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# A study of the effect of pigmentation on the film properties of ethocel : Part II. a study of the effect of sun light on the color of pigments.

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# PART I

# A STUDY OF THE EFFECT OF PIGMENTATION ON THE FILM PROPERTIES OF ETHOCEL

# PART II

# A STUDY OF THE EFFECT OF SUN LIGHT ON THE COLOR OF PIGMENTS

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PART I

A Study of the Effect of Pigmentation on the Film Properties of Ethocel

PART II

A Study of the Effect of Sun light on the color of Pigments

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Approved by the Examining Committee.

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# PART I

# A STUDY OF THE EFFECT OF PIGMENTATION ON THE FILM PROPERTIES OF ETHOCEL

## ABSTRACT

The purpose of this investigation was to determine quantitatively the effect of pigmentation on the film properties of ethocel lacquer. This study was confined to the determination of tensile strength, percentage elongation at failure, softening and melting points of the films. Pigments were ground in the ethocel lacquer containing three parts ethocel, one part 276V-9 Dow resin and sixteen parts of solvent by weight.

Softening and melting points of the films were determined and were found to increase uniformly with increasing amounts of the pigments.

The tensile strength of ethocel film with titanium dioxide as a pigment increased from 317 $Kgm/Cm^2$ to 425 $Kgm/Cm^2$ by adding 2 percent followed by a decrease. Similar but less marked results were observed with lithopone, barytes and dicalite.

# INTRODUCTION

A considerable amount of work has been reported on the effect of pigmentation of films obtained from vehicles containing oil and resin combinations. Some data have been reported on the film properties of pigmented cellulose nitrate (3), but it is only recently that the importance of studying the film properties of pigmented ethocel was realized. This lack of interest in ethocel can be traced to the relatively recent appearance of this material commercially. It is today competing with nitro cellulose in the manufacture of lacquers. Until very recently ethocel has been selling at a price higher than that of nitro-cellulose. The properties were considered similar to nitro-cellulose, but recent studies have shown that it offered greater advantages than nitro-cellulose in having a greater resistence to ultra-violet rays, greater flexibility and toughness (4). When these facts were brought to light, a great deal of effort was made to manufacture ethyl-cellulose at a price comparable with nitro-cellulose. With its increasingly greater application it became more and more important that the film properties of pigmented ethocel be studied.

Little work has been reported on the pigmented film properties of ethocel, especially on those properties which have a direct bearing on the lacquer containing ethyl cellulose. Hence, it was considered that more information on the effect of inorganic fillers and pigments on the ethocel film properties would be desirable. This was of special interest since it might be of great advantage to

raise the melting point of a lacquer film without affecting the other properties. An increase in the softening point of such films would open new fields for the application of ethocel. It could be used for protection or for insulation of those parts of electrical instruments which experience temperature rise during operation. Again, if an increase in tensile strength of ethocel film could be achieved, it would be of considerable importance to the lacquer industry and the wrapping film industry.

There were indications from certain past work that the presence of these fillers in small amounts might accomplish that purpose but no quantitative work has been reported on the subject.

The general aspects of this problem included the desire to determine what effect the pigmentation of lacquers have on film properties. It had always been assumed and realized that pigmentation did decrease flexibility and tensile strength but it had never been confirmed as far as the available literature on the subject is concerned.

# HISTORICAL

Ethocel is a relatively new product which is today competing with nitro-cellulose in the manufacture of lacquers. It has the advantage of greater flexibility, greater toughness and has greater resistance to ultra-violet light (3). Ethocel is being put on the market by American manufacturers at a much lower cost than in 1937. At the same time, these manufacturers have been carrying on extensive research for the development of better and cheaper methods of making ethocel, and a great deal of research is being conducted to investigate the properties of ethocel.

Little quantitative work has been reported on the study of the effect of pigmentation on lacquers. However, there is some indirect evidence which leads one to expect that the properties of lacquers films could be modified by the addition of pigments.

It has been pointed out (2) that the application of colloid chemical techniques to the study of high polymers has shown that they consist of mixtures of molecules of different size or degree of polymerization, so that the large molecules of cellulose derivatives for instance, yield stronger, and shorter molecules yield weaker films. However if a small amount of low molecular weight material is added to a much larger quantity of high molecular weight material an increase in film strength is observed. This is believed to be the result of filling up the gaps between the large molecules by the smaller molecules. In 1946, Dunn and Baier

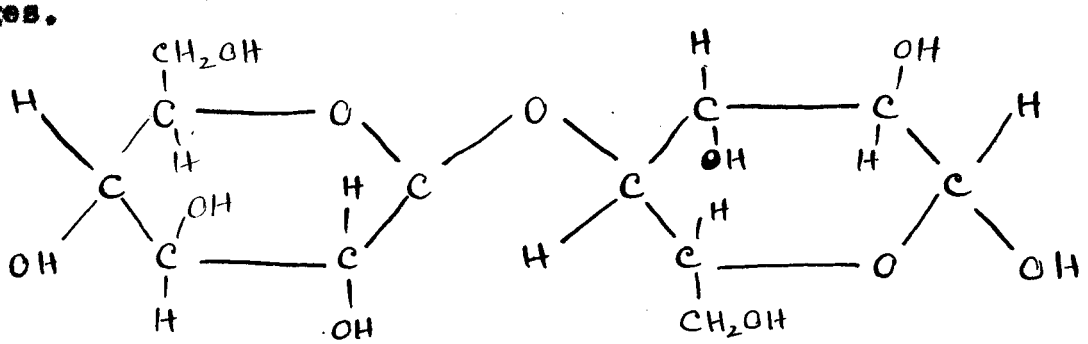
after a long experimental study presented some data which showed that the tensile strength of paint films (linseed oil as vehicle) was increased by the addition of titanium dixoide. Some such effect was also obtained with other inorganic pigments to a lesser degree.

# THEORETICAL

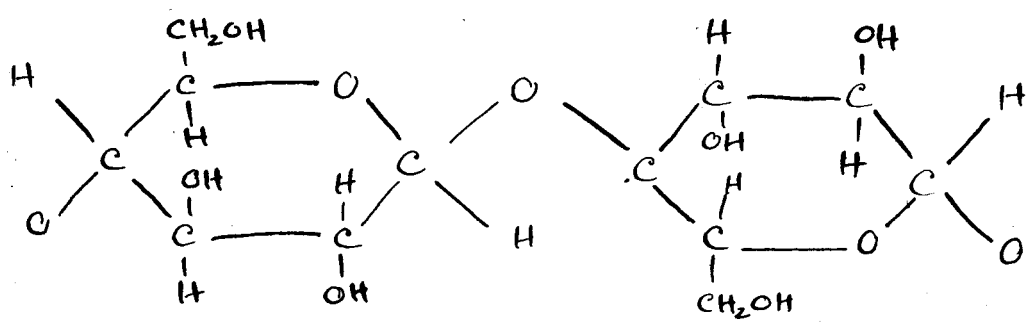
To explain and to account for the behaviour of certain pigments when admixed with a lacquer containing ethocel, it will be advisable to study the structure and physical properties of the constituents. The constituents under consideration are ethocel, a resin, toluene and ethanol as solvent and diluent constituting the lacquer; and titanium dioxide, barytes, lithopone, dicalite, santocel, celite, or china clay as the pigmenting agents. None of these pigments mentioned have any appreciable chemical reactivity with the lacquer constituents; hence chemical properties will not be considered.

Cellulose:

A cellulose molecule consists of a long chain of cellobiose units joined together by means of B-Glucosidic linkages.



Cellobiose

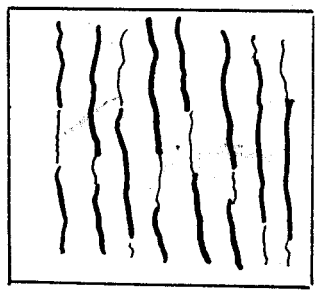


Cellulose

The terminal groups of the cellulose molecules are hydroxyl groups (-OH), there being four hydroxyl groups in the end residue (21).

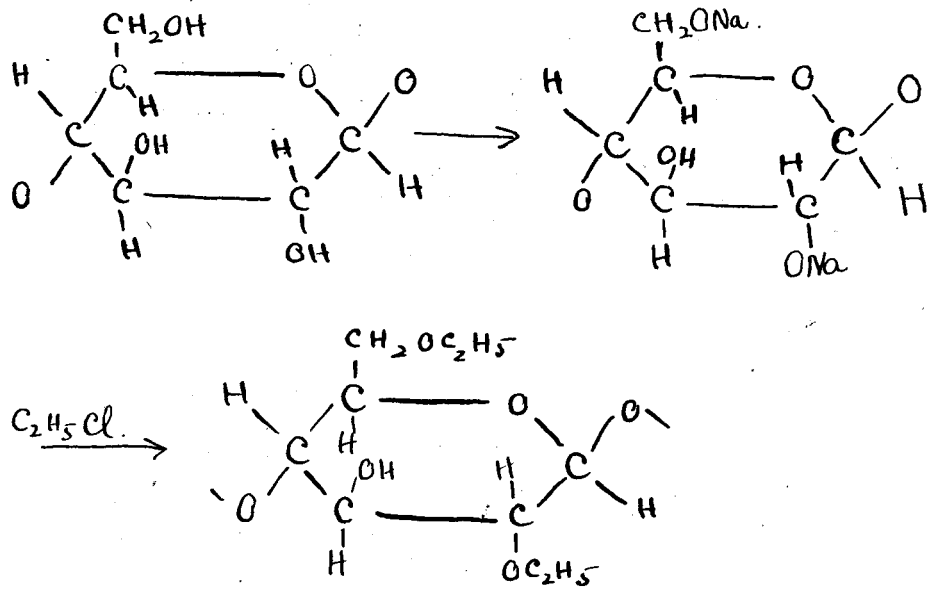
The molecular weight of cellulose has been determined by various methods and is found to vary with different methods used, ranging from 30,000 to 450,000.

By X-Ray studies, it has been found that cellulose chains or at least some parts of them exist in an oriented parallel, crystalline system, shown in the figure by darker lines, with amorphous divisions interspersed along the molecular chain.



Cellulose Micelles (19)

Ethyl-cellulose is an ether of cellulose. Its manufacture consists of converting cellulose into alkali cellulose by treatment with strong aqueous solutions of sodium hydroxide. This alkali cellulose is alkylated with such reagents as ethyl chloride or ethyl sulphate (6). The formation of diethyl cellulose may be indicated as follows:



There may be one, two, or three ethoxy groups per glucose unit. The percentage simply represents the average number of substituents groups per glucose unit.

To avoid degeneration of the cellulose and the alkylating agent, the alkylation is accomplished with very careful temperature control. When the reaction is completed, the reagent and the by-products are separated by washing and by distillation. By repeated washings with water, the purification of ethocel is finally completed.

Certain physical properties of ethyl cellulose depend upon the degree of alkylation, as for example, solubility. A product having 27 percent ethoxy content is soluble in water, alchol and acid, but, as the percentage of ethoxyl increases above 27 percent, thw water solubility decreases and the solubility in organic solvents including drying oils increases(21).

The tensile strength of the degraded fiberous products like ethyl cellulose is much lower than that of natural cellulose film. The tensile strength here depends upon the secondary valence forces.

In the rupture of this short chained, less oriented structure, the slippage of the chains past one another is of primary importance. The degree of orientation, the chain length, the chemical nature of the chain and the presence or absence of any plasticizing agent (including moisture) are all effective in the determination of the secondary valence force which will be exhibited. These intermolecular attractive forces in turn determine the ease with which constituent chains will slip past one another. Under such conditions the tensile strength of these degraded fibers is somewhat lower than that of native cellulose.

The tensile strength and elongation of ethocel films are directly related to the intrinsic viscosity of the material used. These properties are higher and the toughness and flexibility of the films are greater with the higher viscosity types of ethocel . There is an improvement in the film strength and flexibility with increased intrinsic viscosity of the cellulosic material (22).

The effect of the inclusion of resins is to give ethocel lacquers hardness, adhesion, and gloss. The hard resins increase these properties to the greatest extent. Ethocel and the resin used require solvents which will

dissolve each of them, so that they may form a lacquer suitable for spraying or brushing.

The solvents used in the lacquer industry have a wide range of boiling points and evaporation rates. The evaporation rate greatly affects the final condition of the film. A fast evaporating solvent may cause small pits or holes and these imperfections will cause low flexibility by uneven distribution of stresses.

The softening and melting points of ethocel films or any lacquer film can be determined with a certain amount of accuracy on a "Denis Shelton" (10) melting point bar. This apparatus consists of a solid copper rectanguler bar about sixteen inches long. The bar is heated at one end by means of an electric heating element so that there is a gradient in temperature along the bar. Details of this apparatus are discussed later on.

The softening point of a film is that temperature at which the film becomes appreciably plastic.(22) The melting point of a film is the temperature at which the film begins to stick to the bar. The softening and melting point of ethocel are dependent to some extent upon the Ethoxy content of the cellulose molecule. It has been found that the greater the number of Ethoxyl groups attached to the cellulose molecule, the lower are the softening and melting points. This can be seen from the softening and melting point curves of figure 1 (22).

A plasticizer added to ethocel, lowers the softening and melting points, but the variation of softening and melting points with ethoxy content follows a similar trend as in figure 1. Such an effect is shown by the curves in figure 2 (22). The resins usually employed in the lacquer industry have a melting point range of from 0 degree centigrade to 150 degrees centigrade. They can be used to vary the character of the films.

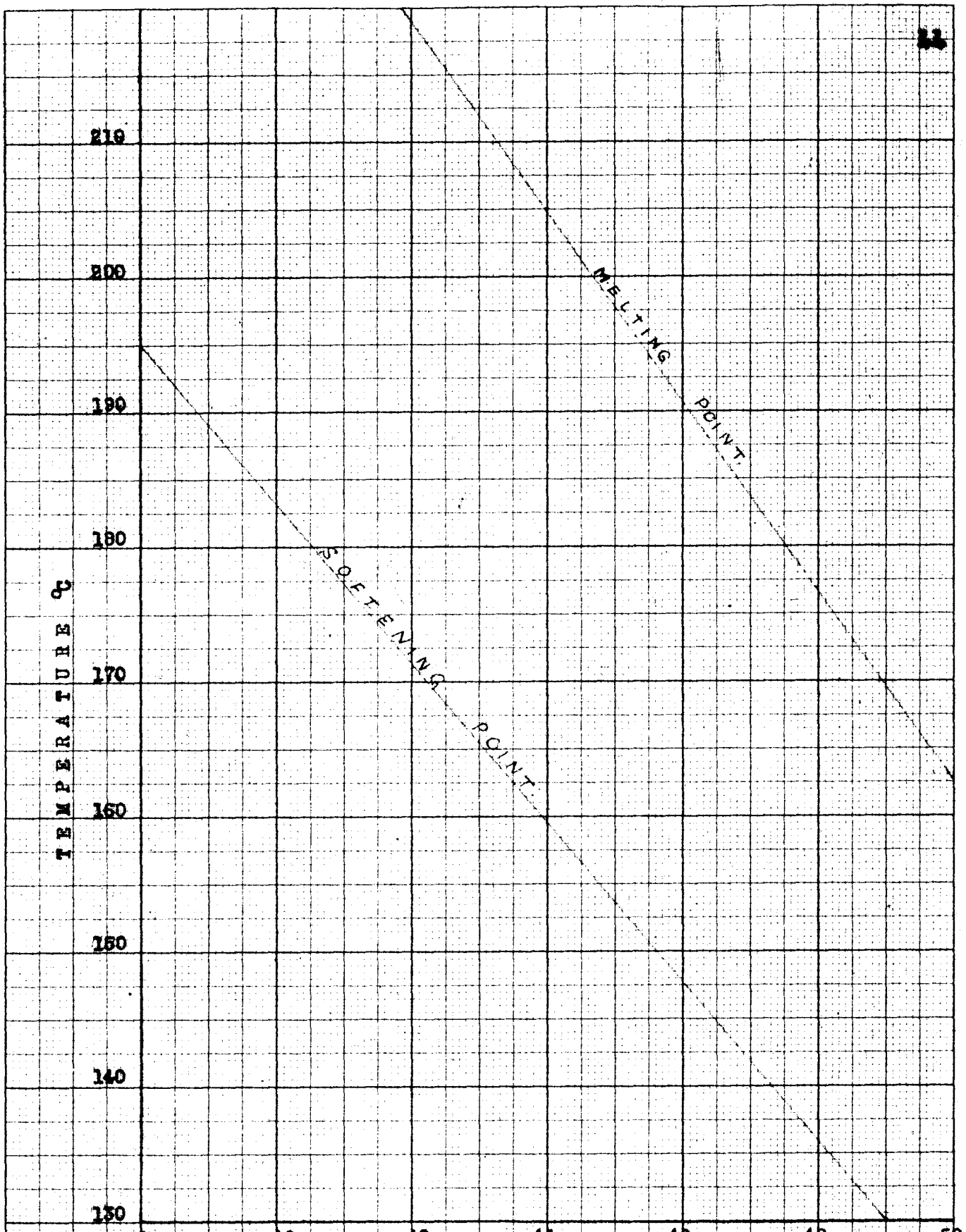



Fig. 1. Variation of Melting Point of Ethocel Films with Ethoxy-Content

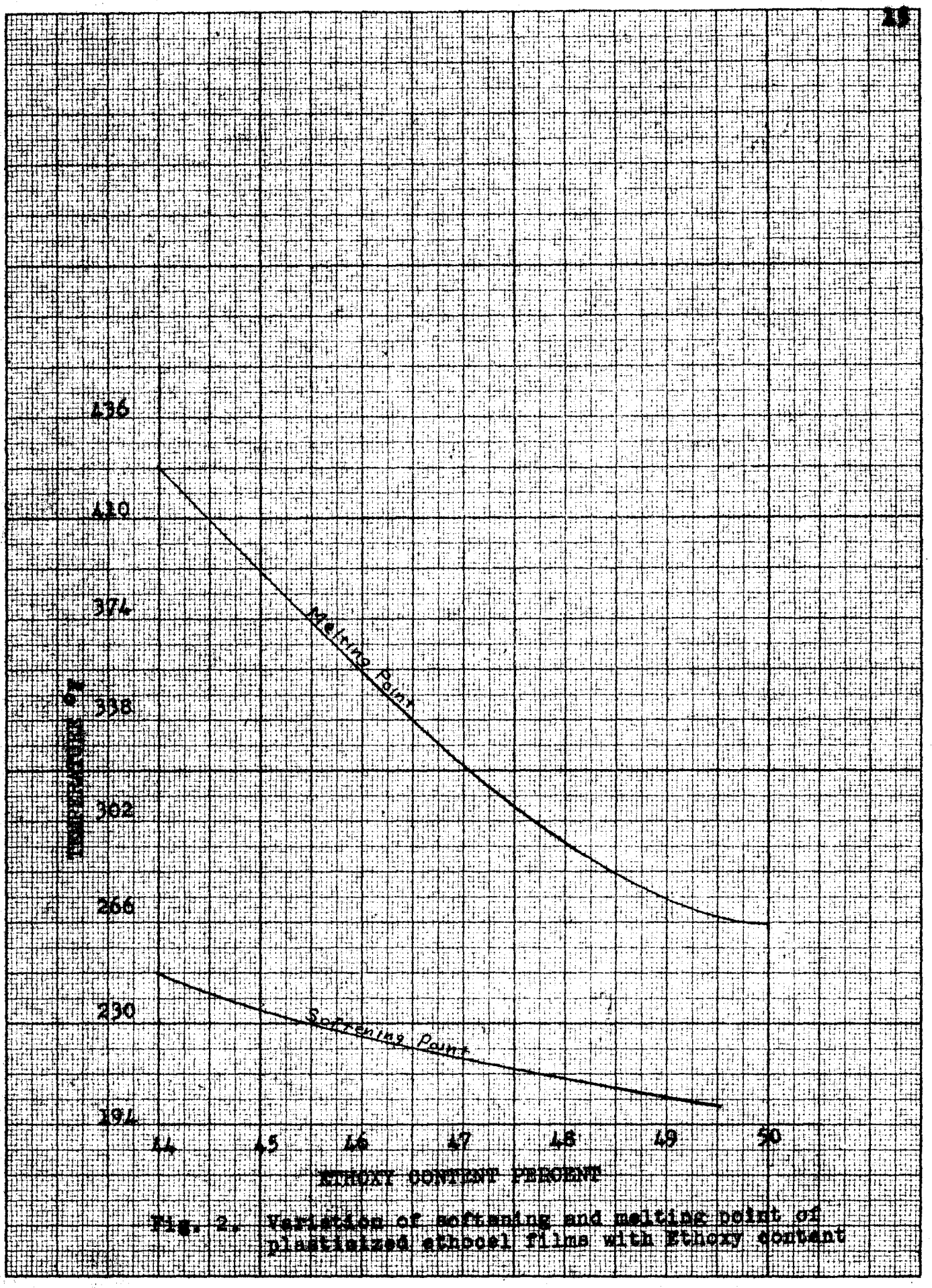



Fig. 2. Variation of softening and melting point of plasticized ethocel films with Ethoxy content

Ethocel has been found to be compatible with a great variety of natural and synthetic resins. It is completely compatible with pure phenolics, modified phenolics, rosin, rosin esters, and toluene sulfonamide formaldehyde. The solvent used for determining the compatibility data is 80:20 toluene-ethanol solution since this solvent produces low solution viscosity and, in general, high strength of deposited ethocel film. Alcohol has the property of reducing the viscosity of the solution. The resin may increase the hardness of the film so that the tensile strength increases and flexibility decreases. Yet some other resin may affect the hardness very slightly but may not decrease the flexibility at all, and finally the resin may work like a plasticizer as shown by the curves in figure 3 (22). The first class of resins is classified as hard resins, second as medium, and the last as soft resins. Resins producing results lying between these classes are also available so that any desired condition can be obtained.

Lacquers differ from oleoresinous paints and enamels in this respect, that pigments are incorporated to give the desired color to the lacquer. An average paint can contain six or eight pounds of pigment per gallon, but such a large amount, if used in a lacquer, will yield a product of low durability and poor adhesion (23). The high volatile content of lacquers as compared with oleoresinous

material shows that there is less binder to hold the pigment particles together. Thus the pigments used in lacquers are somewhat different from those used in other types of finishing materials. In general pigments of low oil absorption, high hiding power, and greater strength give the best results. Both pigment volume concentrations and specific surface of the pigments are important. A decrease in the particle size of pigments is accompanied by an increase in viscosity (15).

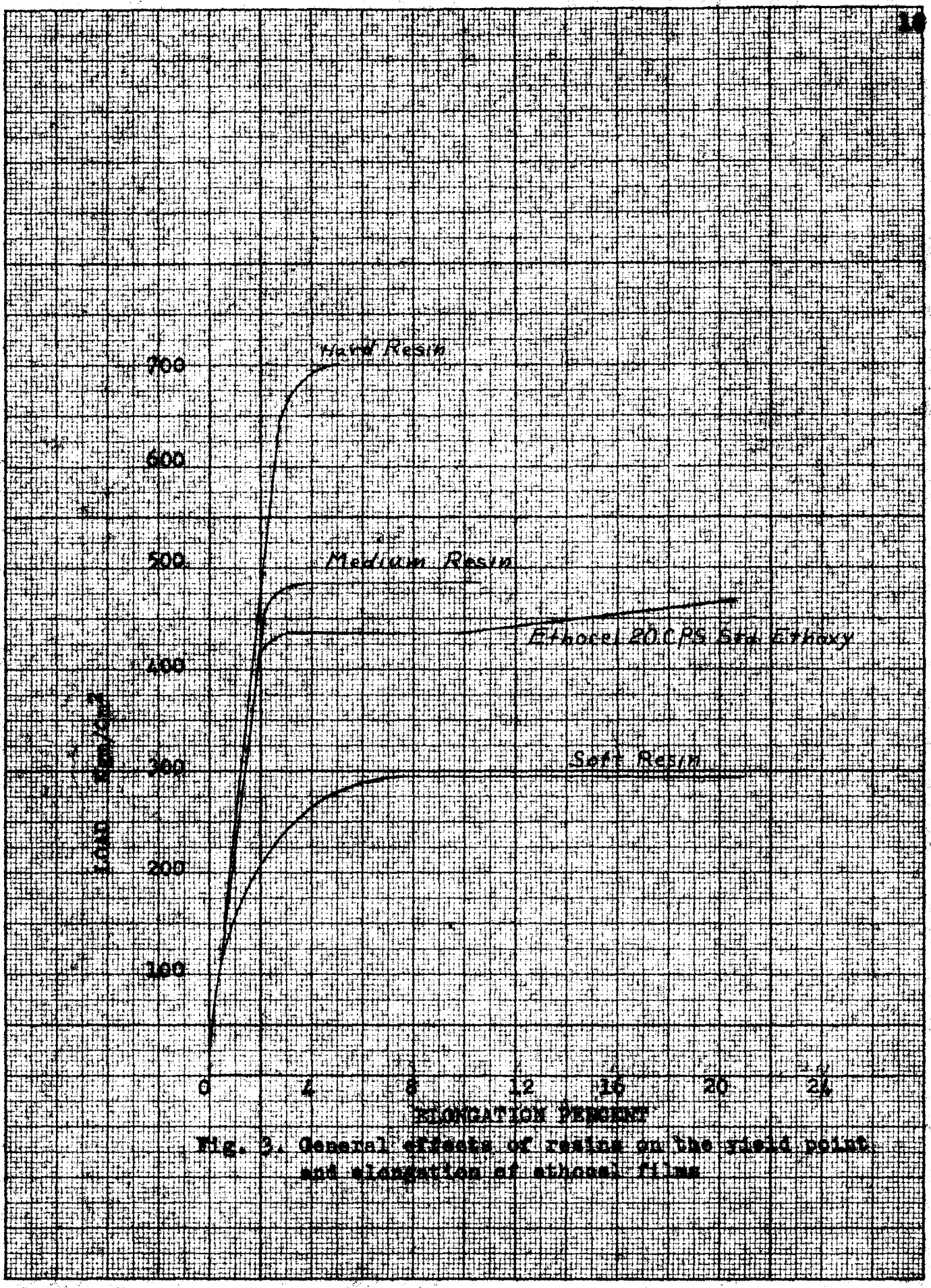



Fig. 3. General effects of resins on the yield point and elongation of ethocel films

Particle shape is another factor that affects the physical properties of a pigment. Few commercial pigments are uniformly spherical, and many are platelike or acicular (20). Following is given an account of the characteristics and behavior of the various pigments used in this study. The most important pigment is titanium dioxide pigment. The most outstanding property of titanium dioxide is its extreme opacity, which is much higher than that of any other white pigment. It has a specific gravity of 3.9, and an average mean particle size diameter of 0.3 microns. It is nonreactive with virtually all types of vehicles or media in which white pigments are used.

In small proportions, it has been found to improve elasticity, continuity and gloss of cellulose nitrate films produced (16).

Barytes ($BaSO_4$) is one of the heaviest pigments known. It has small amounts of CuSO and $Fe_2O_3$ as impurities. Its specific gravity is 4.476 and its average particle size is 2 to 5 microns. It has no covering power, very low oil absorption, and a relatively low bulking value. It is inert to the varnish or paint constituents usually employed.

Lithopone ($BaSO_4 ZnS$) is transparent and has an extremely low tinting strength; hence it makes an excellent base for both colored and white pigments. It is stable towards alkalies and acids. It has a high specific gravity,

low bulking power, and low oil absorption.

China clay ($Al_2O_3 2SiO_2 2H_2O$) is a white powder of lamellar shaped particles of extremely fine, and soft texture. It has a specific gravity of 2.6 and particle size varying from 2 to 10 microns. As indicated by its specific gravity, china clay is a very bulky material; however its covering power in oil or varnish vehicle is poor. Its oil absorption varies considerably and is dependent to a great extent on particle size. It is quite permanent to light and not affected by either acids or alkalis.

Santocel is a light weight, finely divided, porous form of silica produced chemically from silica aerogel. Silica Aerogel differs from the conventional silica gel principally in the availability of its surface and its dry bulk density. It is not hygroscopic, the liquid phase having been removed without otherwise altering the structure of the aerogel. Air replaces the liquid removed giving a structure much like that of uncompressed sponge.

Santocel is made of sub-ultramicroscopic fibers of silica having a diameter of about 25 to 35 angstroms spaced about 300 angstroms apart and arranged similarly to fibers of cotton in cotton batting. The air volume within the particle is about 94 percent. The true specific gravity of santocel incorporated in a vehicle is the same as any other form of silica, namely 2.2. The specific surface of santocel is high, being on the order of 600

square meters per gram, and the surface is somewhat active. This huge surface combined with the porosity accounts for the high oil absorption which cannot be measured by conventional means. The refractive index is equal to 1.464.

Bentonite is a clay containing for the most part "montmorillonite." The montmorillonite clay molecule has two silicon-oxygen sheets with one aluminum oxygen sheet sandwiched between them. Because of this peculiar molecular structure and fineness of particles, bentonite clay goes into a colloidal suspension in water without the use of any physical means. However it should be noted that bentonite clay particles become energized only when wetted. Bentonite analysis shows the presence of small impurities of iron, magnesia, lime, soda and potash.

Dicalite material has been known by many names, among which infusarial earth, keisalguhr, diatomite, diatomaceous earth, and diatomaceous silica are best known. Diatomaceous silica has been preferred as the most truly descriptive and more nearly the correct technical and chemical designation. Dicalite weighs only 19.6 pounds per cubic foot. Surface area is extremely large, ranging from 3,000 to 5,000 square feet per pound. Absortiveness is high. It is chemically inert, physically it is amorphous in character, soft and friable. It is heat resistent and has a high infra red reflectance, but it produces a dead flat finish with no angular sheen.

Instead of being approximately spherical or otherwise fairly uniform in shape, the microscopic particles of Diatomaceous silica are more likely to be long and slender, "boat shaped," "flaky," or "discoid."

# EXPERIMENTAL

DENIS MELTING POINT APPARATUS

This instrument was designed for determining the melting point of a great variety of materials at any temperature from 25 to 200 degree centigrade. It conformed in principle to the apparatus originally proposed by Dr. L.M. Denis of Cornell University.

The heated stage of the Denis apparatus consisted of a bar of copper, one inch square and 17 inches long, heated by an electric cartridge inserted into one end. The temperature of any point along the top surface of this bar was determined by touching it with a chisel pointed element of heavy constantan wire. The thermocouple developed at the point of contact between these two dissimilar metals created an e.m.f. which was proportional to the temperature at that point. This e.m.f. could be measured by a potentiometer circuit. As the bar was heated at one end only there was a thermal gradient along its surface so that a wide range of temperature could be obtained. If the lacquer film was laid on the bar, a portion would melt, and the rest would consist of partly hard party softened material. The line of demarcation between the softened and the melted film constituted the melting point of the film (10).

SCOTT TENSILE-TESTER

Scott-Tensile Tester consisted of a vertical steel rod about one inch in diameter supported on a heavy base.

On top of this rod was a clamp carrying a shaft through it having a movable segmental scale attached to it. The scale was divided into two parts, one part ranging from 0 to two pounds. This was to be used for weak films while the other scale ranged from 0.0 to 10.0 pounds and was to be used for stronger films. A 10 pound weight was attached behind the scale. The scale had a "catch" which with the help of a ratchet and pawl arrangement let the scale move in front of a fixed pointer in one direction only.

Attached to the same shaft that carried this scale was a pulley arrangement on which was balanced a weight on one side and a clamp on the other which was used for holding one end of the film. Below this clamp there was another similar clamp attached to a gear and"clutch" arrangement, so that it could be moved up and down freely if necessary. This clamp was connected to the pulley in such a way that it moved down with a certain desired speed on connecting it to the motor by the help of the clutch.

As the lower clamp moved down, it pulled the upper clamp by way of the film and thus the segmental scale tilted pushing the 10 pound weight upward exerting a uniformly increasing weight. A vertical scale in millimeters was provided next to the film so that the elongation could be measured. As soon as the film broke, the segmental scale would stop moving, and the reading in pounds could be read directly.

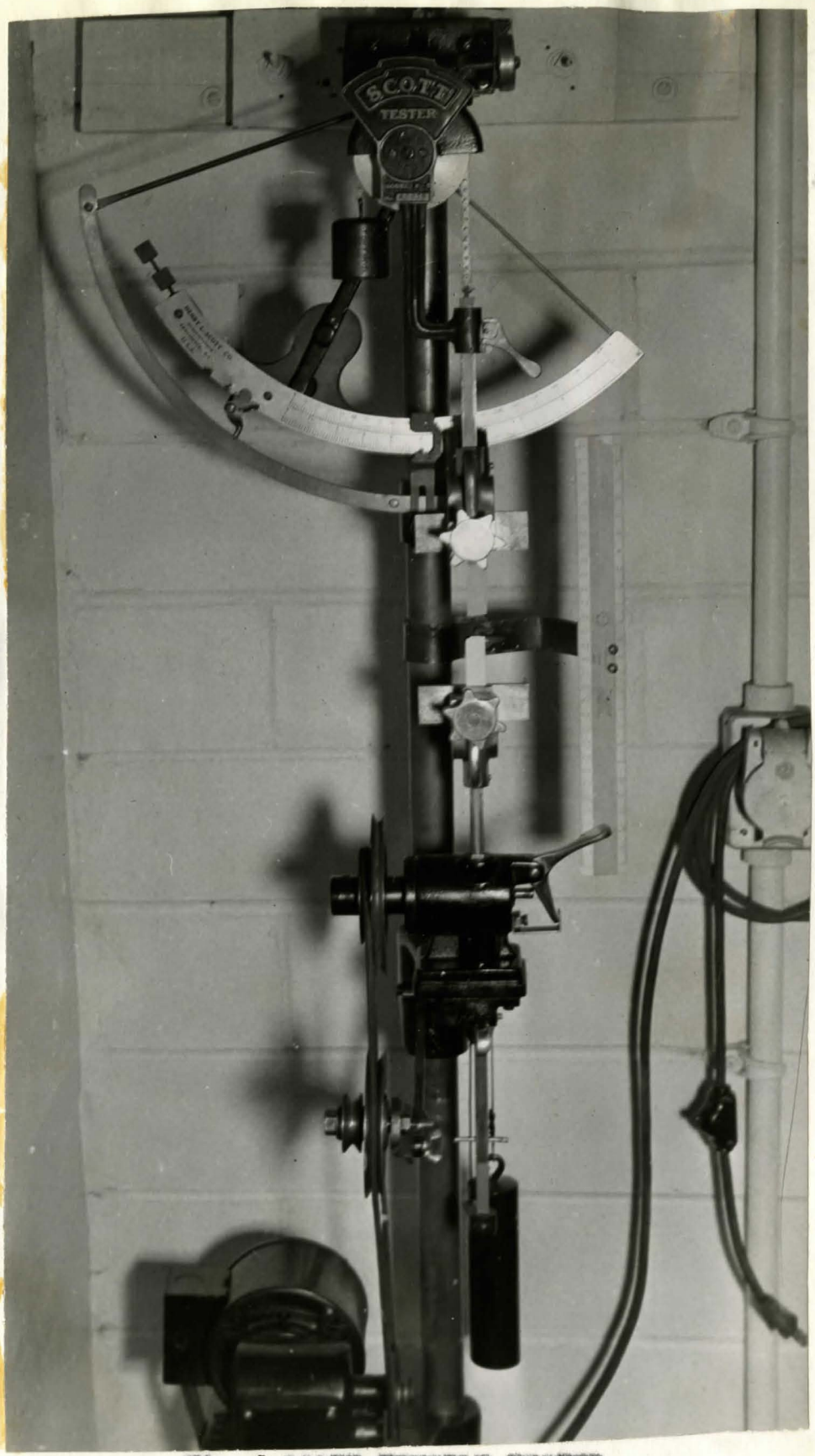



Fig. 3 SCOTT TENSILE TESTER

MATERIALS USED

| | | |
|---|---|---|
| Ethyl alcohol..... | Specific gravity | 0.798 |
| | Boiling point | 80°C |
| Toluene..... | Specific gravity | 0.865 |
| | Boiling point | 110°C |
| Resin ..... | 276 - V9 Dow Resin | |
| Sodium dichromate ..... | Commercial | |
| Ethocel - (Dow) ..... | Standard | |
| | Ethoxy content 48.5%-49.5% | |
| | Solubility--free of haze and granularity in a 20% solution in 80:20 Tol-Ethanol | |
| | Stability--more than 90% retentention of original viscosity after 16 hours heating in a closed vessel at 120°C | |
| Moisture content ..... | less then 2.0% | |
| Ash content ..... | less than 0.15% | |
| Chlorides (as Nacl)..... | less then 0.05% | |
| Physical form ..... | free-flowing white granules | |

PIGMENTS

1. Santocel - No. 45 Monsanto Chemical Co.
2. Bentonite clay No. 290 American Colloid Co.
3. China clay

PIGMENTS (cont'd)

4. Celite 165 S or 110 Johns Manville Co.
5. Dicalite "L" grade, Dicalite Company
6. Barytes, Kentucky Color and Chemical Co.
7. Lithopone
8. Titanox

Solvent Composition

Ethanol ..... 20% by volume

Toluene ..... 80% by volume

The experimental study consisted of two parts: First, the determination of the softening and melting points and second the determination of tensile strength and percent elongation at the breaking point of ethocel films containing pigments.

It was decided that lacquers would be prepared containing 75/25. Ethocel 276-V9 Resin in 80/20 toluene/ethanol. The above mentioned fillers or pigments were to be ground or ball milled into these lacquers in the ratios indicated below: 1.0%, 3.0%, 5.0%, 20.0%, 50.0% pigment.

These lacquers were to be cast to give a film of approximately two mils dry thickness. The film was to be air dried for at least two hours and then dried at 70 degrees centigrade for two hours. After conditioning at 50% relative humidity at 70-75 degrees F for at least twenty four hours it was to be cut into testing strips and the following data

were to be obtained:

1. Softening point and melting point.
2. Percent elongation at breaking point.
3. Tensile strength in kilograms per square cm.

The softening and melting points would be determined by means of a melting point bar. Percent elongation and tensile strength should be determined by a Scott Tensile Tester.

The first step was to prepare a test sample of the lacquer which could be cast into a film of two mils dry thickness. The caster or the doctor blade could be manipulated to lay a wet film from 1.0 mils to 50 mils thickness. The films were laid on 12 by 6 inch glass plates, having a uniform surface. Before the films were laid, the glass plates were soaked in a chromic acid solution, washed thoroughly with warm water and dried under cover, so that no dust particles could get on the surface of the plates. Usually, plates were left overnight so that complete dryness could be insured. Films were then cast over the plates with the lacquers prepared.

The lacquers were prepared in a glass bottle of 500 ml. capacity, and enough solvent was added to dissolve the solids so that there was no need to heat the lacquer. Shaking or rolling the bottle on the mixing rolls achieved this purpose. The whole mass was allowed to rest until all the air bubbles had escaped.

By repeated trials, it was found that 4.0 gms of solvent per gm. of solids was a little over the minimum amount of solvent that would give a smooth and evenly moving lacquer under the film caster. The dry thickness of the film could not be predicted from the wet thickness hence a number of films were laid with wet thickness varying from 10 to 25 mils. Films were allowed to dry on the glass plates for two hours at room temperature under cover, removed from the glass plates, and conditioned for twenty four hours at a 50 2% relative humidity and a temperature of 70 ± 3 degrees F.

The films deposited were about 11.0 cm wide and 0.002 0.0005 inches thick. At least four strips were cut from each film with a razor blade using a rectangular template 0.5 inches wide. The test strips were clamped in a Scott Tensile Tester so that the length of the film between the jaws was 3.90 inches. With the 5 Kgm weight on the load arm, the lower jaw was pulled downward uniformly at the rate of 25.4 m.m. per minute. As the film was pulled down, it lifted the weight on the load arm, an ever increasing load being applied. The elongation was read direct from a scale graduated in millimeters. The weight in pounds at the yield point was read from the scale and tensile strength computed in Kgm/sq.cm. The thickness of the film was measured at various places, and it was believed that the film would yield at the point of least thickness.

After the test sample had been subjected to the Scott Tester the thickness at the yield point was again measured by a "Randall-Stickney" measuring gauge, and the thickness checked with the previous value noted. These two values usually differed slightly. The thickness after the test was usually less than the original thickness due to an elongation of the film. However sometimes, contrary to all expectations, the film thickness at the yield point was found greater than the minimum thickness observed previously. This condition might be the result of some inherent defect of the film, causing a weakness at that spot. Such samples were discarded. At least four readings were taken to determine the Tensile Strength and the yield point of the film. Most of the time the readings did not agree because of the error in the Scott-Tensile Tester, which has been estimated by some workers to be from 5.0 - 10.0 percent.

Softening and melting points of the films were determined on the "Dennis-Shelton" melting point bar as described preficusly. The film was laid down in the middle of the hot bar. After thirty seconds one end of the film lying over the cooler side of the bar was lifted and pulled upwards, until either the whole of the film came off the bar or a part stuck to the bar, and part broke off. The temperature of the bar at the point where the film broke was measured immediately by means of a thermocouple on a sliding arm,

as described before and gave the melting point of the film. The temperature at the point where the film became plastic and started to adhere slightly to the bar was also measured as the softening point of the film. Four readings were taken for each film and a mean value was recorded.

