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The effects of temperature and humidity on the sensitometric characteristics of the photographic emulsion (Eastman Kodak SO-1213 and Plus-X Aerecon aerial film)

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Thesis

THE EFFECTS OF TEMPERATURE AND HUMIDITY ON THE SENSITOMETRIC CHARACTERISTICS OF THE PHOTOGRAPHIC EMULSION. (EASTMAN KODAK SO-1213 AND PLUS-X AERECON AERIAL FILM)

by

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Approved
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The author also wishes to express his appreciation to the personnel of ITEK Corporation for their aid in the preparation of this thesis; in particular to Henry Sproul for his invaluable aid in the design and fabrication of the Thermosensitometric Test Unit used in the experimental work.

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INTRODUCTION

Need for the Study

Present day reconnaissance systems employed in vehicles exceeding the speed of sound must be able to withstand elevated temperatures for prolonged periods of time. This problem will become even more acute in the reconnaissance vehicles of the future. The ideal system would be one which is unaffected by any rise in temperature but, since this is not the case, refrigeration is required. In order to save space and weight through the use of the minimum amount of refrigeration the designer must know what temperatures the reconnaissance system can tolerate without adverse results.

The components of a visual reconnaissance system most affected by heat are the photographic emulsion and the focal length of the cameras. This paper is an investigation of temperature effects on the photographic emulsion at various humidities. In order to be realistic in its application the method of testing the photographic emulsion was carried out in a manner simulating its use in a reconnaissance vehicle.

Past Work in the Field

Considerable work has been done on the effects of humidity and temperature on the photographic emulsion. Renwick,[6] Sheppard and Wightman,[7] and Dimitroff[1] did considerable work on the effects of humidity on photographic sensitivity. These studies show that the sensitivity or speed of an emulsion* decreases as the relative humidity

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*The word "emulsion" will refer to photographic emulsion from here forward.

is increased. Other studies on the effect of temperature upon emulsions have been made by Webb,[8] Howell,[3] and Evans.[2]

Webb's results showed that the effect of temperature on emulsion sensitivity is so intimately connected with the intensity level at which the exposures are made that such measurements have little significance unless the intensity of the exposures is specified. In addition, variation in sensitivity with temperature is shown to be altered somewhat by the wavelength of the exposing radiation and the type of emulsion employed. Because of these results the intensity level of the exposure used in this experiment is specified and is kept constant throughout. Webb's investigation concerned the effect of temperature on reciprocity failure for several types of emulsions and for radiations of different wavelengths. In this work all exposures were made such that one-half of the emulsion was exposed with white light and the other half through a sheet of Wratten number 25 filter. This filter was used because of its use in aerial photography.

Howell's work was concerned with the effects of prolonged heating before and/or after exposure. Super-XX Aero film was used in his tests. He found that there was a decrease in gamma (contrast) as the film was heated to higher temperatures and that the greatest loss in gamma resulted when the emulsion was heated before exposure. The emulsion exhibited a definite increase in speed in both cases up to temperatures of 220° F. Speed determinations were based on the Weston system. In this system film speed is equal to $4/E_w$ where log E_w is the exposure in log meter candle seconds equal to the sum of gamma and fog level.

The experimental work in this paper was performed on two new emulsions manufactured by Eastman Kodak Company for use in aerial reconnaissance. These emulsions are (1) Eastman SO1213 (emulsion number SO1213-1-1) and (2) Plus-X Aerecon (emulsion number SO1166-3-1). Because of conversations with other workers in the field, different results were expected from these two emulsions. The results verify these opinions.

Statement of the Problem

As indicated, the problem resolves itself into devising a method for determining the effects of elevated temperatures and various humidities upon photographic emulsions and using this method to test two emulsions: Eastman Kodak SO1213 and Plus-X Aerecon. The method devised should approximate actual conditions and usage that will be encountered in the reconnaissance vehicle. Thus exposures are made at three equally separated times in each heating cycle; the first one at the start of the run, the second at the mid-way point, and the last at the end of the run. The method should also be simple and economical in operation so that results can be obtained inexpensively and in a minimum of time. It was with these aims that this experiment was conducted.

