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THE EFFECT OF TURBID WATER IN THE OPTICAL PATH OF A PHOTOGRAPHIC SYSTEM ON THE MODULATION TRANSFER FUNCTION OF THAT SYSTEM

SENIOR RESEARCH THESIS

by

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and

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ABSTRACT

Various levels of a turbid suspension were introduced into a specially constructed tank and photographs of a variable transmittance sinusoidal object containing a step tablet were taken. The resulting images were processed and measured on a micro-densitometer to obtain the modulation transfer functions of the system.

Results indicate that with increasing turbidity there is a speed loss, increased flare or reduced contrast, and decreasing modulation transfer functions. The increasing flare is not the only factor causing the demodulation of the underwater images.

INTRODUCTION

Recent emphasis on the importance of underwater environment for both tactical and commercial needs has produced an accompanying demand for information regarding the performance of the photographic process as applied to underwater conditions.

The nature of this environment, however, does not facilitate any type of general investigation, because of its great complexity and variability in both chemical and physical composition. Rapid movement of the water, or turbulence, combined with differential temperature layers, produces continuous changes of its optical properties. The nature of the illumination of underwater objects is an even more important consideration. The most influential characteristic of the water however, is its transportation of physical impurities, ranging in size from microscopic particles to small rocks.

The variability caused by these impurities is not limited to just their size, but includes such considerations as shape, concentration, and spectral absorption characteristics. These impurities in the water cause the light passing through it to be either absorbed, transmitted, or reflected in all directions. Each particle, acting as a secondary light source, invariably redirects part of the light toward the camera lens. There are two types of scattering. The first type, Rayleigh scattering, takes place when the linear dimension of the particle is considerably smaller than the wavelength of the illumination, thus exhibiting spectrally selective scatter proportional to $1/\lambda^4$.[1] The second type is a non-selective scatter which is caused by the larger particles. Those particular

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[1] Jenkins and White, Fundamentals of Optics, McGraw Hill Co., New York, N.Y., 1950.

particles approximating the wavelength of light exhibit a combination of both types of scattering. Those much greater in size have only non-selective characteristics. Because of the overwhelming influence of acqueous-borne particles in the production of underwater photographic images, any basic research into the nature of these images must logically begin with the investigation of the particle effect, i.e., turbidity.

Up to this time, there has been little experimentation concerning the effect of turbidity on underwater images. Considerable work has been published on photography in turbid atmospheres, where similar problems are encountered. Surveys of the effect on resolving power and contrast changes due to the effect of atmospheric turbidity have indicated an increase in flare, or contrast reduction, with increased turbidity, and a corresponding decrease in resolving power.[1] However, there has been no indication of how influential this contrast loss was, and whether it was the sole factor in determining the degradation of the image.

The significance of these investigations have been limited because of the uncontrollable and unrepeatable aspects of natural turbidities. The practical implications have been limited because of the use of the subjective measure of resolving power in describing image degradation.

To overcome these difficulties, the authors made three innovations in procedure, in order to establish a controlled experiment. It was first necessary to obtain a standard repeatable medium. "Conforming to practice" in this case was out of the question due to the extreme differences in water, ranging from an extremely muddy harbor to the clearest and purest of mountain lakes. Because of these conditions, repeatability took preference and dispersions in distilled water were selected.

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[1] Tupper and Nelson, Photographic Engineering, Vol. 6, No. 2, 1955.

The second innovation was that of the use of a repeatable suspension of controlled particle size as the standard turbidity. A calcium oxalate suspension produced from oxalic acid and calcium chloride was selected because of its ease of preparation, non-selective scatter and low solubility product. (See appendix) The magnitude and repeatability of the turbidity were indicated by three measurements; nephelometric, photometric transmittance and chemical composition expressed as parts per million.

The modulation transfer function, (MTF) of the system was chosen as the most suitable method for the description of image quality degradation. By mathematical manipulation it was possible to evaluate the MTF of the turbidity alone. From these data, inferences could be made about whether the contrast reduction, or flare, was the sole or primary factor causing demodulation of the image.

PROCEDURE

METHOD

A Kodak variable transmittance sinusoidal test object, (3" X 4"), and a #2 calibrated step wedge were sandwiched between two sheets of optical glass at one end of a specially constructed tank, (Diagram 1) 1.5 meters long, containing 70 liters of water. The target was illuminated with a light box producing a diffuse field with a standard deviation of 0.5% of uniformity. (Diagram 2) Illumination was received at the opposite end of the tank, where a Leica 35mm, M2 camera with a Summarex f/1.5, 85mm lens recorded the images. The lens had a resolving power of 395 lines/mm at f/4 and produced a system magnification of .075. A standard suspension of calcium oxalate was produced, and successive aliquots were added to the system to produce the controlled turbidity. Photographs were taken of the objects at each level of