The experiment was conducted at room temperature. The softening point could not be measured accurately as no specific indication of the plasticity of the film could be observed. The film would not become plastic at any one spot; the softening extended over an area of about four square cm. The boundary line could not be observed clearly; hence the softening point was determined approximably and was taken at a point where the film seemed to become plastic as well as adhered slightly to the bar.

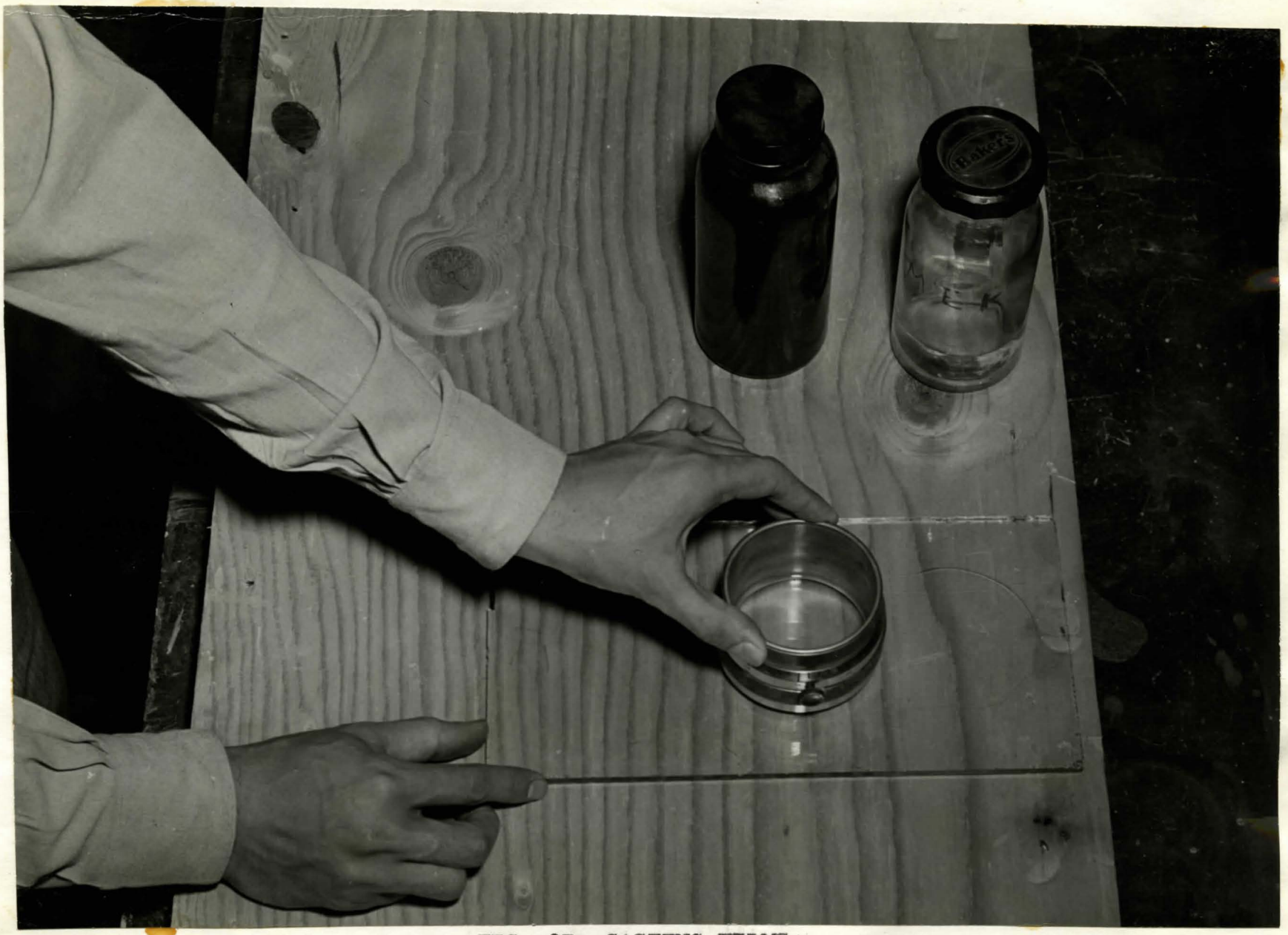


FIG. 3B CASTING FILMS

INCORPORATION OF THE PIGMENTS

The pigment was weighed according to the percentage required and was put into a bottle of 250 ml. capacity, specially selected because of its thick walls which would withstand the pounding and grinding action of the steel balls. A fixed number of steel balls of different sizes was put in with the lacquer and the bottle was put on mixing rolls.

This milling and grinding was carried out for twenty-four hours and the lacquer was cast on clean glass plates with the Dow film caster. Here again the difficulty arose that there was no relation between the dry film thickness and the wet film thickness, hence the wet film thickness had to be attempted a few times before the required film was made. However, after working with these films for sometime, facility was acquired, so that a satisfactory wet thickness of the film could be predicted to get a film of two mils dry thickness. But because of the difference in specific gravity, oil absorption, and bulking values of the different materials, use of this forecasting technique was not without its failures. The rate at which the casting blade was moved had to be standardized because it was observed that the thickness of the film was inversely proportional to the speed with which the doctor blade was moved on the glass plate. This was especially true when the amount of lacquer used was less than ¼ inch deep in the Dow Caster cup. Hence, a certain speed was hit upon and all the films

were laid at that speed. The wet films were allowed to dry for two hours, removed from the glass plates and dried in air for an hour. Removing the films from the glass plates was found to be difficult and required special care and techn nique; however, it was finally accomplished. Covering the films with a warm damp cloth greatly facilitated the removal of films. These films were then suspended in a small electric oven maintained at a temperature of 70 ± 3 degrees C. The films always became plastic and deformed; therefore, the oven drying procedure had to be changed. After some experimentation it was observed that if the temperature was slowly raised for two hours, this deformation of films caused by premature softening could be avoided. In all the determinations, the above procedure of drying was followed. These dired films were then placed in a constant humidity chamber and kept at a temperature and relative humidity of 70 ± 3 degrees F and 50 percent respectively. Films were conditioned in this chamber for twenty-four hours, then removed and cut into strips one half inch wide by the help of a sharp razor blade and a steel template. Tensile strength, percent elongation, softening point and melting point were then determined as described before. To insure that the distribution of the pigment was uniform in the lacquer, all films were examined under a microscope, and any samples with an uneven pigment distribution were discarded.

In some cases(santocel) it was observed that the

amount of pigment exceeded the limit, and agglomeration of the pigment took place in the film. These films could not be used for experimentation, and no results could be obtained for such films.

# DISCUSSION OF RESULTS

The results obtained are presented in table I. Only the maximum tensile strength, highest softening and melting points and the maximum percent elongation are presented.

TABLE I PHYSICAL PROPERTIES OF PIGMENTS

| PIGMENT | FILM STRENGTH Kgm/cm² | PERCENT PIGMENT | SOFTENING POINT OF | PERCENT PIGMENT |
|---|---|---|---|---|
| Ethocel | 317 | 0.0 | 77.0 | 0 |
| Titanox | 425 | 1.0 | 92.0 | 2.0 |
| Lithopone | 350 | 3.0 | 91.0 | 20.0 |
| Barytes | 328 | 3.0 | 83.0 | 10.0 |
| Celite | 313 | 1.0 | 108.0 | 50.0 |
| Dicalite | 368 | 5.0 | 93.0 | 50.0 |
| Santocel | 299 | 3.0 | 83.0 | 10.0 |
| Bentonite | 309 | 1.0 | 98.0 | 50.0 |
| China clay | 313 | 2.0 | ---- | ---- |

| PIGMENT | MELTING POINT | PERCENT PIGMENT | PERCENT ELONGATION | PERCENT PIGMENT |
|---|---|---|---|---|
| Ethocel | 92.0 | 0 0 | 5.9 | 0 0 |
| Titanox | 104.0 | 3.0 | 9.0 | 5.0 |
| Lithopone | 105.0 | 50.0 | 6.25 | 3.0 |
| Barytes | 101.5 | 10.0 | 8.19 | 1.0 |
| Celite | 132.0 | 50.0 | 6.25 | 2.0 |
| Dicalite | 121.0 | 50.0 | 6.88 | 5.0 |
| Santocel | 102.0 | 3.0 | 5.20 | 3.0 |
| Bentonite | 115.0 | 50.0 | 6.25 | 3.0 |

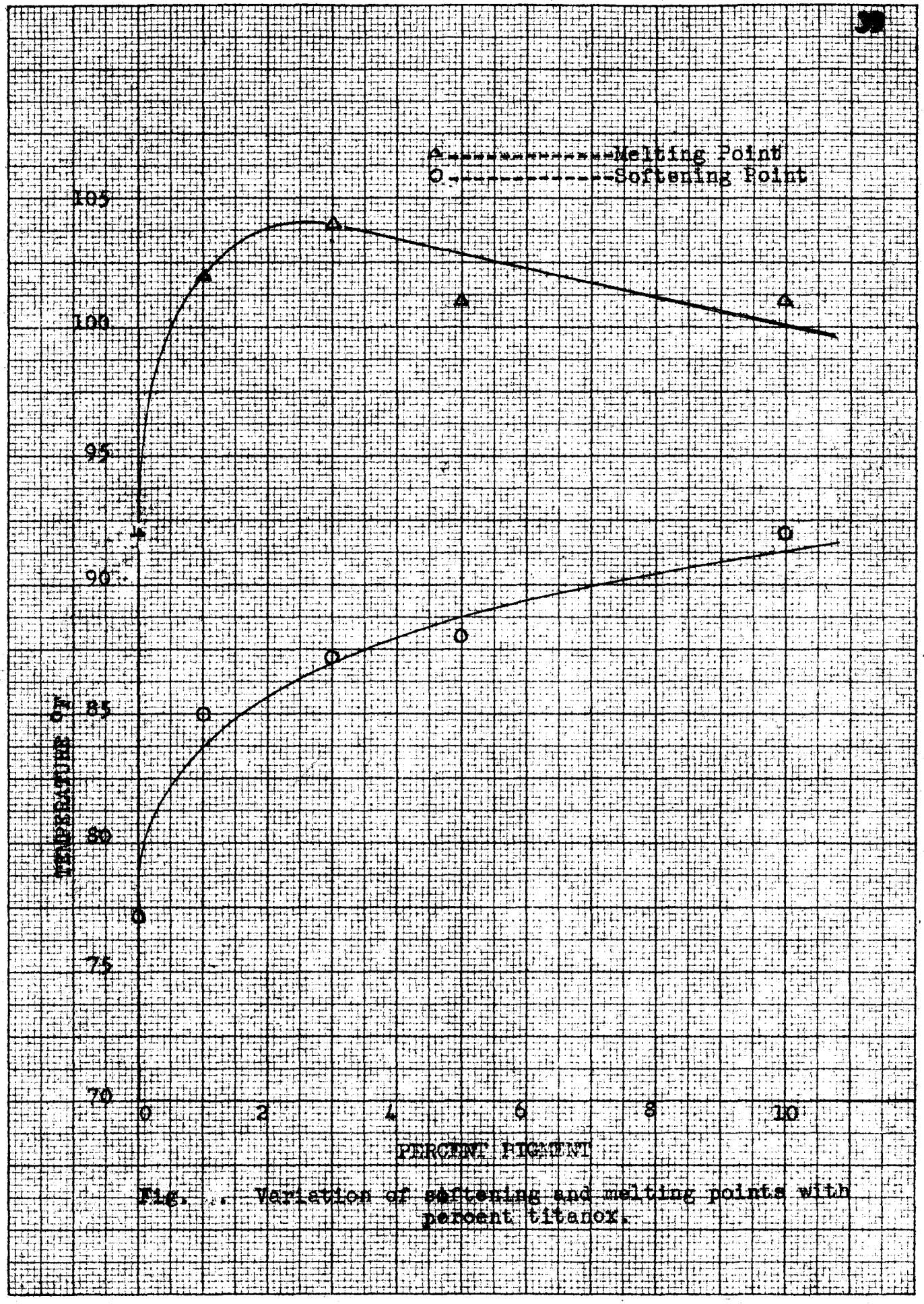



Fig. ... Variation of softening and melting points with percent titanox.

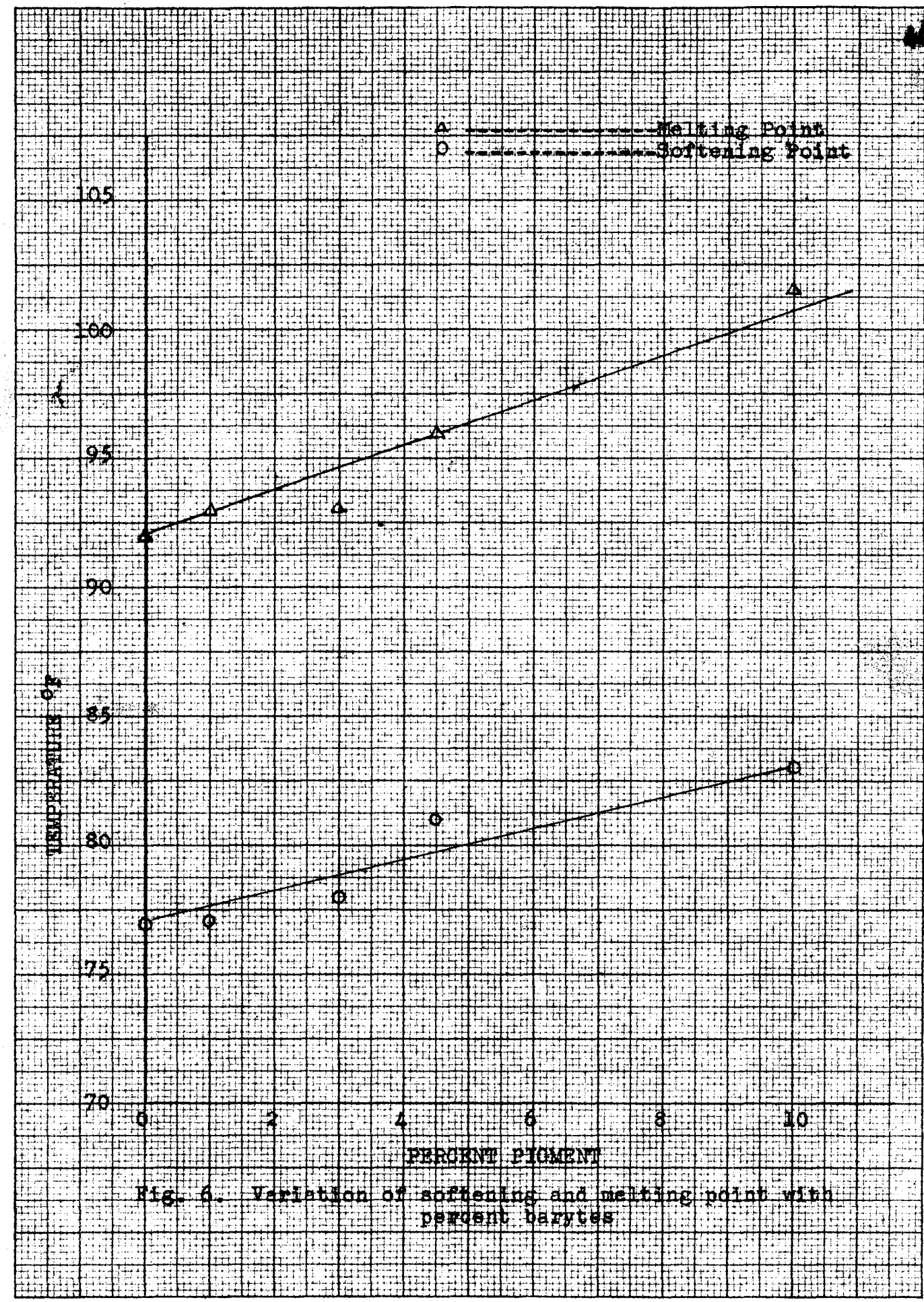



Fig. 6. Variation of softening and melting point with percent barytes

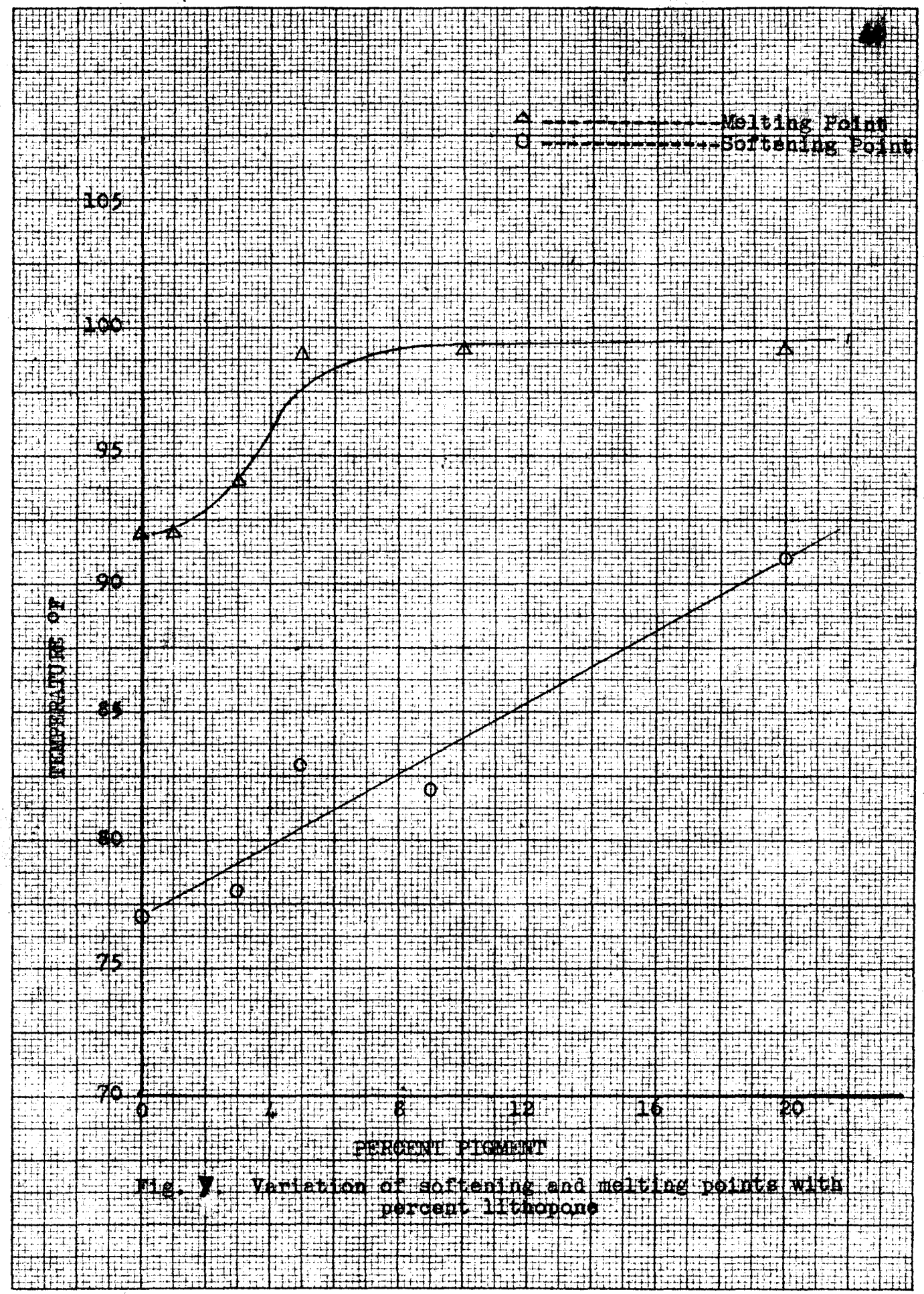



Fig. 7. Variation of softening and melting points with percent lithopone

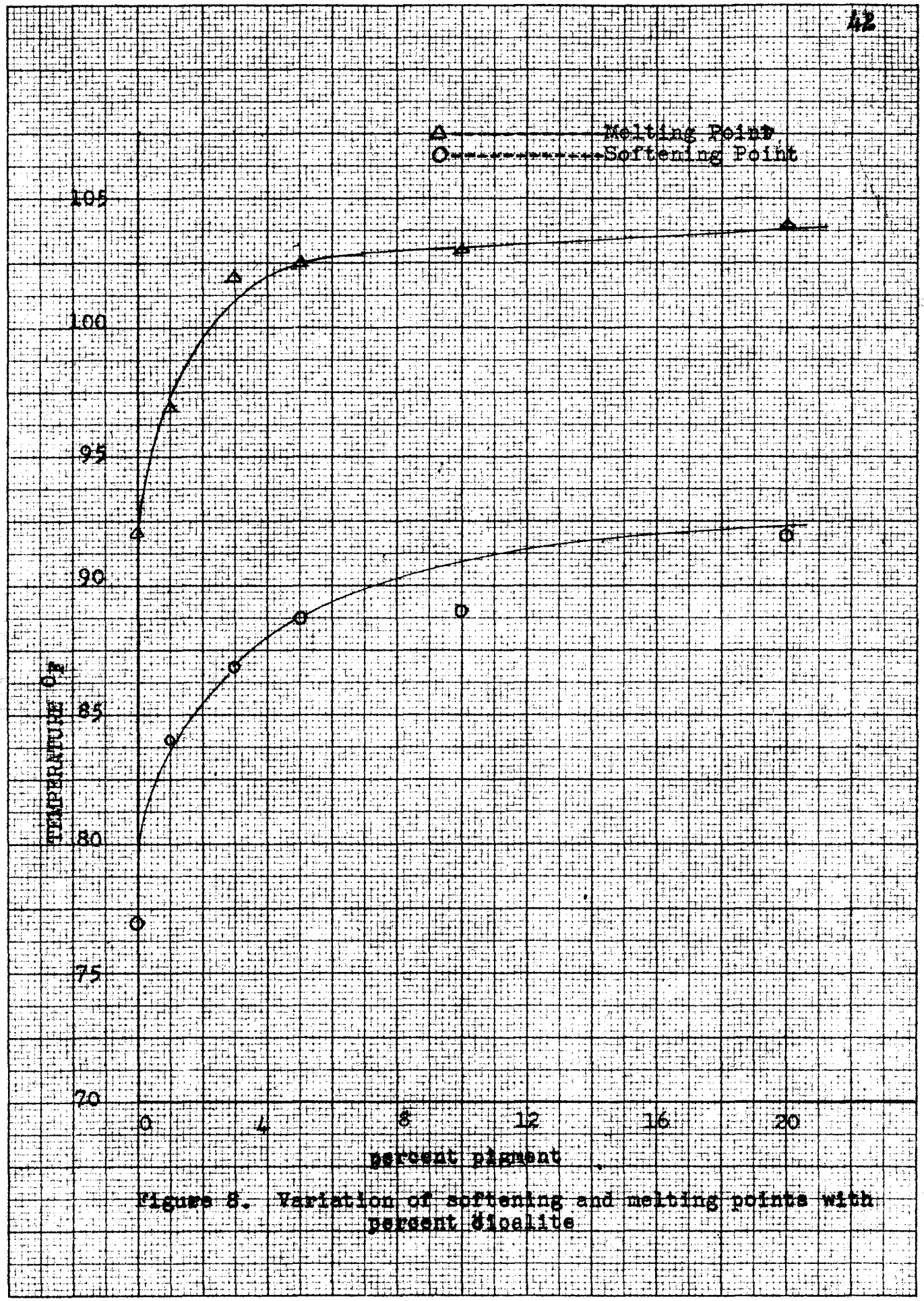



Figure 8. Variation of softening and melting points with percent dipalite

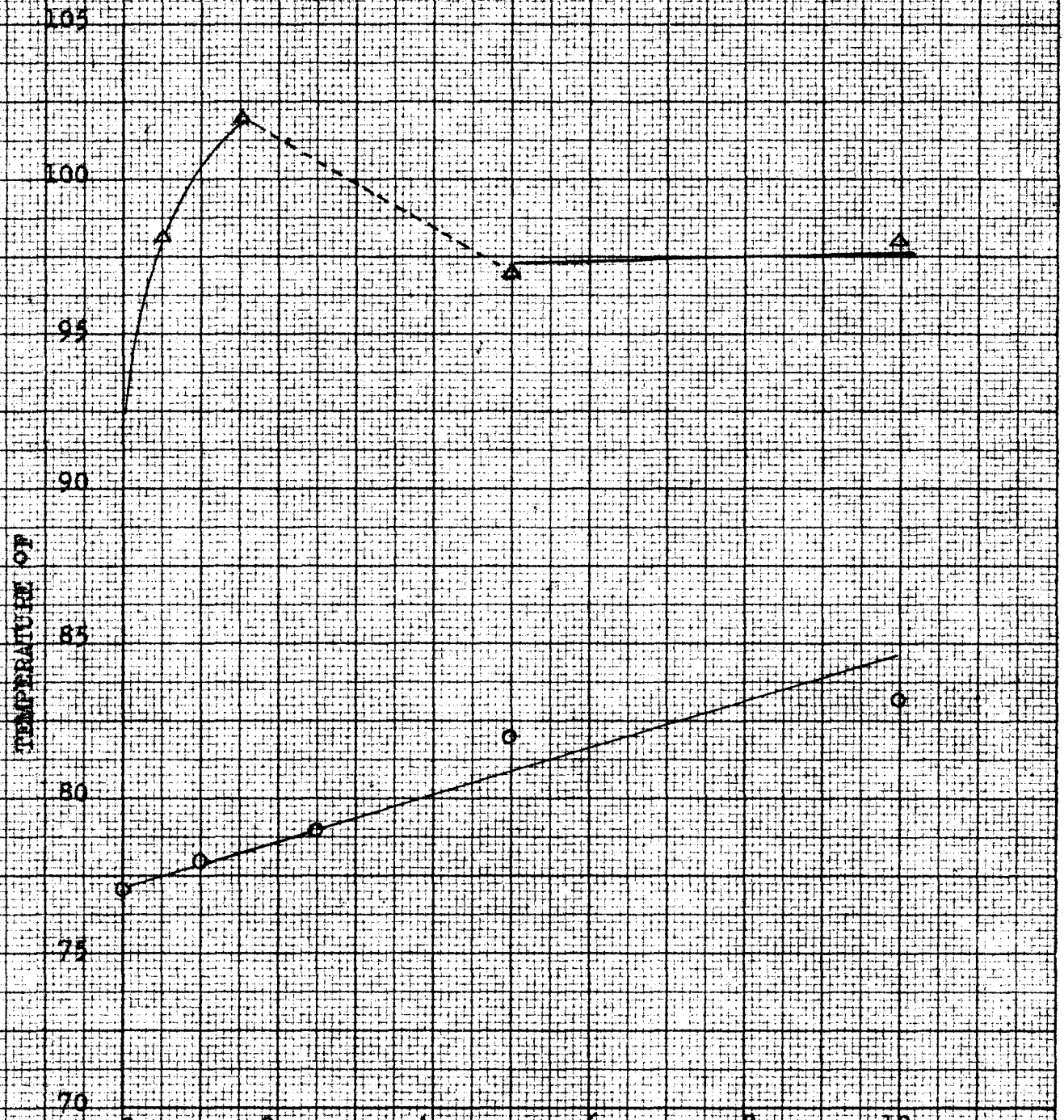



Fig. 9. Variation of softening and melting point with percent santocel

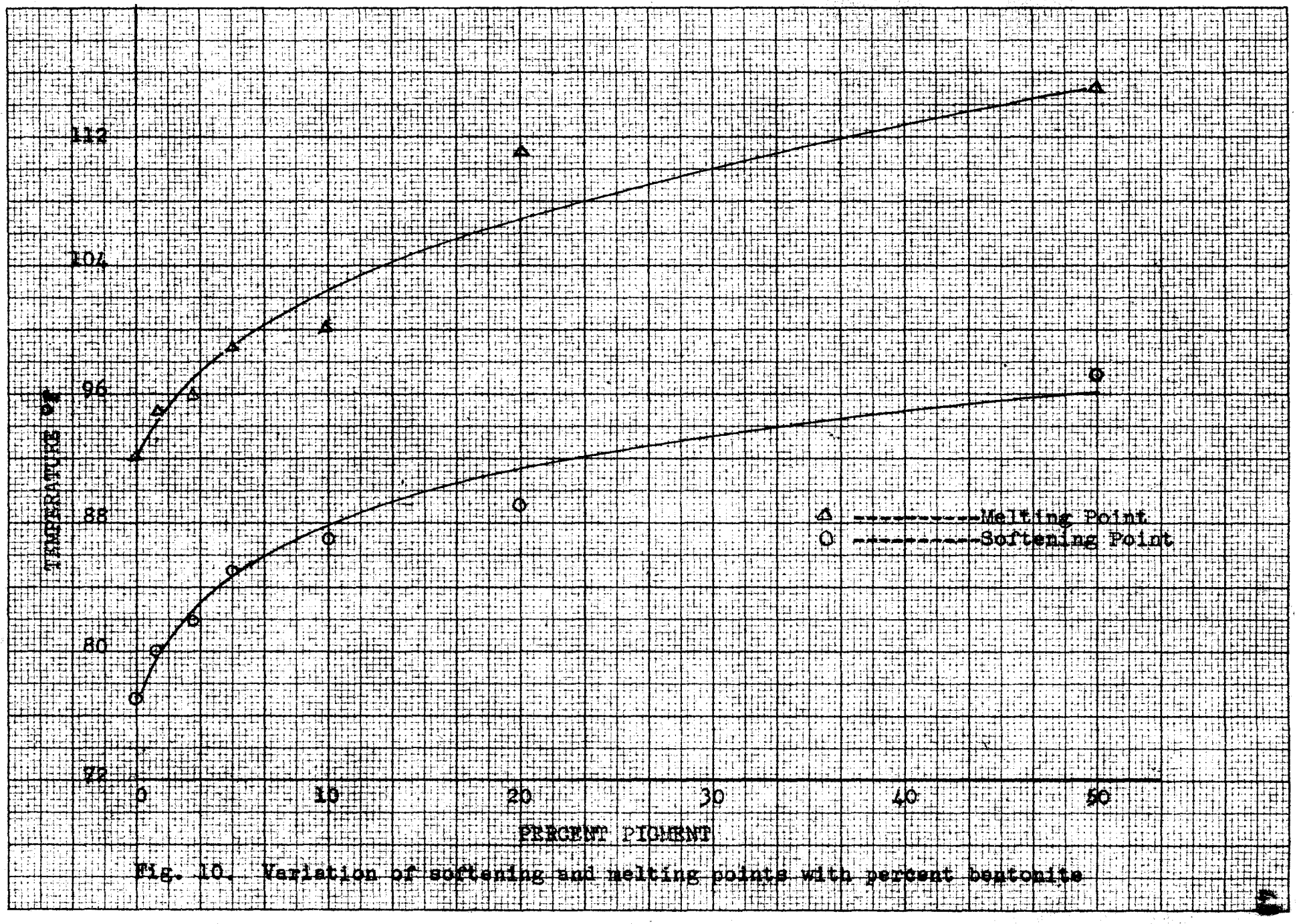



Fig. 10. Variation of softening and melting points with percent bentonite

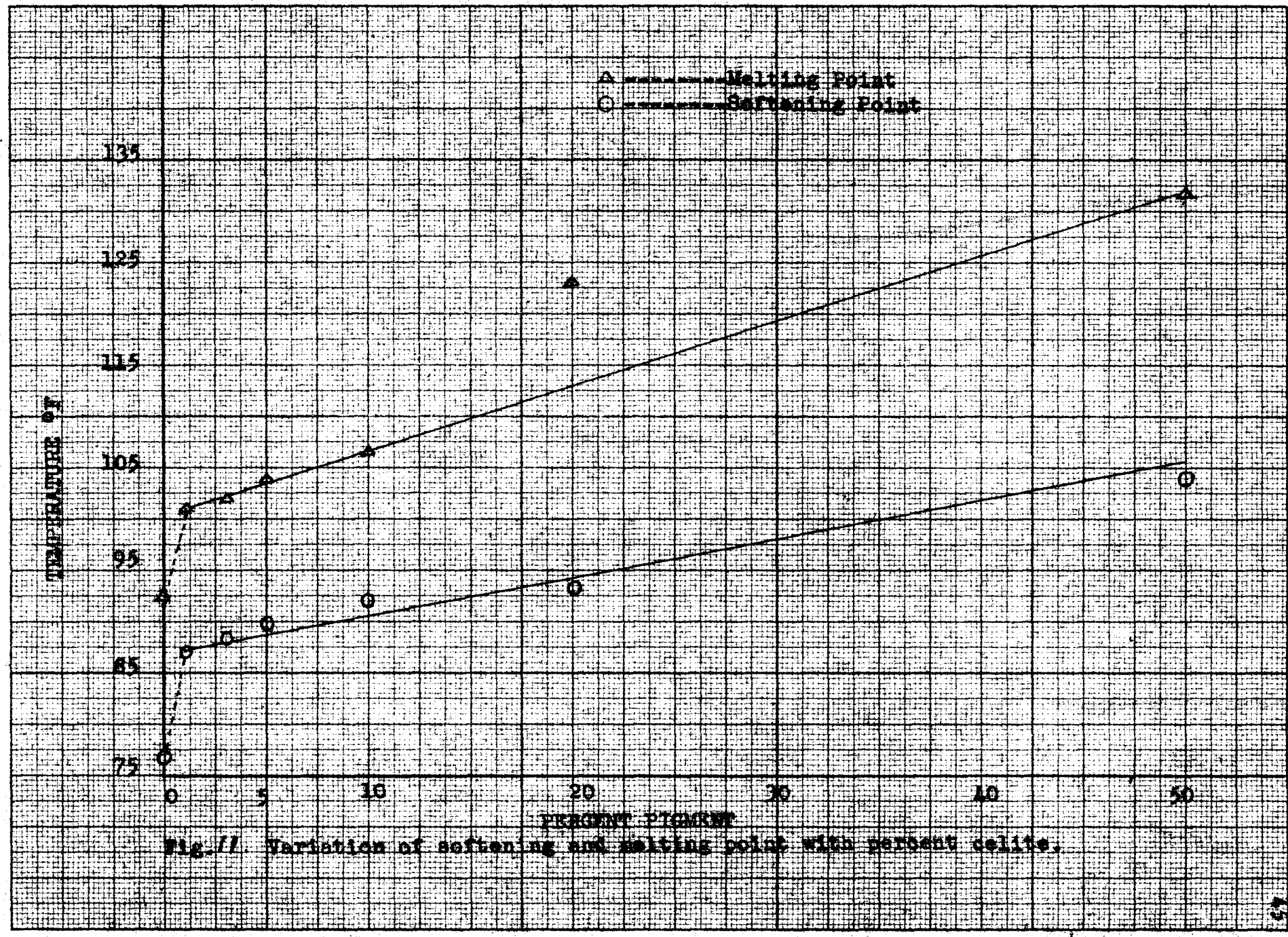



Fig. II. Variation of softening and melting point with percent celite.