In the first part of the experiment, tests were run at room temperature, 100° F, 150° F, 175° F, 200° F, 220° F, and 240° F. No humidity control was used at temperatures of 150° F and over because heating the surrounding air which was at a relative humidity of 30% or less to 150° F and over decreased the relative humidity to a value of less than three percent. Concentrated sulfuric acid was used as a dessicant at room temperature and 100° F to achieve an atmosphere of approximately

zero percent relative humidity.

The second part of the experiment consisted of testing the two emulsions at temperatures of 100° F, 125° F, 150° F and room temperature with various relative humidities for four hour heating cyles. Runs were made at temperatures of 125° F and 150° F with relative humidites of 25%, 50%, 75%, and 100%. At 100° F only 50%, 75%, and 100% relative humidites were accomplished and at room temperature only 75% and 100%.

Chapter II

EXPERIMENTAL PROCEDURES

Discussion

To test the photographic properties of emulsions in the laboratory, sensitometric methods are employed.* In this method the emulsion is usually exposed by means of a modulated tungsten source in combination with a filter such that mean noon sunlight is approximated. In this experiment the light source was modulated by a step wedge.

After exposure, the emulsion is processed in a prescribed manner and the resulting densities are read and then plotted against log exposure on special graph paper. This results in the well known H and D curve first derived by Hurter and Driffield. From these curves the contrast (gamma) and speed (sensitivity) of the emulsion can be determined.

Speed may be measured in various ways but for the purposes of this investigation three methods were used. Speed of the emulsion exposed to white light was measured as (1) half-gamma speed and (2) speed equal to the fog level plus a density of 1.0. Speed of the emulsion exposed through the red filter was measured at a density of 0.5 plus fog.

(1) Half-gamma speed is computed as one-half the reciprocal of the exposure ($E_{\gamma/2}$) in meter-candle-seconds measured at the point on the curve where the gradient is equal to $\gamma/2$. Thus:

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*For a more detailed account of sensitometric methods, one of the General References should be consulted.

$$S_{\gamma/2} = \frac{0.5}{E_{\gamma/2}}$$

(2) Speed equal to fog level plus a density of 1.0 is computed as the reciprocal of the exposure ($E_{(D = 1.0 + \text{fog})}$) in meter-candle-seconds measured at the point on the curve where the density is equal to 1.0 fog. Thus:

$$S_{(D = 1.0 + \text{fog})} = \frac{1}{E_{(D = 1.0 + \text{fog})}}$$

(3) The speed of the emulsion exposed through the red filter was computed as the reciprocal of the exposure ($E_{(D = 0.5 + \text{fog})}$) in meter-candle-seconds measured at the point on the curve where the density is equal to 0.5 + fog. The value of 0.5 was used because the maximum density for SO1213 when exposed through the red filter was rarely greater than 1.0. Thus:

$$S_{(D = 0.5 + \text{fog})} = \frac{1}{E_{(D = 0.5 + \text{fog})}}$$

Special Equipment

In order that the requirements of the experiment be complied with, a container was constructed to hold the film strips. This is called a Thermo Sensitometric Test Unit (Figure 1) and will be referred to as the test unit from here forward. This test unit is cylindrical in shape and consists of a top which slides into the bottom and rests on four leaf springs.

The top contains a hexagonal film holder which takes 35 mm x 9-inch film strips. When in position this holder is suspended over a glass plate. The test unit is constructed so that it fits over the step tablet on an Eastman IB sensitometer. Exposures are made through the glass plate and at the time of exposure, the top of the test unit is pressed down against the leaf springs so that the film holder rests firmly on a felt gasket on the glass. This prevents light leaks.

After exposure the film holder can be rotated to bring another film strip into position for an exposure. A fan is located in the top of the test unit to provide air circulation along with a thermocouple to record temperature. There is space for two glass containers in the bottom to hold the sulfuric acid used for humidity control. One of these containers is directly under the fan so that equilibrium between the solutions and the atmosphere in the test unit will be reached as soon as possible.

Experimental Procedure

In the actual testing, both emulsions were carried through together. Four film strips (35 mm x 9") were cut from each roll of film and preconditioned in a dessicator for twelve to eighteen hours over a solution of sulfuric acid which maintained the atmosphere inside the dessicator at a relative humidity of 50 percent.