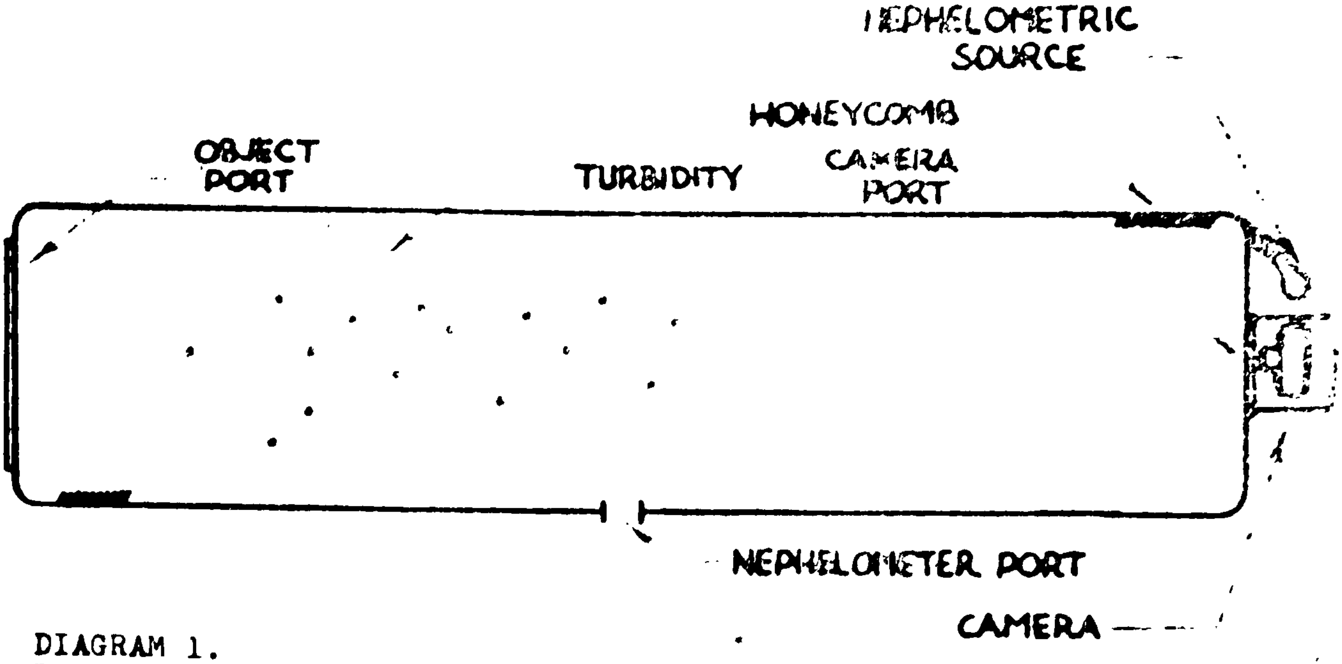
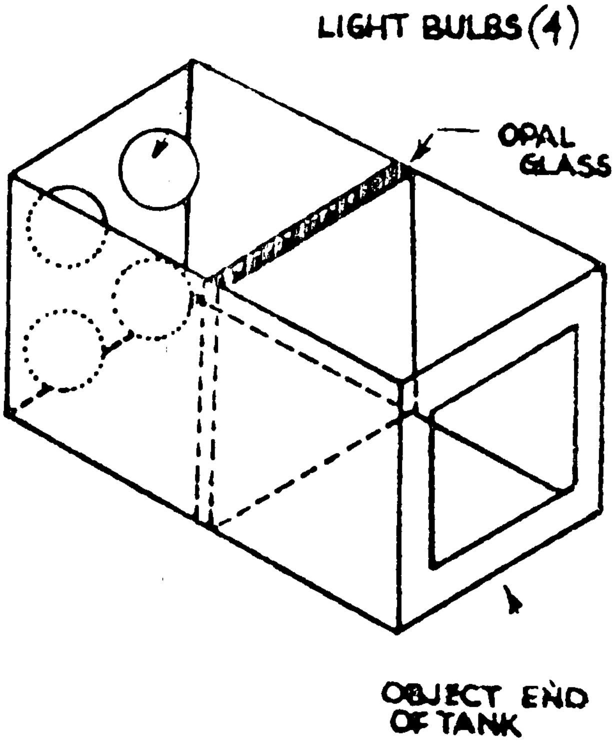


DIAGRAM 1.

Tank: The tank, 150 cm. X 20 cm. X 30 cm. was constructed of 3/16" Aluminum, anodized black. Windows of optical quality plate glass, ½" thick, were placed at the ends. Halfway between the two ends on the side, a glass covered ½" hole was placed for nephelometric measurement. All inside surfaces were covered with expanded Aluminum honeycomb, ¼ high, for light baffles. The honeycomb was also anodized black.

DIAGRAM 2.

Light Source: Illumination was achieved by a specially constructed light box fastened to the object end of the tank. A voltage regulator controlled 4-60 watt light bulbs behind a sheet of 1/8" opal glass 18 Cm. from the object.



concentration, including the distilled water blank. (See appendix) The images were recorded on Recordak SO-281 film, chosen for its high resolution quality and moderate contrast.

The films, processed in D-76 for 7 minutes under normal conditions in a Nikor tank, were measured on an Ansco Auto-Recording Micro-Densitometer, Model IV, on loan from the United States Air Force.

DATA ANALYSIS

Characteristic curves were derived from the #2 step tablet at each level of turbidity and plotted, showing contrast loss. A speed point at density 1.0 was chosen and the log E deviations were calculated indicating photometrically the changes in transmittance due to the particles. The modulation transfer characteristics of the system at various levels of turbidity were calculated by the standard photometric procedure.