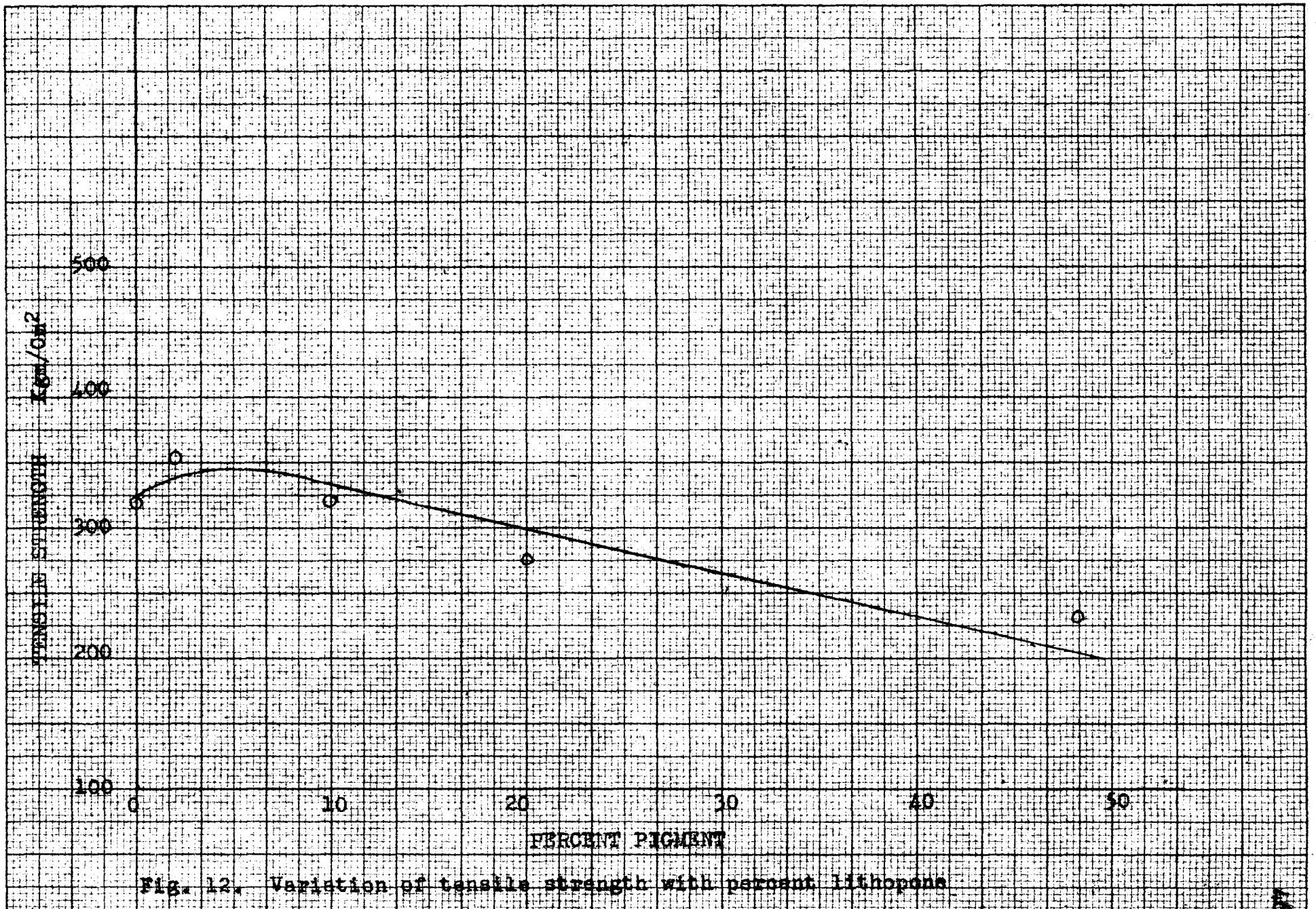



Fig. 12. Variation of tensile strength with percent lithopone

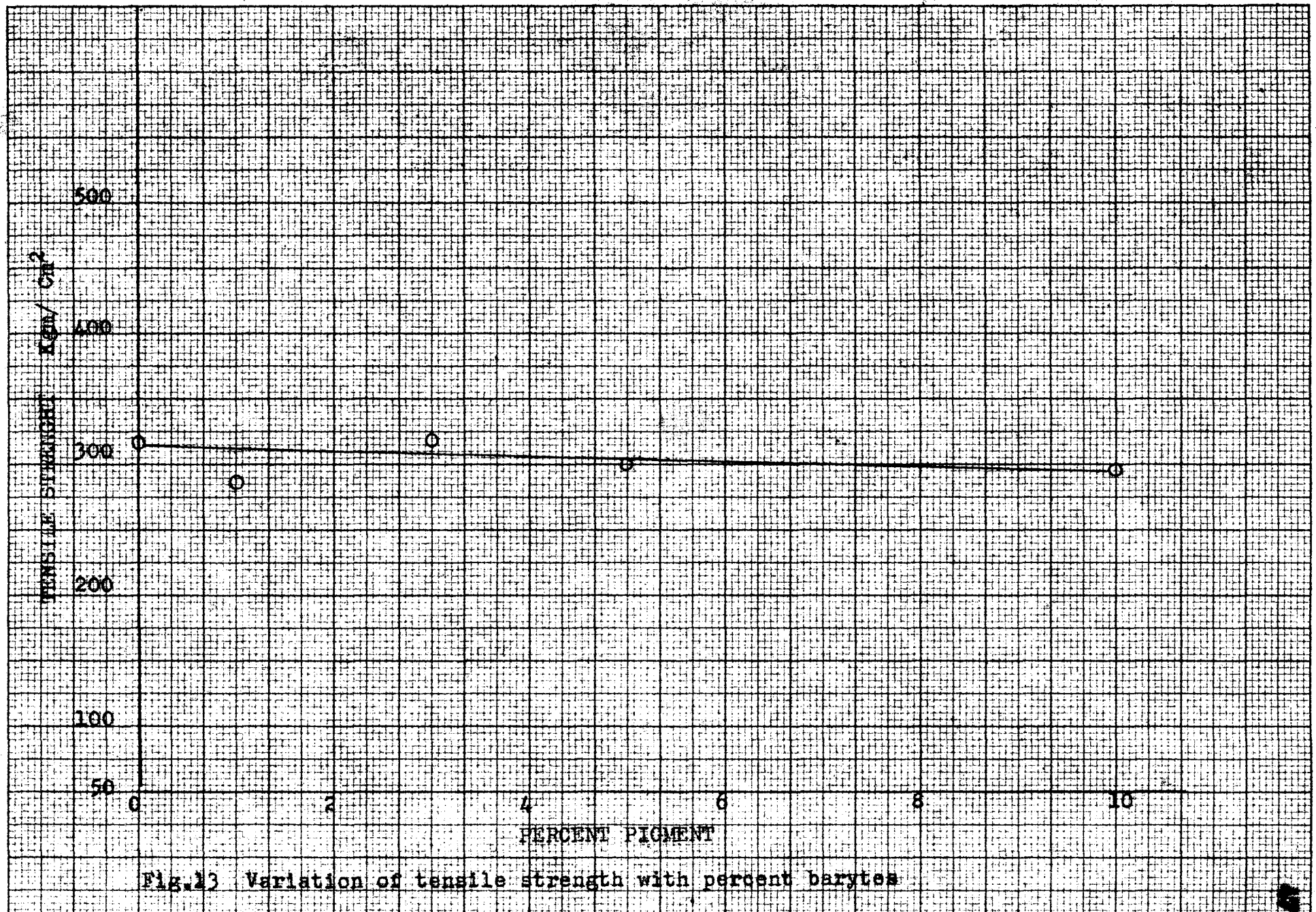



Fig.13 Variation of tensile strength with percent barytes

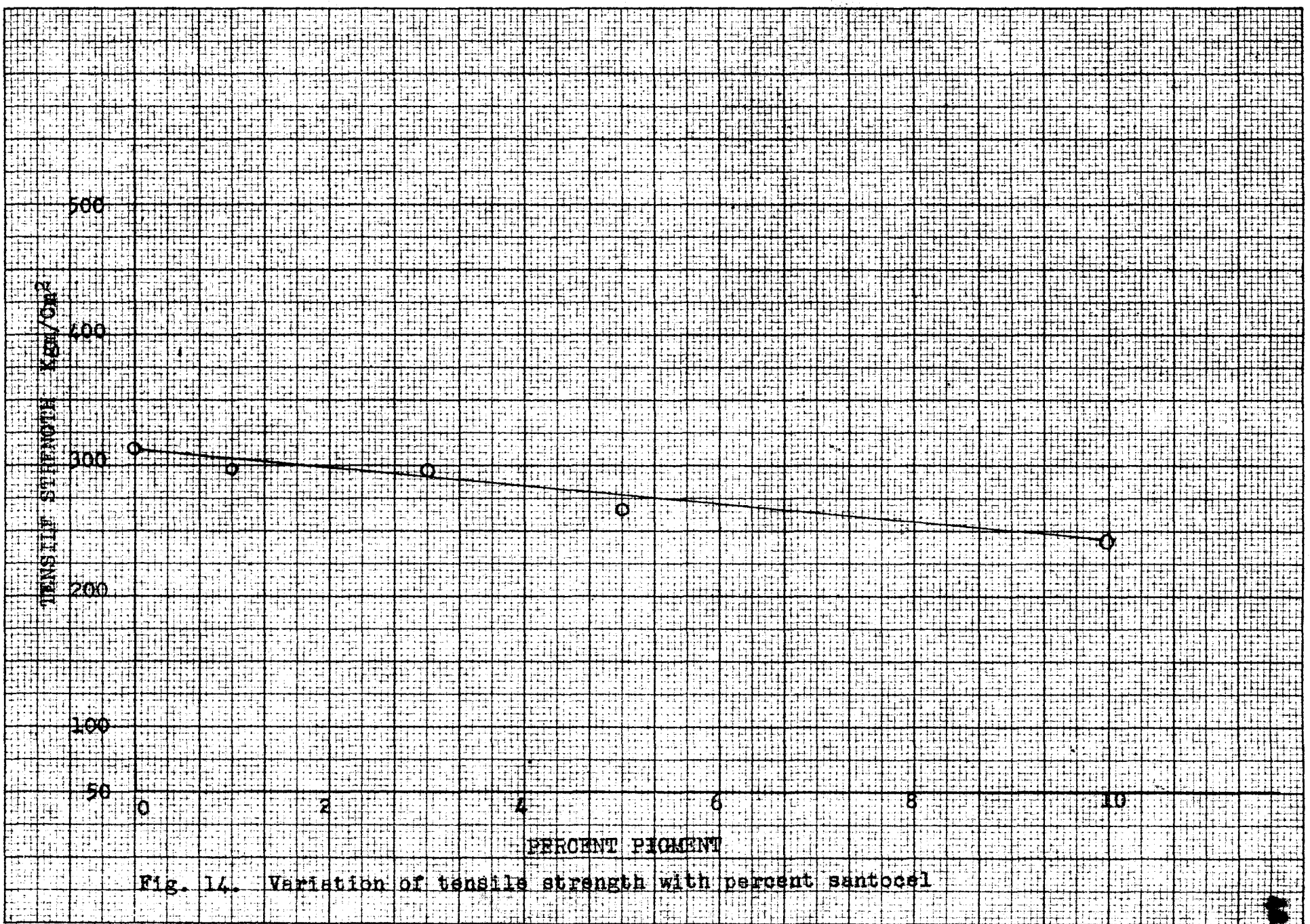



Fig. 14. Variation of tensile strength with percent santocel

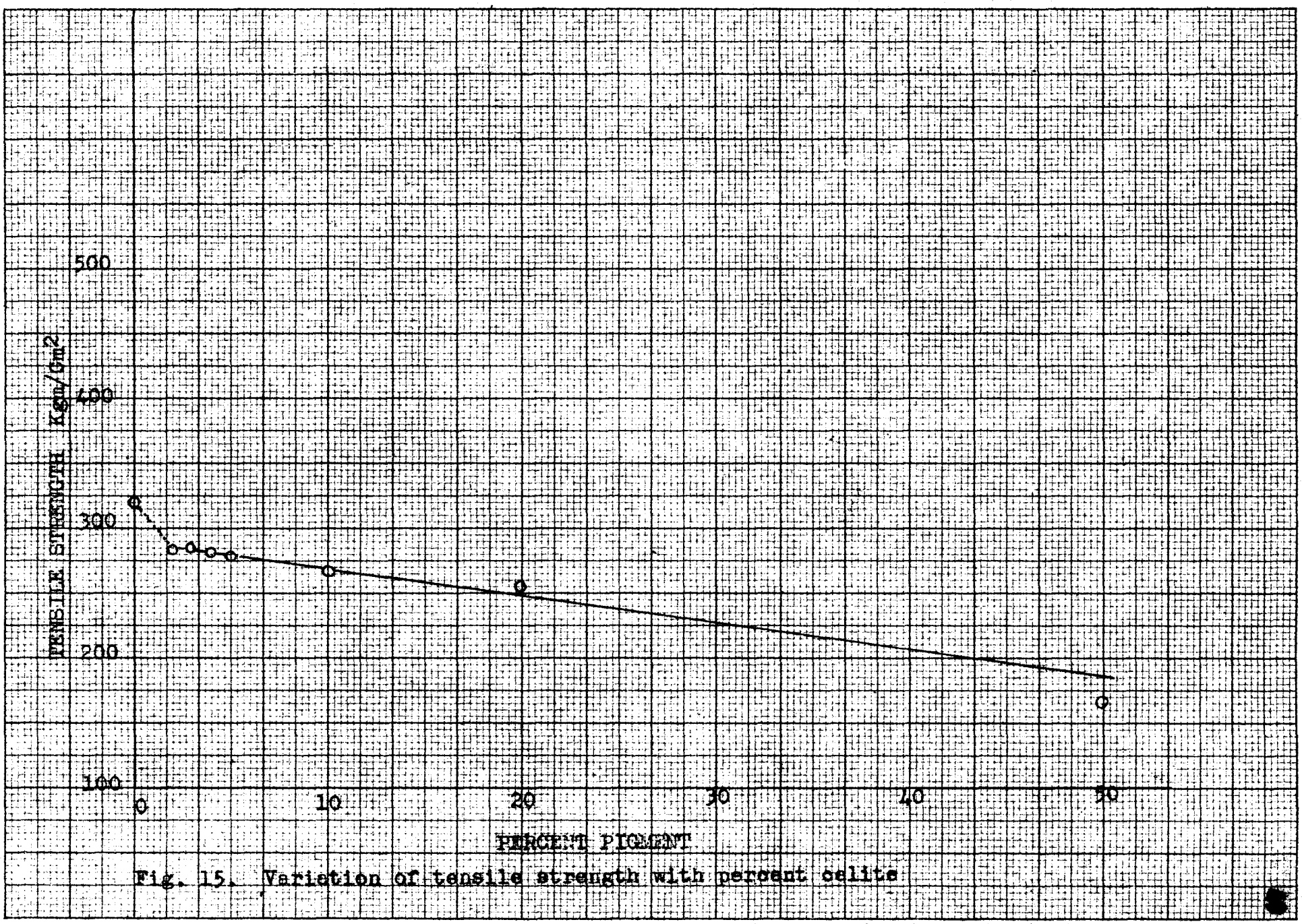



Fig. 15. Variation of tensile strength with percent celite

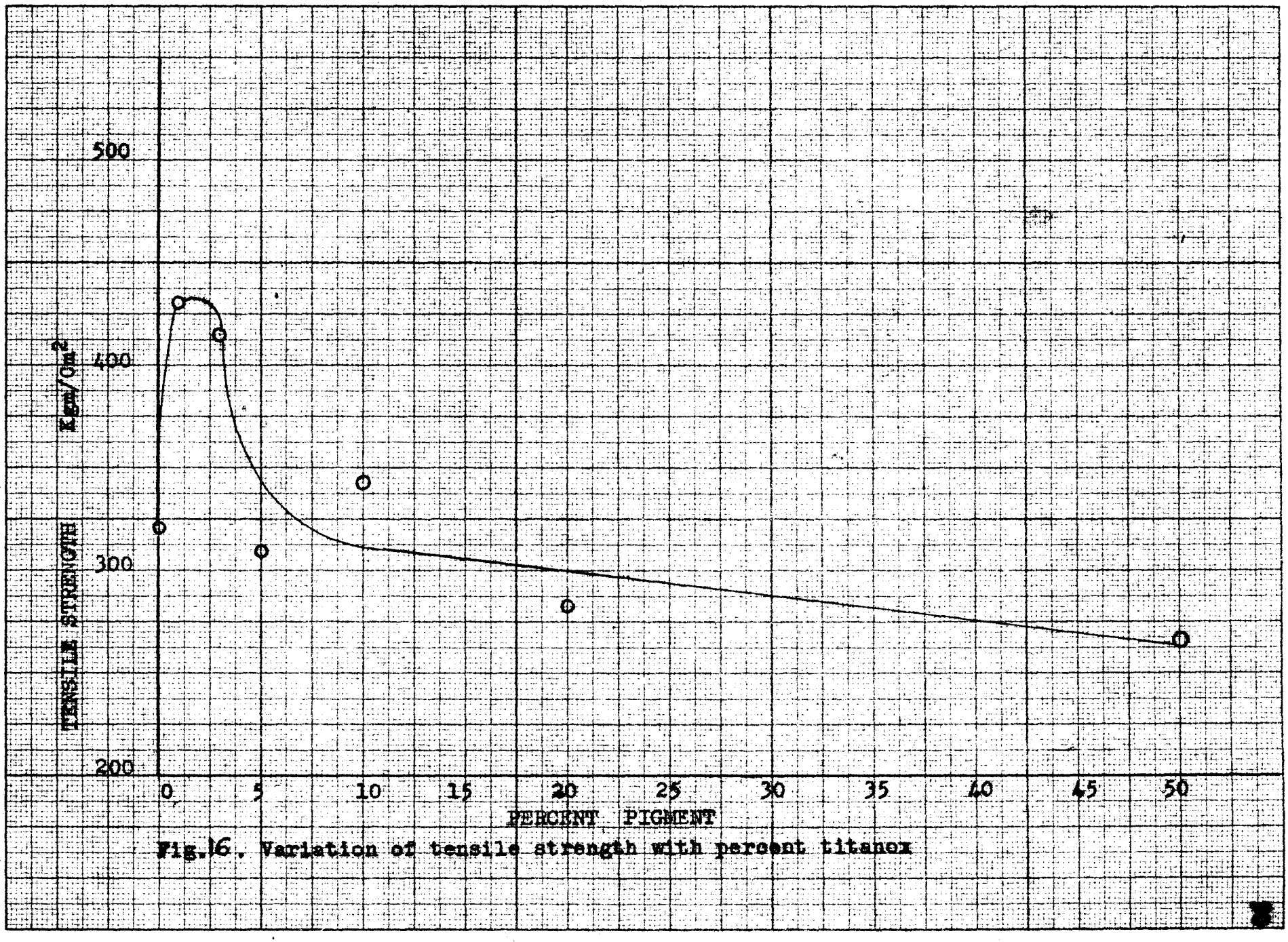



Fig. 16. Variation of tensile strength with percent titanox

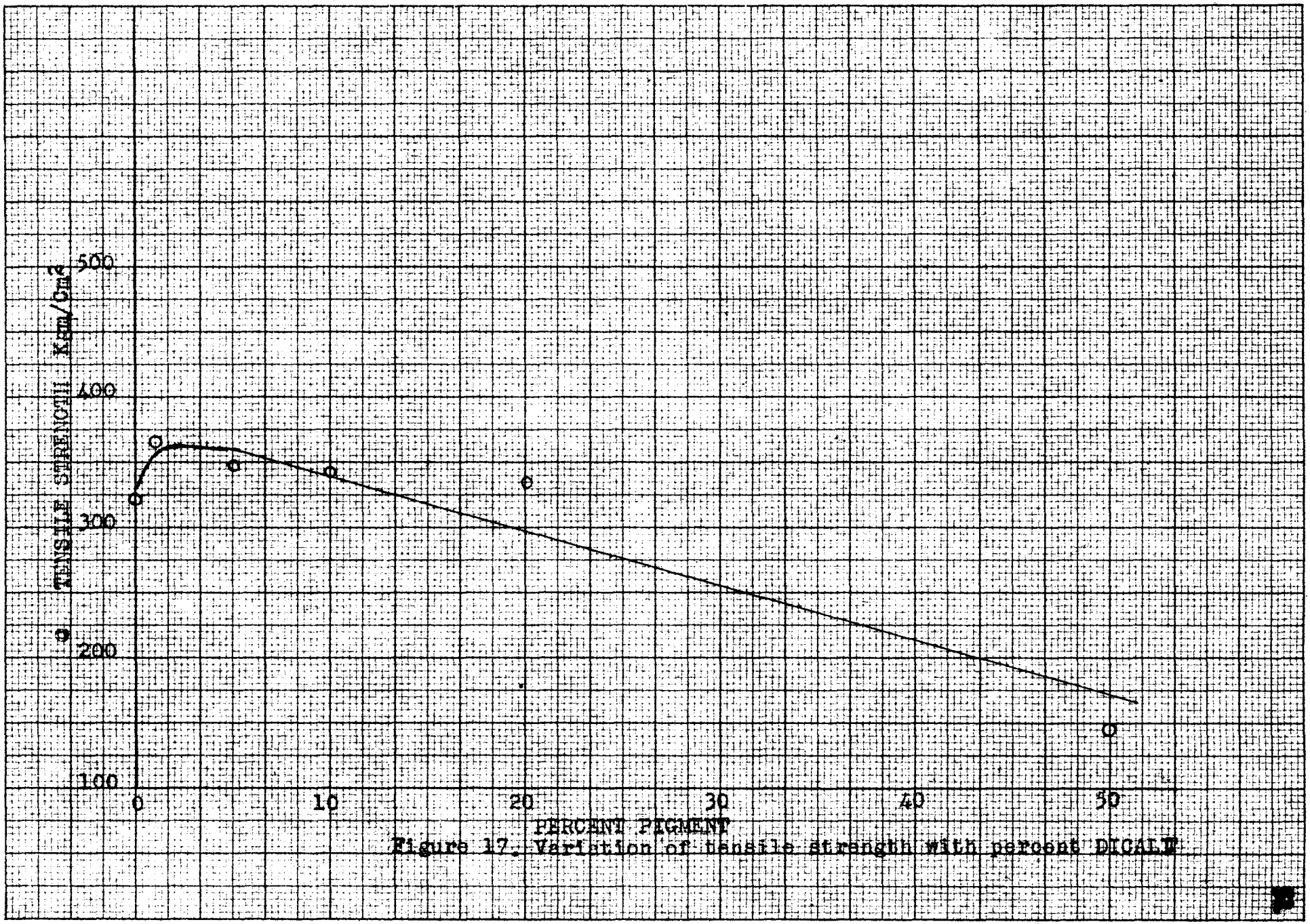



Figure 17. Variation of tensile strength with percent DICALITE

PERCENT ELONGATION

Percent Elongation was found to be maximum when 5.0% titanox was used ie an increase from 6.0 % to 10.0%. Similar but less marked effects were noted in lithopone, celite, barytes, and china clay. See tables II - X.

After examining the results given in table I and the graphs drawn in figure 12 to 17, it can be seen that titanox imparted the maximum tensile strength to ethocel films. Dicalite and lithopone also show favorable results but the extent to which they affect the tensile strength is not very great, namely, an increase of 33 $Kg/cm^2$ for lithopone and 11 $Kgm/cm^2$ for barytes (Barium Sulfate).

It must be kept in mind, however, that these values are correct within experimental error of 5.0 percent. The Scott-Tensile Tester used had an error of 5.0 percent, and the readings obtained for percent elongation were not exact. They are correct within an error of 10.0 percent. Hence these data do not provide a measure of the physical properties under examination but show a general trend.

The reasons for the increased tensile strength of ethocel films when titanox is incorporated in them may be found in the colloidal nature of the mixture.

Ethocel is polar in nature due to an uneven distribution of the electric charges in its molecule. It is quite possible that, titanox for example, being in a

colloidal form offers a foundation, on and around which an adhesive protective envelope, consisting of long chain, active (polar) molecules of ethyl cellulose is formed due to adsorption phenomenon. These ethyl cellulose molecule being still active orient themselves in such a manner as to form a branched interlaced structure with the other long chains of similar ethyl cellulose molecules. Thus these residual intermolecular attractive forces regain the strength which was lost during the degradation of a cellulose molecule chain.

It may be noticed that out of the siliceous pigments, only dicalite imparted an increase in the tensile strength of the films. The rest of the silica extenders have been produced chemically and are in the form of simple particles without any complicated structure but dicalite is composed of diatomaceous silica particles which have a complicated structure. These particles may be thin and long or flaky and discoid or may be curved and boat shaped, with numerous pores and indentations. The diatom structure of dicalite was probably the cause of an increased tensile strength.

Because of their shape and structure these diatoms have a definite interlacing action in the lacquer mixture, providing a lattice through which the polar molecules of ethocel form chains and micelles thus imparting a strength to the film.

# CONCLUSION

The results have definitely shown that pigmentation of the lacquer did have an effect upon the film properties. The old conception that pigmentation invariably produced weakness in the films, did not have any justification.

Titanox was found to have a remarkable ability to produce an all round improvement in the desired properties. It increased the tensile strength, raised the softening and melting points, percentage elongation of the film at failure was affected considerably. A lacquer containing 2.0% titanox had the follow properties:

Melting point . . . . . 120 degrees F.

Softening point . . . . . 86 degrees F.

Tensile strength . . . . . 425 $Kg/cm^2$

Percentage Elongation at failure . . 5.0%

Of the siliceous pigments dicalite seemed to be the most promising. A lacquer containing 3.0% dicalite had the following properties:

Melting point . . . . . 102 degrees F.

Softening point . . . . . 88.0 degrees F.

Tensile strength .. . . . . 364 $Kg/cm^2$.

Percentage elongation at failure . . 4.40%

TABLE II

ETHOCEL LACQUER WITHOUT PIGMENT

| Film Thickness Mils | Tensile Strength $Kgm/cm^2$ | Percent Elongation | Film Thickness Mils | Softening Point | Melting Point |
|---|---|---|---|---|---|
| 2.60 | 319 | 5.9 | 1.7-2.6 | 75.5 | 91.5 |
| 1.90 | 316 | 6.0 | 1.7-2.6 | 78.0 | 92.0 |
| 1.70 | 314 | 3.8 | 1.7-2.6 | 77.0 | 93.0 |

TABLE III

PIGMENT - - TITANOX

| Percent Pigment On solids | Film Thickness Mils | Tensile Strength $Kgm/cm^2$ | Percent Elongation | Film Thickness Mils | Softening Point F | Melting Point F |
|---|---|---|---|---|---|---|
| 1.0 | 1.9 | 425 | 4.62 | 1.6-2.2 | 84.5 | 102.0 |
| | 1.9 | 420 | 4.43 | 1.6-2.2 | 85.5 | 100.4 |
| | 1.5 | 432 | 5.00 | 1.6-2.2 | 85.0 | 102.4 |
| 3.0 | 2.35 | 418 | 5.00 | 2.0-2.5 | 87.0 | 104.0 |
| | 2.20 | 417 | 3.75 | 2.0-2.5 | 88.0 | 104.0 |
| | 2.00 | 408 | 3.75 | 2.0-2.5 | 87.0 | 105.0 |
| 5.0 | 2.84 | 308 | 9.00 | 2.5-2.6 | 88.0 | 101.0 |
| | 2.50 | 308 | 10.00 | 2.5-2.6 | ---- | 101.0 |
| | 2.50 | 307 | 8.75 | 2.5-2.6 | ---- | 100.5 |

TABLE III-(cont'd)

PIGMENT - - TITANOX

| Percent Pigment On Solids | Film Thickness Mils | Tensile Strength Kgm/cm2 | Percent Elongation | Film Thickness Mils | Softening Point F | Melting Point F |
|---|---|---|---|---|---|---|
| 10.0 | 2.60 | 341 | 6.00 | 2.5-2.7 | 89.0 | 100.0 |
| | 2.50 | 340 | 6.30 | 2.5-2.7 | 93.0 | 101.5 |
| | 2.50 | 342 | 5.90 | 2.5-2.7 | 92.0 | 102.0 |
| 20.0 | 2.60 | 284 | 3.00 | 2.3-2.7 | 90.0 | 102.0 |
| | 2.50 | 283 | 3.20 | 2.3-2.7 | 92.0 | 101.5 |
| | 2.40 | 284 | 3.50 | 2.3-2.7 | 90.5 | 103.0 |
| 50.0 | 2.80 | 271 | 2.50 | 2.2-2.8 | 89.5 | 103.5 |
| | 2.50 | 293 | 2.50 | 2.2-2.8 | 89.0 | 103.0 |
| | 2.30 | 288 | 2.50 | 2.2-2.8 | 89.5 | 104.0 |

TABLE IV

LITHOPONE

| Percent Pigment On Solids | Film Thickness Mils | Tensile Strength Kgm/cm2 | Percent Elongation | Film Thickness Mils | Softening Point F | Melting Point F |
|---|---|---|---|---|---|---|
| 1.0 | 3.1 | 290 | 5.875 | ------ | 87.0 | 91.0 |
| | 3.1 | 307 | 5.000 | 2.4-3.1 | 87.0 | 92.0 |
| | 2.4 | 281 | 3.750 | 2.4-3.1 | 88.0 | 92.0 |
| 3.0 | 2.2 | 348 | 6.250 | 2.2-2.5 | 76.0 | 94.0 |
| | 2.2 | 357 | 6.250 | 2.2-2.5 | 76.0 | 95.0 |
| | 1.8 | 350 | 5.620 | 2.2-2.5 | 81.0 | 94.0 |
| 5.0 | 2.3 | 348 | 3.375 | 2.2-2.6 | 83.0 | 99.0 |
| | 2.2 | 332 | 3.75 | 2.2-2.6 | 82.5 | 98.5 |
| | 2.2 | 340 | 3.75 | 2.2-2.6 | 84.0 | 99.0 |

TABLE IV (cont'd)

LITHOPONE

| Percent Pigment On Solids | Film Thickness Mils | Tensile Strength Kgm/cm2 | Percent Elongation | Film Thickness Mils | Softening Point F | Melting Point F |
|---|---|---|---|---|---|---|
| 10.0 | 2.5 | 326 | 5.5 | 1.7-2.5 | 81.5 | 101.0 |
| | 2.4 | 311 | 3.75 | 1.7-2.5 | 82.0 | 99.0 |
| | 2.2 | 322 | 4.75 | 1.7-2.5 | 81.5 | 99.0 |
| 20.0 | 3.1 | 278 | 3.75 | 2.1-2.8 | 91.0 | 99.0 |
| | 2.8 | 265 | 3.75 | 2.1-2.8 | 91.0 | 98.5 |
| | 1.6 | 281 | 6.25 | 2.1-2.8 | 91.0 | 98.5 |
| 50.0 | 3.0 | 225 | 2.50 | 2.2-3.0 | (large variation) | 105.0 |
| | 2.3 | 232 | 3.13 | 2.2-3.0 | | -- |
| | 2.2 | 236 | 3.13 | 2.2-3.2 | | 102.5 |

TABLE V

CELITE

| Percent Pigment On Solids | Film Thickness Mils | Tensile Strength Kgm/cm$^2$ | Percent Elongation | Film Thickness Mils | Softening Point F | Melting Point F |
|---|---|---|---|---|---|---|
| 1.0 | 1.8 | 313.0 | 3.90 | 1.8-2.5 | 87.0 | 101.5 |
| --- | --- | ----- | ---- | ------- | 87.0 | 102.0 |
| --- | --- | ----- | ---- | ------- | 88.0 | 102.0 |
| 2.0 | 2.4 | 281.0 | 6.25 | 1.8-2.0 | 88.0 | 102.0 |
| 3.0 | 2.2 | 280.0 | 5.00 | ------- | ---- | 102.0 |
| 4.0 | 2.5 | 281.0 | 6.25 | ------- | ---- | ----- |
| 5.0 | 2.2 | 280.0 | 5.50 | 1.9 | 90.0 | 104.0 |
| | 2.1 | 275 | 5.20 | ------- | ---- | ----- |

TABLE V (cont'd)

CELITE

| Percent Pigment On Solids | Film Thickness Mils | Tensile Strength $Kgm/cm^2$ | Percent Elongation | Film Thickness Mils | Softening Point F | Melting Point F |
|---|---|---|---|---|---|---|
| 10.0 | 2.5 | 266.0 | 4.4 | 2.4 | 91.5 | 107.0 |
| 20.0 | 2.3 | 251.0 | 5.0 | 1.8-2.3 | 92.0 | 123.0 |
| | 1.8 | 257 | 3.8 | 1.8-2.3 | 94.0 | 123.0 |
| | 2.3 | 258 | 5.0 | 1.8-2.3 | 93.0 | 123.0 |
| 50.0 | 2.2 | 163 | 1.25 | 1.8-2.8 | 108.0 | 132.0 |
| | 2.6 | 162 | 1.83 | 1.8-2.8 | 105.0 | 131.0 |
| | 2.8 | 181 | 1.25 | 1.8-2.8 | 107.0 | 132.0 |

TABLE VI

DICALITE

| PERCENT PIGMENT ON SOLIDS | FILM THICKNESS MILS | TENSILE STRENGTH Kgm/cm$^2$ | PERCENT ELONGATION | FILM THICKNESS MILS | SOFTENING POINT F | MELTING POINT F |
|---|---|---|---|---|---|---|
| 1.0 | 1.7 | 364 | 3.75 | 1.7-2.0 | 84.0 | 97.5 |
| | 1.8 | 361 | 3.75 | 1.7-2.0 | 85.0 | 97.0 |
| | 2.0 | 359 | 5.0 | 17-2.0 | 84.0 | 97.0 |
| 3.0 | 1.9 | 365 | 4.4 | 2.4-1.8 | 88.0 | 102.0 |
| | 1.8 | 360 | 4.0 | 2.4-1.8 | 87.0 | 102.0 |
| | 1.8 | 361 | 4.2 | 2.4-1.8 | 87.0 | 102.0 |
| 5.0 | 2.4 | 362 | 6.88 | 2.4-2.5 | 88.0 | 102.0 |
| | 2.4 | 368 | 5.00 | 2.4-2.5 | 90.0 | 102.5 |
| | 2.5 | 337 | 5.00 | 2.4-2.5 | 88.0 | 102.5 |

TABLE VI (cont'd)

DICALITE

| Percent Pigment On Solids | Film Thickness Mils | Tensile Strength $Kgm/cm^2$ | Percent Elongation | Film Thickness Mils | Softening Point F | Melting Point F |
|---|---|---|---|---|---|---|
| 10.0 | 2.6 | 341 | 5.0 | 2.2-2.5 | 87.0 | 102.0 |
| | 2.5 | 340 | 5.3 | 2.2-2.5 | 89.0 | 103.0 |
| | 2.5 | 339 | 4.8 | 2.2-2.5 | 89.5 | 103.0 |
| 20.0 | 1.8 | 329 | 3.75 | 1.5-1.8 | 92.0 | 104.0 |
| | 1.5 | 353 | 3.75 | 1.5-1.8 | 93.0 | 104.0 |
| | 1.7 | 335 | 4.00 | 1.5-1.8 | 91.5 | 102.0 |
| 50.0 | 2.5 | 180 | 0.125 | 2.5 | (varied much) | 121.0 |
| | 2.7 | 109 | 0.125 | 2.5-3.0 | (varied much) | 121.0 |
| | 3.0 | 114 | 0.125 | ----- | (varied much) | 124.0 |

TABLE VII

BARYTES

| Percent Pigment On Solids | Film Thickness Mils | Tensile Strength $Kgm/cm^2$ | Percent Elongation | Film Thickness Mils | Softening Point F | Melting Point F |
|---|---|---|---|---|---|---|
| 1.0 | 2.3 | 297 | 6.25 | 2.3-2.8 | 76.0 | 93.5 |
| | 2.8 | 300 | 8.19 | 2.3-2.8 | 77.0 | 92.5 |
| | 2.5 | 275 | 5.75 | 2.3-2.8 | 77.0 | 93.0 |
| 3.0 | 2.2 | 321 | 7.50 | 2.2-1.8 | 76.0 | 93.3 |
| | 1.8 | 328 | 6.25 | 2.2-1.8 | 78.0 | 93.5 |
| | 2.0 | 318 | 6.00 | 2.2-1.8 | 78.0 | 94.0 |
| 5.0 | 2.4 | 305 | 7.5 | 2.0-2.5 | 81.0 | 96.6 |
| | 2.1 | 309 | 6.0 | 2.0-2.5 | 81.5 | 96.0 |
| | 1.75 | 297 | 5.0 | 2.0-2.5 | 81.0 | 95.5 |
| 10.0 | 2.3 | 295 | 5.25 | 2.0-2.3 | 83.5 | 101.5 |
| | 2.3 | 295 | 3.75 | 2.0-2.3 | 82.5 | 101.5 |
| | 2.0 | 295 | 3.75 | 2.0-2.3 | 83.0 | 100.5 |

TABLE VIII

SANTOCEL

| Percent Pigment On Solids | Film Thickness Mils | Tensile Strength $Kgm/cm^2$ | Percent Elongation | Film Thickness Mils | Softening Point F | Melting Point F |
|---|---|---|---|---|---|---|
| 1.0 | 2.30 | 299 | 4.38 | 2.3-2.5 | 77.0 | 97.0 |
| | 2.10 | 295 | 4.35 | 2.3-2.5 | 78.0 | 98.0 |
| | 2.30 | 294 | 4.38 | 2.3-2.5 | 78.0 | 98.0 |
| 3.0 | 3.0 | 299 | 5.000 | 2.4-3.5 | 76.5 | 98.0 |
| | 2.5 | 298 | 5.20 | 2.4-3.0 | 79.0 | 102.0 |
| | 2.4 | 297 | 5.12 | 2.4-3.0 | 79.5 | 102.0 |
| 5.0 | 2.60 | 271 | 3.12 | 2.1-2.6 | 82.57 | 96.5 |
| | 1.7 | 273 | 3.12 | 2.1-2.6 | 82.0 | 96.5 |
| | 2.1 | 267 | 3.12 | 2.1-2.6 | 82.5 | 97.6 |
| 10.0 | 2.5 | 250 | 3.125 | 2.5-2.6 | ---- | 96.0 |
| | 3.0 | 244 | 3.00 | 2.5 | 82.5 | 98.0 |
| | 2.6 | 246 | 3.22 | 2.5 | 83.0 | 98.0 |

Conglomeration of pigment took place about 10.0% pigment.

TABLE IX

BENTONITE

| Percent Pigment On Solids | Film Thickness Mils | Tensile Strength Kgm/cm2 | Percent Elongation | Film Thickness Mils | Softening Point F | Melting Point F |
|---|---|---|---|---|---|---|
| 1.0 | 2.3 | 309 | 5.5 | 2.4 | 80.0 | 95.0 |
| 2.0 | 2.2 | 295 | --- | --- | ---- | ---- |
| 3.0 | 2.7 | 287 | 4.080 | 2.1-2.7 | 82.0 | 95.5 |
| | 2.1 | 307 | 6.250 | 2.1-2.7 | 82.0 | 96.0 |
| | 2.2 | 275 | 4.125 | 2.1-2.7 | 81.4 | 97.0 |
| 4.0 | 2.2 | 274 | ----- | ------- | ---- | ---- |
| 5.0 | 2.55 | 274 | ----- | 2.5 | 85.0 | 98.0 |
| --- | ---- | --- | ----- | --- | ---- | 99.0 |
| --- | --- | --- | ----- | --- | --- | 99.0 |

TABLE IX (cont'd)

BENTONITE

| Percent Pigment On solids | Film Thickness Mils | Tensile Strength Kgm/cm2 | Percent Elongation | Film Thickness Mils | Softening Point F | Melting Point F |
|---|---|---|---|---|---|---|
| 10.0 | 1.8 | 297 | 2.50 | 1.8-3.2 | 87 | 98.0 |
| | 2.1 | 294 | 2.32 | 1.8-3.2 | | 98.0 |
| | ---- | --- | ---- | ------- | --- | 98.5 |
| 20.0 | 2.0 | 257 | 1.39 | 2.0-3.0 | 88.5 | 111.5 |
| | 3.0 | 259 | 2.00 | 2.0-3.0 | 88.8 | 111.0 |
| | 1.8 | 250 | 1.80 | 2.0-3.0 | 89.0 | 111.0 |
| 50.0 | 1.8 | 239 | 2.50 | 1.8-2.2 | 93.0 | 112.0 |
| | 1.8 | 243 | 1.25 | 1.8-2.2 | 98.0 | 115.0 |
| | 1.7 | 212 | 2.30 | 1.8-2.2 | 98.0 | 115.0 |

TABLE X

CHINA CLAY

| Percent Pigment | Film Thickness | Tensile Strength Kgm/cm2 | Percent Elongation |
|---|---|---|---|
| 1.0 | 1.9 | 302 | 6.25 |
| 2.0 | 2.1 | 313 | 8.75 |
| 3.0 | 1.9 | 309 | 7.5 |
| 4.0 | 1.8 | 305 | 5.0 |
| 5.0 | 1.9 | 300 | 6.2 |

# PART II

## A STUDY OF THE EFFECT OF SUN LIGHT ON THE COLOR OF PIGMENTS

### INTRODUCTION

It has been known for some time that there is a change in the color of a coating as time progresses but no quantitative work has been reported to determine the extent and the direction in which the color change takes place. This change is very slow and is hardly noticeable by the eye, if examined at short intervals. However, after a longer period, normally a fading of color becomes noticeable and the coating produces a slightly changed appearance. However, fading does not necessarily take place to produce a color which is undesirable, on the contrary it has been observed that certain tints, tones, and shades, resulting from fading are quite desirable. With this in view, it was considered that if the change in color with time of certain pigments in a vehicle could be known prior to its application, steps could be taken either to check that fading by the incorporation of inhibiting materials or to formulate paint such that on exposure it would degrade to a color which would not seem unpleasant or that, the faded color might be even more appealing to the eye.

This investigation was designed to study the dry exposure characteristics of the different pigments in a series of five tints per pigment when they were incorporated as paint. The work was begun at the suggestion of the Louisville Paint and Varnish Club as a worthwhile contribution to the knowledge in the field.

# HISTORICAL

Albert H. Munsell was the first person in the United States of America who organized and put into a definite system, vague ideas and disconnected statements regarding the measurement of color (24). He reasoned that the color appearance of objects was apparent only in objects and so proposed to set up a series of colored papers which varied equally in all directions in the color domain in terms of visual appearance. He did not consider the physical variables involved, but restricted himself to the color as such, viewed under standardized conditions. A color atlas was produced by him, containing examples of colors which varied in roughly uniform steps over a large range of surface colors.

Munsell defined the three variables of color as hue, value, and chroma. Hue was that quality by which one color family is distinguished from another, as red from green, or green from blue. It is due to the difference in wavelengths of light falling on our eyes, producing different color sensations. Value is the lightness of a color. It is that quality by which we distinguish a light color from a dark one. Color values are loosely called tints and shades, but these terms are frequently misapplied. A tint should be a light value, and a shade a dark value.

Chroma is the strength of a color. A color might be weak, or it might be intensely strong, for example Brick Red and Vermillion red, the former is weak, while the latter is strong.

These three aspects of color were arranged into a three dimensional color solid having a vertical black to white axis. Around this were arranged the lines in equal angular spacing and chroma was defined as the distance from the axis at any particular color value.

It was intended that the sample to be specified should be held near the atlas and the position of the sample with respect to the actual chips determined. The specification of the color thus consisted of a numerical statement of its position on the scales of the solid.

It must be noted, however, that these small matte surfaced chips represent only one type of surface, their energy distributions are unique, and therefore they are not suitable for comparison with all types of possible distributions.

In 1943, a committee of the Optical Society of America studied the Munsell system and recommended a respacing of the colors based on a purely psychological approach (16).

The basis of this system is the series of international agreements commonly referred to as the I.C.I. system (or the CIE system in England and on the Continent). This international Commission on Illumination (Commission Internationale d'Eclairage) adopted as a standard for international use a luminosity curve, color-mixture curves for these imaginary standard lights, a specific energy distribution for a basic light source, several supplementary light sources and a number of apertures.

The three values which define a certain color, in the O.S.A. system are called Hue, Brightness and Saturation, roughly corresponding with the Hue, Value and Chroma, respectively, of the Munsell System.

The calculation of the excitation values for a sample lead to three numerical results. Two of these are the trichromatic coefficients X and Y, representing the fractional amounts of the red and the green primaries necessary to produce a hue and saturation match with the sample and a third Z, representing the luminance of the sample. The I.C.I. diagram is plotted in terms of X and Y and the value of Z is written beside the point.

Equal distances in the I.C.I. diagram do not mean equal visual differences. In fact it has been demonstrated that it is not possible to construct a chromaticity diagram in which perceptible differences are represented by the same distances at each point.(19) To overcome this difficulty Judd L. Scoffield and Hunter put forward another system which is actually an improvement on the I.C.I. system.

These three workers defined a coordinate system in two dimensions, $\alpha$ and $\beta$, in which, for colors of the same monochromatic reflectances, equal distances on the graph are equal approximately to equal perceptual color difference.

These coordinates are defined in terms of the I.C.I. Coordinates as:

$$\alpha = \frac{2.4266X - 1.3631Y - 0.3214}{1.0000X + 2.2633Y + 1.1054}$$

$$\beta = \frac{0.5710X + 1.2447Y - 0.5708}{1.0000X + 2.2633Y + 1.1054}$$

or in terms of the Blue, Amber, and Green readings of the Hunter multi-purpose reflectometer as: (18)

$$\alpha = \frac{A - G}{A + B + 2G} \quad , \quad \beta = \frac{0.4(G - B)}{A + B + 2G}$$

X and Y have already been explained. A, B, and G represent the scale value on the H. Reflectometer as compared to a standard value.

# APPARATUS

HUNTER MULTIPURPOSE REFLECTOMETER

1) Plan of the Instrument:

Figure 19 is a diagram of the Hunter Reflectometer with a partial elevation through Q-Q to show the path of the gloss beam. This pencil of light is separated from the entrant beam by the small aluminum mirror F, and finally reaches a stationary photocell, N, termed the Gloss Photocell, by way of the Gloss Surface H, which is in position to receive the beam at 45 degrees, and reflect it at -45 degrees along the path toward the gloss photocell. The lines indicating both the centers and the edges of the light paths from the source to the respective photocells are heavy. The positions of all elements necessary for the operation of the instrument are shown. The elevated part of the gloss beam between the mirrors, F and I, is omitted in the plan but is shown in the partial elevation. The instrument is designed to operate according to a null method. Light from the single source is divided into two paths, each of which ultimately reaches a barrier-layer photocell. The two cells are connected with polarities opposing to the terminals of the galvanometer, giving the current balancing circuit. The light diverges from the filament of the projection lamp, C, and passes through a round window in the aluminum insulating shield B. Beyond this shield, the beam may pass through one of several spectrally selective filters on a disk E, and reach the collimating lens mounted in the wall of the

instrument housing.

The approximately parallel beam leaving this lens then proceeds in large part, to the vertically placed reflecting surface, G, on which it is incident at 45 degrees. The reflection photocell, A, to which the scales are attached views the reflection surface from a variable distance.

