 0.00114 X_8
	III					0.535	0.0223	0.239	2.49	0.00837	0.0054	0.204	0.000463
F	I	Σ	9	92	0.670	0.506**	0.460**	0.000	0.201	0.121	−0.112	0.074	0.138
	II			$\hat{y}_2$ = − 33.8		+ 2.70 X_1	+ 0.237 X_2	− 0.00002 X_3	+ 4.20 X_4	+ 0.00984 X_5	− 0.00584 X_6	+ 0.124 X_7	+ 0.000539 X_8
	III					0.505	0.0502	0.225	2.25	0.00882	0.00569	0.182	0.000424
G	I	Persistency (3000)	8	104	0.442	0.324**	0.099	−0.103	−0.134	−0.242*	−0.425**	0.470**	
	II			$\hat{y}_4$ = 87.2		+ 10.9 X_1	+ 0.124 X_2	− 1.54 X_3	− 16.5 X_4	− 0.129 X_5	− 0.153 X_6	+ 5.86 X_7	
	III					3.23	0.127	1.50	12.5	0.0529	0.0333	1.12	
H	I	Persistency (3000)	8	92	0.575	0.258*	0.486**	−0.099	0.005	−0.088	−0.137	0.429**	
	II			$\hat{y}_4$ = − 84.1		+ 7.75 X_1	+ 1.56 X_2	− 1.35 X_3	+ 0.632 X_4	− 0.0470 X_5	− 0.0476 X_6	+ 4.68 X_7	
	III					3.16	0.306	1.48	12.3	0.0579	0.0376	1.07	
I	I	Σ (3000)	8	104	0.410	0.338**	0.169	−0.001	−0.282**	−0.081	−0.403**	0.177	
	II			$\hat{y}_5$ = 60.2		+ 2.24 X_1	+ 0.0419 X_2	− 0.0035 X_3	− 0.708 X_4	− 0.00835 X_5	− 0.0282 X_6	+ 0.389 X_7	
	III					0.635	0.0249	0.2955	0.245	0.0104	0.00654	0.221	
J	I	Σ (3000)	8	92	0.597	0.276*	0.585**	0.019	−0.153	0.092	−0.067	0.061	
	II			$\hat{y}_5$ = 21.6		+ 1.52 X_1	+ 0.371 X_2	+ 0.0490 X_3	− 3.20 X_4	+ 0.00902 X_5	− 0.00428 X_6	+ 0.112 X_7	
	III					0.579	0.056	0.272	2.25	0.0106	0.00689	0.197	
K	I	Persistency	9	94	0.589	0.529**	−0.362**	0.158	0.195	−0.185	−0.099	0.167	−0.250*
	II			$\hat{y}_1$ = − 381		+ 29.0 X_1	− 0.794 X_2	+ 4.27 X_3	+ 47.0 X_4	− 0.141 X_5	− 0.0577 X_6	+ 5.41 X_7	− 0.0146 X_8
	III					5.03	0.221	2.88	25.6	0.0811	0.0627	3.46	0.00614
L	I	Persistency	9	82	0.597	0.508**	−0.092	0.223	0.169	−0.209	−0.046	0.152	−0.296**
	II			$\hat{y}_1$ = − 339		+ 30.7 X_1	− 1.07 X_2	+ 7.72 X_3	+ 42.3 X_4	− 0.211 X_5	− 0.0291 X_6	+ 4.94 X_7	− 0.0174 X_8
	III					6.09	1.35	3.94	28.8	0.115	0.0723	3.75	0.00656
M	I	Σ	9	94	0.462	0.577**	−0.400**	−0.014	0.194	0.084	−0.099	−0.165	0.139
	II			$\hat{y}_2$ = − 11.8		+ 2.79 X_1	− 0.0759 X_2	− 0.0322 X_3	+ 3.99 X_4	+ 0.00543 X_5	− 0.00493 X_6	− 0.456 X_7	+ 0.000678 X_8
	III					0.429	0.0188	0.245	2.18	0.00690	0.00534	0.295	0.000522
N	I	Σ	9	82	0.436	0.518**	0.047	−0.001	0.213	0.072	−0.010	−0.188	0.096
	II			$\hat{y}_2$ = − 18.3		+ 2.62 X_1	+ 0.0454 X_2	− 0.00337 X_3	+ 4.47 X_4	+ 0.00596 X_5	− 0.000524 X_6	− 0.510 X_7	+ 0.000451 X_8
	III					0.505	0.112	0.327	2.39	0.00955	0.00600	0.311	0.000544

NOTE: Item I is $r_{12.3\text{---}n}$ Partial Correlation Coefficient
II is Multiple Regression Equation
III is $s_{b12.3\text{---}n}$ Standard Error of the Partial Regression coefficient for each multiple correlation A, B, C etc.
104 Observations includes all samples of mixed liquor
94 Observations includes all samples of mixed liquor excepting samples from sewage treatment plant survey
92 Observations includes all samples of mixed liquor excepting samples containing digester supernatant from run No. 5
82 Observations includes all samples of mixed liquor excepting samples from sewage treatment plant survey and samples containing digester supernatant from run No. 5

No. of variables m	No. of observations n	Degrees of Freedom n-m	Highly Significant at 99% confidence level if r exceeds **	Significant at 95% confidence level if r exceeds *
9	104	95	0.260	0.200
9	94	85	0.275	0.211
9	92	83	0.278	0.213
9	82	73	0.296	0.227
8	104	96	0.259	0.199
8	92	84	0.277	0.212