[1]

Dividing the blank curve into the curves for the levels of turbidity, thus eliminating the components of the system other than the turbidity, allowed direct calculations of the gross effect of turbidity. To determine the effect of the particles alone, the internally derived characteristic curves were used for calculation of the modulation, thereby eliminating the effect of contrast loss. (See appendix)

Using the principle of the tone reproduction cycle, a comparison was made of original tones and the tones modulated by the contrast loss.

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[1] Robert L. Lamberts, Applied Optics, Vol. 2., p. 273, March 1963.

RESULTS

The introduction of the calcium oxalate suspension into the system caused changes in the internally derived characteristic curves as is indicated in figure 1. Two changes are evident; with increasing turbidity there is a speed loss and an overall reduction in average gradient caused by flare.

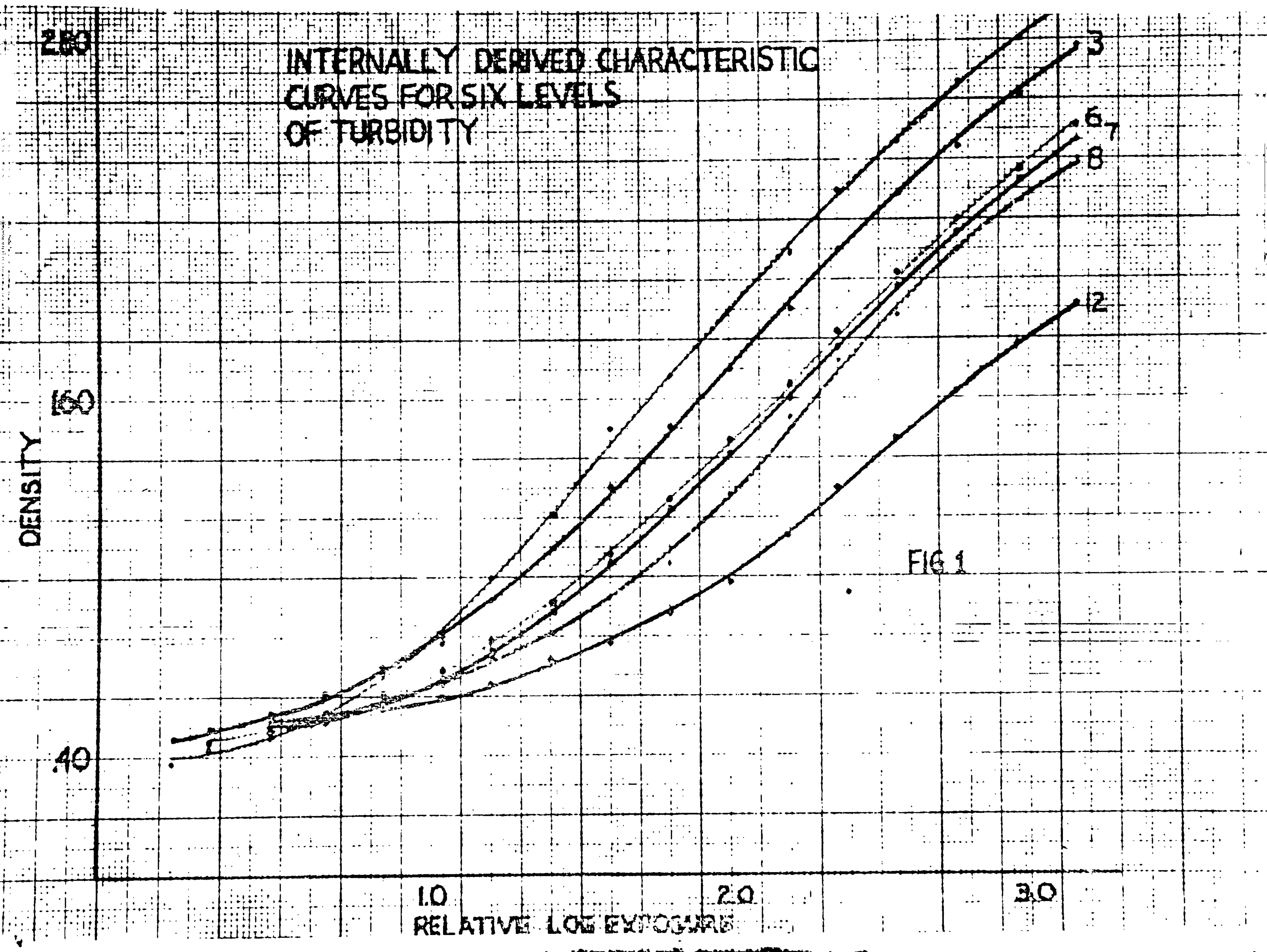
The speed loss, at a density of 1.0, was used as a measure of the change in transmittance of the system, and is illustrated in figure 2.