The plane mirror, F, intercepts a small part of the cylindrical beam and reflects it upward to incidence at 45 degrees on the horizontally placed gloss surface, H. The light reflected by this surface at the angle of mirror reflection, -45 degrees, strikes mirror I, which is in the same plane as mirror F. The center of this gloss beam is thereby returned to the horizontal plane and passes through a lens and gloss aperture where an image of the source is formed. Behind this aperture is the semidiffusing reflector, M, adjustable in its angular position to control the fraction of light directed from it to the gloss cell, N. Several different apertures in a disk may be interchanged to vary the spread of the light in the gloss beam passed toward the gloss cell for measurement.

Two scales are ruled on the arm attached to the movable reflection cell, one for reflection, R, the other for gloss, S. Stray light which might register on the photocells is reduced to a minimum by painting interior surfaces of the instrument a dull black, by mounting the movable reflection cell in a tunnel, and by dividing the instrument

interior into compartments separated by the sheet metal partitions indicated by light dotted lines in figure 7.

ACCELERATED WEATHERING MACHINE

The accelerated weathering unit consists of a sheet copper cylinder about three feet in diameter and about three and half feet in height. An electric arc arrangement is provided in the center of this cylinder. The carbon electrodes are removed at a definite speed towards each other by means of an electric clockwork, the motion of the electrodes is proportional to the rate at which the arc consumes the carbon. The carbon arc arrangement is enclosed in a framework of metal with special heat-resistent glass windows to allow a minimum transmission of radiation.

Along the inside of the outer cylindrical vessel are a large number of hooks from which test panels can be suspended. This cylinder revolves round its vertical axis at the rate of one-half revolution per hour. There is also a spray nozzle which may be made to spray water over the surface of the panels and thus give the effect of rain. The central arc light chamber is connected through a duct to an exhaust fan, which removes the fumes and gases evolved. The arc chamber can be lifted out of the main chamber for the purpose of cleaning and the replacement of the carbon electrodes. An electric meter keeps a record of the time the instrument is in operation. The top and bottom of the unit are covered by means of copper sheeting to prevent a strong exposure to the eye.

67

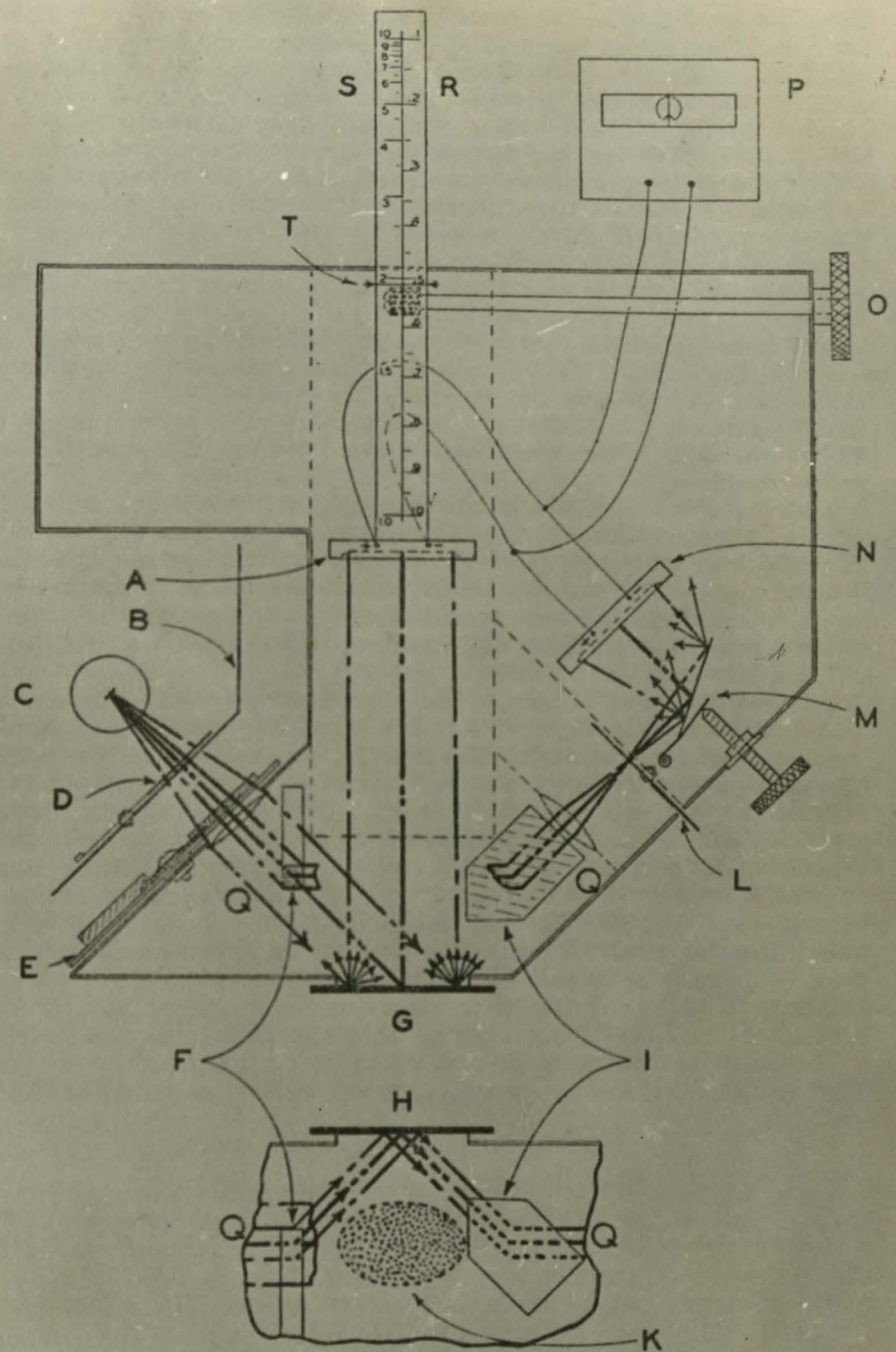



**FIGURE 7.**—*Diagram of multipurpose reflectometer.*

*A*, reflection photocell; *B*, aluminum shield; *C*, lamp; *D*, shutter; *E*, filter disk; *F*, small mirror which divides beam; *G*, reflection surface; *H*, gloss surface; *I*, aluminum mirror; *K*, cross section of area through which light passes between reflection surface and reflection photocell; *L*, disk containing gloss apertures; *M*, screw and semidiffusing reflector; *N*, gloss photocell; *O*, knob to move cells and scales; *P*, galvanometer; *R*, reflection scale; *S*, gloss scale; and T, index. Elevation through *Q*–*Q* at the bottom shows how light is directed up to the gloss surface, *H*, from the plane of the other beams of the instrument below.

Figure 19 - Diagram of Multipurpose Reflectometer

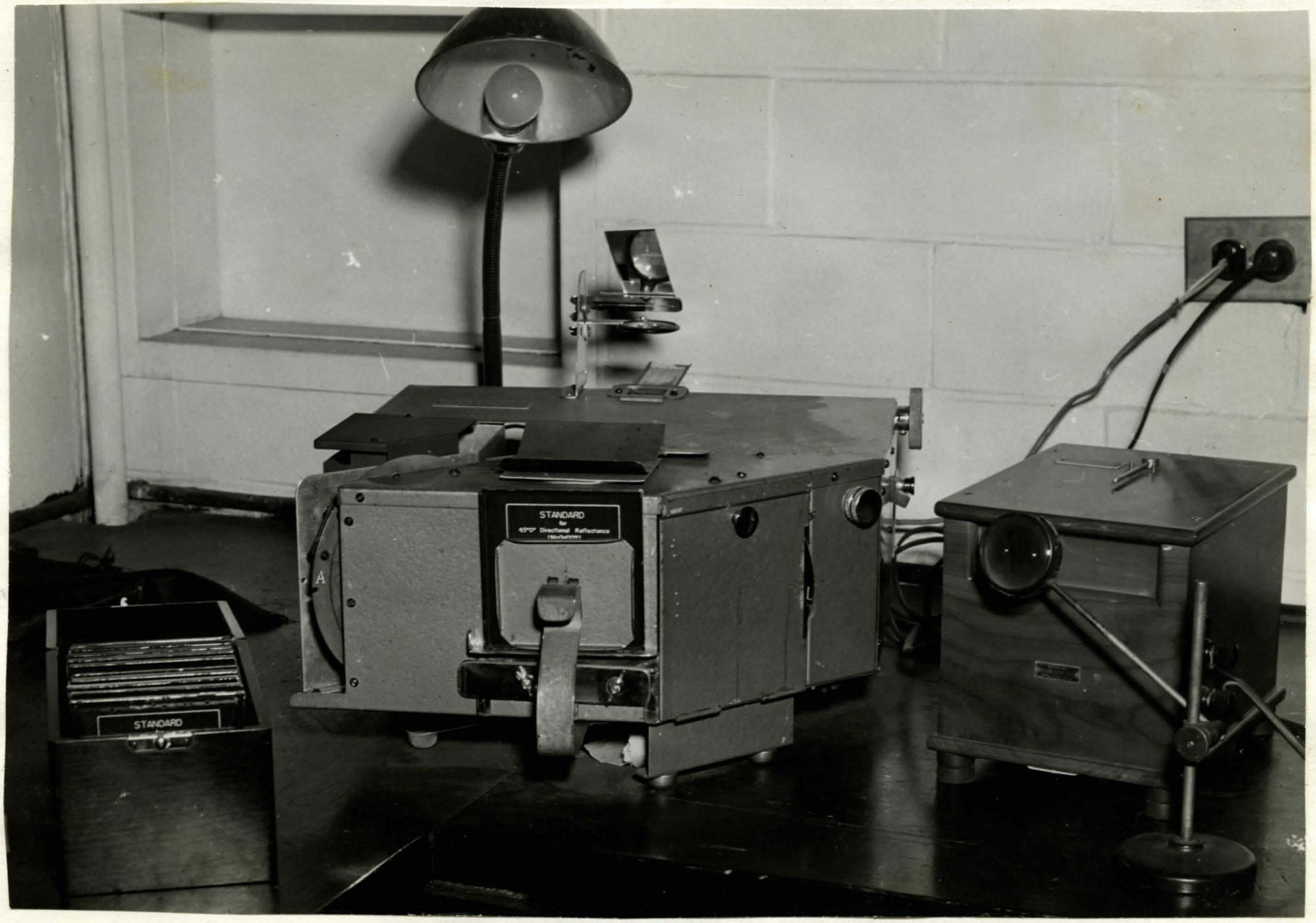



FIG. 20A HUNTER MULTIPURPOSE REFLECTOMETER

# EXPERIMENTAL

In general the experimental part of this work consisted of measuring the change in 45 degrees, 0 degrees, apparent reflectance, relative to a standard, through filters for tristimulus colorimetry .. The change in the apparent reflectance was brought about by exposure to ultra violet light. To begin with there were three identical sets of thirty panels each, out of which, two sets having the same 45 degree, 0 degree apparent reflectance had to be chosen. Each set was further divided into six sets having the follow- paint compositions spray coated on them.

All panels were sprayed on both sides with 52-P-18 zinc chromate primer and air dried at least 72 hours. Two coats of colors were then sprayed on each panel, allowing at least 72 hours air drying between coats.

COMPOSITION OF COLOR PAINTS

The vehicle for all the colors was the same, namely, Glyptol number 2504 reduced with mineral spirits to 50 per cent N.V. and napthenate driers and National Aniline Anti-Skin Agent added as follows: 0.075% cobalt, 0.5% lead and 0.4% anti skin agent, based on the non-volatile. Viscosity of the above was from F-G. Constants on glyptol number 2504.

CONSTANTS OF SOLUTION:

Solids Content --- Weight.....59-61%

Solvent -------Petroleum Spirits

Viscosity (G.H.) . . . . . U-W

Color- - -(Gardner). . . . . 8 Man

Acid No. of Solution . . . . . 4-6

Pounds per gallon . . . . . 7.7

RESIN SOLIDS CONSTANTS:

Phthalic Anhydride . . . . . 24%

Rosin or derivative . . . . . None

Phenolic Resins . . . . . None

Oil Acids Content . . . . . 60%

Type of oil . . . . . Soya

PIGMENTS:

Yellows:

Y-1-3#-#2518 Ex. Lt. Yellow Per Gal. Vehicle

1-Y-1 - 1½# #2518 Ex. Lt. Yellow Per Gal. Vehicle
1-Y-2 -1½" # 2601½ Lt. Yellow

Y-2-3#-#2601½ Lt. Yellow

1-Y-2 - 1½# -#2601½ Lt. Yellow Per Gal. Vehicle
1-Y-3 - 1½# -#2603 Med. Yellow Per Gal. Vehicle

Y-3-3#-#2303 - Med. Yellow Per Gal. Vehicle

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Oranges:

O-1 -#3 - #2604 Lt. Yellow Per Gal. Vehicle

1-O-1 -1½# -#2604 Lt. Orange Per Gal. Vehicle
1-O-2 -1½# -#2213 Med. Orange

O-2-3# -#2213 Med. Orange Per Gal. Vehicle

O-3-3# -#2209 Dr. Orange Per Gal. Vehicle

O-4-3# -#2206 Ex. Dark Orange

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Reds:

R-1-12 oz # 1077 Ex. Lt. Toluidine, Per Gal. Vehicle

R-3-12 oz # 1073 Dk. Toluidine Per Gal. Vehicle

2-R-3 - 18 oz # 1073 Dk. Toluidine Per Gal. Vehicle
1-R-5 - 4 oz # 1079 D.D.D.Toluidine Per Gal.Vehicle

1-R-3 -4oz # 1073 Dk. Toluidine Per Gal. Vehicle
2-R-5 -8oz # 1078 D.D.D. Toluidine Per Gal.Vehicle

R-5-12 oz #1078 D.D.D. Toluidine Per Gal. Vehicle

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Greens:

G-1-16 oz. #8405 Lt. Green Per Gal. Vehicle

G-2-16 oz. #8410 Med. Green Per Gal. Vehicle

2-G-2 -10.67 oz #8410 Med. Green Per Gal.Vehicle
1-G-3 - 5.33 oz #8425 Dk. Green Per Gal. Vehicle

G-3-16 oz- #8425 Dk. Green Per Gal. Vehicle

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Phthalocyanine Blues:

PB-1-4oz. #4845 Zulu Blue Per Gal. Vehicle
8 oz. Ti-Pure R-610*

3-PB-1 -4 oz. #4845 Zulu Blue Per Gal. Vehicle
1-PB-2- 6.5 oz. Ti-Pure R-610*

1-PB-1 - 4 oz. #4845 Zulu Blue
1-PB-2 - 5 oz. Ti-Pure R-610

1-PB-1 - 4 oz. #4845 Zulu Blue
3-PB-2 - 3.5 oz. Ti-Pure R-610 Per Gal. Vehicle

PB-2 - 4 oz. #4845 Zulu Blue
2 oz. Ti-Pure R-610 Per Gal. Vehicle

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Milori Blues:

MB-1 - 4 oz. #4022 Milori Blue Per Gal. Vehicle
8 oz. Ti-Pure R-610

3-MB-1 - 4 oz. #4022 Milori Blue Per Gal. Vehicle
1-MB-2 - 6.5 oz. Ti-Pure R-610 Per Gal. Vehicle

1-MB-1 - 4 oz. #4022 Milori Blue
1-MB-2 - 5 oz. Ti-Pure R-610 Per Gal. Vehicle

1-MB-1 - 4 oz. #4022 Milori Blue
3-MB-2 - 3.5 oz Ti-Pure R-610 Per Gal. Vehicle

MB-2 - 4 oz #4022 Milori Blue
2 oz Ti-Pure R-610 Per Gal. Vehicle

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

* Ti-Pure R-610 is Rutile non-chalking $TiO_2$

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Out of these three sets of panels, all having the same paint composition were put together for the determination of 0 degree, 45 degrees, apparent reflectance, on the Hunter Reflectometer. These reflectance readings were taken in the following manner:

The light source in the machine was turned on and the reflectometer was allowed to warm up for about fifteen minutes. This precaution was found necessary because small changes in the temperature of the machine caused a change in the reflecting surfaces thus giving an erroneous reading. This warming up of the instrument continued even after the first fifteen minutes, but the effect was not marked, however, constant care had to be taken to keep the adjustments corresponding to the standard used.

Standards consisted of a set of twelve metal plaques with magnesium oxide surfaces; each plaque had a different value or degree of greyness. The plaques with a smaller degree of greyness were used for lighter colors, while those with a lighter degree of greyness were used for deeper colors which reflected less light. The readings for Blue, Green, and Amber filters were specified on each standard and the instrument was set corresponding to these readings and with the help of the screw controlled the reflecting surface M in figure 7, or by varying the apertures on the disc E. The standard was replaced by the panel and the readings for B, A, G, filters taken. Readings taken for each of the three filters were in the order B,A, and G. The reason for following this sequence was that the reflectance is not very much with a blue filter hence the reading can be taken easily, without moving violently the mirror attached to the quartz wire in the galvanometer. Otherwise stresses imparted to the

wire might be released later on, when least expected; giving a ridiculous reading. To be on the safe side, before taking the final reading, the scale on the reflectometer was slowly moved so that a very small current passed through the galvanometer, shifting the mirror slightly. By repeating this a couple of times it was insured that all the stresses in the wire were released.

Care was taken that there was no draft in the room, which might change the temperature of the instrument.

Probably the heating up of the instrument had some effect on the photocells. There are some absorbed as well as adsorbed gases on the elements of the photocells, which are given off on heating, thus changing the nature of the atmosphere of the cell.

If this phenomenon was taking place then it is evident that an equilibrium was reached after some time because after a certain time the readings remained constant. As has been explained before different sized apertures are provided in the instrument for the light passing on to the gloss cell. The size of the aperture had to be decreased sometimes to cut out some of the light going to the gloss cell.

In this way the readings for all the panels were taken and out of the three presumably identical panels, two having the same or nearly the same readings were separated. In this way two sets of thirty panels each were obtained.

One of these sets was kept for future reference and the panels in the other were exposed to the ultra violet light in the weathering unit. The exposure was dry and was for about twelve hours at a time, although it had to be increased to twenty four hours as the change in the reflectance became small.

Actually the exposed panels were divided into two sets of fifteen each and one set was exposed while the other was being measured for 0 degrees, 45 degrees apparent reflectance. After each exposure the panels were allowed to come to room temperature before the readings were taken. Also care was taken that panels were inserted in the reflectometer in exactly the same position, every time. This procedure was continued till all the panels had been exposed for about three hundred hours.

Readings of the reflectometer are given in the appendix. A sample calculation is shown in Table I. for the panel 1-PB-1, 3-PB-2. The rest of the calculations have been omitted and only the calculated results have been shown in the Tables II to XXVII.

H' - Change in Hue

S' - Change in Saturation

L' - Change in Brightness

These values of Brightness, Saturation and Hue have been plotted with respect to exposure time in the graphs in figure 1-28, showing the general trend of the

qualities of a color. From experience and general observations an empirical equation has been developed by the paint industry, correlating hue, brightness, and saturation.

$$\text{Permanence} = 4G + 2S + H$$

where

G = Greyness or Brightness

S = Saturation

H = Hue

It has been found that as long as the sum of these three terms of the equation is less than ten, the customer will not object to the change in color. But when this value goes beyond fifteen then the customer can easily notice the change in color and will object to it.

The above mentioned equation is true for darker colors, because the change in Hue is not objected to as much as the change in Brightness. On the other hand in case of yellows, the change in Hue is considered undesirable even though there may be considerable greying. As a rule customers do not like a yellow going towards red or green. Hence for yellow pigments the equation should be modified and becomes,

$$P = 4G + S + 2H$$

In both cases when the value of S is positive, it should be omitted. Thus by picking values of G, S, and H from the curves, values of permanence can be calculated and rate curve can then be drawn, as is shown in figure 29, the data for which is given in table XXVIII.

Three panels have been selected for this table namely PB-1, PB-2, and a 1:3 mixture of these two pigments. From the curves on page 84, it can be seen that up to about 150 hours the individual pigments have a tendency to change at a rate which is less than that of the mixture. However, after 200 hours the permanence rate of the mixture becomes comparable to that of the individual pigment. Anyway, the final permanence value, in all three cases, is well within the limiting value of ten. In this series of Blues the panel with the mixture 1-PB-1, 1-PB-2, has not been considered as the value of S' and H' were too high to be correct, evidently there was some error in the original readings of the reflectometer.

These rate curves could be drawn for the rest of the pigments but this long procedure is unnecessary for the present purposes. A more convenient and quite adequate way is to simply determine the Permanence after 300 hours and see whether it is below ten or not. Permanence values have been calculated for the rest of the panels and given in the table XXIX.

TABLE II

PERMANENCE- $\frac{4G + 2S + H}{10}$ (OMIT POSITIVE VALUES OF S)

PANEL - PB- 2

| Hrs. | G. | S. | H. | Rate |
|---|---|---|---|---|
| 25 | -1.2 | 0.0 | 2.6 | 0.74 |
| 50 | -1.4 | 0.0 | 4.2 | 0.98 |
| 75 | -1.6 | 0.0 | 5.0 | 1.14 |
| 100 | -1.6 | -1.6 | 5.3 | 1.49 |
| 125 | -1.6 | -3.2 | 5.6 | 1.84 |
| 150 | -1.2 | -4.8 | 5.9 | 2.03 |
| 175 | -0.4 | -6.4 | 6.0 | 2.04 |
| 200 | 0.0 | -8.0 | 6.0 | 2.20 |
| 225 | 0.0 | -9.6 | 6.0 | 2.25 |
| 250 | 0.0 | -4.2 | 6.0 | 2.84 |
| 275 | 0.0 | -12.6 | 6.0 | 3.12 |
| 300 | 0.0 | -13.4 | 6.0 | 3.28 |

TABLE II (cont'd)

PANEL - PB-1

| Hrs | G. | S. | H. | Rate |
|---|---|---|---|---|
| 25 | 0.0 | 2.4 | 1.6 | 0.16 |
| 50 | 0.0 | 3.6 | 4.6 | 0.46 |
| 75 | 1.2 | 3.4 | 6.4 | 1.12 |
| 100 | 1.4 | 1.6 | 7.0 | 1.26 |
| 125 | 1.6 | 0.2 | 7.6 | 1.44 |
| 150 | 1.8 | 2.0 | 7.8 | 1.90 |
| 175 | 1.9 | 3.6 | 7.8 | 2.26 |
| 200 | 2.0 | 5.4 | 7.8 | 2.66 |
| 225 | 2.2 | 7.2 | 7.8 | 3.10 |
| 250 | 2.4 | 8.8 | 7.8 | 3.50 |
| 275 | 2.6 | 10.4 | 7.8 | 3.90 |
| 300 | 2.8 | 12.0 | 7.8 | 4.70 |

TABLE II (cont'd)

PANEL 1-PB-1
3-PB-2

| Hrs | G. | S. | H. | Rate |
|---|---|---|---|---|
| 25 | -2.0 | -0.4 | 2.0 | 0.16 |
| 50 | -2.4 | -1.0 | 3.8 | 0.46 |
| 75 | -2.7 | -1.4 | 4.2 | 1.12 |
| 100 | -2.8 | -1.9 | 4.6 | 1.26 |
| 125 | -3.2 | -2.4 | 5.0 | 1.44 |
| 150 | -3.3 | -2.8 | 5.4 | 1.90 |
| 175 | -3.5 | -3.2 | 5.7 | 2.26 |
| 200 | -3.6 | -3.6 | 6.0 | 2.66 |
| 225 | -3.7 | -4.0 | 6.4 | 3.10 |
| 250 | -3.8 | -4.5 | 6.8 | 3.50 |
| 275 | -3.9 | -5.0 | 7.2 | 3.90 |
| 300 | -4.0 | -5.5 | 7.7 | 4.70 |

## TABLE XXIX

### PERMANENCE RATING

| | | |
|---|---|---|
| 4. | 1-R-5<br>2-R-3 | 0.88 + 9.5 + 0.5 = 10.84 |
| 5. | MB-5 | 0.80 + 9.2 + 0.5 = 10.5 |
| 6. | MB-1 | 2.0 + 28 + 3 = 33.0 |
| 7. | MB-2 | 0.4 + 72 + 5.2 = 77.6 |
| 8. | 1-MB-2<br>3-MB-1 | 2.0 + 31.6 + 5.4 = 39.0 |
| 9. | 1-MB-1<br>1-MB-2 | 4.0 + 28.0 + 6.0 = 38.0 |
| 10. | 1-MB-1<br>3-MB-2 | 2.4 + 29.2 + 5.4 = 37.0 |
| 11. | 0-2 | 0.0 + 9.4 + 1.7 = 11.1 |
| 12. | 0-3 | 5.2 + 3.0 + 1.4 = 9.6 |
| 13. | 1-0-1<br>1-0-2 | 1.2 + 8.8 + 1.5 = 11.5 |
| 14. | 0-4 | 0.0 + 10.0 + 1.7 = 11.7 |
| 15. | 0-1 | 0.8 + 13.6 + 2.8 = 17.2 |
| 16. | Y-1 | 47.2 + 18.0 + 0.6 = 71.2 |
| 17. | 1-Y-1<br>1-Y-2 | 30.4 + 1.0 + 1.5 = 32.9 |
| 18. | Y-2 | 40.4 + 5.0 + 0.0 = 45.4 |
| 19. | 1-Y-3<br>1-Y-2 | 34.4 + 4.2 + 0.3 = 38.9 |
| 20. | Y-3 | 16.0 + 4.2 + 4.0 = 24.2 |

TABLE XXIX (cont'd)

| | | |
|---|---|---|
| 21. | G-1 | $\bar{0.4} + \bar{20.6} + \bar{5.3} = 26.3$ |
| 22. | G-3 | $\bar{4.0} + \bar{15.6} + \bar{2.2} = 21.8$ |
| 23. | 1-G-2<br>2-G-3 | $\bar{0.4} + \bar{19.6} + \bar{2.0} = 22.0$ |
| 24. | 2-G-2<br>1-G-3 | $\bar{4.4} + \bar{19.0} + 2.7 = 26.1$ |

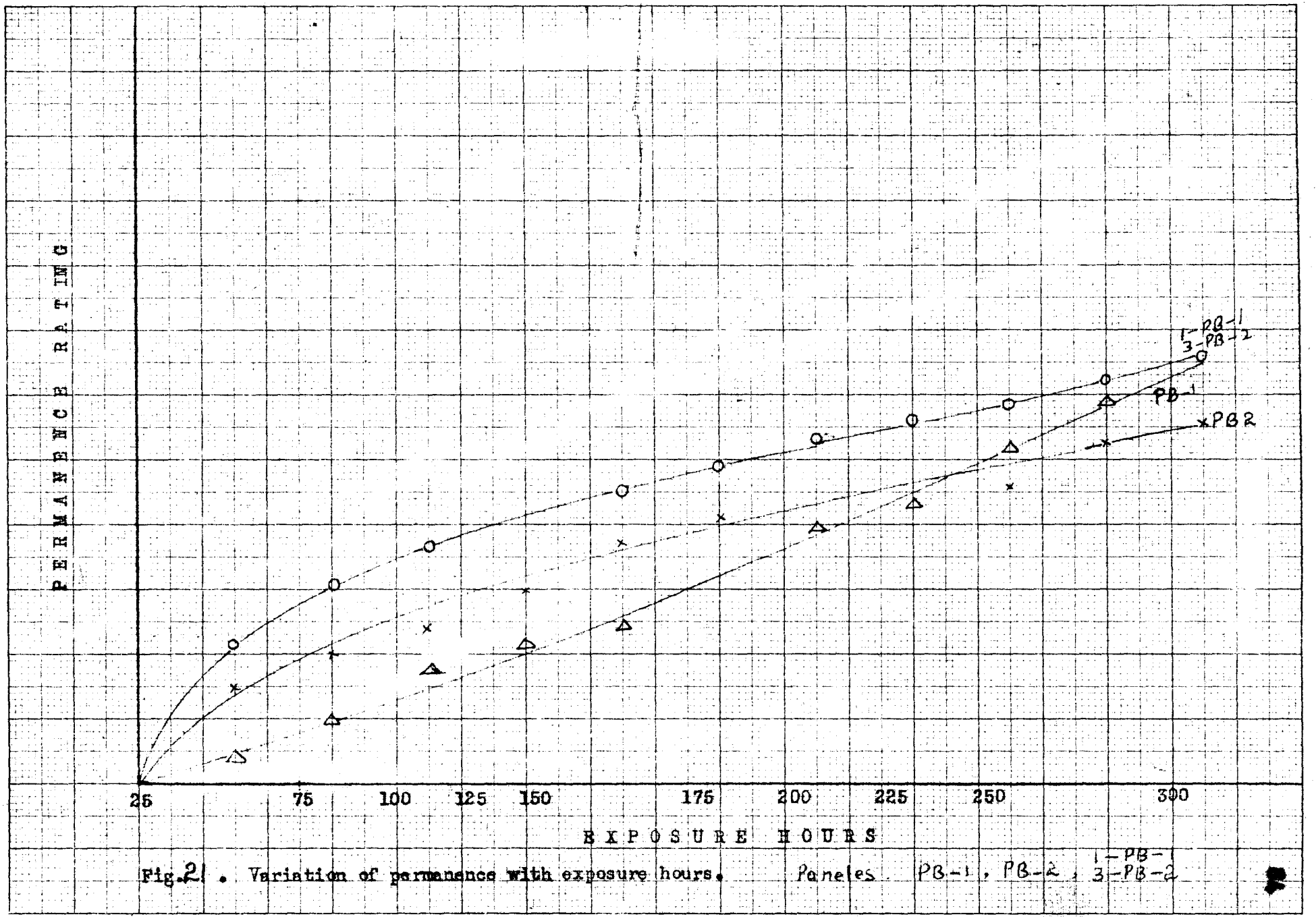



Fig. 2. Variation of permanence with exposure hours. Panels PB-1, PB-2, 1-PB-1, 3-PB-2

The results of the above calculations show that with the exception of panels number 4, 5, 11, 12, 13, and 14 of Table number XXIX the other panels have exceeded the permanence limit but permanence values of panels number 7, 16, and 18 are too high to be true, indicating some error in original readings.

The curves for panel R-5 show that there is an increase in saturation S' over the original color which is quite desirable.

In the Y series the results for the panel 1-Y-2, 1-Y-3 are intermediate between those of Y-2 and Y-3. The saturation, hue, and brightness curves for Y-1 again seem to be off. Probably the initial readings were incorrect.

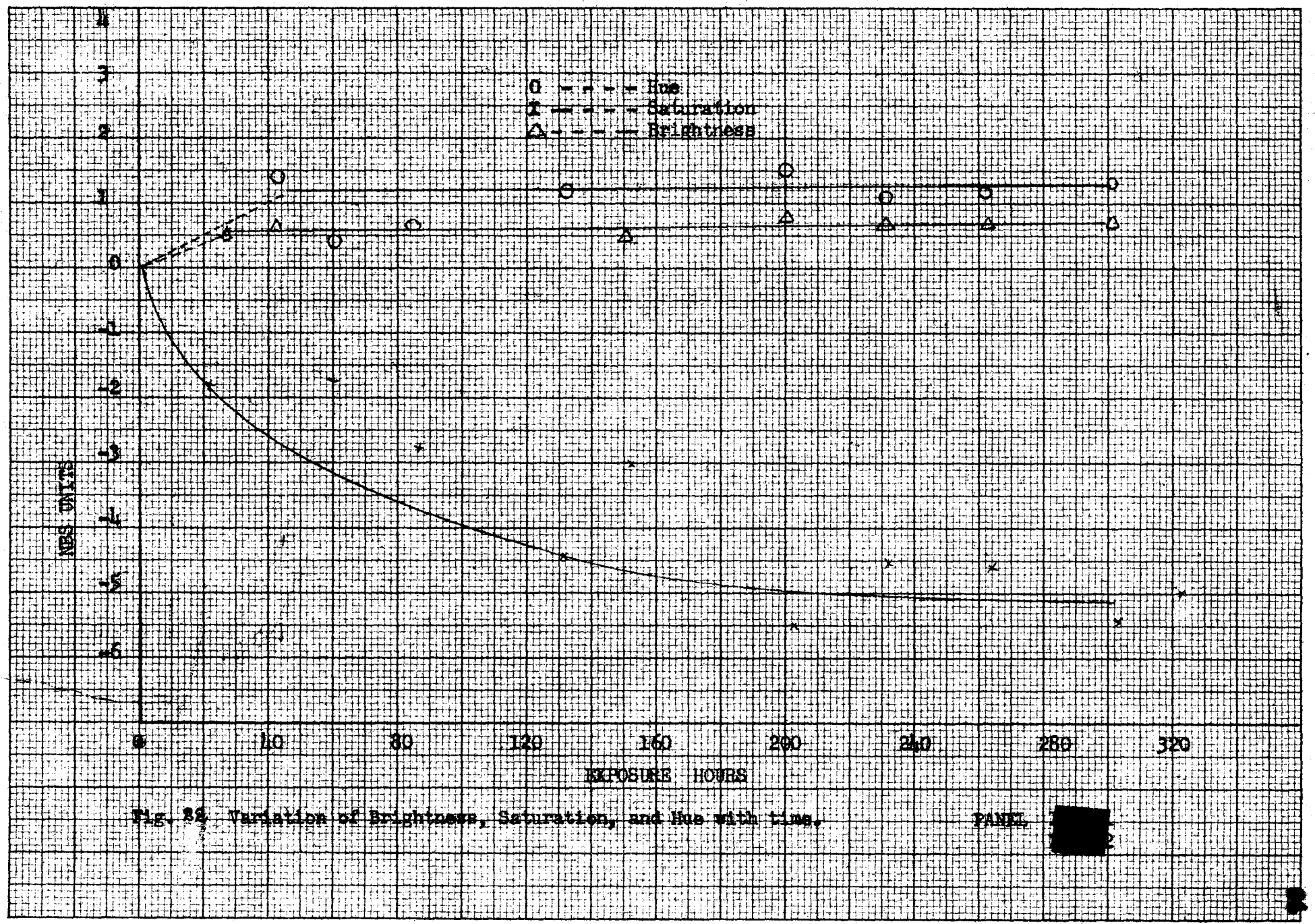



Fig. 84 Variation of Brightness, Saturation, and Hue with time.

PANEL [redacted]

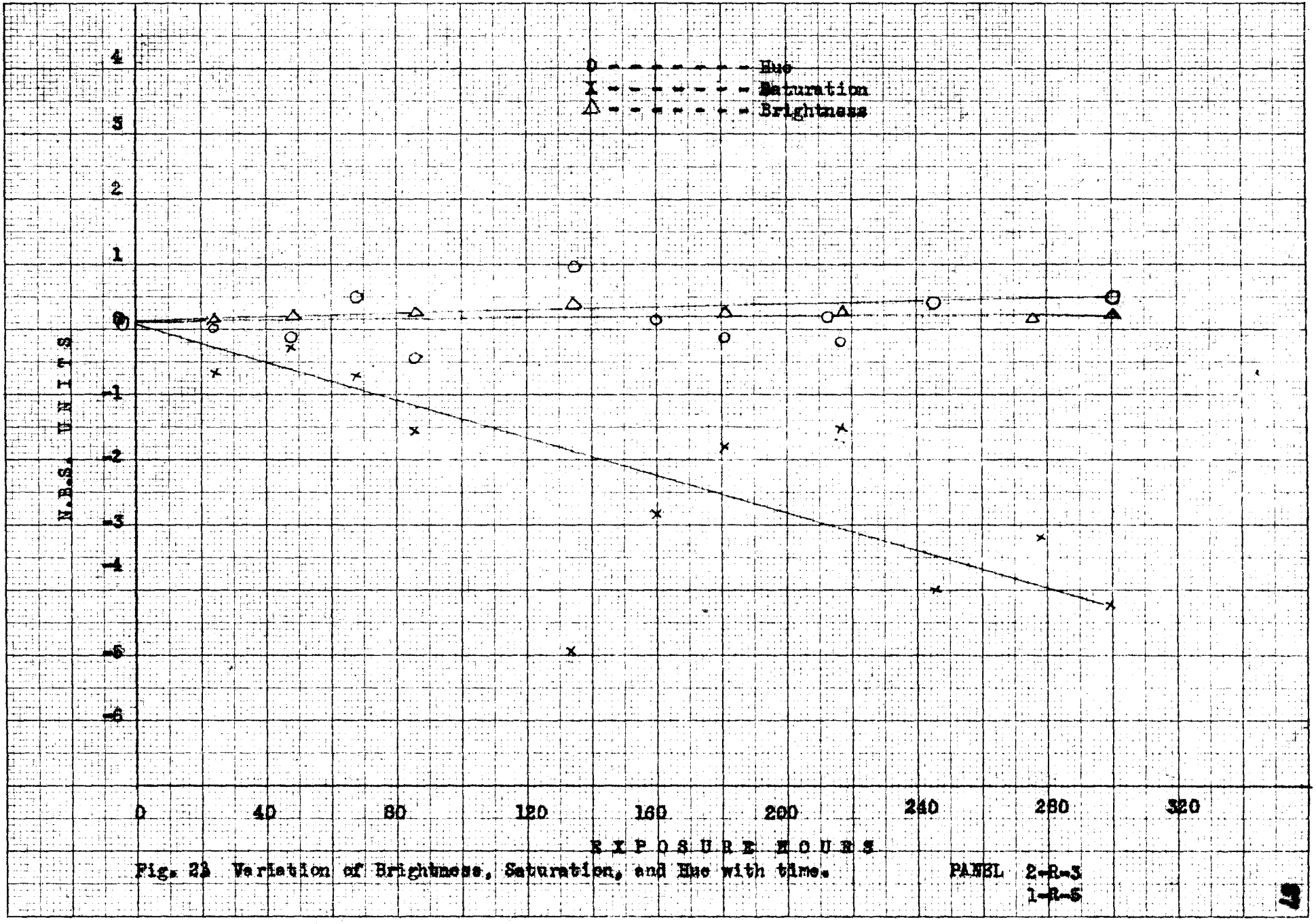



Fig. 23 Variation of Brightness, Saturation, and Hue with time. PANEL 2-R-3
1-R-5

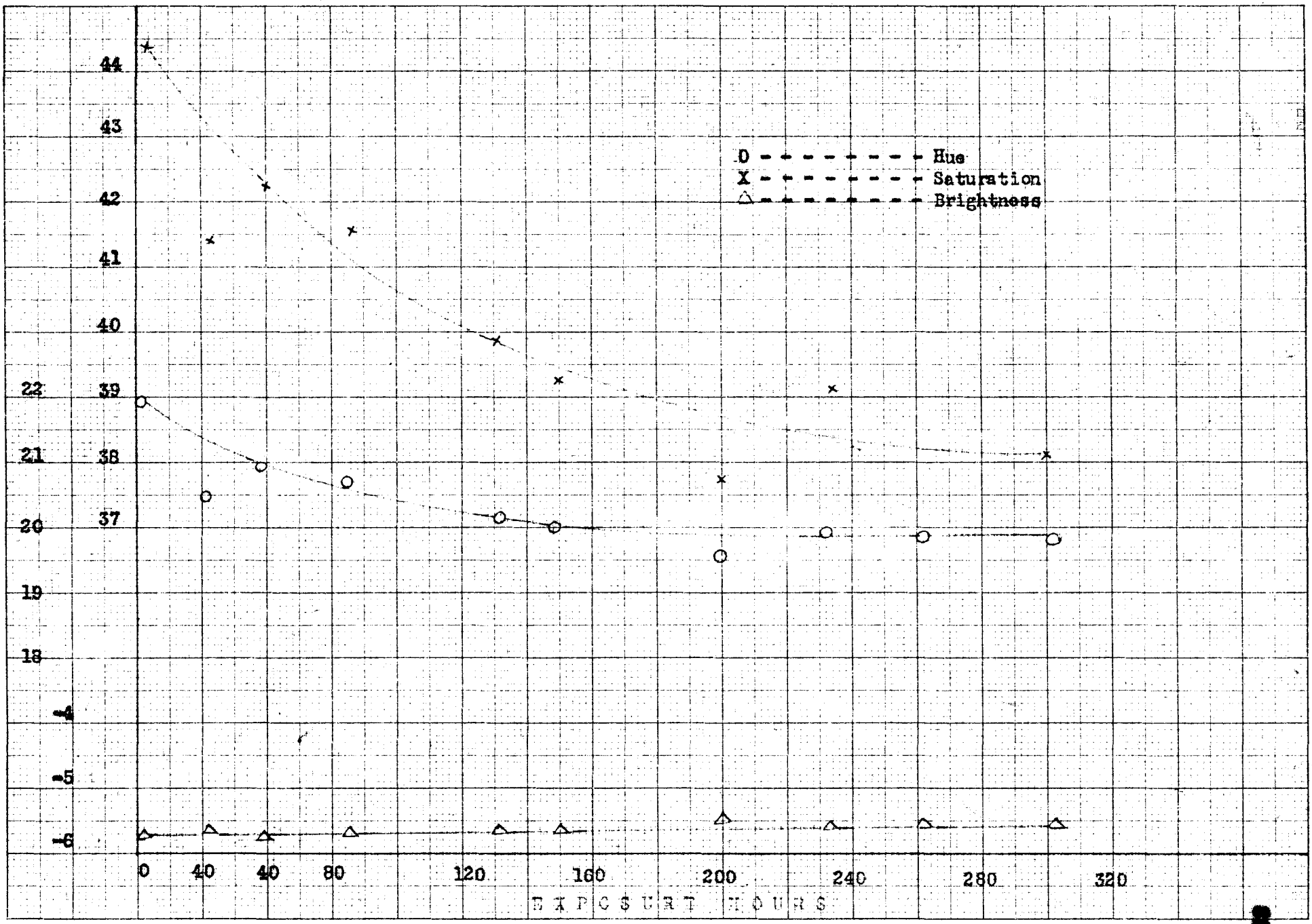



Fig. 84. Variation of Brightness, Saturation, and [illegible]