Figure 3, graphically illustrates the reduction of average gradient, or contrast, due to the introduction of turbidity.

Figure 4 indicates the renditions of the object luminances through the various concentrations of turbidity.

The changes in the MTF of the complete system due to increasing turbidity, are shown in figure 5, whereas in figure 6, the curves for turbidity have been divided by the blank, thus eliminating the components of the system and indicating the MTF of turbidity alone.

By obtaining the modulations of the images from the internally derived characteristic curves (figure 1.) the image demodulations caused by contrast reductions or flare, were eliminated. When MTF curves obtained in this manner were divided by their blank, (zero turbidity) the result is ~~as~~ shown in figure 7.



INTERNALLY DERIVED CHARACTERISTIC CURVES FOR SIX LEVELS OF TURBIDITY

FIG 1

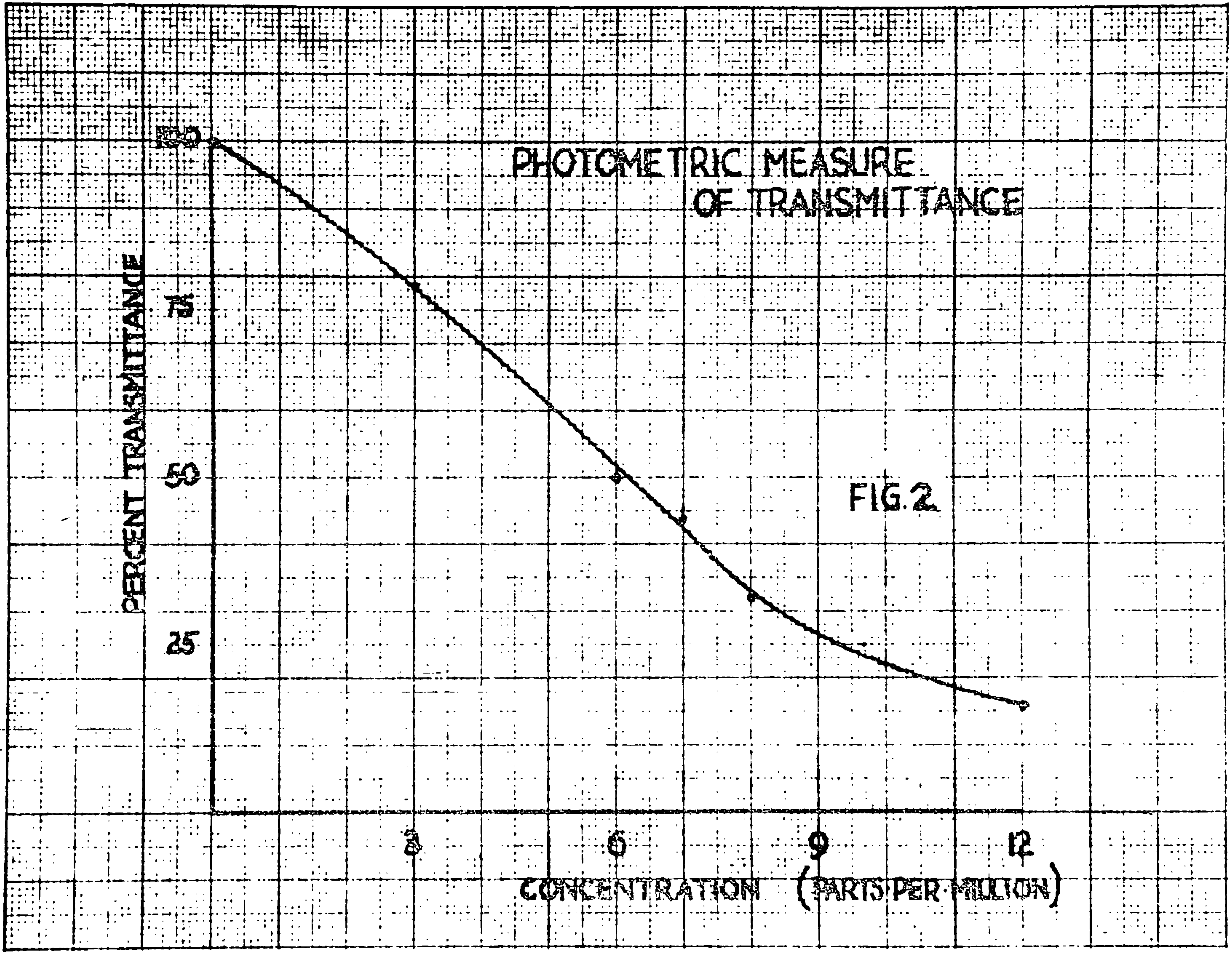
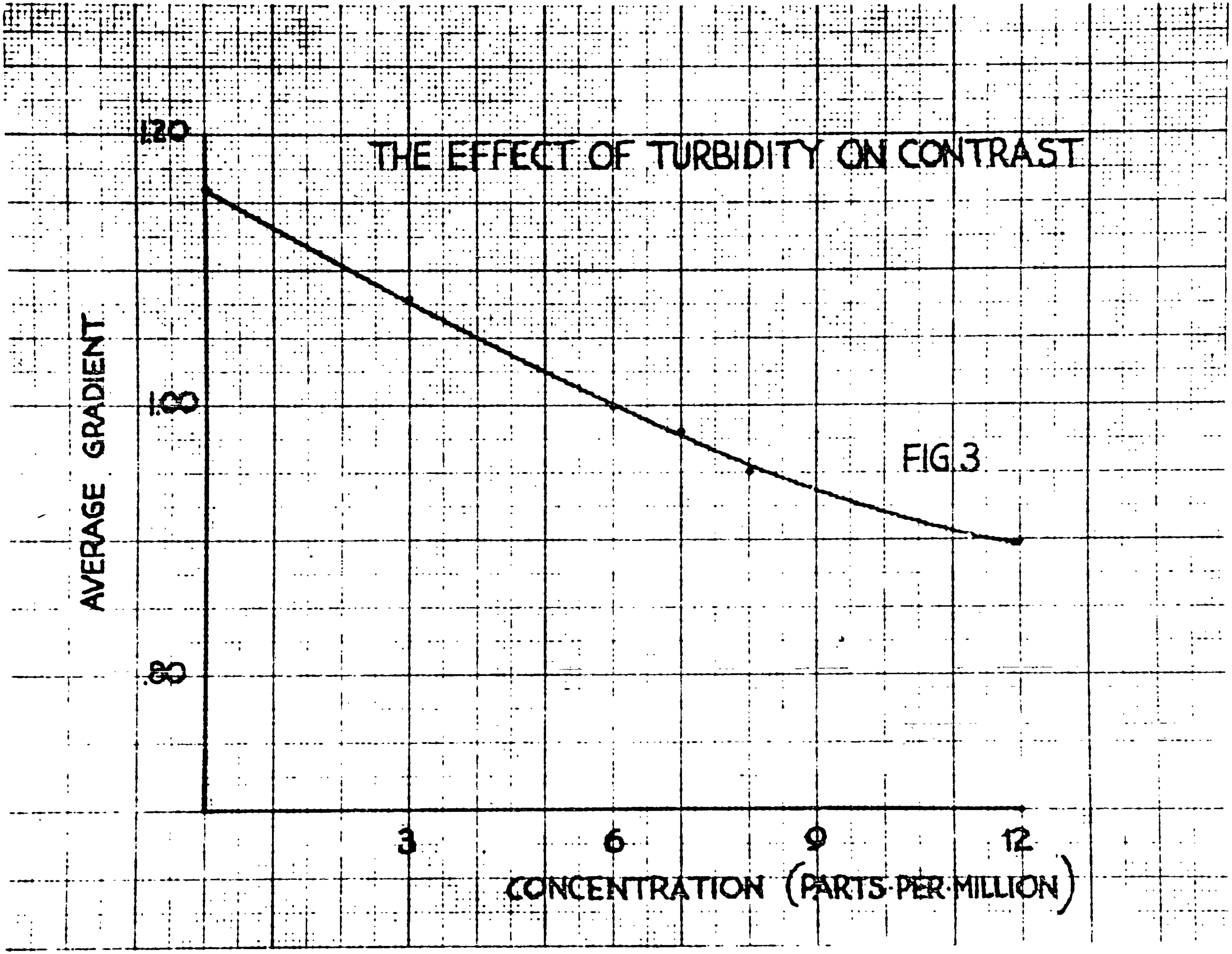

PHOTOMETRIC MEASURE OF TRANSMITTANCE

FIG.2



THE EFFECT OF TURBIDITY ON CONTRAST

FIG 3

THE EFFECT OF TURBIDITY ON IMAGE ILLUMINANCES

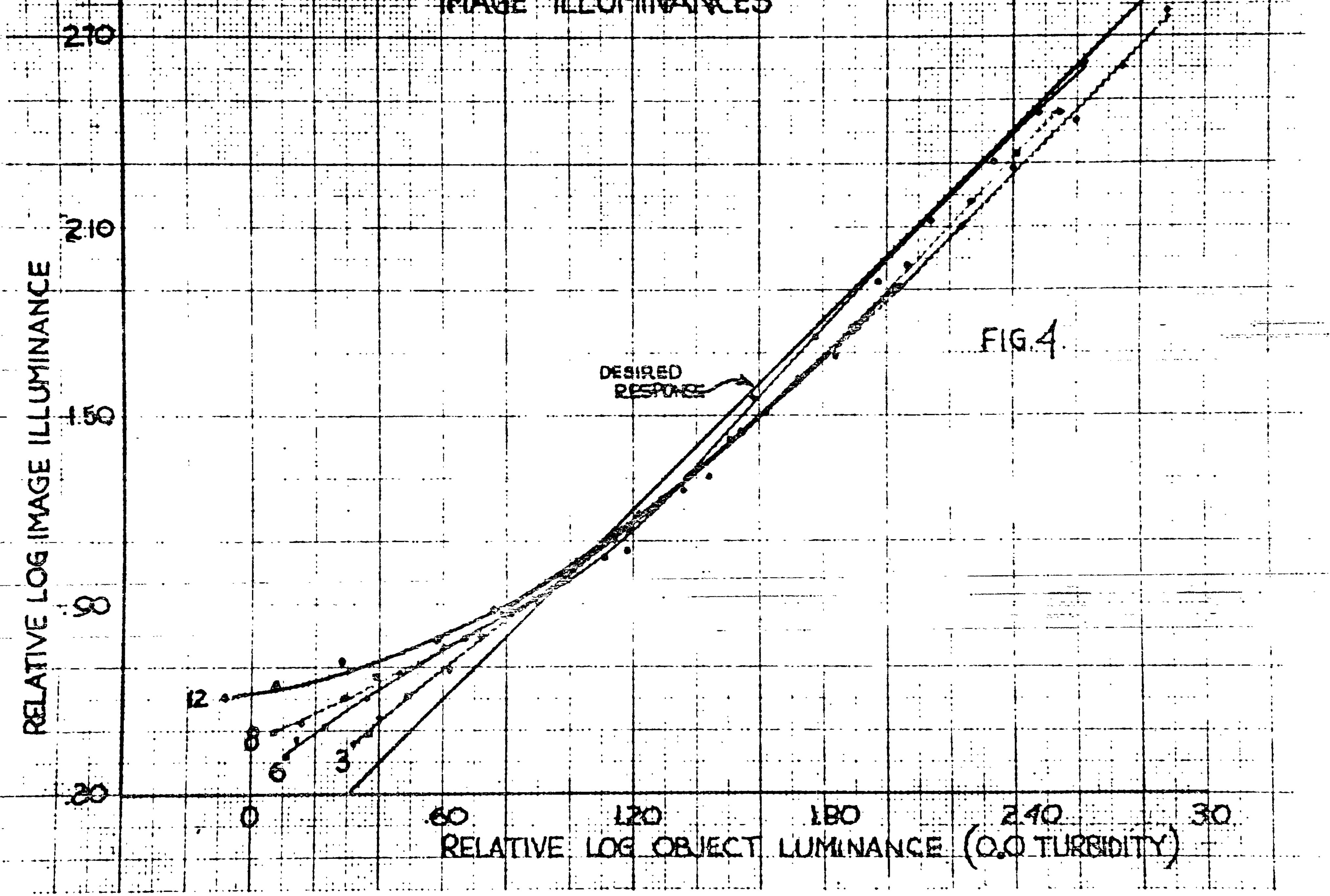
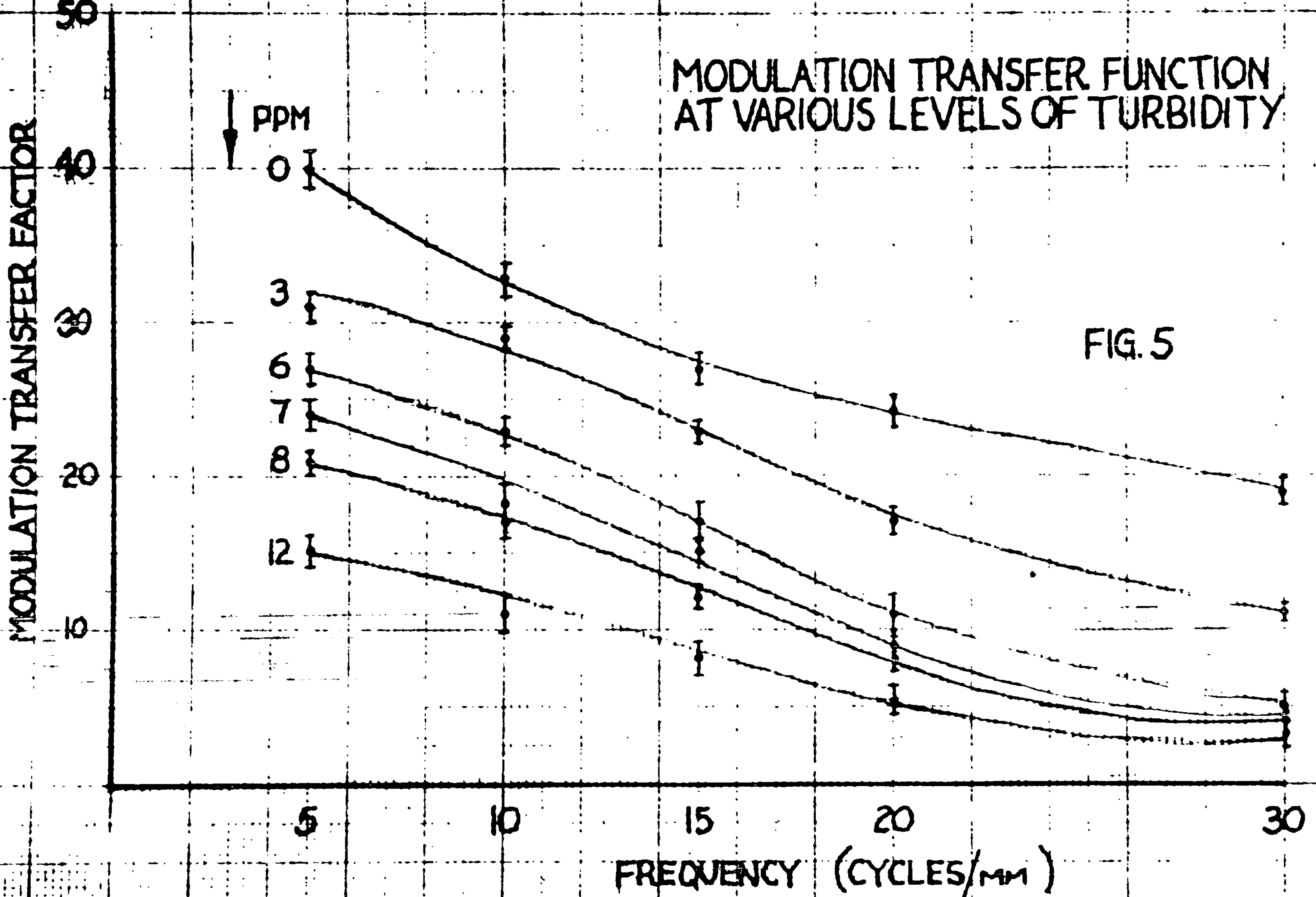