I-R-3
2-R-1

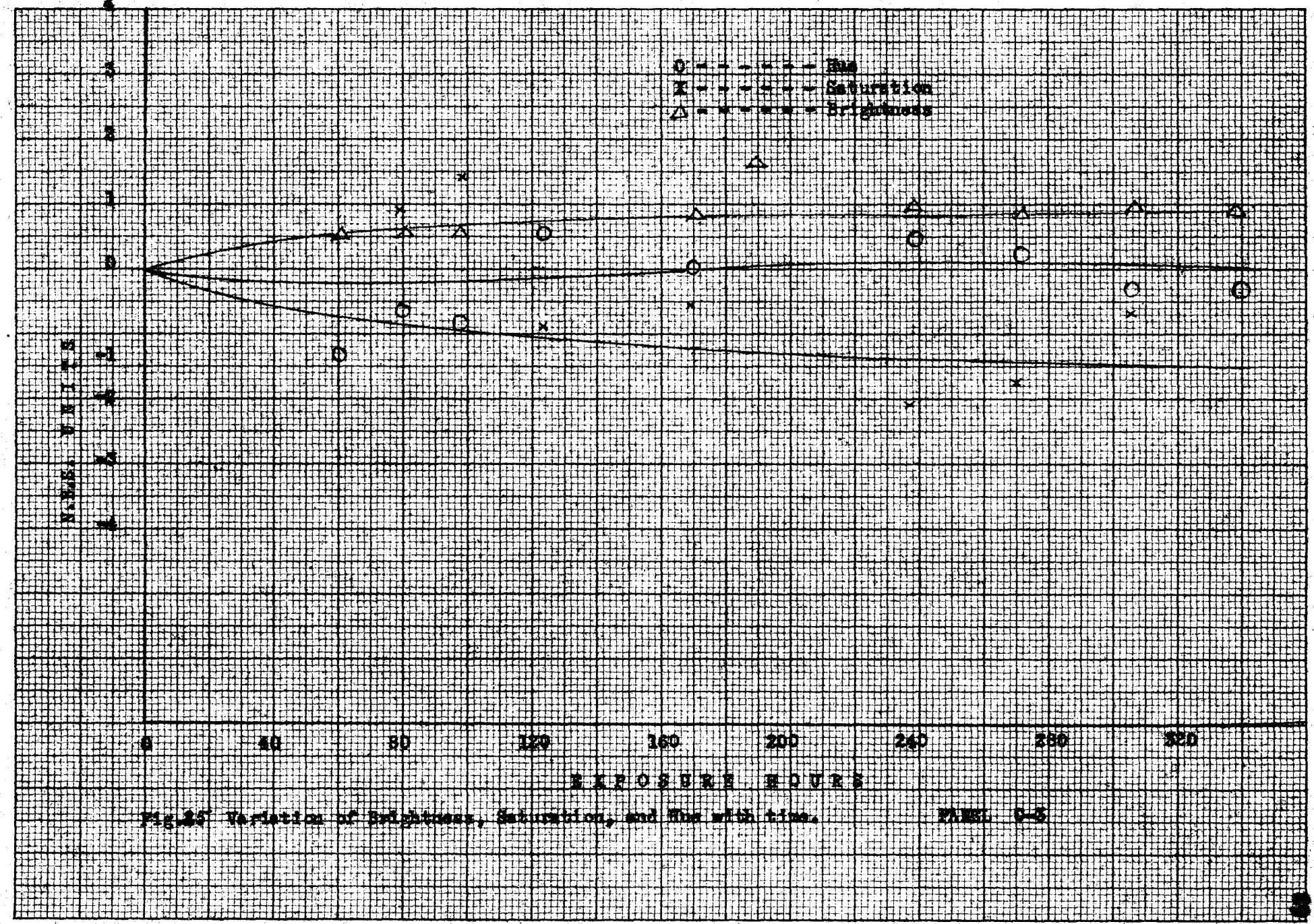



Fig. 25 Variation of Brightness, Saturation, and Hue with time. PANEL P-5

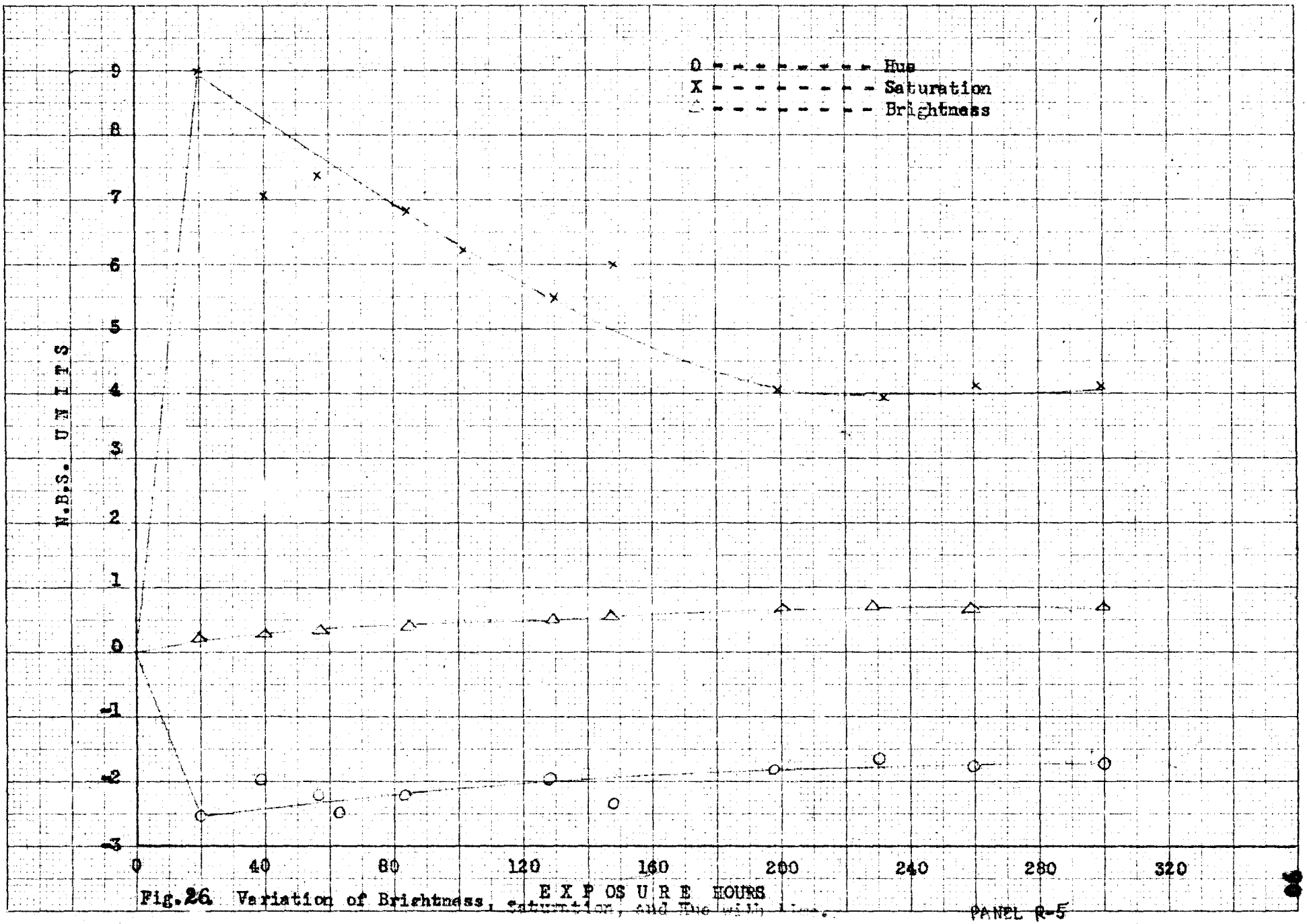



Fig.26 Variation of Brightness, Saturation, and Hue with time.

PANEL R-5

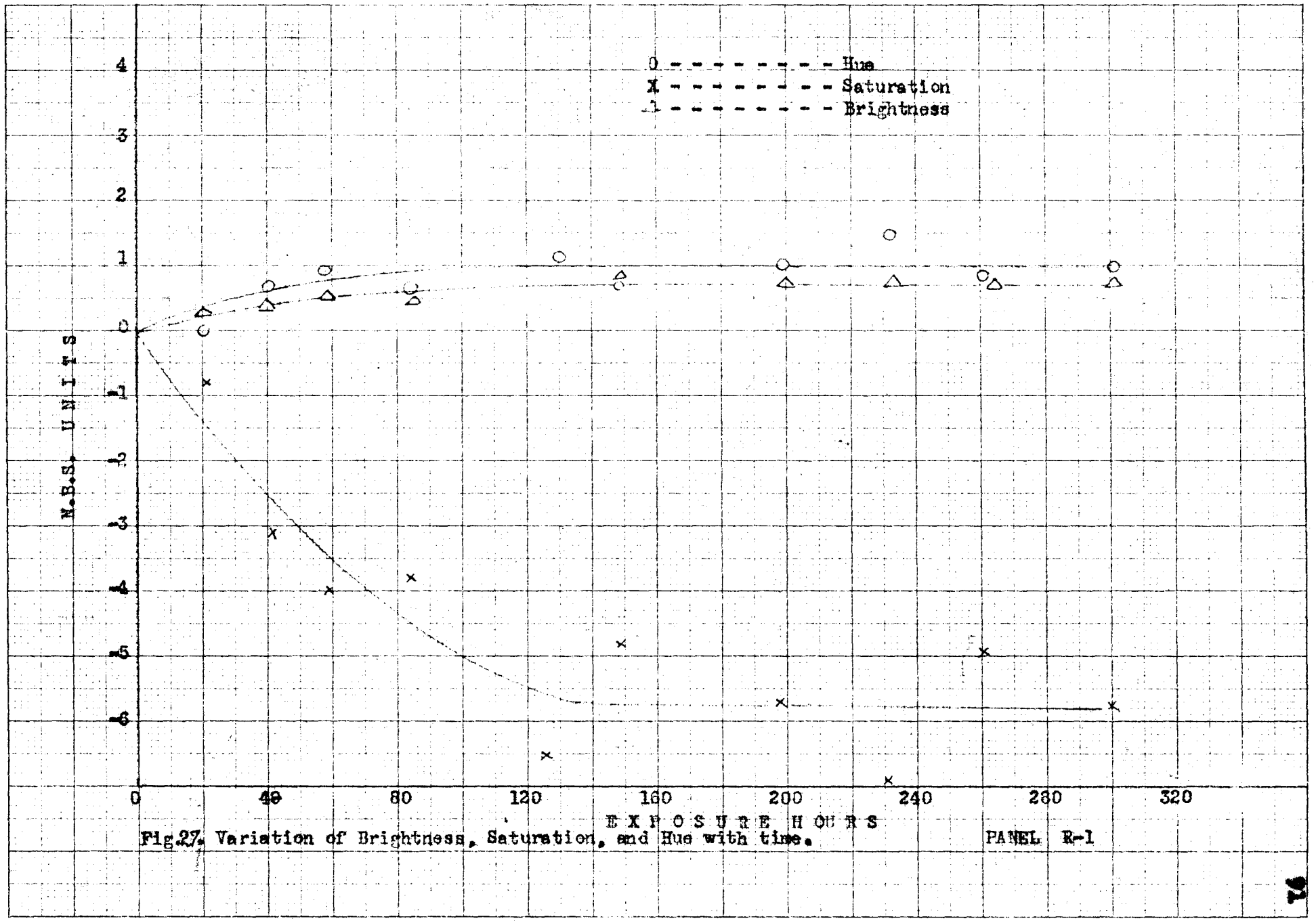



Fig.27. Variation of Brightness, Saturation, and Hue with time. PANEL R-1

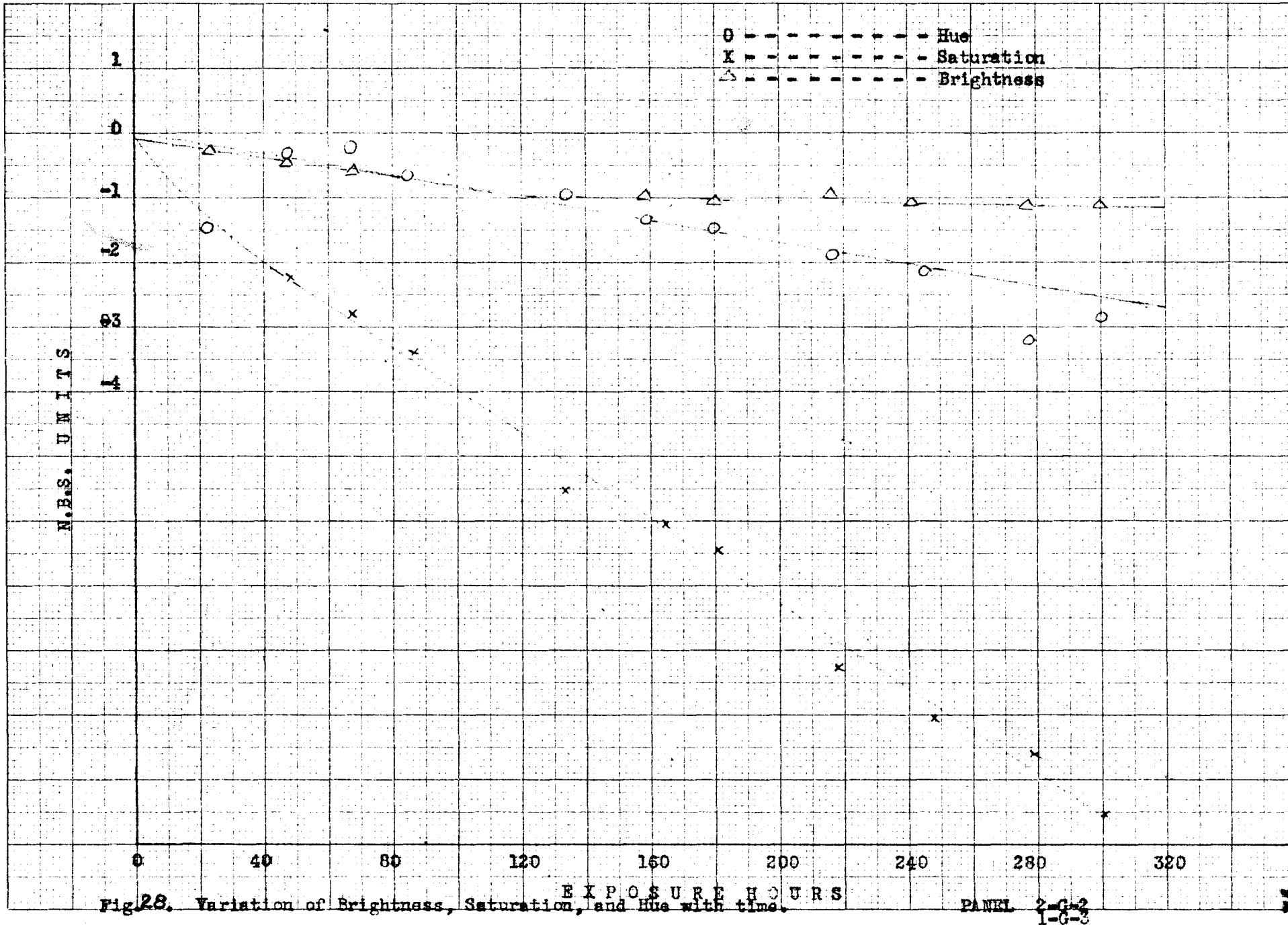



Fig.28. Variation of Brightness, Saturation, and Hue with time.

PANEL 2-C-2
1-C-3

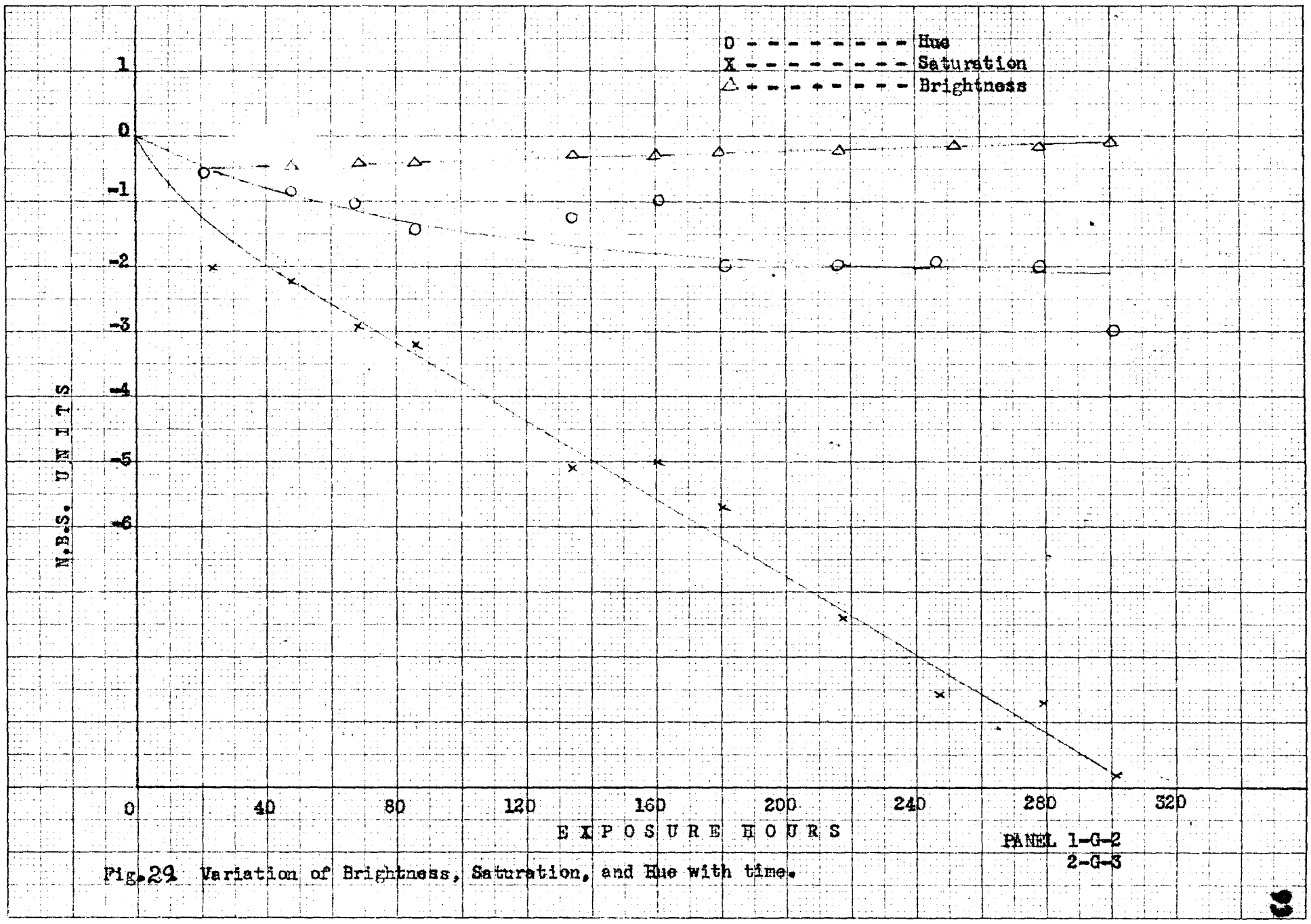



Fig. 29 Variation of Brightness, Saturation, and Hue with time.

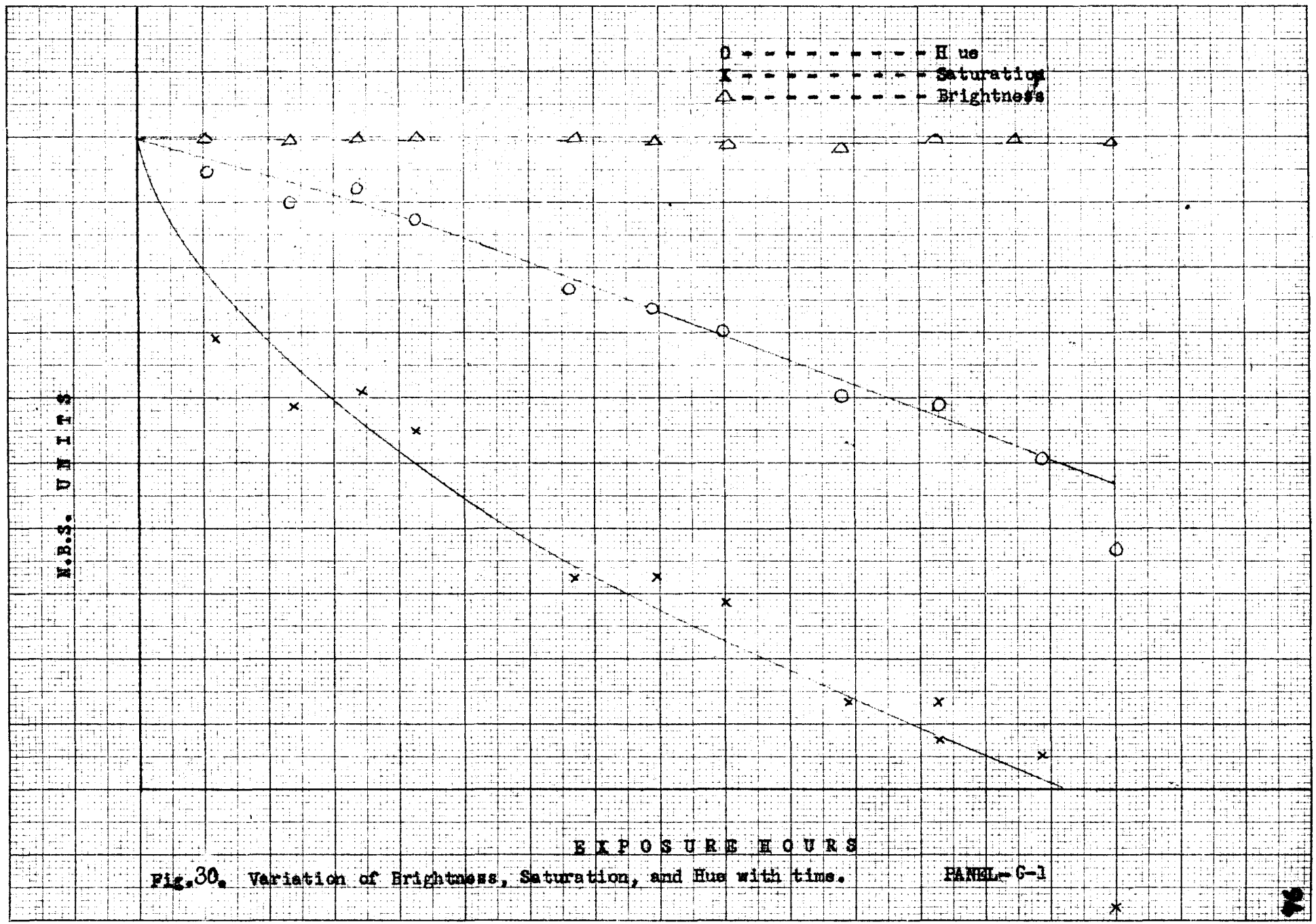



Fig.30. Variation of Brightness, Saturation, and Hue with time. PANEL-C-1

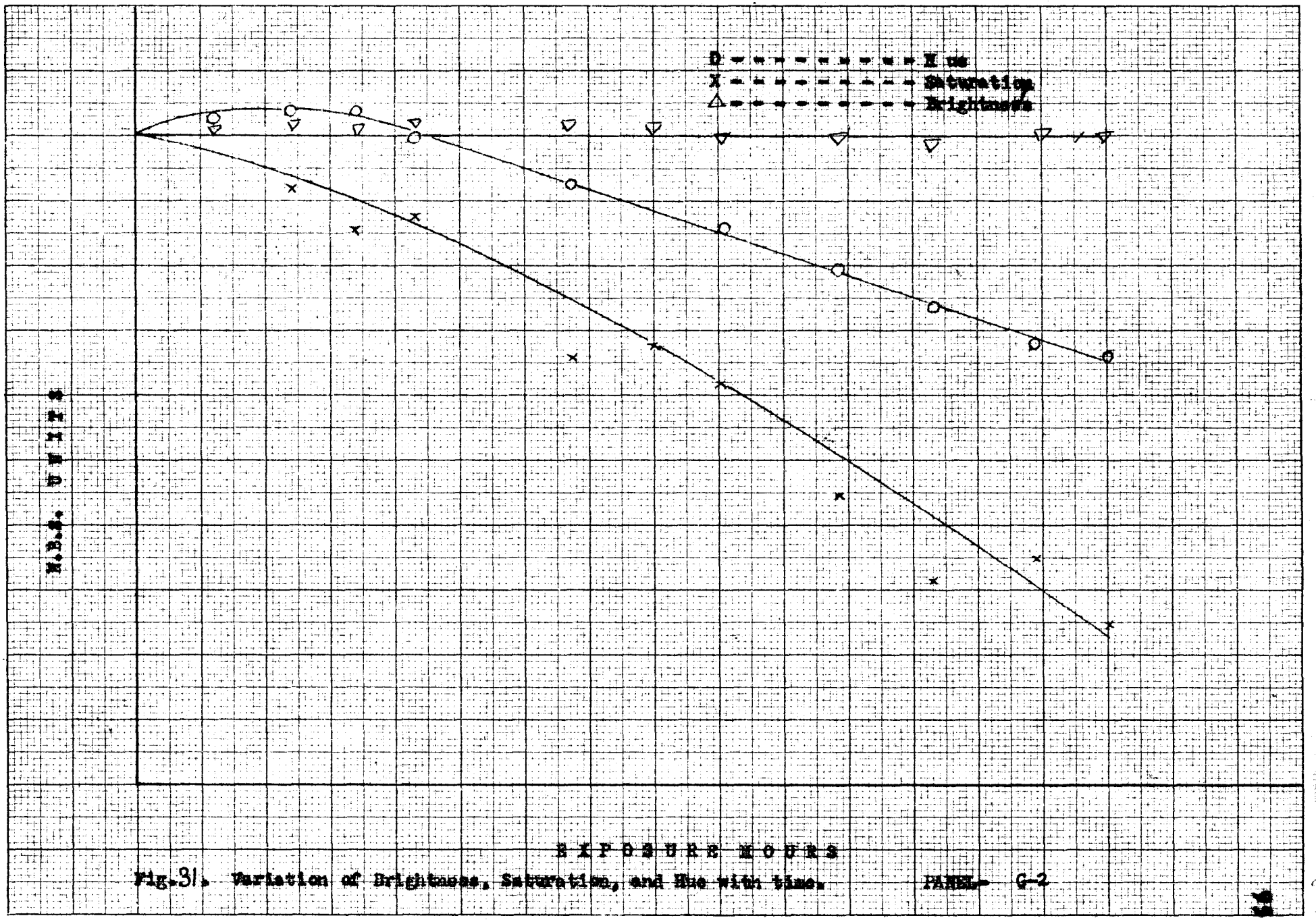



Fig.31. Variation of Brightness, Saturation, and Hue with time. PANEL- G-2

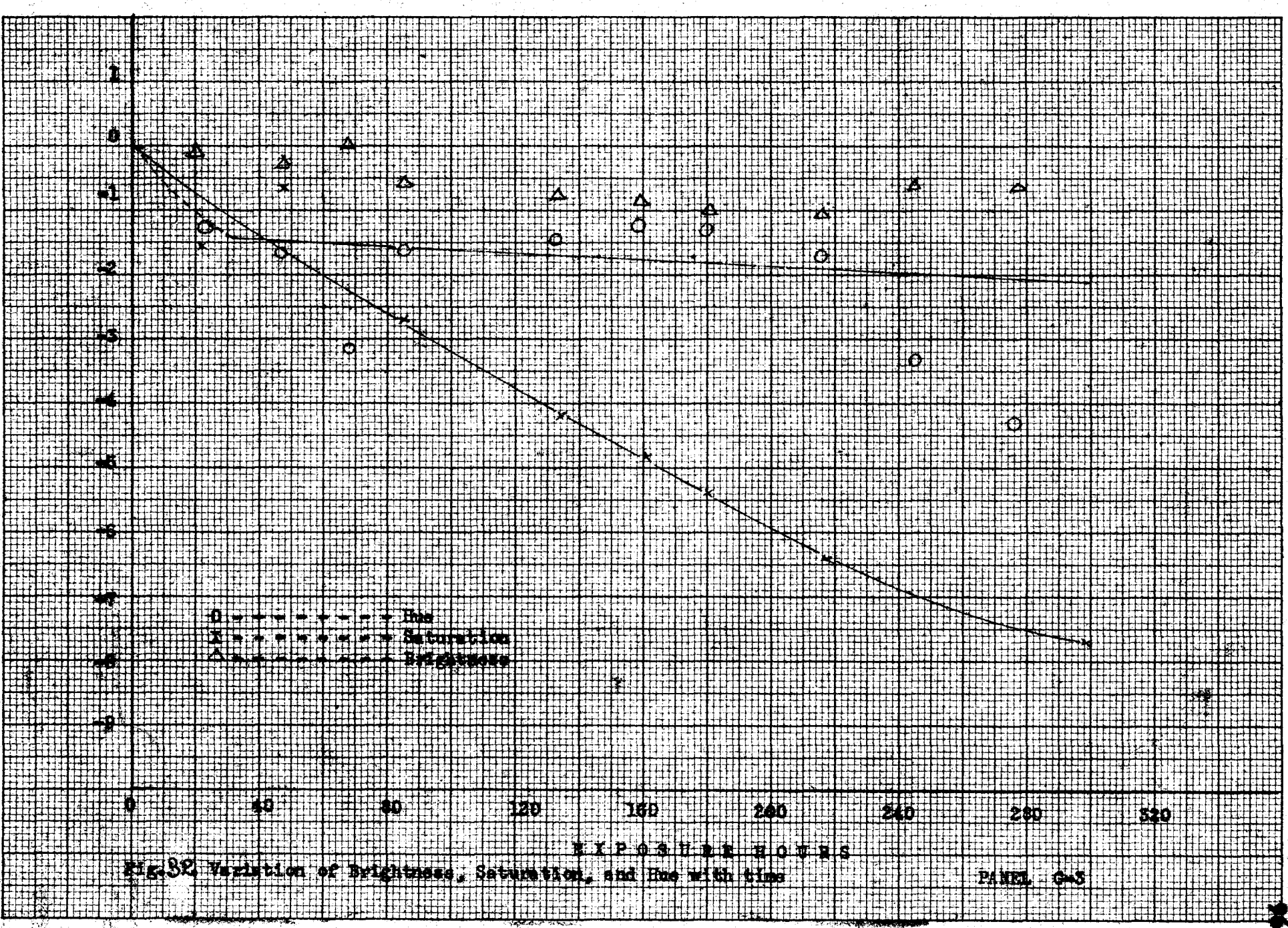



Fig.32 Variation of Brightness, Saturation, and Hue with time PANEL G-3

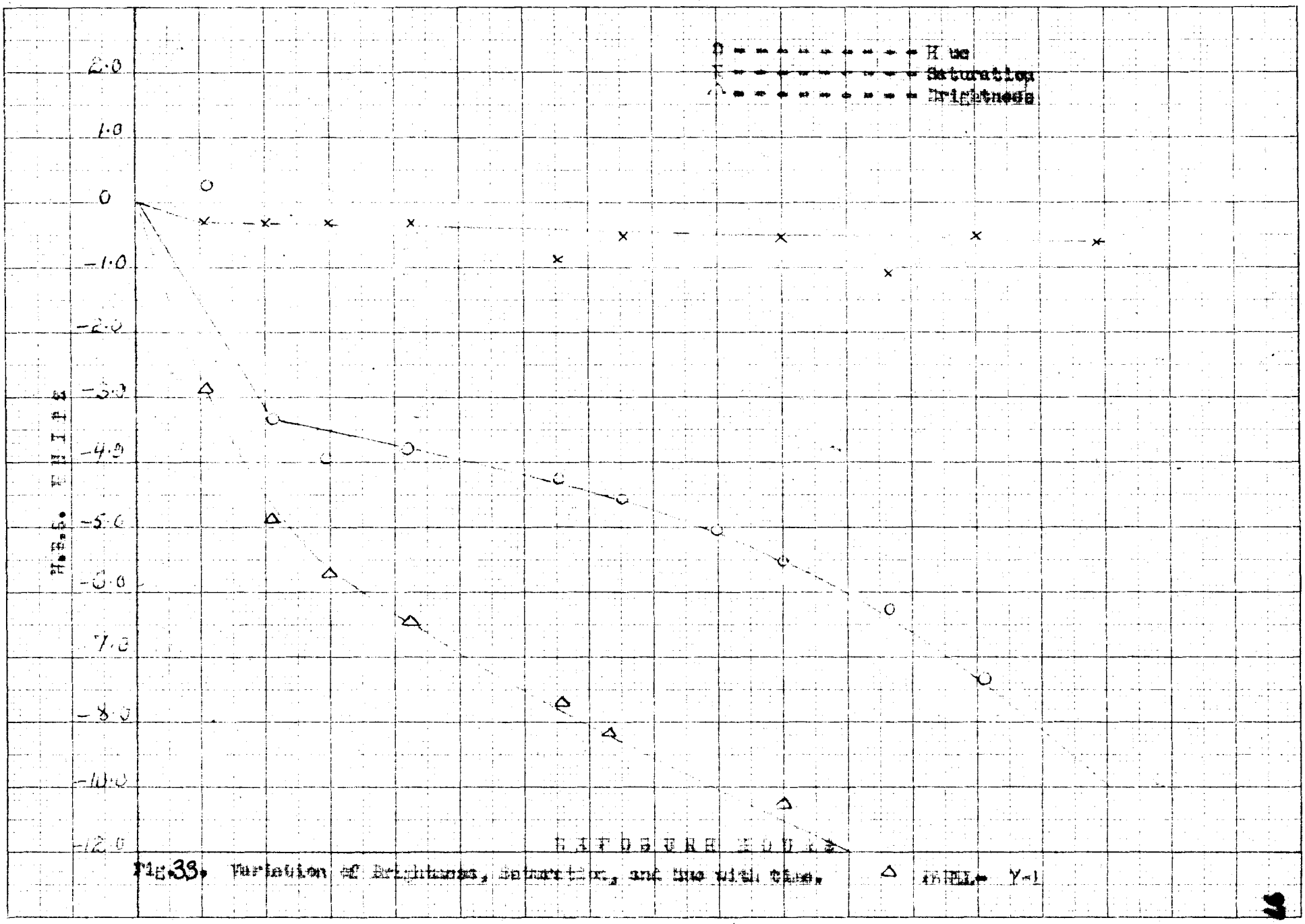



Fig.38. Variation of Brightness, saturation, and hue with time. △ SHELL Y-1

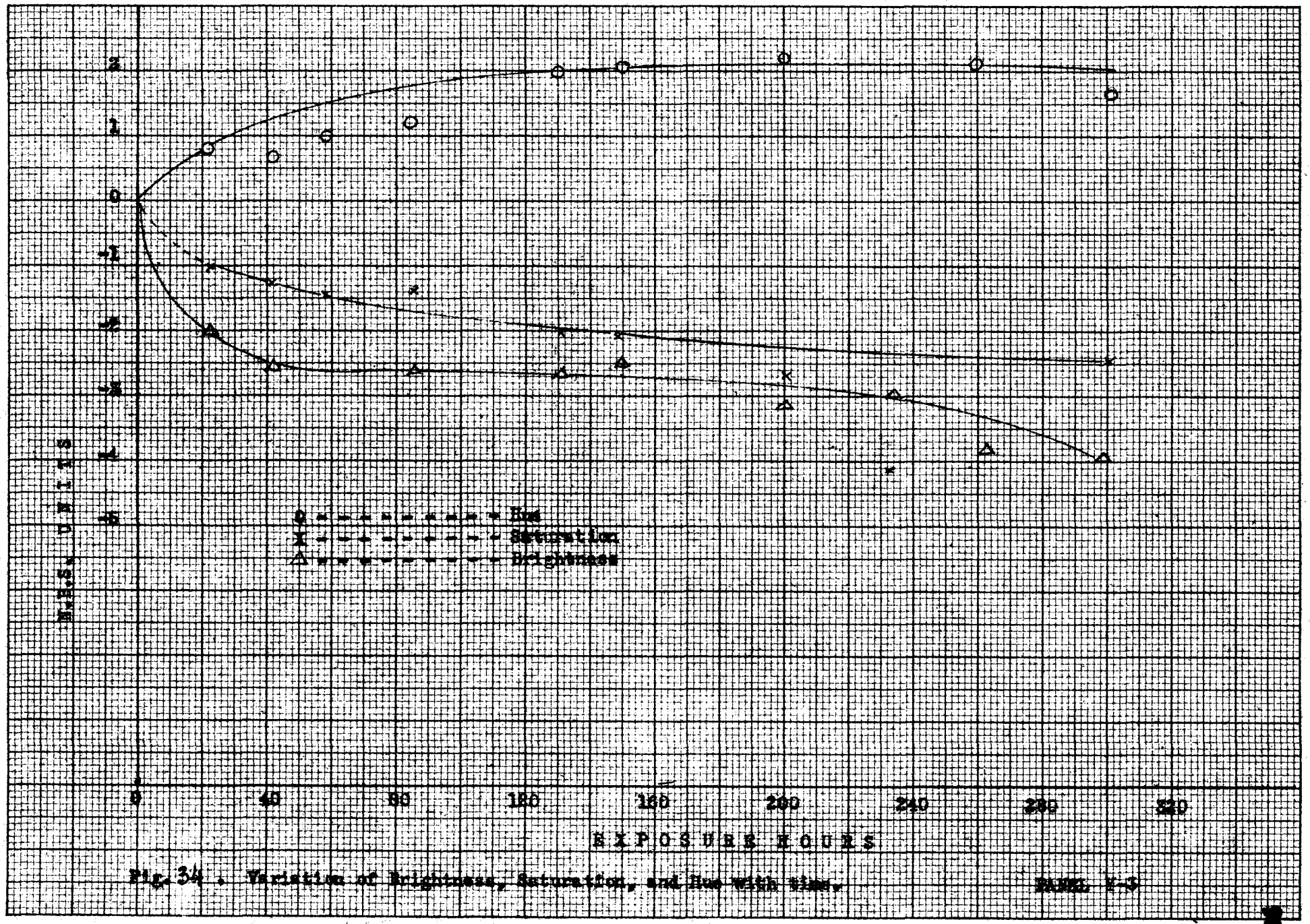



Fig. 34. Variation of Brightness, Saturation, and Hue with time.

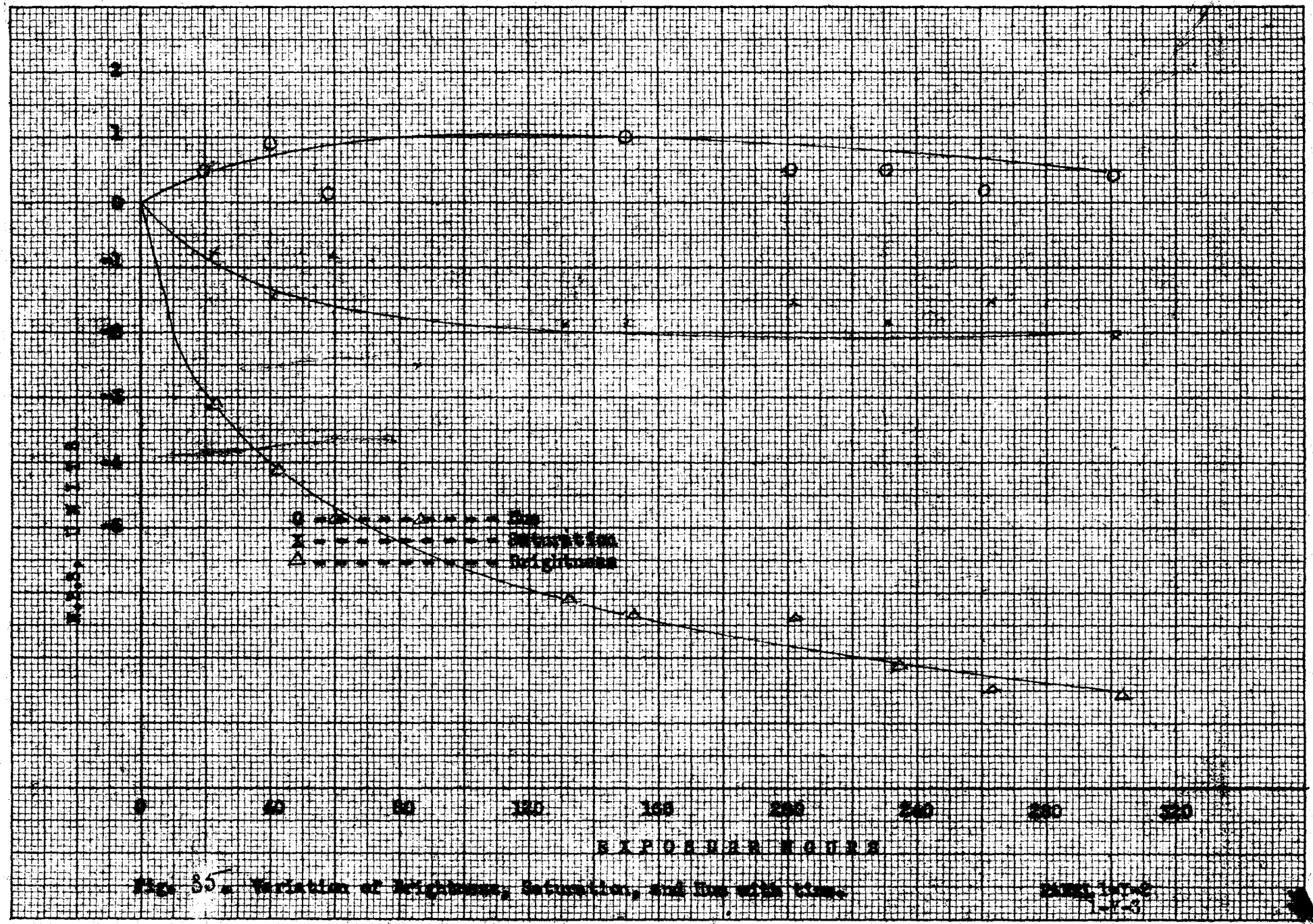



Fig. 35. Variation of Brightness, Saturation, and Hue with Time.