FIG. 4



MODULATION TRANSFER FUNCTION AT VARIOUS LEVELS OF TURBIDITY

FIG. 5

MODULATION TRANSFER FUNCTION OF TURBIDITY

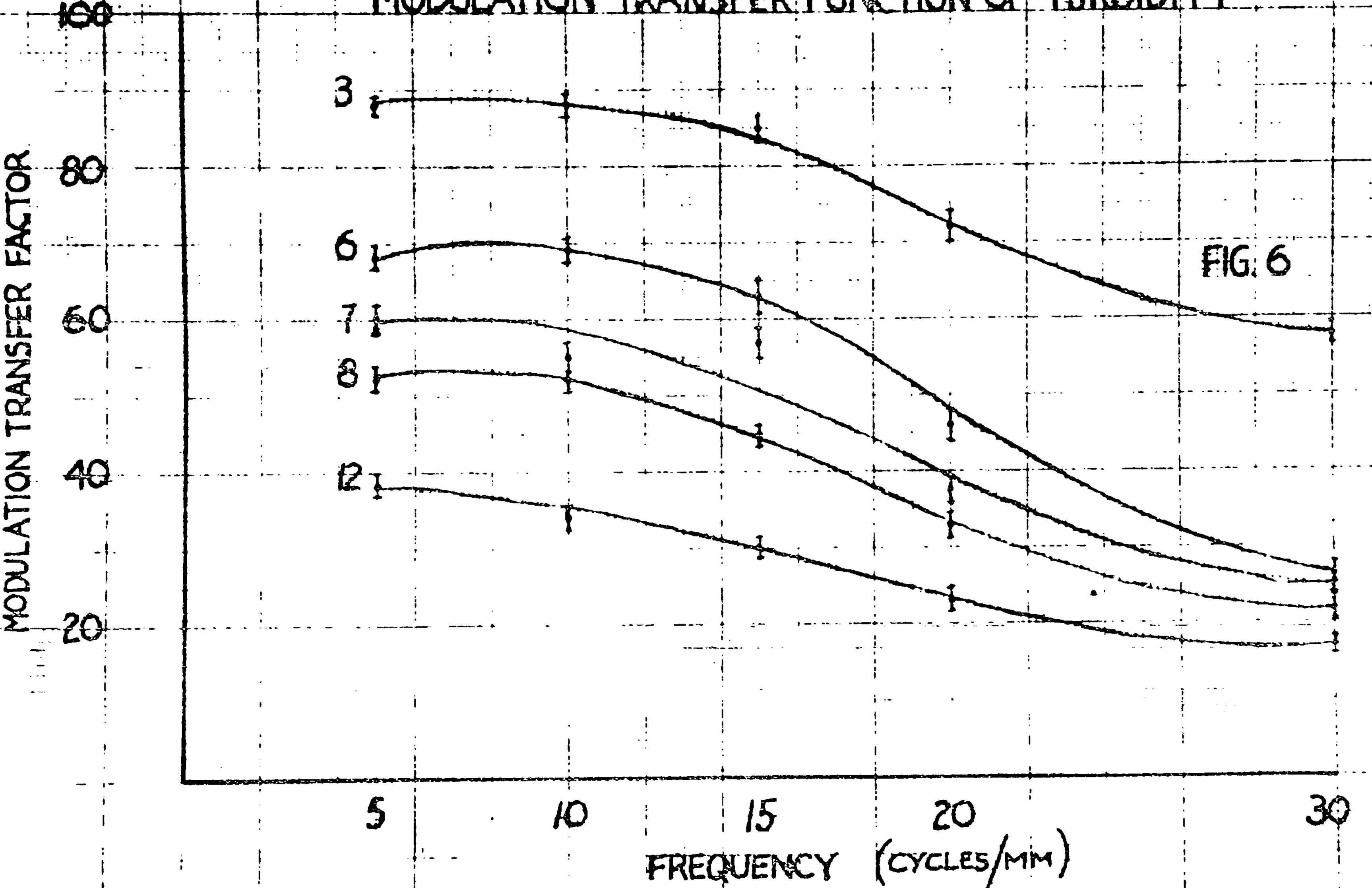


FIG. 6

MODULATION TRANSFER FUNCTION OF TURBIDITY WITH THE EFFECT OF CONTRAST REDUCTION ELIMINATED

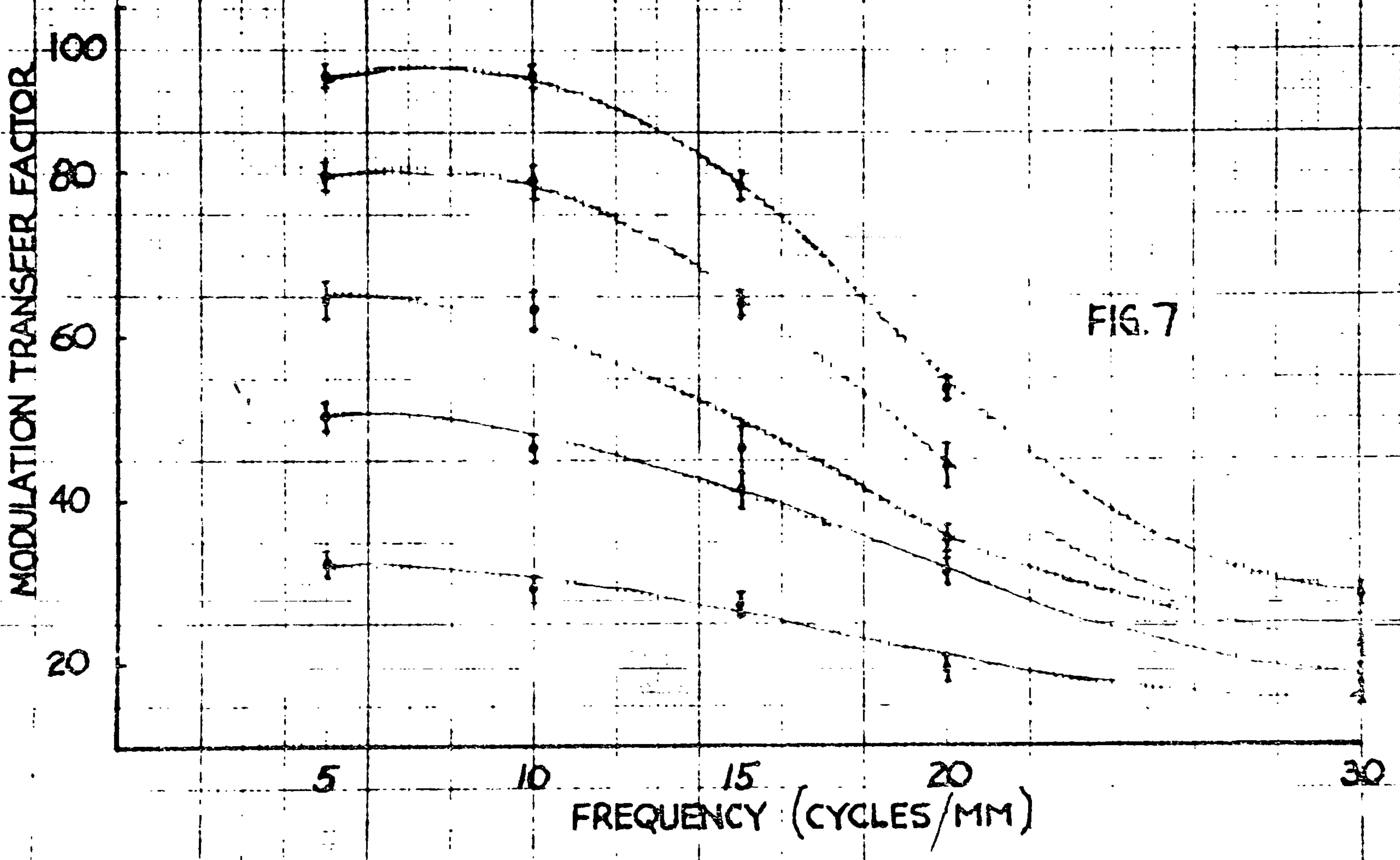


FIG. 7

DISCUSSION OF RESULTS

Applications to areas other than this experiment's limited environment, must be done with thoughtful reservation.