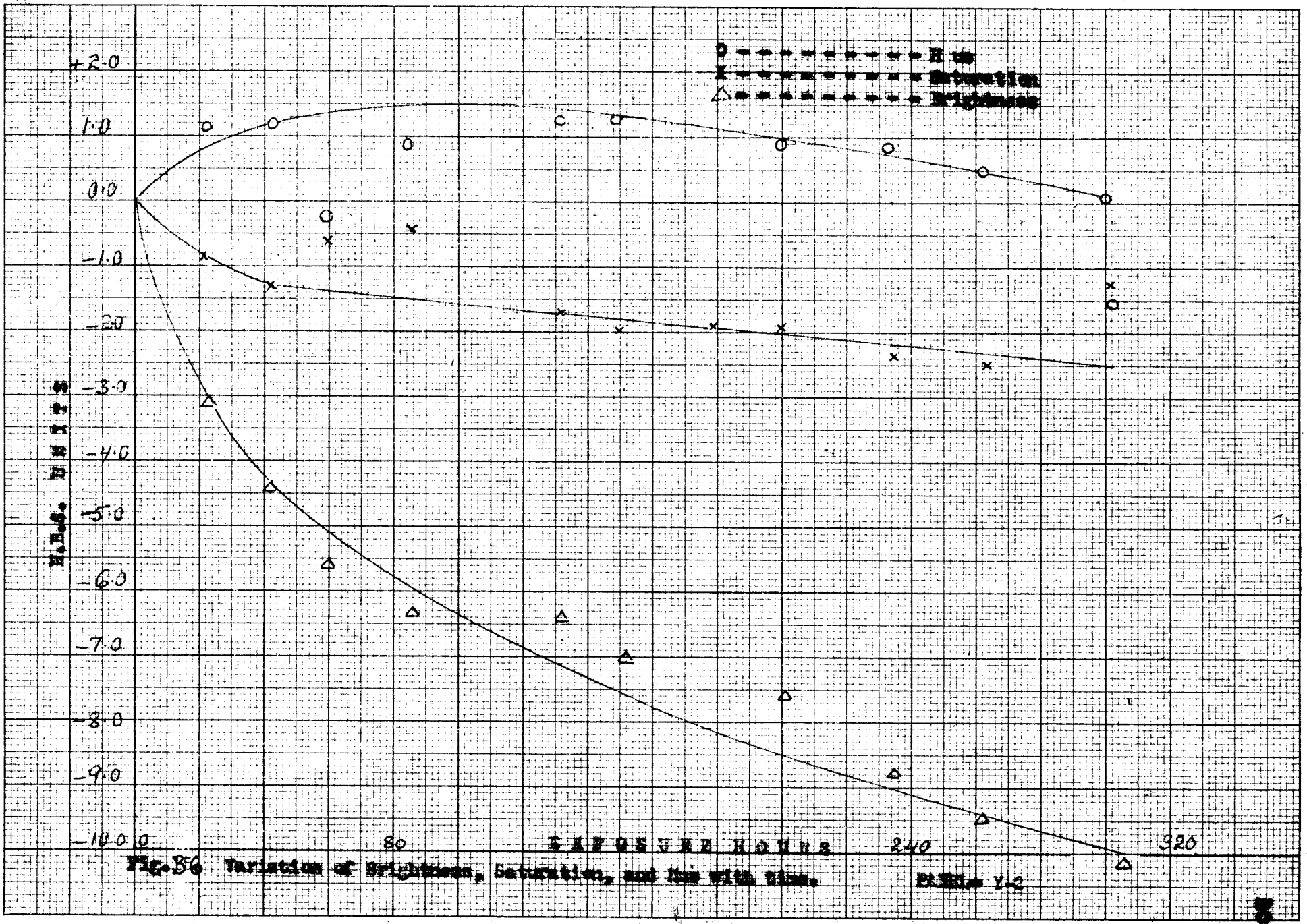



Fig. 36 Variation of Brightness, Saturation, and Hue with time. Plate Y-2

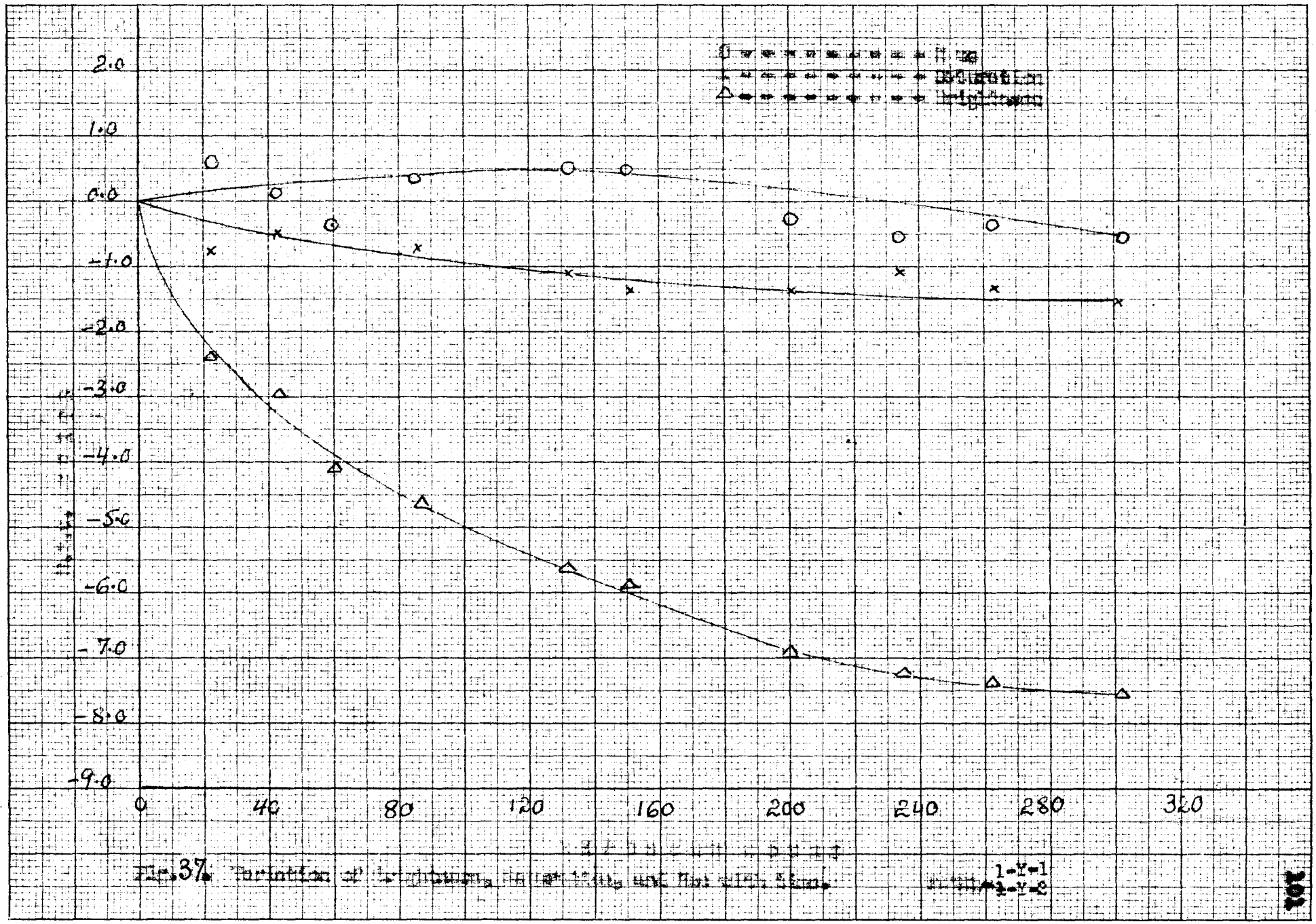
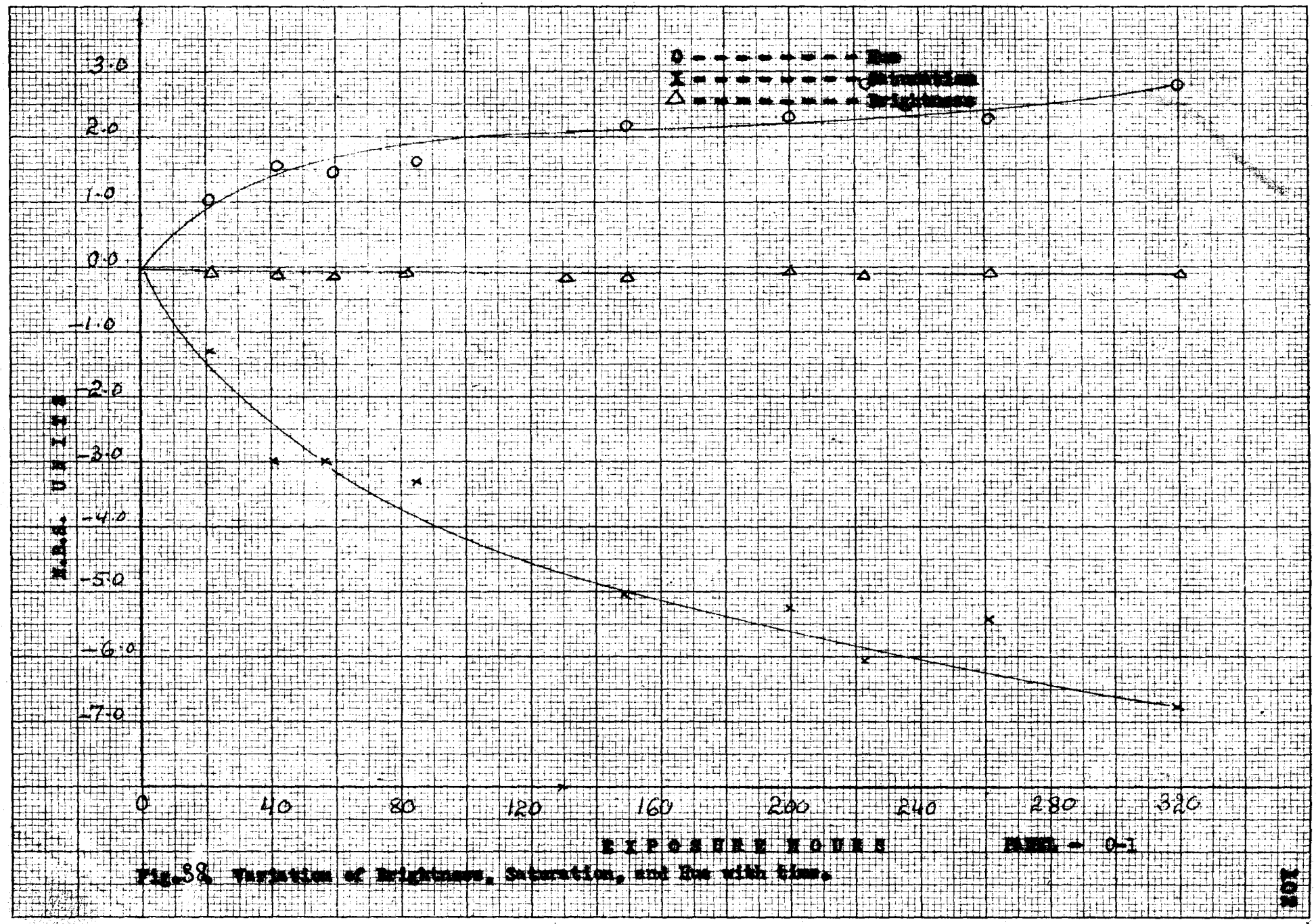



Fig. 37. Variation of [illegible] with [illegible]


Hue
Saturation
Brightness
3·0
2·0
1·0
0·0
-1·0
-2·0
-3·0
-4·0
-5·0
-6·0
-7·0
Readings
0
40
80
120
160
200
240
280
320
EXPOSURE HOURS
Fig.38 Variation of Brightness, Saturation, and Hue with time.

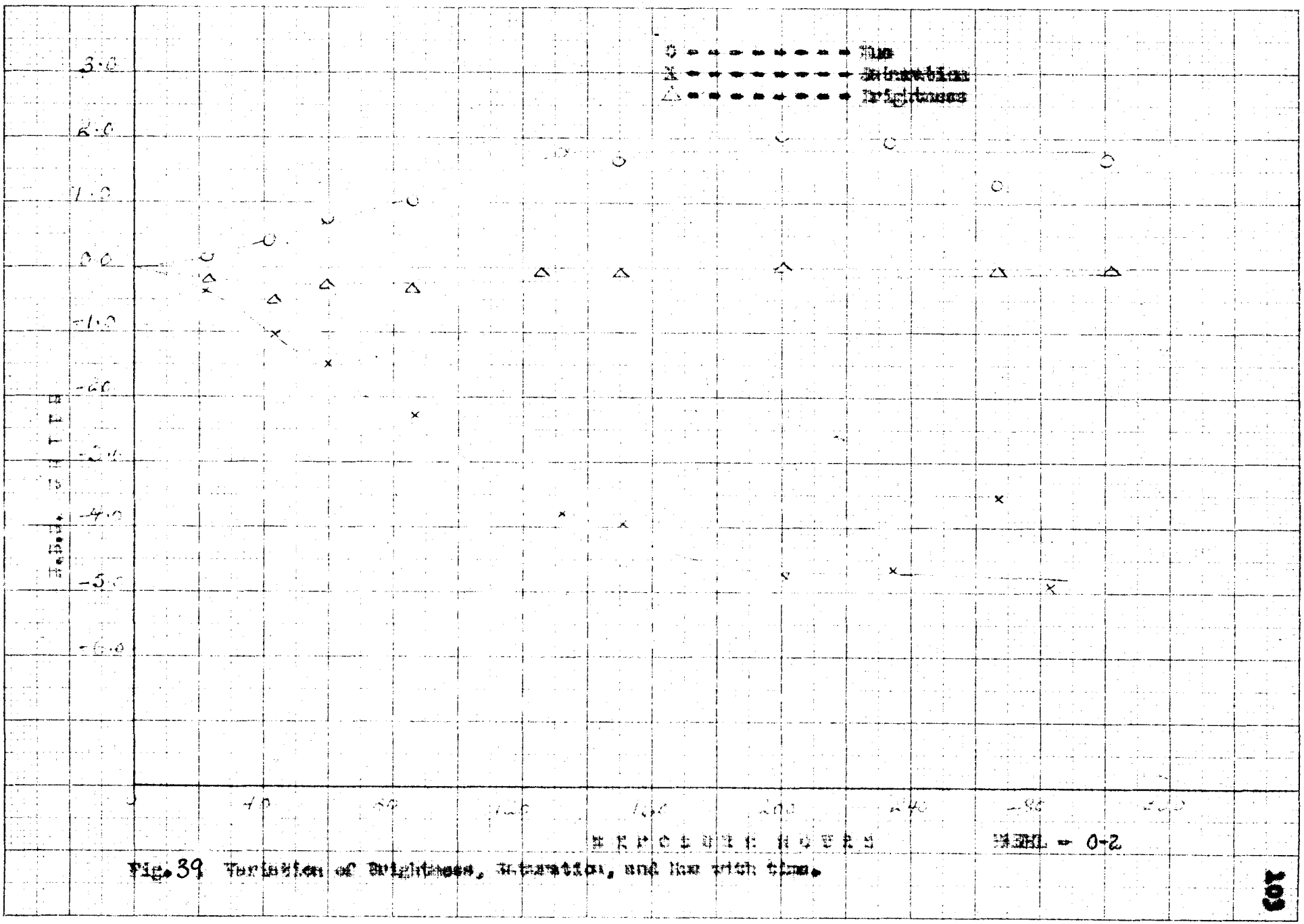



Fig. 39 Variation of Brightness, Intention, and Sun with time.

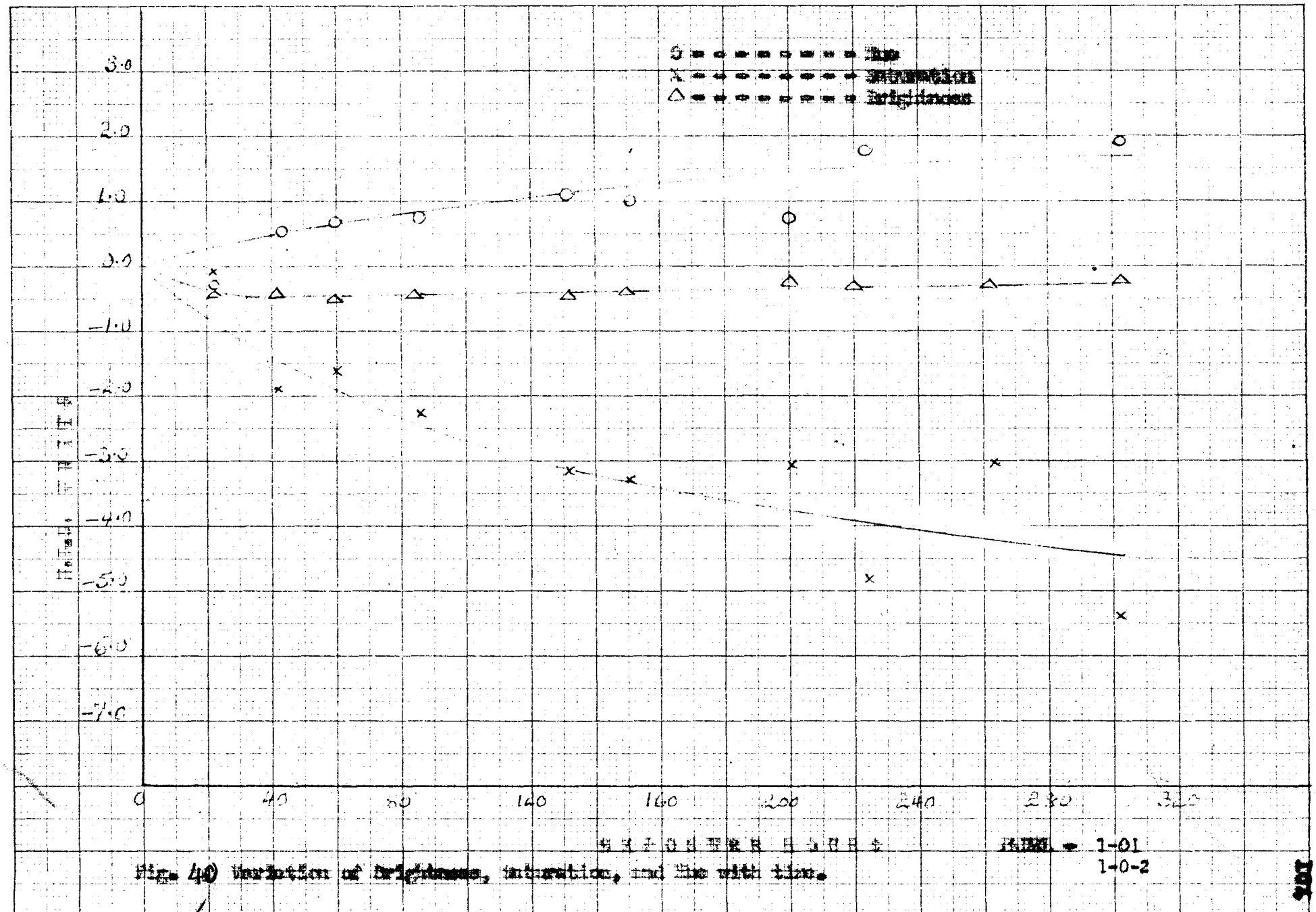



Fig. 40 Variation of brightness, intensity, and Hα with time.

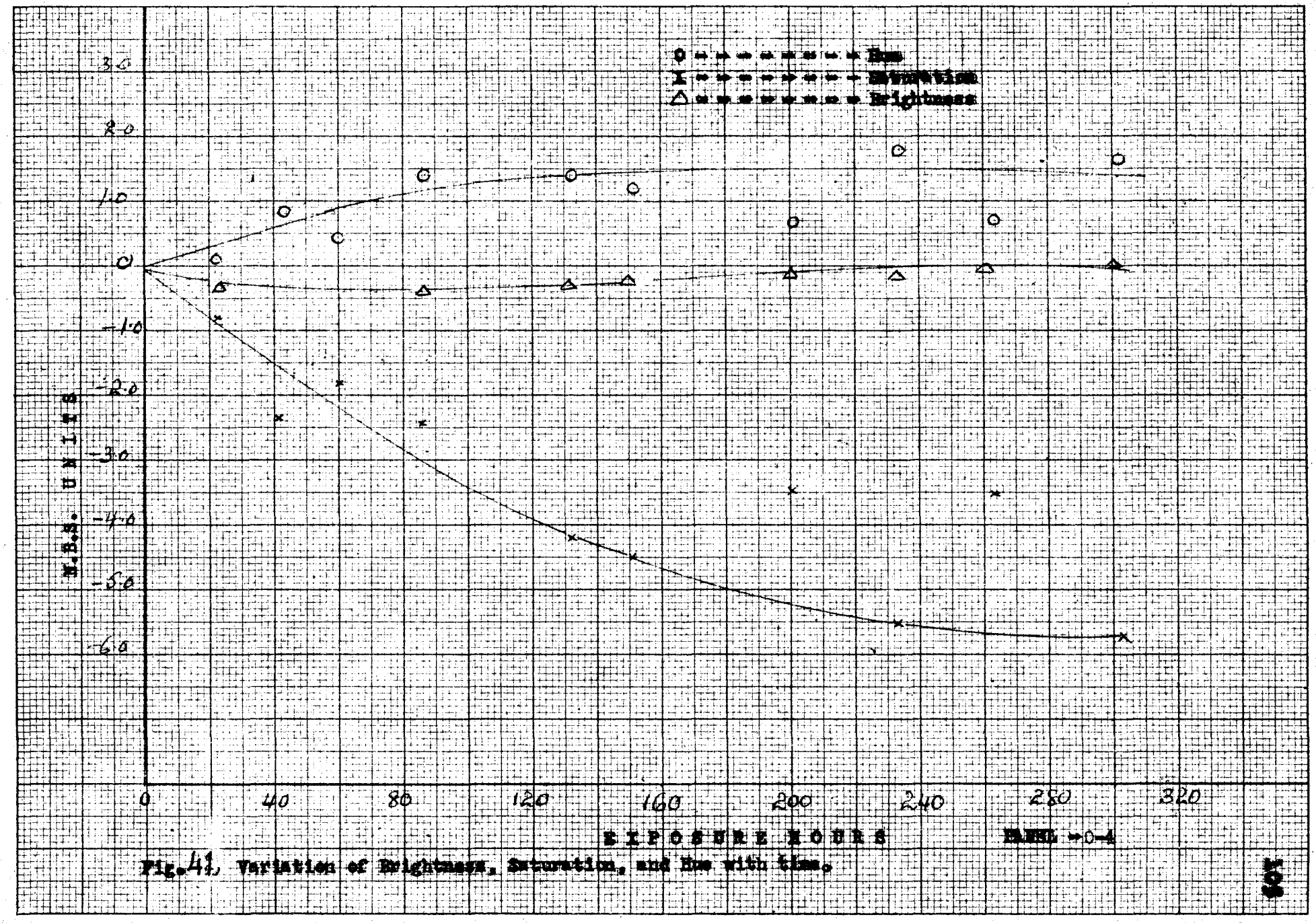



Fig. 41. Variation of Brightness, Saturation, and Hue with time.

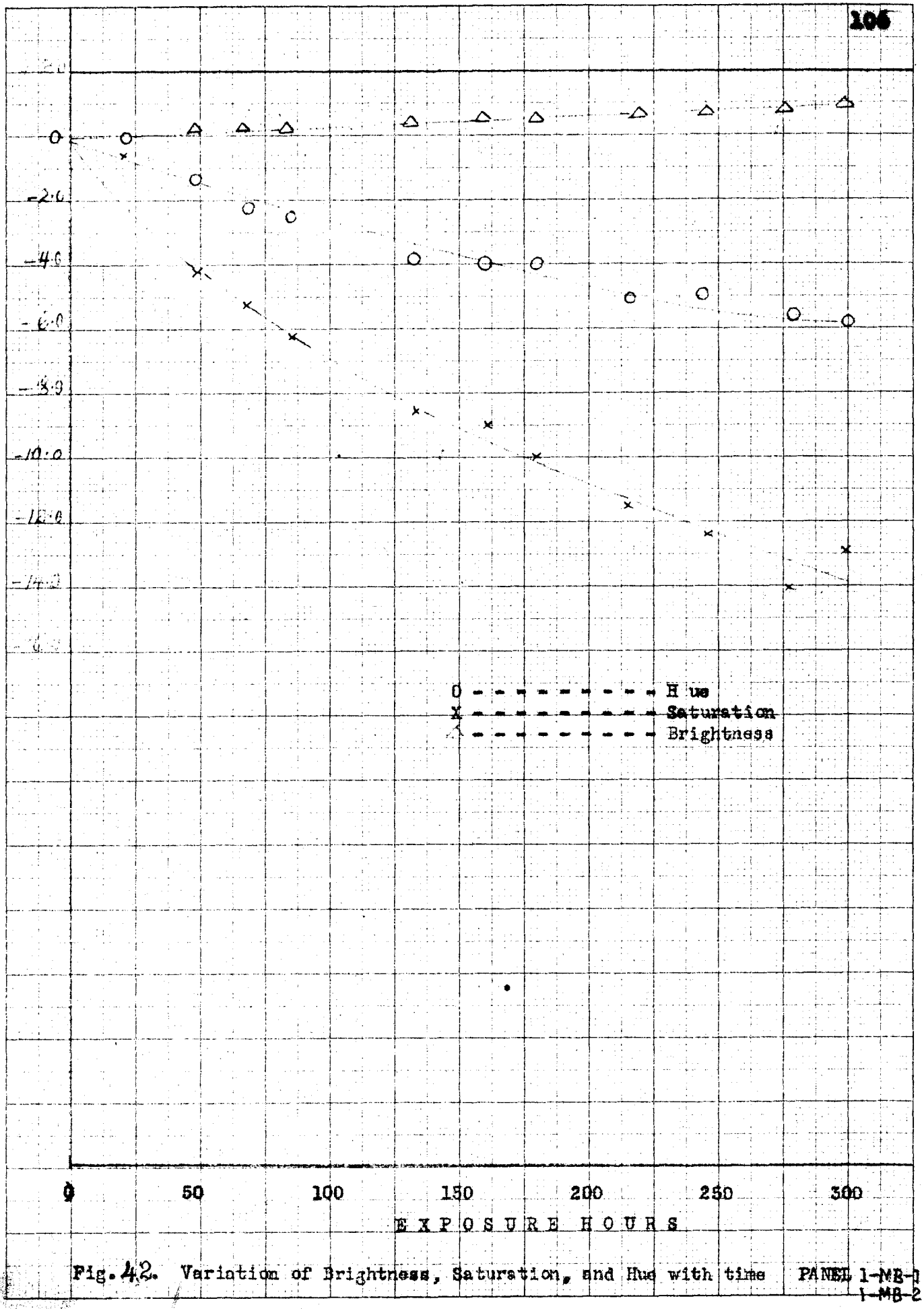



Fig. 42. Variation of Brightness, Saturation, and Hue with time PANEL 1-MB-1
1-MB-2

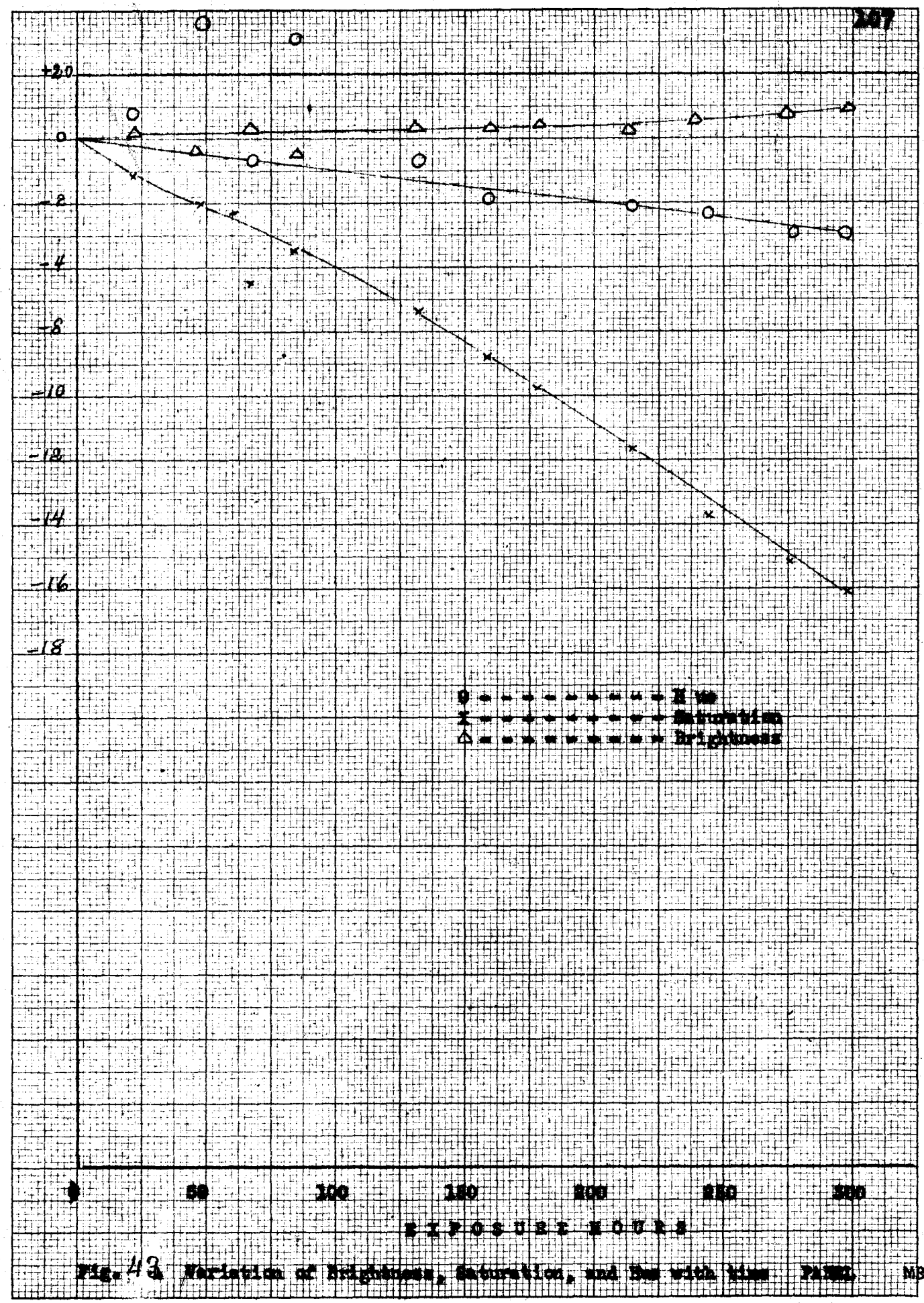



Fig. 43 Variation of Brightness, Saturation, and Hue with time PAINT MB-1

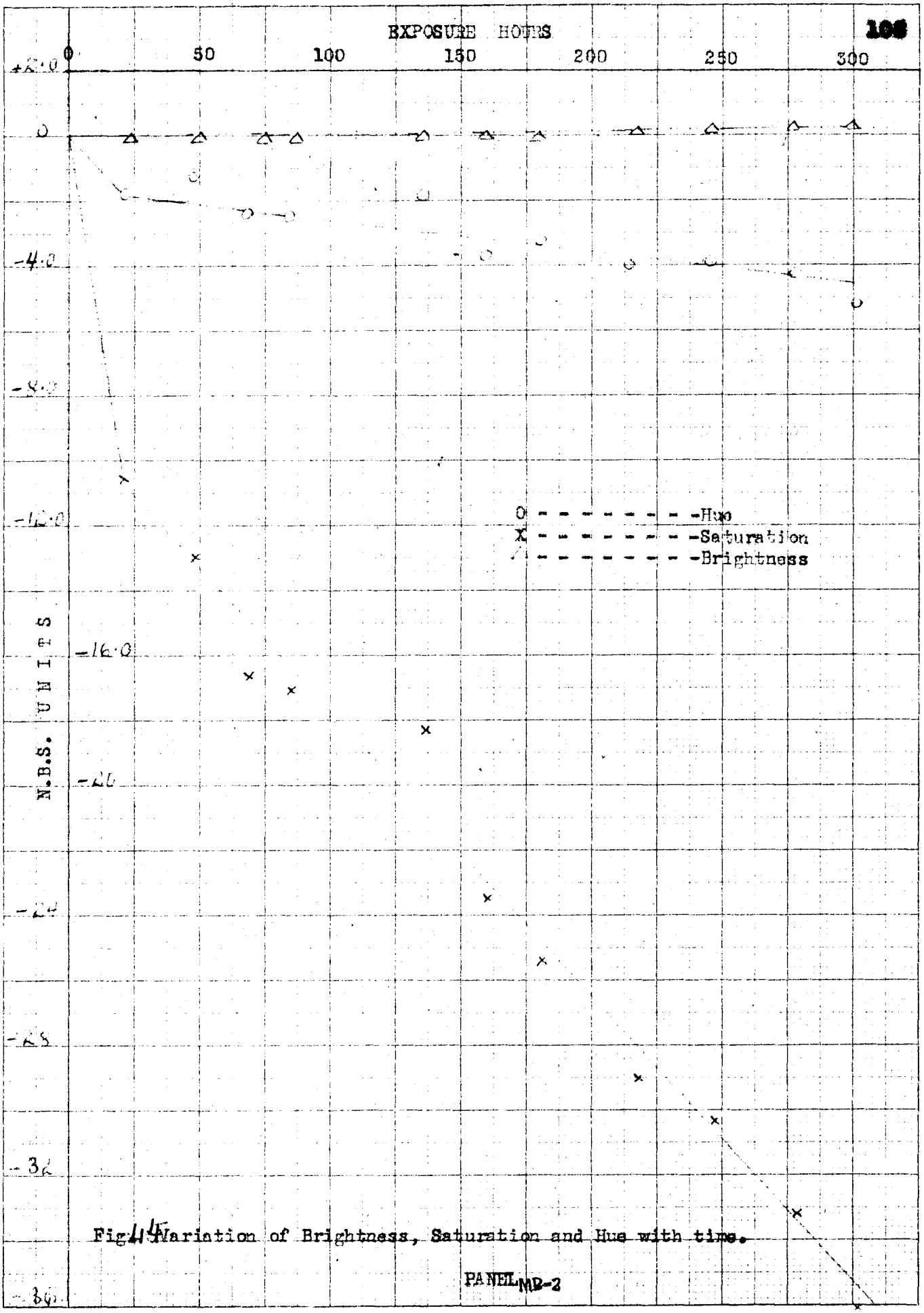



Fig 14 Variation of Brightness, Saturation and Hue with time.

PANEL MB-2

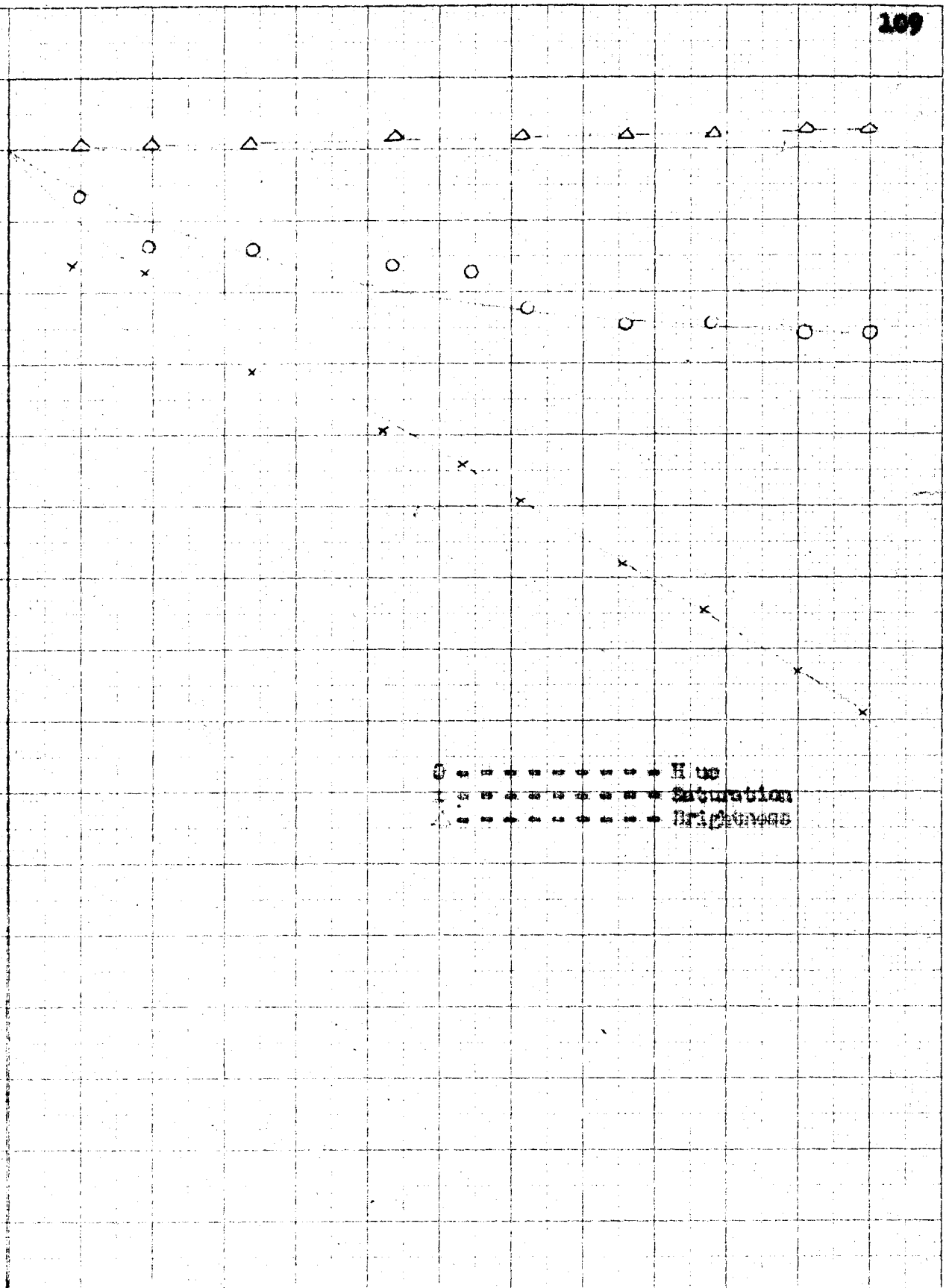



Fig. 45. Variation of Brightness, Saturation, and Hue with time Smith 1-PB-2
3-PB-1

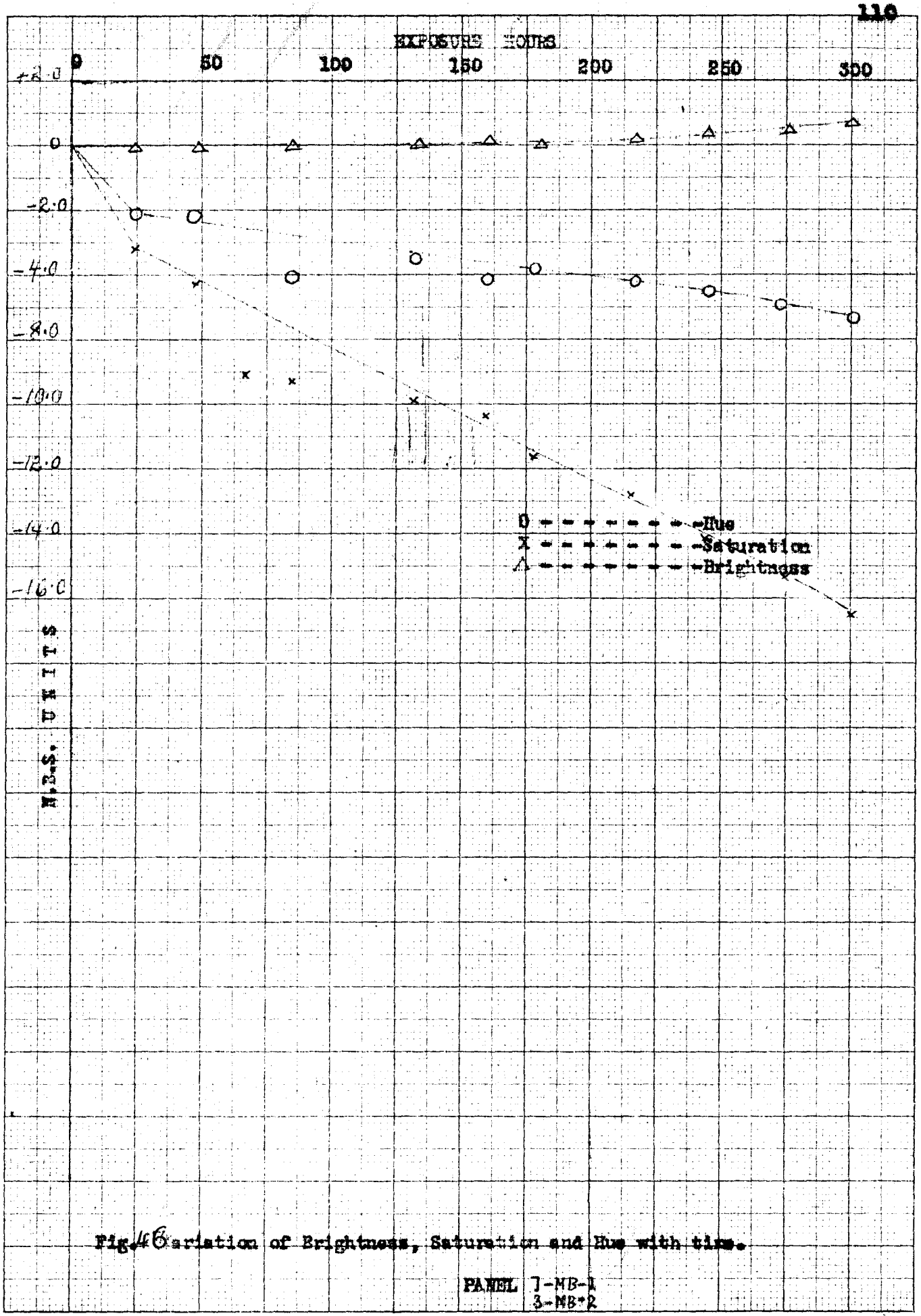



Fig. 46 Variation of Brightness, Saturation and Hue with time.

PANEL 1-MB-1
3-MB-2

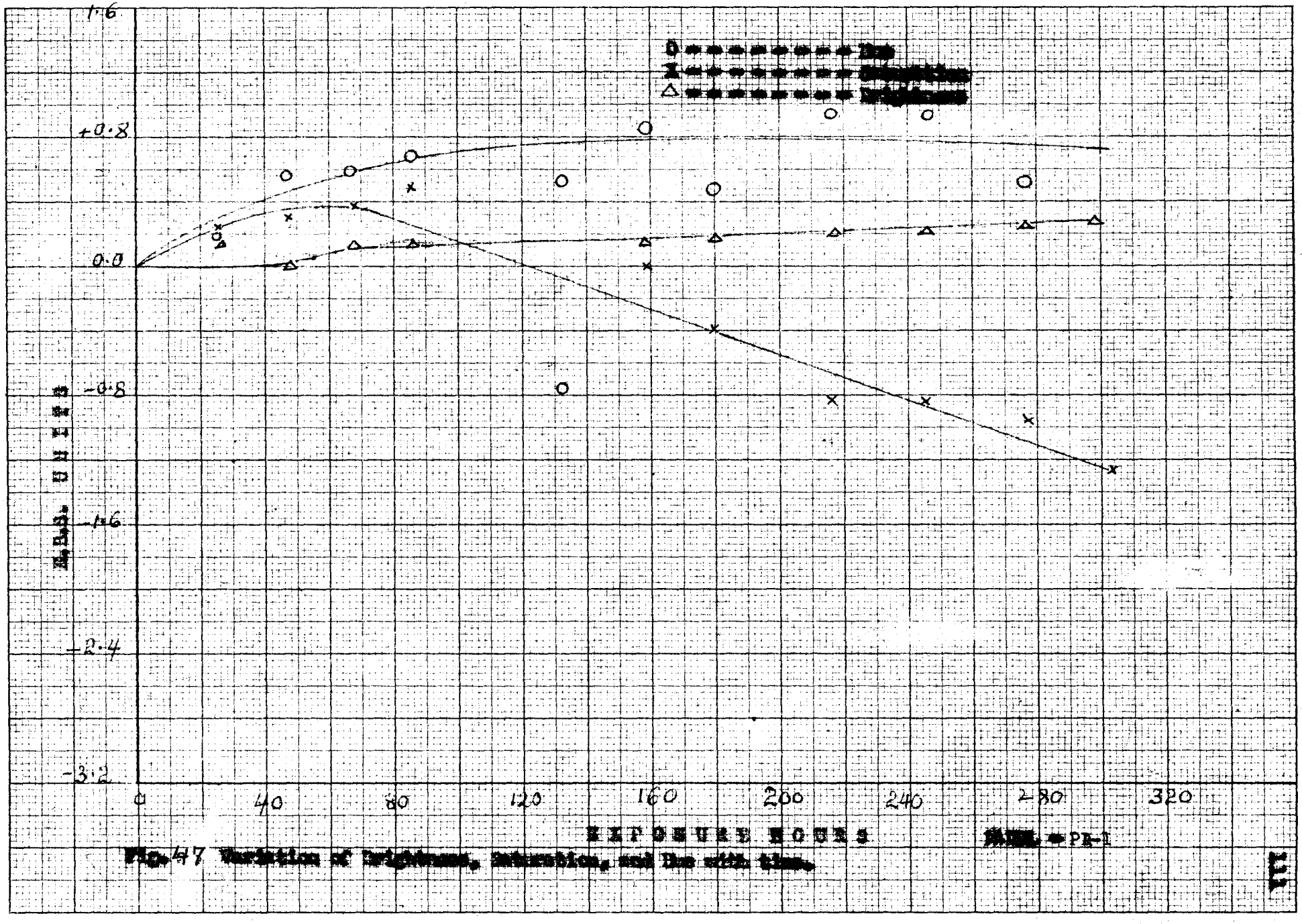



Fig. 47 Variation of brightness, saturation, and Hue with time.

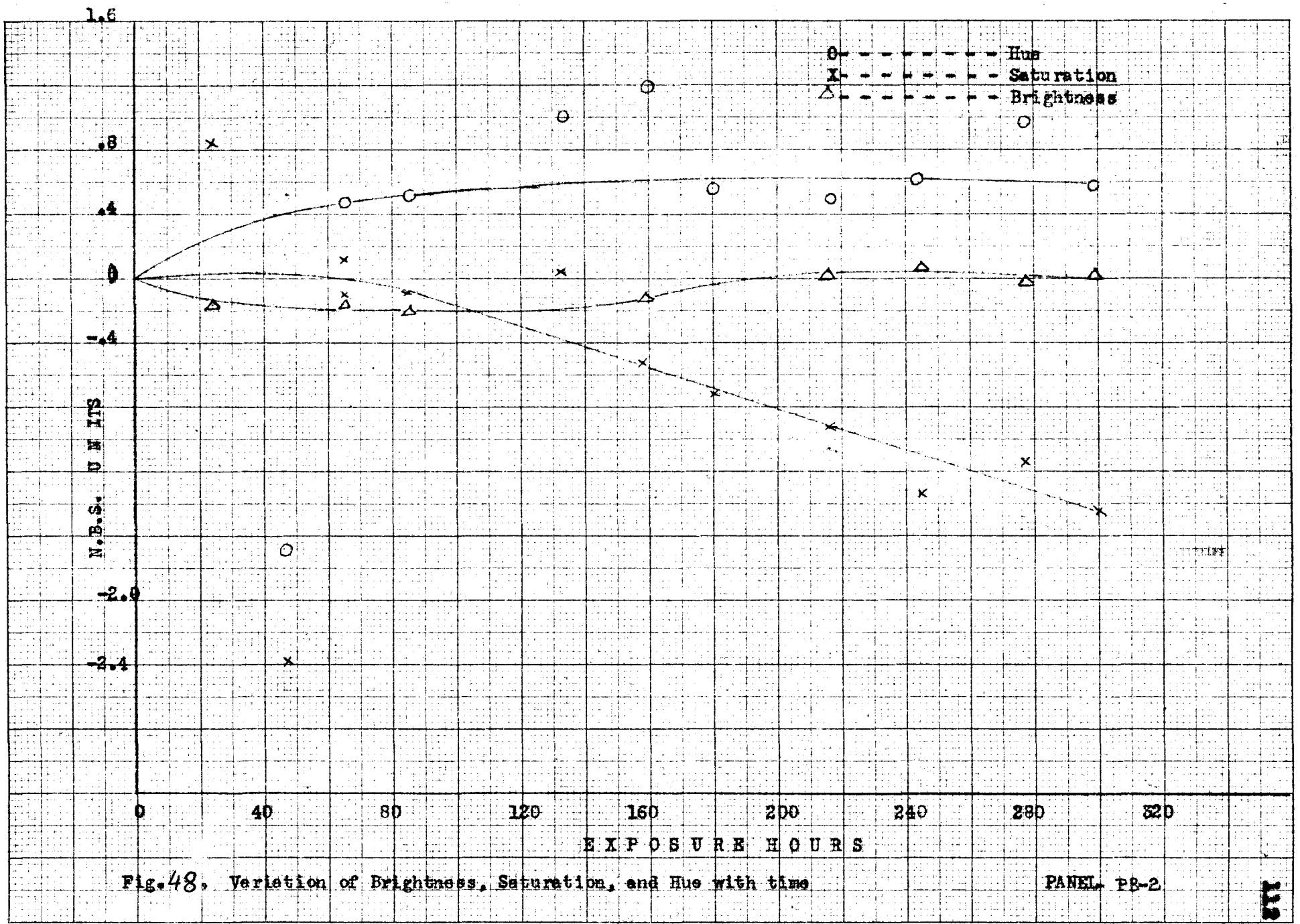



Fig. 48. Variation of Brightness, Saturation, and Hue with time PANEL P8-2

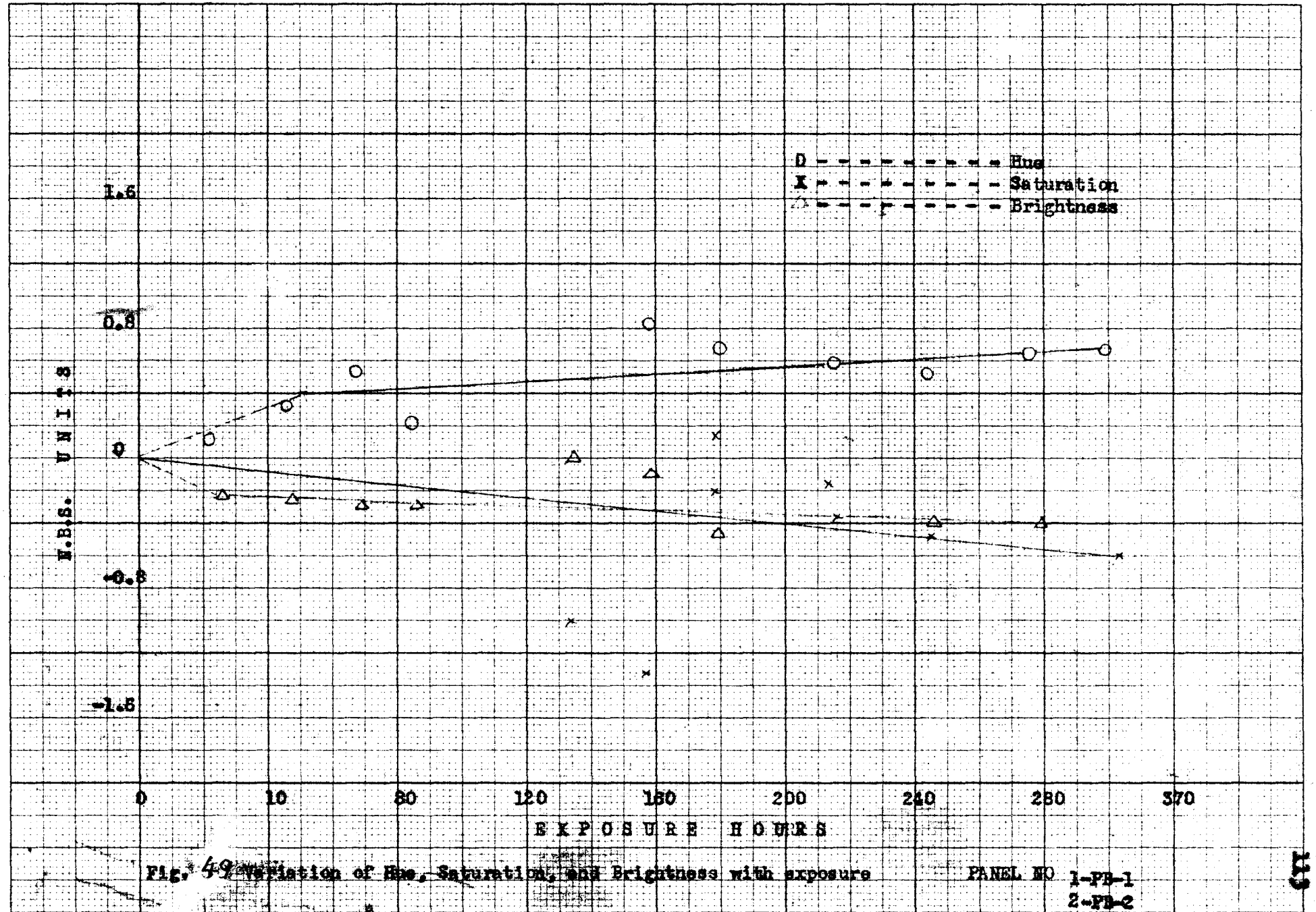



Fig. 49 Variation of Hue, Saturation, and Brightness with exposure PANEL NO 1-PB-1
2-PB-2

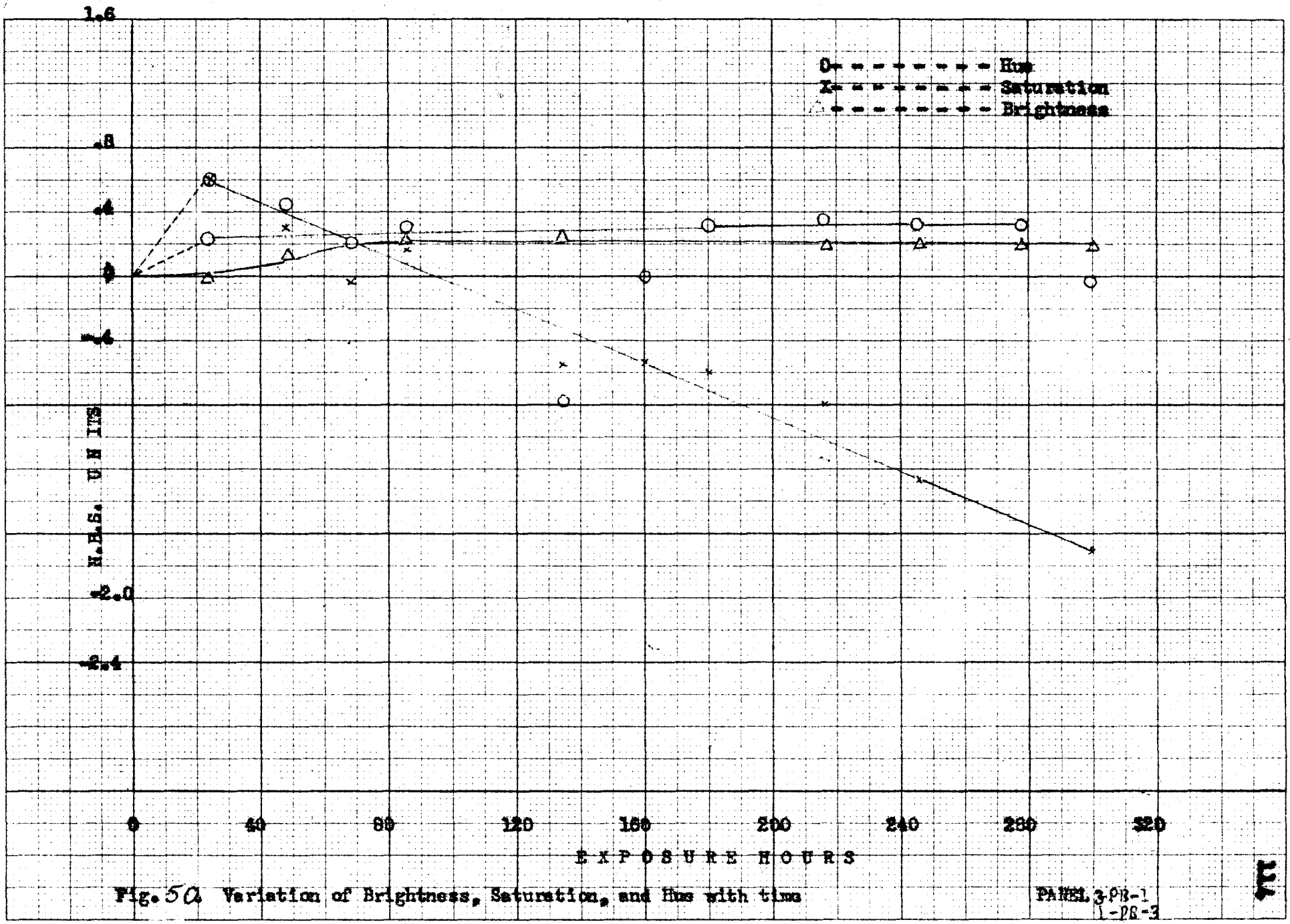



Fig. 5a Variation of Brightness, Saturation, and Hue with time

PANEL 3 PB-1
1-PB-3

# CONCLUSIONS

The results show that the following pigments and pigment mixtures have the capacity to withstand the action of ultra violet light for 300 hours without changing undesirably. In other words the fading takes place in such a manner as to produce a final color which either did not differ from the original or it changed for the better, producing a color of higher saturation then the original. A list of these pigments is as follows:

1. Extra light toluidine
2. Dark toluidine
3. D.D.D. toluidine
4. Mixture of dark toluidine and D.D.D. toluidine in the ratio of 2:1
5. Milori blue # 40222 Ti pur R-610
6. Medium Orange
7. Dark Orange
8. Extra dark orange

It is reasonable to conclude that the pigments given in the above list are mainly responsible for the characteristic fading shown by the coatings. The vehicle and the resins did not have any noticeable effect. Driers may have some effect on the pigments but it has yet to be determined.

The rest of the pigments and pigment mixtures tried, need a change in their composition or need some additives which would prevent undesirable fading.

TABLE I HUNTER REFLECTOMETER READINGS WITH SAMPLE CALCULATIONS

PANEL 27: 1-PB-1
3-PB-2

| Hrs | Machine Readings | | | Corrected Readings | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | B | A | G | B | A | G | A+2G+B | A-G | 0.4(G-B) |
| | 0.5 | 0.1 | 0.1 | | | | | | |
| 0 | 0.3250 | 0.1740 | 0.1820 | 0.0136 | 0.0349 | 0.2654 | -0.0213 | -0.0588 | -0.0588 |
| 23 | 0.3190 | 0.1730 | 0.2090 | 0.1785 | 0.0135 | 0.0342 | 0.2604 | -0.0207 | -0.0577 |
| 47 | 0.3175 | 0.1734 | 0.4074 | 0.1777 | 0.0136 | 0.0340 | 0.2592 | -0.2592 | -0.0205 |
| 67 | 0.3170 | 0.1740 | 0.4060 | 0.1774 | 0.0136 | 0.0339 | 0.2588 | -0.0203 | -0.0574 |
| 85 | 0.3140 | 0.1745 | 0.4065 | 0.1757 | 0.0142 | 0.0339 | 0.2571 | -0.0203 | -0.0567 |
| 133 | 0.3170 | 0.1800 | 0.4170 | 0.1774 | 0.0147 | 0.0349 | 0.2614 | -0.1207 | -0.0570 |
| 159 | 0.3170 | 0.1855 | 0.4143 | 0.1774 | 0.0133 | 0.0346 | 0.2613 | -0.0199 | -0.0571 |
| 180 | 0.3140 | 0.1765 | 0.3990 | 0.1757 | 0.0135 | 0.0333 | 0.2556 | -0.0200 | -0.0570 |
| 216 | 0.3130 | 0.1726 | 0.4020 | 0.1752 | 0.0137 | 0.0335 | 0.2557 | -0.0200 | -0.0567 |
| 245 | 0.3120 | 0.1754 | 0.4023 | 0.1746 | 0.0137 | 0.0336 | 0.2555 | -0.0199 | -0.0564 |
| 277 | 0.3103 | 0.1745 | 0.3990 | 0.1736 | 0.0136 | 0.0333 | 0.2538 | -0.0197 | -0.0561 |
| 300 | 0.3090 | 0.1760 | 0.4010 | 0.1728 | 0.0136 | 0.0334 | 0.2534 | -0.0191 | -0.0558 |

TABLE I (Cont'd) HUNTER REFLECTOMETER READINGS WITH SAMPLE CALCULATIONS

PANEL 27: 1-PB-1
3-PB-2

| Hrs. | $\alpha$ | $\beta$ | $\alpha^2$ | $\beta^2$ | $Y^{\frac{1}{2}}$ | $K=100$ $\frac{\Delta L'}{K \cdot \Delta Y^{\frac{1}{2}}}$ | $Y^{\frac{1}{4}}$ | $\frac{1}{A \cdot Y^{\frac{1}{4}}}$ | $\sqrt{\alpha^2+\beta^2}$ |
|---|---|---|---|---|---|---|---|---|---|
| 0 | -0.0803 | -0.2216 | 0.0064 | 0.0491 | 0.1868 | ------ | 0.4322 | ------ | 0.2356 |
| 23 | -0.0795 | -0.2216 | 0.0063 | 0.0491 | 0.0049 | -0.19 | 0.4300 | 0.4311 | 0.2354 |
| 47 | -0.0791 | -0.2218 | 0.0063 | 0.0492 | 0.0044 | -0.24 | 0.4294 | 0.4308 | 0.2356 |
| 67 | -0.0784 | -0.2218 | 0.0061 | 0.0492 | 0.0241 | -0.27 | 0.4291 | 0.4307 | 0.2352 |
| 85 | -0.0790 | -0.2205 | 0.0062 | 0.0486 | 0.0041 | -0.23 | 0.4291 | 0.4307 | 0.2341 |
| 133 | -0.0792 | -0.2281 | 0.0063 | 0.0476 | 0.0068 | -0.00 | 0.4322 | 0.4322 | 0.2322 |
| 159 | -0.0762 | -0.2285 | 0.0058 | 0.0477 | 0.1860 | -0.08 | 0.4313 | 0.4318 | 0.2313 |
| 180 | -0.0782 | -0.2230 | 0.0061 | 0.0497 | 0.1825 | -0.43 | 0.4272 | 0.4297 | 0.2362 |
| 216 | -0.0782 | -0.2217 | 0.0061 | 0.0490 | 0.1830 | -0.38 | 0.4278 | 0.4300 | 0.2352 |
| 245 | -0.0779 | -0.2207 | 0.0061 | 0.0487 | 0.1833 | -0.35 | 0.4281 | 0.4302 | 0.2341 |
| 277 | -0.0776 | -0.2210 | 0.0060 | 0.0488 | 0.1825 | -0.43 | 0.4272 | 0.4297 | 0.2341 |
| 300 | -0.0773 | -0.2202 | 0.0060 | 0.0485 | 0.1828 | -0.40 | 0.4276 | 0.4299 | 0.2335 |

TABLE I (Cont'd) HUNTER REFLECTOMETER READINGS WITH SAMPLE CALCULATIONS

PANEL 27: 1-PB-1
3-PB-2

| Hrs. | 2 Av. $\sqrt{\alpha^2+\beta^2}$ | 3 $\Delta\sqrt{\alpha^2+\beta^2}$ | 4 700(1) | $\Delta S' =$ (3)(4) | $\frac{\beta}{\alpha}$ | arc tan $\frac{\beta}{\alpha}$ | 5 $\Delta\phi$ | 6 12.2(1) | 7 (6)(2) | $\Delta H'$ (7)(5) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.2355 | ---- | ---- | ---- | 2.7594 | 250.0814 | -- | -- | -- | -- |
| 23 | 0.2356 | -0.0002 | 301.8 | -0.0604 | 2.7748 | 250.1814 | 0.1000 | 5.259 | 1.238 | 0.1238 |
| 47 | 0.2354 | 0.0 | 301.6 | 0.0 | 2.8040 | 250.3720 | 0.2906 | 5.256 | 1.238 | 0.3598 |
| 67 | 0.2349 | -0.0004 | 301.5 | -0.1206 | 2.8291 | 250.5333 | 0.4519 | 5.255 | 1.237 | 0.5590 |
| 85 | 0.2339 | -0.0015 | 301.5 | -0.4523 | 2.7911 | 250.2883 | 0.2069 | 5.255 | 1.234 | 0.2553 |
| 133 | 0.2335 | -0.0034 | 302.5 | -1.029 | 2.7534 | 250.0394 | -0.0420 | 5.273 | 1.233 | -0.0518 |
| 159 | 0.2349 | -0.0043 | 302.4 | -1.3 | 2.8701 | 250.7908 | 0.7094 | 5.268 | 1.230 | 0.8726 |
| 180 | 0.2354 | -0.0006 | 300.8 | 0.1805 | 2.8515 | 250.6758 | 0.5944 | 5.242 | 1.237 | 0.7353 |
| 216 | 0.2349 | -0.0004 | 301.0 | -0.1204 | 2.8389 | 250.5950 | 0.5136 | 5.246 | 1.235 | 0.6343 |
| 245 | 0.2349 | -0.0015 | 301.1 | -0.4517 | 2.8331 | 250.5583 | 0.4769 | 5.248 | 1.233 | 0.5880 |
| 277 | 0.2346 | -0.0015 | 300.8 | -0.4512 | 2.8479 | 250.6519 | 0.5705 | 5.242 | 1.231 | 0.7023 |
| 300 | -- | -0.0021 | 300.9 | -0.6319 | 2.8486 | 250.6564 | 0.5750 | 5.245 | 1.230 | 0.7073 |

TABLE II HUNTER REFLECTOMETER READINGS AND RESULTS - Medium Blue

PANEL NO 21 - MB-2

| | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| Hrs | B | A | G | B | A | G | △ L' | △ S' | △ H' |
| | 0.5 | 0.1 | 0.1 | | | | | | |
| 0 | 0.1620 | 0.1525 | 0.2770 | 0.0871 | 0.0115 | 0.0222 | - | - | - |
| 23 | 0.1445 | 0.1570 | 0.2740 | 0.0768 | 0.0120 | 0.0219 | -0.10 | -10.58 | -1.797 |
| 47 | 0.1410 | 0.1605 | 0.2730 | 0.0748 | 0.0123 | 0.0218 | -0.14 | -12.94 | -1.648 |
| 67 | 0.1365 | 0.1620 | 0.2740 | 0.0722 | 0.0125 | 0.0219 | -0.10 | -16.65 | -2.490 |
| 85 | 0.1365 | 0.1635 | 0.2745 | 0.0722 | 0.0126 | 0.0220 | -0.07 | -17.11 | -2.513 |
| 133 | 0.1354 | 0.1680 | 0.2750 | 0.0716 | 0.0130 | 0.0220 | -0.07 | -18.33 | -1.860 |
| 159 | 0.1287 | 0.1670 | 0.2770 | 0.0682 | 0.0131 | 0.0222 | 0 | -23.48 | -3.681 |
| 180 | 0.1265 | 0.1700 | 0.2760 | 0.0666 | 0.0132 | 0.0221 | -0.03 | -25.44 | -3.319 |
| 216 | 0.1230 | 0.1745 | 0.2775 | 0.0646 | 0.0136 | 0.0222 | 0 | -28.94 | -4.019 |
| 245 | 0.1230 | 0.1780 | 0.2805 | 0.0646 | 0.0140 | 0.0225 | 0.10 | -30.45 | -3.924 |
| 277 | 0.1207 | 0.1810 | 0.2830 | 0.0633 | 0.0143 | 0.0227 | 0.17 | -33.25 | -4.307 |
| 300 | 0.1193 | 0.1843 | 0.2865 | 0.0625 | 0.0146 | 0.0231 | 0.30 | -36.15 | -5.232 |

TABLE III HUNTER REFLECTOMETER READINGS AND RESULTS - Medium Blue

PANEL NO 23 - 1-MB-1
1-MB-2

| Hrs. | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| | L B | .1 A | .1 G | B | A | G | △ L' | △ S' | △ H' |
| 0 | 0.1570 | 0.2605 | 0.5140 | 0.1561 | 0.0219 | 0.0438 | - | - | - |
| 23 | 0.1485 | 0.2720 | 0.5180 | 0.1476 | 0.0230 | 0.0441 | 0.07 | -0.5770 | .0662 |
| 47 | 0.1435 | 0.2790 | 0.5230 | 0.1428 | 0.0236 | 0.0446 | 0.19 | -4.334 | -1.272 |
| 67 | 0.1403 | 0.2808 | 0.5195 | 0.1397 | 0.0238 | 0.0443 | 0.12 | -5.164 | -2.252 |
| 85 | 0.1377 | 0.2850 | 0.5210 | 0.1371 | 0.0242 | 0.0444 | 0.14 | -6.192 | -2.595 |
| 133 | 0.1330 | 0.2970 | 0.5325 | 0.1325 | 0.0254 | 0.0455 | 0.40 | -8.592 | -3.935 |
| 159 | 0.1325 | 0.3005 | 0.5348 | 0.1320 | 0.0257 | 0.0457 | 0.45 | -8.993 | -4.003 |
| 180 | 0.1290 | 0.3040 | 0.5330 | 0.1285 | 0.0261 | 0.0455 | 0.40 | -10.093 | 4.139 |
| 216 | 0.1265 | 0.3124 | 0.6400 | 0.1260 | 0.0267 | 0.0462 | 0.56 | -11.420 | -5.210 |
| 245 | 0.1245 | 0.3170 | 0.5400 | 0.1240 | 0.0273 | 0.0462 | 0.56 | -12.488 | -5.027 |
| 277 | 0.1213 | 0.3250 | 0.5460 | 0.1208 | 0.0281 | 0.0467 | 0.58 | -14.077 | -5.770 |
| 300 | 0.1223 | 0.3150 | 0.5560 | 0.1218 | 0.0281 | 0.0476 | 0.89 | -12.89 | -6.337 |

TABLE IV HUNTER REFLECTOMETER READINGS AND RESULTS - Medium Blue

PANEL NO. 24 - 3-MB-1
1-MB-2

| Hrs. | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| | B L | A .1 | G .5 | B | A | G | △ L' | △ S' | △ H' |
| 0 | 0.1850 | 0.3110 | 0.1000 | 0.1837 | 0.0267 | 0.0512 | - | - | - |
| 23 | 0.1743 | 0.3280 | 0.1015 | 0.1733 | 0.0284 | 0.0520 | 0.17 | -3.303 | -1.212 |
| 47 | 0.1725 | 0.3223 | 0.1022 | 0.1714 | 0.0278 | 0.0524 | 0.26 | -3.474 | -2.053 |
| 67 | 0.1655 | 0.3353 | 0.1015 | 0.1645 | 0.0291 | 0.0520 | 0.17 | -4.537 | -4.347 |
| 85 | 0.1645 | 0.3390 | 0.1023 | 0.1635 | 0.0294 | 0.0524 | 0.26 | -6.212 | 2.686 |
| 133 | 0.1600 | 0.3465 | 0.1030 | 0.1591 | 0.0302 | 0.0528 | 0.35 | -7.722 | -3.251 |
| 159 | 0.1580 | 0.3530 | 0.1035 | 0.1571 | 0.0308 | 0.0531 | 0.41 | -8.764 | -3.425 |
| 180 | 0.1540 | 0.3528 | 0.1035 | 0.1531 | 0.0308 | 0.0531 | 0.41 | -9.600 | -4.357 |
| 216 | 0.1440 | 0.3640 | 0.1040 | 0.1482 | 0.0318 | 0.0534 | 0.48 | -11.447 | -4.821 |
| 245 | 0.1490 | 0.3775 | 0.1060 | 0.1482 | 0.0331 | 0.0545 | 0.72 | -12.689 | -4.800 |
| 277 | 0.1447 | 0.3865 | 0.1065 | 0.1440 | 0.0341 | 0.0548 | 0.78 | -14.444 | -5.133 |
| 300 | 0.1445 | 0.4000 | 0.1083 | 0.1438 | 0.0353 | 0.0558 | 0.99 | -15.517 | -5.179 |

TABLE V HUNTER REFLECTOMETER READINGS AND RESULTS - Medium Blue

PANEL NO. 22 - 1-MB-1
3-MB-2

| | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| Hrs. | B L | A 0.1 | G 0.1 | B | A | G | △ L' | △ S' | △ H' |
| 0 | 0.1290 | 0.2021 | 0.3020 | 0.1285 | 0.0161 | 0.0326 | - | - | - |
| 23 | 0.1190 | 0.2125 | 0.3965 | 0.1185 | 0.0172 | 0.0330 | 0.11 | -3.40 | -2.047 |
| 47 | 0.1150 | 0.2100 | 0.3950 | 0.1144 | 0.0176 | 0.0328 | 0.05 | 4.317 | -2.161 |
| 67 | 0.1065 | 0.2095 | 0.3930 | 0.1058 | 0.0179 | 0.0327 | 0.02 | 7.083 | -3.981 |
| 85 | 0.1070 | 0.2220 | 0.3960 | 0.1063 | 0.0181 | 0.0330 | 0.11 | 7.271 | -4.067 |
| 133 | 0.1060 | 0.2270 | 0.3955 | 0.1053 | 0.0186 | 0.0329 | 0.08 | 7.865 | -3.516 |
| 159 | 0.1054 | 0.2275 | 0.3990 | 0.1047 | 0.0187 | 0.0333 | 0.19 | 8.320 | -4.087 |
| 180 | 0.1030 | 0.2315 | 0.3975 | 0.1021 | 0.0191 | 0.0331 | 0.13 | 9.480 | -3.516 |
| 216 | 0.1010 | 0.2375 | 0.4000 | 0.1000 | 0.0190 | 0.0333 | 0.19 | 10.676 | -4.135 |
| 245 | 0.1000 | 0.2450 | 0.4070 | 0.0990 | 0.0240 | 0.0340 | 0.38 | 12.110 | -4.515 |
| 277 | 0.0990 | 0.2515 | 0.4120 | 0.0980 | 0.0210 | 0.0344 | 0.49 | 13.178 | -4.652 |
| 300 | 0.0980 | 0.2585 | 0.4210 | 0.0970 | 0.0217 | 0.0352 | 0.70 | 14.419 | -5.374 |

TABLE VI HUNTER REFLECTOMETER READINGS AND RESULTS - Peacock Blue

PANEL NO. 30 - PB-1

| Hrs | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| | L B | 0.1 A | 0.5 G | B | A | G | △ L' | △ S' | △ H' |
| 0 | 0.2805 | 0.2741 | 0.1100 | 0.2802 | 0.0232 | 0.0567 | - | - | - |
| 23 | 0.2865 | 0.2770 | 0.1115 | 0.2862 | 0.0235 | 0.0575 | .17 | 0.2394 | 0.2031 |
| 47 | 0.2850 | 0.2770 | 0.1105 | 0.2847 | 0.0235 | 0.0569 | 0.04 | 0.3076 | 0.5684 |
| 67 | 0.2880 | 0.2800 | 0.1110 | 0.2878 | 0.0239 | 0.0573 | 0.13 | 0.3763 | 0.6054 |
| 85 | 0.2885 | 0.2799 | 0.1113 | 0.2883 | 0.0237 | 0.0574 | 0.15 | 0.4488 | 0.6862 |
| 133 | 0.2876 | 0.2835 | 0.1150 | 0.2874 | 0.0241 | 0.0593 | 0.54 | -0.6528 | -0.7540 |
| 159 | 0.2860 | 0.2844 | 0.1114 | 0.2857 | 0.0242 | 0.0573 | 0.13 | 0 | 0.8640 |
| 180 | 0.2840 | 0.2850 | 0.1115 | 0.2837 | 0.0242 | 0.0575 | 0.17 | -0.3765 | 0.4864 |
| 216 | 0.2845 | 0.2930 | 0.1120 | 0.2842 | 0.0250 | 0.0577 | 0.21 | -0.8218 | 0.9610 |
| 245 | 0.2845 | 0.2930 | 0.1120 | 0.2842 | 0.0250 | 0.0577 | 0.21 | -0.8218 | 0.9610 |
| 277 | 0.2830 | 0.2925 | 0.1123 | 0.2827 | 0.0249 | 0.0579 | 0.25 | -0.9590 | 0.5398 |
| 300 | 0.2825 | 0.2930 | 0.1130 | 0.2822 | 0.0250 | 0.0582 | 0.31 | -1.268 | 0.2810 |

TABLE VII HUNTER REFLECTOMETER READINGS AND RESULTS - Peacock Blue

PANEL NO. 26 - PB-2

| | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| Hrs. | B | A | C | B | A | C | ΔL' | ΔS' | ΔH' |
| | 0.5 | 0.1 | 0.1 | | | | | | |
| 0 | 0.2280 | 0.1295 | 0.2840 | 0.1253 | 0.0093 | 0.0228 | - | - | - |
| 23 | 0.2260 | 0.1285 | 0.2790 | 0.1241 | 0.0092 | 0.0224 | -0.13 | 0.8415 | -0.1734 |
| 47 | 0.2065 | 0.1290 | 0.2780 | 0.1129 | 0.0093 | 0.0223 | -0.17 | -2.4140 | -1.6960 |
| 67 | 0.2267 | 0.1300 | 0.2890 | 0.1245 | 0.0093 | 0.0224 | -0.13 | 0.1086 | 0.4876 |
| 85 | 0.2235 | 0.1290 | 0.2770 | 0.1227 | 0.0093 | 0.0222 | -0.20 | -0.1084 | 0.5136 |
| 133 | 0.2270 | 0.1325 | 0.2880 | 0.1249 | 0.0096 | 0.0223 | -0.17 | 0.0543 | 1.1450 |
| 159 | 0.2250 | 0.1255 | 0.2805 | 0.1236 | 0.0099 | 0.0224 | -0.13 | -0.5158 | 1.2070 |
| 180 | 0.2255 | 0.1353 | 0.2825 | 0.1238 | 0.0098 | 0.0227 | -0.03 | -0.7341 | 0.5723 |
| 216 | 0.2245 | 0.1367 | 0.2845 | 0.1233 | 0.0100 | 0.0229 | 0.03 | -0.9202 | 0.4965 |
| 245 | 0.2244 | 0.1390 | 0.2860 | 0.1232 | 0.0102 | 0.0230 | 0.07 | -1.3350 | 0.5990 |
| 277 | 0.2230 | 0.1387 | 0.2830 | 0.1224 | 0.0102 | 0.0227 | -0.03 | -1.1420 | 0.9820 |
| 300 | 0.2230 | 0.1393 | 0.2850 | 0.1224 | 0.0102 | 0.0229 | 0.03 | -1.4420 | 0.5879 |

TABLE VIII HUNTER REFLECTOMETER READINGS AND RESULTS - Peacock Blue

PANEL NO. 29 - 3-PB-1
1-PB-2

| Hrs. | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| | B L | A 0.1 | G 0.5 | B | A | G | △ L' | △ S' | △ H' |
| 0 | 0.2570 | 0.2485 | 0.1000 | 0.2564 | 0.0207 | 0.0512 | - | - | - |
| 23 | 0.2595 | 0.2430 | 0.0983 | 0.2589 | 0.0202 | 0.0508 | -0.09 | 0.6321 | 0.2545 |
| 47 | 0.2643 | 0.2517 | 0.1013 | 0.2637 | 0.0210 | 0.0519 | 0.15 | 0.3336 | 0.4768 |
| 67 | 0.2635 | 0.2534 | 0.1020 | 0.2629 | 0.0213 | 0.0523 | 0.24 | 0 | 0.2312 |
| 85 | 0.2650 | 0.2540 | 0.1020 | 0.2644 | 0.0212 | 0.0523 | 0.24 | 0.2003 | 0.3348 |
| 133 | 0.2630 | 0.2620 | 0.1023 | 0.2624 | 0.0222 | 0.0525 | 0.28 | -0.5344 | -0.7515 |
| 159 | 0.2630 | 0.2590 | 0.1030 | 0.2624 | 0.0217 | 0.0528 | 0.24 | -0.5342 | 0.0368 |
| 180 | 0.2615 | 0.2608 | 0.1024 | 0.2609 | 0.0219 | 0.0525 | 0.28 | -0.6012 | 0.3307 |
| 216 | 0.2625 | 0.2650 | 0.1030 | 0.2619 | 0.0223 | 0.0528 | 0.24 | -0.8014 | 0.3877 |
| 245 | 0.2605 | 0.2670 | 0.1030 | 0.2599 | 0.0225 | 0.0528 | 0.24 | -1.235 | 0.3861 |
| 277 | 0.2603 | 0.2675 | 0.1030 | 0.2597 | 0.0227 | 0.0528 | 0.24 | -3.106 | 0.3681 |
| 300 | 0.2605 | 0.2690 | 0.1040 | 0.2597 | 0.0227 | 0.0534 | 0.48 | -3.414 | -0.0095 |