The changes in the internally derived characteristic curves are attributed to the change in image illuminance with turbidity, illustrated in figure 4. As the turbidity is increased, there is a loss of transmittance caused by the scatter of the particles. Some of the light is reflected towards the camera lens and is distributed equally over the image causing flare which is responsible for the loss in average gradient and the reduction of the slope of the toe region of the curves. These results correlate well with those obtained in the investigations of atmospheric turbidity.

There was a loss in the system modulation anticipated as primarily due to the effect of flare caused by the turbidity. This loss is indicated in figure 5. Dividing out the system's components, a transfer function for the turbidity alone is obtained. If contrast reduction is the sole or primary factor causing demodulation of the image, it is expected that, when it is removed from the transfer function of turbidity, that the remaining function will be a straight line at approximately 100% for all concentrations. However, upon performing this mathematical transformation, the results still indicate a demodulation of the image. This can be interpreted as evidence that the contrast reduction, (flare) is not the sole factor contributing to the loss of image quality.

CONCLUSIONS

In underwater photography, flare, or contrast, reduction, caused by turbidity exhibiting non-selective scatter, is not the only factor causing demodulation of images. Therefore, increasing the average gradient of the photographic materials used in these situations, will not completely compensate for the loss in image quality.

ACKNOWLEDGMENTS

The authors gratefully wish to acknowledge the assistance of the Rochester Institute of Technology's Photographic Science faculty, Dr. K. Hickman, Mr. G.M. Fulmer, and Mr. R.L. Lamberts.

APPENDIX

CALCIUM OXALATE

Discussion: Calcium oxalate is a white crystalline material that is non-toxic and easily prepared. Precipitated according to the conditions listed below, its particle size varied from 20 to 40 microns, or 40-80 times the wavelength of light. The material has a solubility product of 0.0054 g/l at 24°c, which is low enough to make changes in particle size insignificant with the times (15 min.) used.

Preparation: A standard solution of 1400 parts/per/million of calcium oxalate was prepared before each experimental run. 1.2126 grams of calcium chloride were dissolved in 600 m. of distilled water at 24°c. A solution of 1.3776 grams of oxalic acid and 250 ml of distilled water was added to the calcium chloride solution from a separatory funnel at the rate of .5 liters/min. with constant stirring of the calcium chloride.

The precipitate was allowed to stand for 20 minutes with constant stirring at which time 15 ml of NH_4OH were added to adjust the pH to approximately 7.

Each 50 ml aliquot of the suspension produced 1 part/per/million when added to the 70 liters of distilled water in the tank.

NEPHELOMETER

Nephelometric measurements are measurements of the light scattering of particles taken at 90° from the light path, i.e., the Tyndall effect. In this case, it was accomplished with a 150 watt tungsten source at the camera end of the tank, and a Densichron probe and amplifier placed at the middle port. The meter was zeroed on the blank and readings were taken immediately before photographing the object at each level of turbidity. Because at each level of turbidity there was not only increased scattering, but decreased transmittance, these measurements were relative and used only for a verification of the suspension's repeatability. The values are shown graphically on the following page.

EXPERIMENTAL PROCEDURE

1. Produce suspension
2. Fill tank (70 liters distilled water)
3. Cover tank
4. Zero nephelometer at 2.90 (arbitrary)
5. Turn off nephelometric light; turn on light box; photograph objects
6. Turn off light box; uncover tank; add desired turbidity
7. Stir for two minutes with motor mixer
8. Cover tank; take nephelometric measurements
9. Proceed as in Step 4 until desired P/P/M is reached
10. Drain tank; completely clean all apparatus; proceed as in Step 1; (replicate)

MODULATION TRANSFER CALCULATIONS

Maximum and minimum density values were averaged for four replicates as obtained from the micro-densitometer traces of the images. The D max and D min values at each spatial frequency were transformed through the characteristic curve of the emulsion into E max and E min values. The modulations were calculated at each point by dividing the sum of the exposures into their differences. Modulation of the original object, calculated in essentially the same manner as above,[1] was divided into the modulations of the images at the various levels of turbidity, producing a modulation transfer factor at each spatial frequency for each concentration. These data are plotted in figure 5.

The various components of the system, i.e., camera, lens, optical glass, water, etc., are common to each of the

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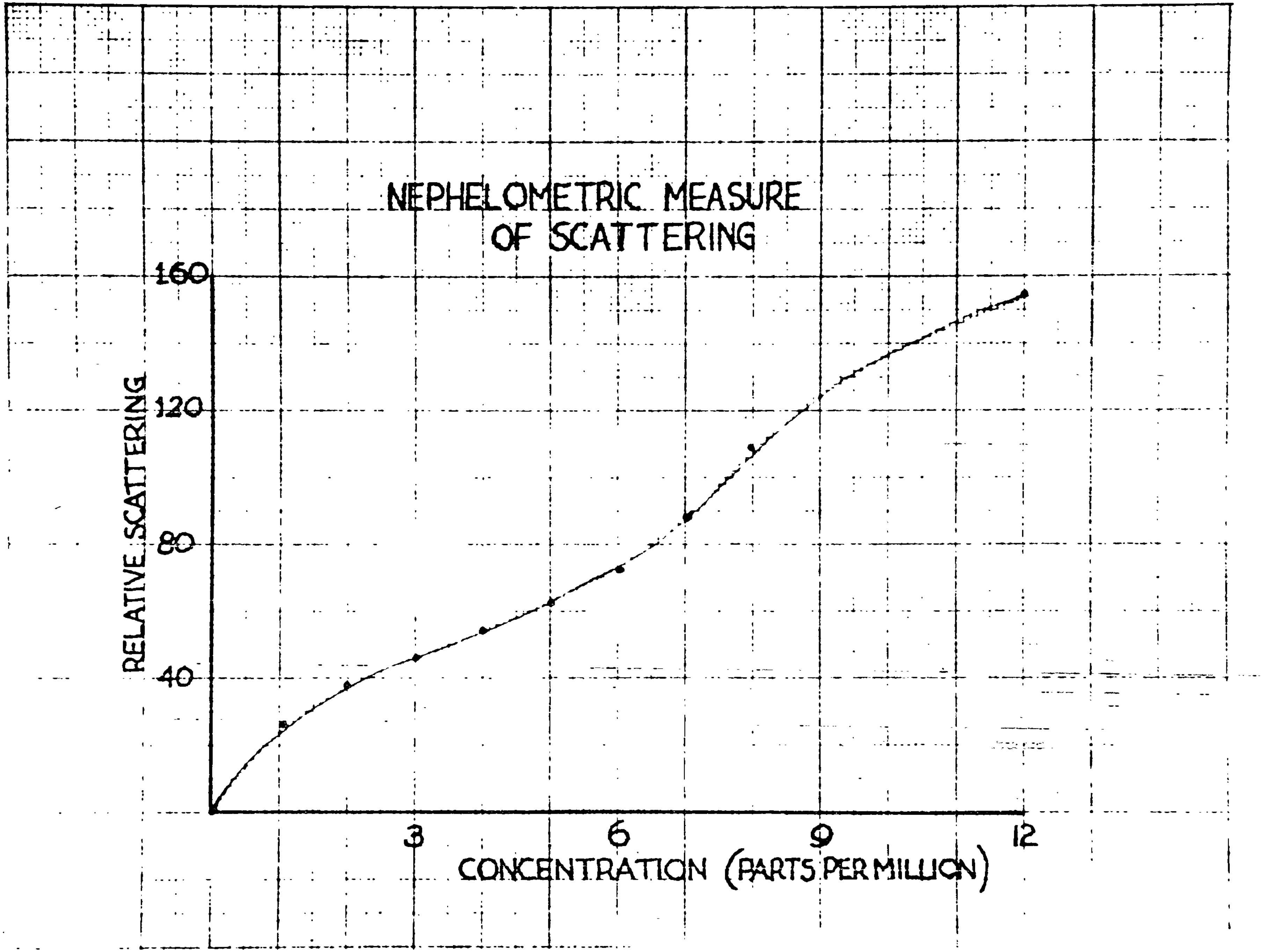
[1] Robert L. Lamberts, Applied Optics, Vol. 2., p. 273, March, 1963.