TABLE IX HUNTER REFLECTOMETER READINGS AND RESULTS - Green

PANEL NO. 20 - G-1

| | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| Hrs | B 0.1 | A 0.1 | G 0.5 | B | A | G | △ L' | △ S' | △ H' |
| 0 | 0.3750 | 0.5350 | 0.1405 | 0.0283 | 0.0483 | 0.0773 | - | - | - |
| 23 | 0.3920 | 0.5470 | 0.1465 | 0.0296 | 0.0495 | 0.0768 | -0.09 | -3.1351 | -0.5914 |
| 47 | 0.3945 | 0.5525 | 0.0063 | 0.0298 | 0.0500 | 0.0767 | -0.11 | -4.1670 | -0.5914 |
| 67 | 0.3943 | 0.5525 | 0.0066 | 0.0298 | 0.0500 | 0.0769 | -0.07 | -3.9103 | -0.8251 |
| 85 | 0.3930 | 0.5580 | 0.0067 | 0.0297 | 0.0505 | 0.0770 | -0.05 | -4.5752 | -1.327 |
| 133 | 0.3965 | 0.5705 | 0.0065 | 0.0300 | 0.0517 | 0.0768 | 0.09 | -6.7490 | -2.397 |
| 159 | 0.3930 | 0.5707 | 0.0065 | 0.0297 | 0.0518 | 0.0768 | -0.09 | -6.796 | -2.846 |
| 180 | 0.3890 | 0.5700 | 0.0053 | 0.0294 | 0.0517 | 0.0762 | -0.20 | -7.1485 | -3.000 |
| 216 | 0.3910 | 0.5820 | 0.0054 | 0.0295 | 0.0528 | 0.0762 | -0.20 | -8.6961 | -4.001 |
| 245 | 0.3910 | 0.5890 | 0.0065 | 0.0295 | 0.0535 | 0.0768 | -0.09 | -9.2945 | -4.168 |
| 277 | 0.3850 | 0.6000 | 0.0065 | 0.0290 | 0.0536 | 0.0767 | -0.11 | -9.4613 | -4.921 |
| 300 | 0.3890 | 0.6045 | 0.0053 | 0.0294 | 0.0550 | 0.0762 | -0.20 | -11.8282 | -6.374 |

TABLE X HUNTER REFLECTOMETER READINGS AND RESULTS - Green

PANEL NO. 19 - G-2

| | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| Hrs. | B 0.1 | A 0.1 | G 0.5 | B | A | G | △ L' | △ S' | △ H' |
| 0 | 0.3620 | 0.3965 | 0.1140 | 0.0271 | 0.0349 | 0.0587 | - | - | - |
| 23 | 0.3740 | 0.4010 | 0.1155 | 0.0281 | 0.0354 | 0.0595 | 0.16 | -0.2416 | 0.2710 |
| 47 | 0.3750 | 0.4010 | 0.1150 | 0.0282 | 0.0354 | 0.0593 | 0.12 | 0.8301 | 0.3981 |
| 67 | 0.3740 | 0.4010 | 0.1144 | 0.0281 | 0.0354 | 0.0589 | 0.04 | 1.413 | 0.3852 |
| 85 | 0.3740 | 0.4050 | 0.1150 | 0.0282 | 0.0357 | 0.0593 | 0.12 | 1.277 | -0.0160 |
| 133 | 0.3450 | 0.4130 | 0.1143 | 0.0382 | 0.0365 | 0.0589 | 0.14 | 3.447 | -0.7846 |
| 159 | 0.3750 | 0.4150 | 0.1150 | 0.0285 | 0.0367 | 0.0593 | 0.12 | 3. 209 | -0.7684 |
| 180 | 0.3660 | 0.4140 | 0.1135 | 0.0275 | 0.0366 | 0.0585 | 0.04 | 3.823 | -1.489 |
| 216 | 0.3690 | 0.4235 | 0.1135 | 0.0278 | 0.0375 | 0.0585 | -0.04 | 5.579 | -2.093 |
| 245 | 0.3700 | 0.4270 | 0.1130 | 0.0278 | 0.0879 | 0.0582 | -0.11 | 6.884 | -2.623 |
| 277 | 0.3607 | 0.4320 | 0.1140 | 0.0271 | 0.0383 | 0.0587 | 0.00 | -6.512 | -3.215 |
| 300 | 0.3650 | 0.4350 | 0.1135 | 0.0274 | 0.0386 | 0.0585 | -0.04 | -7.542 | -3.401 |

TABLE XI HUNTER REFLECTOMETER READINGS AND RESULTS - Green

PANEL NO. 16 - G-3

| | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| Hrs. | B | A | C | B | A | C | △ L' | △ S' | △ H' |
| | 0.1 | 0.1 | 0.1 | | | | | | |
| 0 | 0.3610 | 0.1730 | 0.3530 | 0.0271 | 0.0135 | 0.0291 | - | - | - |
| 23 | 0.3420 | 0.1745 | 0.3460 | 0.0255 | 0.0136 | 0.0285 | -0.18 | -1.673 | -1.276 |
| 47 | 0.3360 | 0.1730 | 0.3430 | 0.0250 | 0.0135 | 0.0282 | -0.27 | -0.7200 | -1.665 |
| 67 | 0.3330 | 0.1730 | 0.3552 | 0.0246 | 0.0135 | 0.0293 | 0.06 | 1.881 | -3.177 |
| 85 | 0.3240 | 0.1730 | 0.3310 | 0.0240 | 0.0135 | 0.0271 | -0.60 | -2.694 | -1.624 |
| 133 | 0.3240 | 0.1750 | 0.3270 | 0.0240 | 0.0137 | 0.0267 | -0.72 | -4.262 | -1.439 |
| 159 | 0.3210 | 0.1750 | 0.3230 | 0.0238 | 0.0137 | 0.0264 | -0.81 | -4.856 | -1.172 |
| 180 | 0.3163 | 0.1740 | 0.3180 | 0.0234 | 0.0137 | 0.0259 | -0.97 | -5.471 | -1.275 |
| 216 | 0.3150 | 0.1785 | 0.3190 | 0.0233 | 0.0136 | 0.0260 | -0.94 | -6.501 | -1.669 |
| 245 | 0.3100 | 0.1780 | 0.3125 | 0.0230 | 0.0140 | 0.0272 | -0.57 | -3.670 | -3.337 |
| 277 | 0.3035 | 0.1805 | 0.3130 | 0.0223 | 0.0140 | 0.0272 | -0.57 | -3.097 | -4.348 |
| 300 | 0.3075 | 0.1833 | 0.3180 | 0.0227 | 0.0143 | 0.0258 | -1.00 | -7.890 | -2.209 |

TABLE XII HUNTER REFLECTOMETER READINGS AND RESULTS - Green

PANEL NO. 17 - 1-G-2
2-G-3

| Hrs. | MACHINE READINGS B | A | G | CORRECTED READINGS B | A | G | CALCULATED I.C.I. VALUES △ L' | △ S' | △ H' |
|---|---|---|---|---|---|---|---|---|---|
| | 0.1 | 0.1 | 0.1 | | | | | | |
| 0 | 0.3300 | -0.1900 | 0.3850 | 0.0245 | 0.0151 | 0.0320 | - | - | - |
| 23 | 0.3425 | 0.2045 | 0.4015 | 0.0256 | 0.0165 | 0.0335 | 0.41 | -2.025 | -0.4805 |
| 47 | 0.3410 | 0.2070 | 0.4040 | 0.0254 | 0.0167 | 0.0337 | 0.47 | -2.206 | -0.7430 |
| 67 | 0.3380 | 0.2083 | 0.4010 | 0.0252 | 0.0168 | 0.0334 | 0.39 | -2.947 | -0.9592 |
| 85 | 0.3345 | 0.2090 | 0.4000 | 0.0249 | 0.0169 | 0.0333 | 0.36 | -3.244 | -1.363 |
| 133 | 0.3318 | 0.2125 | 0.3995 | 0.0247 | 0.0172 | 0.0328 | 0.22 | -5.109 | -1.239 |
| 159 | 0.3302 | 0.2140 | 0.3945 | 0.0245 | 0.0173 | 0.0329 | 0.25 | -4.992 | -0.9812 |
| 180 | 0.3273 | 0.2150 | 0.3925 | 0.0243 | 0.0174 | 0.0327 | 0.19 | -5.700 | -1.955 |
| 216 | 0.3283 | 0.2200 | 0.3930 | 0.0244 | 0.0179 | 0.0327 | 0.19 | -7.362 | -1.460 |
| 245 | 0.3270 | 0.2205 | 0.3870 | 0.0243 | 0.0180 | 0.0322 | 0.05 | -8.623 | -1.928 |
| 277 | 0.3210 | 0.2260 | 0.3920 | 0.0238 | 0.0185 | 0.0327 | 0.19 | -8.758 | -2.045 |
| 300 | 0.3255 | 0.2300 | 0.3940 | 0.0242 | 0.0189 | 0.0329 | 0.05 | -9.885 | -3.035 |

TABLE XIII HUNTER REFLECTOMETER READINGS AND RESULTS - Green

PANEL NO. 18 - 2-G-2
1-G-3

| | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| Hrs. | B | A | G | B | A | G | △L' | △S' | △H' |
| | 0.1 | 0.1 | 0.1 | | | | | | |
| 0 | 0.3750 | 0.2810 | 0.5610 | 0.0282 | 0.0238 | 0.0481 | - | - | - |
| 22 | 0.3690 | 0.2985 | 0.5520 | 0.0277 | 0.0255 | 0.0472 | -0.20 | -5.365 | -1.454 |
| 47 | 0.3650 | 0.2800 | 0.5390 | 0.0272 | 0.0237 | 0.0461 | -0.46 | -8.203 | -0.3163 |
| 67 | 0.3622 | 0.2780 | 0.5335 | 0.0272 | 0.0235 | 0.0456 | -0.58 | -2.801 | -0.2513 |
| 85 | 0.3750 | 0.2790 | 0.5290 | 0.0268 | 0.0236 | 0.0452 | -0.67 | -3.383 | -0.6546 |
| 133 | 0.3520 | 0.2810 | 0.5170 | 0.0263 | 0.0238 | 0.0441 | -0.93 | -5.513 | -0.9535 |
| 159 | 0.3505 | 0.2830 | 0.5170 | 0.0262 | 0.0240 | 0.0441 | -0.93 | -5.935 | -1.355 |
| 180 | 0.3450 | 0.2821 | 0.5105 | 0.0258 | 0.0239 | 0.0435 | -1.07 | -6.475 | -1.481 |
| 216 | 0.3510 | 0.2925 | 0.5170 | 0.0263 | 0.0249 | 0.0441 | -0.93 | -8.302 | -1.850 |
| 245 | 0.3445 | 0.2910 | 0.5090 | 0.0258 | 0.0248 | 0.0434 | -1.10 | -9.063 | -2.113 |
| 277 | 0.3185 | 0.2950 | 0.5090 | 0.0253 | 0.0252 | 0.0434 | -1.10 | -9.646 | -3.211 |
| 300 | 0.3425 | 0.2980 | 0.5110 | 0.0258 | 0.0255 | 0.0435 | -1.07 | -10.554 | -2.882 |

TABLE XIV HUNTER REFLECTOMETER READINGS AND RESULTS - Yellow

PANEL NO. 15 - Y-1

| | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| Hrs. | B | A | G | B | A | G | $\Delta L'$ | $\Delta S'$ | $\Delta H'$ |
| | 0.5 L | L | L | | | | | | |
| 0 | 0.1500 | 0.7680 | 0.7030 | 0.0802 | 0.7682 | 0.7040 | - | - | - |
| 22 | 0.1420 | 0.7130 | 0.6550 | 0.0754 | 0.7142 | 0.6552 | -2.96 | -0.3178 | 0.2742 |
| 42 | 0.1410 | 0.6910 | 0.6240 | 0.0748 | 0.6918 | 0.6239 | -4.91 | -0.3158 | -3.356 |
| 59 | 0.1400 | 0.6780 | 0.6105 | 0.0744 | 0.6786 | 0.6104 | -5.77 | -0.3150 | -3.985 |
| 85 | 0.1380 | 0.6650 | 0.5990 | 0.0731 | 0.6652 | 0.5988 | -6.52 | 0.3143 | -3.795 |
| 131 | 0.1385 | 0.6450 | 0.5800 | 0.0733 | 0.6450 | 0.5799 | -7.75 | -0.8764 | -4.262 |
| 150 | 0.1380 | 0.6420 | 0.5760 | 0.0731 | 0.6420 | 0.5759 | -8.01 | -0.5630 | -4.600 |
| 200 | 0.1360 | 0.6235 | 0.5570 | 0.0719 | 0.6234 | 0.5570 | -9.27 | -0.5607 | -5.573 |
| 233 | 0.1355 | 0.6080 | 0.5410 | 0.0717 | 0.6079 | 0.5411 | -10.34 | -1.117 | -6.321 |
| 262 | 0.1350 | 0.6440 | 0.5344 | 0.0714 | 0.6028 | 0.5345 | -11.71 | -0.5502 | -7.332 |
| 302 | 0.1345 | 0.5090 | 0.5210 | 0.0711 | 0.5090 | 0.5211 | - | - | - |

## TABLE XV HUNTER REFLECTOMETER READINGS AND RESULTS - Yellow

PANEL NO. 13 - Y-2

| Hrs. | MACHINE READINGS B (0.1 L) | A (L) | G (L) | CORRECTED READINGS B | A | G | CALCULATED I.C.I. VALUES △L' | △S' | △H' |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.3965 | 0.6835 | 0.5470 | 0.0300 | 0.6842 | 0.5471 | - | - | - |
| 22 | 0.3983 | 0.6225 | 0.5010 | 0.0301 | 0.6224 | 0.5012 | -3.16 | -0.8932 | 1.100 |
| 42 | 0.3975 | 0.6000 | 0.4830 | 0.0301 | 0.5998 | 0.4833 | -4.44 | -1.3040 | 1.131 |
| 59 | 0.3980 | 0.5810 | 0.4665 | 0.0301 | 0.5809 | 0.4672 | -5.61 | -0.6494 | -0.2764 |
| 85 | 0.3935 | 0.5680 | 0.4565 | 0.0297 | 0.5679 | 0.4572 | -6.34 | -0.4122 | 0.8451 |
| 131 | 0.3970 | 0.5650 | 0.4557 | 0.0301 | 0.5649 | 0.4564 | -6.40 | -1.7070 | 1.178 |
| 150 | 0.4053 | 0.5545 | 0.4470 | 0.0307 | 0.5545 | 0.4476 | -7.06 | -1.9380 | 1.223 |
| 200 | 0.4080 | 0.5450 | 0.4390 | 0.0309 | 0.5451 | 0.4394 | -7.67 | -1.934 | 0.8442 |
| 233 | 0.4145 | 0.5260 | 0.4290 | 0.0314 | 0.6261 | 0.4243 | -8.82 | -2.392 | -0.8266 |
| 262 | 0.4020 | 0.5150 | 0.4150 | 0.0304 | 0.5150 | 0.5150 | -9.54 | -2.500 | 0.4468 |
| 302 | 0.4135 | 0.5090 | 0.4060 | 0.0314 | 0.5091 | 0.4057 | -10.27 | -1.277 | -1.538 |

TABLE XVI HUNTER REFLECTOMETER READINGS AND RESULTS - Yellow

PANEL NO. 11 - Y-3

| | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| Hrs. | B | A | G | B | A | G | $\triangle L^*$ | $\triangle S^*$ | $\triangle H^*$ |
| | 0.1 L | L | L | | | | | | |
| 0 | 0.3290 | 0.6780 | 0.5185 | 0.0244 | 0.6787 | 0.5185 | - | - | - |
| 22 | 0.3400 | 0.6370 | 0.4890 | 0.0253 | 0.6370 | 0.4893 | -2.06 | -1.003 | 0.7824 |
| 42 | 0.3450 | 0.6280 | 0.4820 | 0.0258 | 0.6280 | 0.4820 | -2.55 | -1.236 | 0.6672 |
| 59 | 0.3450 | 0.6270 | 0.4820 | 0.0258 | 0.6270 | 0.4824 | -2.55 | -1.413 | 0.9852 |
| 85 | 0.3430 | 0.6250 | 0.4810 | 0.0256 | 0.6250 | 0.4814 | -2.63 | -1.413 | 1.201 |
| 131 | 0.3470 | 0.6220 | 0.4807 | 0.0260 | 0.6218 | 0.4811 | -2.65 | -2.060 | 1.946 |
| 150 | 0.3510 | 0.6240 | 0.4824 | 0.0263 | 0.6240 | 0.4830 | -2.51 | -2.061 | 2.044 |
| 200 | 0.3595 | 0.6110 | 0.4730 | 0.0270 | 0.6109 | 0.4736 | -3.19 | -2.643 | 2.333 |
| 233 | 0.3600 | 0.6050 | 0.4765 | 0.0270 | 0.6048 | 0.4771 | -2.94 | -4.115 | 5.468 |
| 262 | 0.3600 | 0.6010 | 0.4650 | 0.0270 | 0.6008 | 0.4657 | -3.77 | -2.462 | 2.121 |
| 302 | 0.3725 | 0.5990 | 0.4625 | 0.0272 | 0.5987 | 0.4632 | -3.95 | -2.460 | 1.682 |

TABLE XVII HUNTER REFLECTOMETER READINGS AND RESULTS - Yellow

PANEL NO. 14 - 1-Y-1
1-Y-2

| Hrs. | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| | B 0.1 | A L | G L | B | A | G | △L' | △S' | △H' |
| 0 | 0.4445 | 0.6740 | 0.5540 | 0.0381 | 0.6745 | 0.5589 | - | - | - |
| 22 | 0.4925 | 0.6290 | 0.5230 | 0.0379 | 0.6290 | 0.5231 | -2.43 | -0.7204 | 0.6167 |
| 42 | 0.4970 | 0.6210 | 0.5150 | 0.0383 | 0.6208 | 0.5150 | -3.00 | 0.4790 | 1.095 |
| 59 | 0.4940 | 0.6020 | 0.4490 | 0.0881 | 0.6018 | 0.4992 | -4.11 | -0.4775 | -0.3452 |
| 85 | 0.4884 | 0.5920 | 0.4910 | 0.0377 | 0.5918 | 0.4913 | -4.67 | -0.7148 | 0.3227 |
| 131 | 0.4930 | 0.5740 | 0.4770 | 0.0380 | 0.5738 | 0.4776 | -5.65 | -1.128 | 0.5048 |
| 150 | 0.4990 | 0.5710 | 0.4745 | 0.0385 | 0.5709 | 0.4752 | -5.83 | -1.364 | 0.4463 |
| 200 | 0.5010 | 0.5540 | 0.4590 | 0.0387 | 0.5540 | 0.4597 | -6.96 | -1.359 | -0.2507 |
| 233 | 0.5030 | 0.5500 | 0.4550 | 0.0388 | 0.5501 | 0.4557 | -7.25 | -1.121 | -0.5680 |
| 262 | 0.4950 | 0.5470 | 0.4530 | 0.0382 | 0.5471 | 0.4537 | -7.40 | -1.357 | -0.3809 |
| 302 | 0.5050 | 0.5450 | 0.4510 | 0.0390 | 0.5451 | 0.4517 | -7.55 | -1.592 | -0.5728 |

TABLE XVIII HUNTER REFLECTOMETER READINGS AND RESULTS - Yellow

PANEL NO. 12 - 1-Y-2
1-Y-3

| | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| Hrs. | B | A | C | B | A | C | △ L' | △ S' | △ H' |
| | 0.1 L | L | L | | | | | | |
| 0 | 0.0350 | 0.7050 | 0.5480 | 0.0262 | 0.7060 | 0.5481 | - | - | - |
| 22 | 0.3500 | 0.6430 | 0.5010 | 0.0267 | 0.6431 | 0.5012 | -3.23 | -0.8337 | 0.4622 |
| 42 | 0.3600 | 0.6250 | 0.4880 | 0.0270 | 0.6250 | 0.4883 | -4.15 | -1.481 | 0.8813 |
| 59 | 0.3590 | 0.6140 | 0.4770 | 0.0269 | 0.6138 | 0.4776 | -4.92 | -0.8290 | 0.0890 |
| 85 | 0.3555 | 0.6050 | 0.4770 | 0.0260 | 0.6048 | 0.4776 | -4.92 | -2.546 | 2.781 |
| 131 | 0.3630 | 0.5890 | 0.4600 | 0.0272 | 0.5888 | 0.4607 | -6.16 | -1.886 | 0.9639 |
| 150 | 0.3650 | 0.5850 | 0.4570 | 0.0274 | 0.5884 | 0.4557 | -6.38 | -1.885 | 0.9785 |
| 200 | 0.3690 | 0.5840 | 0.4550 | 0.0277 | 0.5838 | 0.4557 | -6.52 | -1.648 | 0.4385 |
| 233 | 0.3720 | 0.5720 | 0.4460 | 0.0280 | 0.5718 | 0.4466 | -7.20 | -1.879 | 0.4286 |
| 262 | 0.3660 | 0.5662 | 0.4410 | 0.0275 | 0.5661 | 0.4415 | -7.58 | -1.642 | 0.1920 |
| 302 | 0.3880 | 0.5640 | 0.4400 | 0.0293 | 0.5639 | 0.4405 | -7.67 | -2.111 | 0.3432 |

TABLE XX HUNTER REFLECTOMETER READINGS AND RESULTS - Orange

PANEL NO. 8 - O-2

| | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| Hrs. | B | A | G | B | A | G | $\Delta L'$ | $\Delta S'$ | $\Delta H'$ |
| | 0.1 L | L | L | | | | | | |
| 0 | 0.1970 | 0.3870 | 0.2030 | 0.0135 | 0.3867 | 0.2016 | - | - | - |
| 22 | 0.1937 | 0.3840 | 0.2015 | 0.0133 | 0.3837 | 0.2001 | -0.18 | -0.2611 | 0.1401 |
| 42 | 0.1975 | 0.3765 | 0.1685 | 0.0136 | 0.3762 | 0.1171 | -0.50 | -1.029 | 0.4297 |
| 59 | 0.1983 | 0.3790 | 0.2004 | 0.0136 | 0.3787 | 0.1990 | -0.29 | -1.499 | 0.7837 |
| 85 | 0.2010 | 0.3770 | 0.2004 | 0.0139 | 0.3767 | 0.1990 | -0.29 | -2.388 | 1.066 |
| 131 | 0.2050 | 0.3770 | 0.2020 | 0.0142 | 0.3767 | 0.2006 | -0.11 | -3.750 | 1.821 |
| 150 | 0.2150 | 0.3770 | 0.0220 | 0.0150 | 0.3767 | 0.2006 | -0.11 | -3.938 | 1.615 |
| 200 | 0.2200 | 0.3765 | 0.2030 | 0.0154 | 0.3762 | 0.2016 | 0 0 | -4.785 | 2.046 |
| 233 | 0.2205 | 0.3750 | 0.2020 | 0.0154 | 0.3748 | 0.2006 | -0.11 | -4.688 | 1.193 |
| 267 | 0.2200 | 0.3785 | 0.2023 | 0.0154 | 0.3782 | 0.2009 | -0.08 | -3.516 | 1.286 |
| 302 | 0.2204 | 0.3765 | 0.2025 | 0.0157 | 0.3762 | 0.2011 | -0.06 | -4.951 | 1.767 |

TABLE XIX HUNTER REFLECTOMETER READINGS AND RESULTS - Orange

PANEL NO. 10 - O-1

| Hrs. | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| | B 0.1 L | A L | G L | B | A | G | △ L' | △ S' | △ H' |
| 0 | 0.2150 | 0.4340 | 0.3420 | 0.0150 | 0.4344 | 0.2412 | - | - | - |
| 22 | 0.2265 | 0.4280 | 0.2405 | 0.0160 | 0.4283 | 0.2397 | -0.15 | -1.378 | 1.008 |
| 42 | 0.2300 | 0.4230 | 0.2405 | 0.0162 | 0.4253 | 0.2343 | -0.19 | -3.042 | 1.496 |
| 59 | 0.2324 | 0.4230 | 0.2400 | 0.0165 | 0.4233 | 0.2393 | -0.19 | -3.140 | 1.430 |
| 85 | 0.2350 | 0.4230 | 0.2400 | 0.0167 | 0.4233 | 0.2397 | -0.15 | -3.395 | 1.555 |
| 131 | 0.2383 | 0.4090 | 0.2404 | 0.0173 | 0.4088 | 0.2398 | -0.19 | -8.809 | 5.041 |
| 150 | 0.2500 | 0.4200 | 0.2405 | 0.0179 | 0.4201 | 0.2398 | -0.14 | -5.065 | 2.153 |
| 200 | 0.2530 | 0.4205 | 0.2415 | 0.0182 | 0.4206 | 0.2407 | -0.14 | -5.288 | 2.327 |
| 233 | 0.2530 | 0.4170 | 0.2405 | 0.0182 | 0.4170 | 0.2398 | -0.05 | -5.053 | 2.810 |
| 267 | 0.2530 | 0.4210 | 0.2410 | 0.0182 | 0.4212 | 0.2403 | -0.09 | -5.429 | 2.257 |
| 302 | 0.2680 | 0.4170 | 0.2410 | 0.0194 | 0.4170 | 0.2408 | -0.09 | -6.662 | 2.810 |

TABLE XXI HUNTER REFLECTOMETER READING AND RESULTS- Orange

PANEL NO. 7 - O-3

| Hrs. | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| | B | A | G | B | A | G | ΔL' | ΔS' | ΔH' |
| | 0.1 L | L | | | | | | | |
| 0 | 0.2130 | 0.2950 | 0.1500 | 0.0133 | 0.2903 | 0.1472 | - | - | - |
| 22 | 0.1970 | 0.3030 | 0.1520 | 0.0135 | 0.3029 | 0.1511 | 0.50 | 2.742 | -1.211 |
| 42 | 0.1990 | 0.3020 | 0.1530 | 0.0137 | 0.3019 | 0.1521 | 0.63 | 1.045 | -0.4591 |
| 59 | 0.1980 | 0.3040 | 0.1535 | 0.0136 | 0.3039 | 0.1526 | 0.59 | 1.524 | -0.6969 |
| 85 | 0.1909 | 0.3004 | 0.1543 | 0.0130 | 0.3002 | 0.1534 | 0.80 | -0.7410 | 0.7763 |
| 131 | 0.2000 | 0.3045 | 0.1558 | 0.0138 | 0.3044 | 0.1549 | 0.99 | 0.3655 | 0.2548 |
| 150 | 0.2066 | 0.3055 | 0.1630 | 0.0143 | 0.3054 | 0.1520 | 1.88 | -6.363 | 3.521 |
| 200 | 0.2105 | 0.3060 | 0.1580 | 0.0146 | 0.3060 | 0.1571 | 1.27 | -1.792 | 0.7944 |
| 233 | 0.2090 | 0.3050 | 0.1570 | 0.0145 | 0.3049 | 0.1561 | 1.14 | -1.444 | 0.5624 |
| 262 | 0.2083 | 0.3090 | 0.1580 | 0.0145 | 0.3091 | 0.1571 | 1.27 | 0.3060 | 0.0598 |
| 302 | 0.2115 | 0.3070 | 0.1580 | 0.0147 | 0.3019 | 0.1571 | 1.27 | -0.3924 | 0.6955 |

TABLE XXII HUNTER REFLECTOMETER READING AND RESULTS - Orange

PANEL NO. 9 - 1-0-1
1-0-2

| | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| Hrs. | B | A | C | B | A | C | △L' | △S' | △H' |
| | 0.1 L | L | L | | | | | | |
| 0 | 0.2055 | 0.4160 | 0.2270 | 0.0142 | 0.4160 | 0.2258 | - | - | - |
| 22 | 0.2150 | 0.4090 | 0.2230 | 0.0150 | 0.4088 | 0.2217 | -0.43 | -0.0963 | 0.24 |
| 42 | 0.2210 | 0.4050 | 0.2230 | 0.0155 | 0.4047 | 0.2217 | -0.43 | 1.829 | 0.59 |
| 59 | 0.2230 | 0.4051 | 0.2225 | 0.0143 | 0.4048 | 0.2212 | -0.49 | 1.107 | 0.63 |
| 85 | 0.2550 | 0.4030 | 0.2220 | 0.0158 | 0.4027 | 0.2212 | -0.49 | 1.107 | 0.63 |
| 131 | 0.2290 | 0.4020 | 0.2230 | 0.0162 | 0.4016 | 0.2217 | -0.43 | -3.081 | 1.11 |
| 150 | 0.2366 | 0.4020 | 0.2230 | 0.0168 | 0.4016 | 0.2217 | -0.43 | -3.274 | 1.03 |
| 200 | 0.2465 | 0.4065 | 0.2250 | 0.0176 | 0.4062 | 0.2238 | -0.21 | -3.085 | 0.74 |
| 233 | 0.2450 | 0.4000 | 0.2240 | 0.0175 | 0.4096 | 0.2227 | -0.33 | -4.817 | 1.8 |
| 267 | 0.2470 | 0.4050 | 0.2242 | 0.0176 | 0.4047 | 0.2229 | -0.31 | -3.035 | 0.68 |
| 302 | 0.2560 | 0.4010 | 0.2250 | 0.0184 | 0.4006 | 0.2238 | -0.21 | -5.350 | 1.90 |

TABLE XXIII HUNTER REFLECTOMETER READINGS AND RESULTS - Red

PANEL NO. 5 - R-1

| Hrs. | MACHINE READINGS B (0.1 L) | A | G (0.5 L) | CORRECTED READINGS B | A | G | CALCULATED I.C.I. VALUES △L' | △S' | △H' |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.1450 | 0.2180 | 0.1475 | 0.0093 | 0.2167 | 0.0775 | - | - | - |
| 22 | 0.1485 | 0.2230 | 0.1493 | 0.0096 | 0.2217 | 0.0786 | 0.20 | -0.8880 | -0.0949 |
| 42 | 0.1500 | 0.2205 | 0.1505 | 0.0097 | 0.2192 | 0.0792 | 0.30 | 3.259 | 0.6764 |
| 59 | 0.1540 | 0.2221 | 0.1520 | 0.0100 | 0.2108 | 0.0780 | 0.48 | 4.006 | 0.8245 |
| 85 | 0.1555 | 0.2225 | 0.1522 | 0.0102 | 0.2112 | 0.0780 | 0.48 | 3.895 | 0.6891 |
| 131 | 0.1603 | 0.2245 | 0.1563 | 0.0106 | 0.2133 | 0.0726 | 0.90 | 6.596 | 1.1360 |
| 150 | 0.1660 | 0.2250 | 0.1595 | 0.0110 | 0.2138 | 0.0716 | 0.73 | 4.875 | 0.6486 |
| 200 | 0.1640 | 0.2235 | 0.1544 | 0.0104 | 0.2122 | 0.0716 | 0.73 | 5.768 | 1.0170 |
| 233 | 0.1640 | 0.2220 | 0.1550 | 0.0109 | 0.2107 | 0.0718 | 0.76 | 6.886 | 1.4600 |
| 262 | 0.1644 | 0.2243 | 0.1543 | 0.0109 | 0.2130 | 0.0716 | 0.73 | 4.986 | 0.8623 |
| 302 | 0.1644 | 0.2240 | 0.1550 | 0.0109 | 0.2127 | 0.0718 | 0.76 | 5.806 | 1.0040 |

TABLE XXIV HUNTER REFLECTOMETER READINGS AND RESULTS - Red

PANEL NO. 4 - R-3

| Hrs. | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| | B | A | G | B | A | G | △ L' | △ S' | △ H' |
| | 0.1 | L | 0.5 | | | | | | |
| 0 | 0.1410 | 0.1990 | 0.1330 | 0.0089 | 0.1976 | 0.6910 | - | - | - |
| 22 | 0.1410 | 0.2020 | 0.1365 | 0.0094 | 0.2006 | 0.0711 | 0.37 | -1.801 | 0.4068 |
| 42 | 0.1465 | 0.2020 | 0.1393 | 0.0094 | 0.2006 | 0.0726 | -0.65 | -4.294 | 1.3222 |
| 59 | 0.1485 | 0.2020 | 0.1365 | 0.0096 | 0.2006 | 0.0711 | 0.73 | -1.837 | 0.314 |
| 85 | 0.1490 | 0.2010 | 0.1370 | 0.0096 | 0.1996 | 0.0713 | -0.41 | -2.882 | -0.6458 |
| 131 | 0.1530 | 0.2000 | 0.1380 | 0.0099 | 0.1980 | 0.0719 | -0.52 | -4.617 | 1.0880 |
| 150 | 0.1525 | 0.2013 | 0.1373 | 0.0099 | 0.1997 | 0.0715 | 0.45 | -3.172 | 0.5228 |
| 200 | 0.1563 | 0.1995 | 0.1390 | 0.0202 | 0.1987 | 0.0724 | 0.62 | -5.720 | 1.3540 |
| 233 | 0.1543 | 0.2000 | 0.1380 | 0.0101 | 0.1986 | 0.0719 | 0.52 | -4.725 | 0.9809 |
| 262 | 0.1535 | 0.1990 | 0.1375 | 0.0100 | 0.1996 | 0.0716 | 0.47 | -4.831 | 0.9926 |
| 302 | 0.1545 | 0.1990 | 0.1380 | 0.0101 | 0.1976 | 0.0719 | 0.52 | -5.627 | 1.2110 |

TABLE XXV HUNTER REFLECTOMETER READINGS AND RESULTS - Red

PANEL NO. 1 - R-5

| Hrs. | MACHINE READINGS B (0.1 L) | A (0.5 L) | G | CORRECTED READINGS B | A | G | CALCULATED I.C.I. VALUES $\Delta L'$ | $\Delta S'$ | $\Delta H' = (7)(5)$ |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.1540 | 0.1410 | 0.1010 | 0.0088 | 0.1285 | 0.0478 | - | - | - |
| 22 | 0.1410 | 0.1423 | 0.0955 | 0.0089 | 0.1410 | 0.0487 | 0.21 | 8.9570 | -2.604 |
| 42 | 0.1434 | 0.1405 | 0.0960 | 0.0090 | 0.1399 | 0.0489 | 0.25 | 7.0900 | -2.017 |
| 59 | 0.1465 | 0.1420 | 0.0965 | 0.0092 | 0.1413 | 0.0492 | 0.32 | 7.3910 | -2.265 |
| 85 | 0.1483 | 0.1420 | 0.0970 | 0.0094 | 0.1413 | 0.0494 | 0.37 | 6.8360 | -2.238 |
| 131 | 0.1500 | 0.1420 | 0.0980 | 0.0097 | 0.1414 | 0.0500 | 0.50 | 5.4640 | -1.980 |
| 150 | 0.1560 | 0.1433 | 0.0982 | 0.0001 | 0.1426 | 0.0501 | 0.52 | 5.9920 | -2.339 |
| 200 | 0.1583 | 0.1423 | 0.0990 | 0.0104 | 0.1416 | 0.0506 | 0.63 | 3.9560 | -1.871 |
| 233 | 0.1560 | 0.1420 | 0.0990 | 0.0101 | 0.1413 | 0.0506 | 0.63 | 3.8900 | -1.699 |
| 262 | 0.1550 | 0.1422 | 0.0990 | 0.0100 | 0.1415 | 0.0506 | 0.64 | 4.0870 | -1.735 |
| 302 | 0.1570 | 0.1423 | 0.0990 | 0.0102 | 0.1416 | 0.0506 | 0.63 | 4.0870 | -1.769 |

TABLE XXVI HUNTER REFLECTOMETER READINGS AND RESULTS - Red

PANEL NO. 2 - 1-R-3
2-R-5

| | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| Hrs. | B .1 | A .5 | G .5 | B | A | G | △ L' | △ S' | △ H' |
| 0 | 0.1580 | 0.2620 | 0.1090 | 0.0091 | 0.1579 | 0.0846 | - | - | - |
| 22 | 0.1453 | 0.2750 | 0.1057 | 0.0093 | 0.1508 | 0.0543 | -5.78 | 44.4 | 21.952 |
| 42 | 0.1473 | 0.2670 | 0.1063 | 0.0095 | 0.1460 | 0.0547 | -5.70 | 41.39 | 20.475 |
| 59 | 0.1486 | 0.2670 | 0.1057 | 0.0096 | 0.1460 | 0.0543 | -5.79 | 42.185 | 20.896 |
| 85 | 0.1490 | 0.2675 | 0.1062 | 0.0096 | 0.1409 | 0.0547 | -5.70 | 41.570 | 20.688 |
| 131 | 0.1510 | 0.2650 | 0.1065 | 0.0098 | 0.1449 | 0.0549 | -5.00 | 39.832 | 20.147 |
| 150 | 0.1535 | 0.2650 | 0.1068 | 0.0100 | 0.1449 | 0.0551 | -5.62 | 39.281 | 20.063 |
| 200 | 0.1555 | 0.2650 | 0.1083 | 0.0102 | 0.1449 | 0.0558 | -5.47 | 37.756 | 19.932 |
| 233 | 0.1540 | 0.2650 | 0.1070 | 0.0100 | 0.1446 | 0.0552 | -5.60 | 39.148 | 19.932 |
| 262 | 0.1565 | 0.2645 | 0.1075 | 0.0108 | 0.1445 | 0.0554 | -5.54 | 38.263 | 19.877 |
| 302 | 0.1565 | 0.2643 | 0.1075 | 0.0108 | 0.1445 | 0.0554 | -5.54 | 38.191 | 19.807 |

TABLE XXVII HUNTER REFLECTOMETER READINGS AND RESULTS - Red

PANEL NO. 3 - 2-R-3
1-R-5

| | MACHINE READINGS | | | CORRECTED READINGS | | | CALCULATED I.C.I. VALUES | | |
|---|---|---|---|---|---|---|---|---|---|
| Hrs. | B 0.1 | A 0.5 | C 0.5 | B | A | C | $\Delta L'$ | $\Delta S'$ | $\Delta H'$ |
| 0 | 0.1440 | 0.3010 | 0.1185 | 0.0092 | 0.1660 | 0.011 | - | - | - |
| 23 | 0.1465 | 0.3010 | 0.1190 | 0.0094 | 0.1660 | 0.641 | 0.06 | 0.6965 | 0.0967 |
| 47 | 0.1485 | 0.3045 | 0.1200 | 0.0096 | 0.1680 | 0.619 | 0.16 | 0.3137 | -0.1564 |
| 67 | 0.1510 | 0.3070 | 0.1215 | 0.0098 | 0.1695 | 0.627 | 0.32 | 0.7682 | 0.4842 |
| 85 | 0.1540 | 0.3020 | 0.1200 | 0.0101 | 0.1666 | 0.619 | 0.16 | 1.569 | -0.4648 |
| 133 | 0.1590 | 0.2990 | 0.1220 | 0.0105 | 0.1644 | 0.300 | 0.38 | 4.996 | 0.9453 |
| 159 | 0.1598 | 0.3008 | 0.1205 | 0.0105 | 0.1659 | 0.320 | 0.22 | 2.860 | 0.1168 |
| 180 | 0.1600 | 0.3030 | 0.1205 | 0.0105 | 0.1672 | 0.200 | 0.22 | 1.849 | -0.1315 |
| 216 | 0.1600 | 0.3040 | 0.1205 | 0.0105 | 0.1677 | 0.220 | 0.22 | 1.535 | -0.2390 |
| 245 | 0.1630 | 0.3003 | 0.1214 | 0.0108 | 0.1657 | 0.270 | 0.32 | 4.050 | 0.4388 |
| 277 | 0.1570 | 0.2974 | 0.1195 | 0.0103 | 0.1639 | 0.170 | 0.12 | 3.241 | 0.4043 |
| 300 | 0.1573 | 0.2970 | 0.1204 | 0.0105 | 0.1637 | 0.210 | 0.20 | 4.255 | 0.5222 |

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# VITA

The author was born in Lahore (Punjab) Pakistan, on August 21, 1922. His father Chaudhri Zahur Ahmad, and mother Saliha Begum, were native to the Province of the Punjab (Pakistan).

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Due to sea passage difficulties Mr. Ahmad had to wait for about eight months during which time he served as an instructor in the Government Leather Tanning Institute, Jullundar. Meanwhile division of British India took place and the author opted for Pakistan.

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