NEPHELOMETRIC MEASURE OF SCATTERING

curves in figure 5. To determine the transfer function for the turbidity alone, they must be removed. Because the blank curve contains all the components of the system but no turbidity, dividing it into the remaining curves produces the transfer function for turbidity alone, illustrated in figure 6.

Elimination of the flare effect was achieved by using the internally derived characteristic curves, (figure 1) which exhibit the contrast loss due to the flare, for the transformation of densities to exposures at each level of turbidity to calculate the modulations. The blank curve's modulation was obtained in the same manner as in figure 5 and still represents the response of the pure system. The modulation transfer factors for all the curves were obtained by dividing the image modulations by the object modulations.

This time, division of the blank modulation transfer factor into the modulation transfer factors for turbidity levels, produced a function of the turbidity with not only the system, but the flare effect eliminated. This is indicated in figure 7.

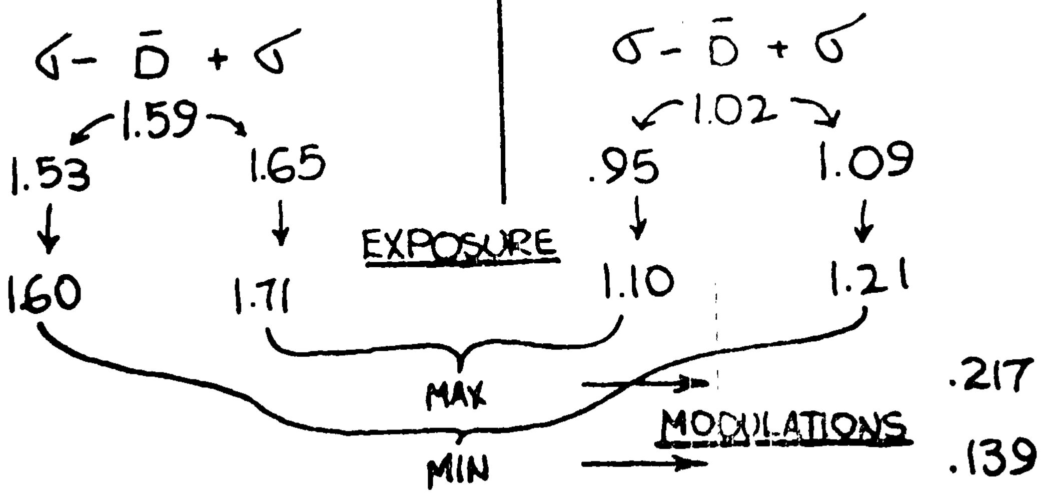
ESTIMATE OF ERROR

Error was estimated for figures 5 and 6 by calculating the standard deviation for the D max and D min obtained from the micro-densitometer trace based on a sample size of four. One standard deviation was added and subtracted to the average D max and D min and the resulting exposures from these densities were obtained. The maximum value of E max and E min were used to obtain the upper limit and the minimum E max and E min were used to obtain the lower limit.

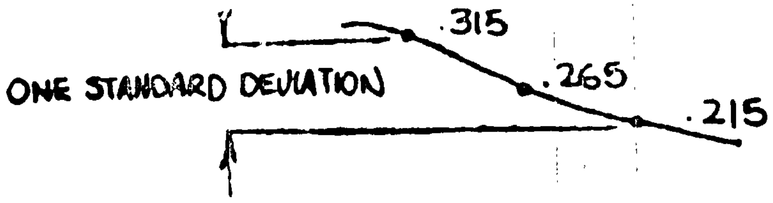
SAMPLE CALCULATION

$\bar{D}$ MAX = 1.59
σ = .063
$\bar{D}$ MAX + σ = 1.65
$\bar{D}$ MAX − σ = 1.53

$\bar{D}$ MIN = 1.02
σ = .069
$\bar{D}$ MIN + σ = 1.09
$\bar{D}$ MIN − σ = .95



MODULATION TRANSFER FACTORS = .216, .315
CALCULATED FACTOR = .265



Confidence limits for figure 6 were obtained by adding the variances of the 2 components that make up each point, i.e., the blank and the turbidity value. The square roots of the results were taken and one standard deviation above and below each point of the graph were plotted.

The error estimate for figure 7 was obtained from a standard deviation calculated from the four modulation transfer factors that made each point.

The confidence on the curve for nephelometric measurements is also one standard deviation obtained from the 4 sets of readings.

The three independent measurements used to indicate the repeatability of the system suggested because of their high degree of correlation, little error. Difficulties were encountered, however, in obtaining day to day, as well as within day, repeatability of the micro-densitometer. The authors believe this factor to be the major cause of experimental error.

CONSIDERATIONS FOR FURTHER WORK

Because of the limitations of the system, only 5 spatial frequencies could be resolved. The authors suggest that more frequencies be used between o and 35 cycles/mm, either by increasing magnification of the present system or by obtaining another target.

Further investigation into the effect of particles in the optical path on image quality should be made with particles of considerably smaller sizes, much less than the wavelength of light, which will exhibit Rayleigh scattering.