An Acme oven was used to heat the test unit throughout the tests. The oven was equipped with a fan to provide better heat distribution. The test unit was preheated and when it came up to the proper temperature, it was removed from the oven and the film was loaded. The film strips were

placed on the holder in an alternate fashion so that a sample of each emulsion could be exposed at the proper time. The test unit was returned to the oven and allowed to heat to the proper temperature. The test unit was then removed from the oven and one of each of the film strips was exposed on an Eastman IB Intensity Scale Sensitometer.

The Eastman IB Intensity Scale Sensitometer was used with lamp number 1643 with a color temperature of 2650°K. This was corrected with a 78AA filter to a daylight source with a color temperature of 5500°K giving an illumination of fifty-five (55) meter candles in the exposure plane. Exposure was for 0.02 seconds through a number 5 Eastman Kodak step tablet, serial number 234-150. This tablet has twenty-one (21) steps each one being $\sqrt{2}$ times denser than the one next to it. An exposure of 0.02 seconds gives an absolute log E value of $\bar{4}.94$ at the densest step under normal conditions. The separation of the film from the normal exposure plane by the glass in the test unit caused a difference of 0.12 log units; this is in close agreement with the value obtained by Evans under similar conditions. Thus the absolute log E value used throughout this experiment is $\bar{4}.82$.

After exposure the test unit was returned to the oven to be heated for one, two, or three hours depending upon the duration of the run. Three runs of different durations were made at each temperature with no humidity control. The runs were made for either two, four, or six hours, the duration of a run being measured from the first exposure to the last exposure. In all cases three exposures were made; the first as indicated above, the second at the mid-point of the run and the third at the end of the run. Thus in a two hour run one sample of each film is

exposed at the start of the test and receives two hours heating after exposure; the next two samples receive one hour of heating, exposure, and then another hour of heating; and the remaining two samples receive two hours of heating, exposure, and then no heat. The four and six hour runs were the same except there were two and four hours respectively between exposures. The temperature of the air inside the test unit was recorded once each minute on strip charts using a Minneapolis Honeywell Electronik recorder.

The film was removed from the test unit immediately after the last exposure. A strip of each film was then exposed on the sensitometer in the normal fashion and the eight strips were placed in the dessicator for two hours before they were developed.

All strips were developed in Eastman Kodak D-19 developer (batch number 5704E) for eight minutes at 68° F with constant agitation. Four strips were developed at one time in a sensitometric processing unit described by Howell.[4]

Densities of the sensitometric strips were read on a Macbeth-Ansco Model 12 densitometer and H and D curves were plotted. The three curves of each emulsion were plotted on the same sensitometric data sheet. This resulted in six curves on each sheet; three exposed with white light and three exposed through the Wratten 25 filter. The following data was extracted from these curves:

1. Speed at density of 1.0 plus fog.
2. Gamma.
3. Half-gamma speed.
4. Filter factor.

5. Speed through red filter at density of 0.5 plus fog.

Humidity Control

Humidity control was achieved by the use of solutions of sulfuric acid according to the figures listed by Wilson.[9] The conditioner was preheated as in the other runs and loaded with film. The sulfuric acid was put in the glass container and placed in the bottom of the test unit as shown in Figure 2. Tape was used to seal the test unit at the section where the top slides into the bottom. This was necessary to create an enclosed space. The test unit was returned to the oven and the same procedure was followed as in the other tests. It took approximately one hour for the test unit to get back up to temperature before the first exposure was made. According to Kanz and Ives[5] a large portion of the adjustment between the emulsion and its surrounding atmosphere is effected within one hour and is almost complete within three to four hours. Their tests were run using open strands of film which is the condition within the test unit. Thus one hour was allowed to elapse before exposure when humidity control was attempted.

Temperature Control

The Minneapolis Honeywell Brown Electronik recorder used in this experiment is considered accurate within $\pm 1.0^{\circ}$ F. The temperature was recorded once each minute from the time the test unit was put in the oven after the film was loaded until the last exposure was made. Temperature control was very good at low temperatures as is shown in Figure 4 but at higher temperatures such was not the case as is illustrated in Figure 5. At time of exposure a temperature drop of

seven degrees occurred which was not allowed for in the initial plan of the experiment. When the top of the test unit was depressed at the time of exposure, air in the test unit was forced out. This air was replaced by the cooler surrounding air when the top was released, thus causing a drop in air temperature. The greater the differential between these two temperatures, the greater the drop. It can be seen from the curves in Figure 6 that the film temperatures did not drop as drastically as the air temperature. The overriding of temperature after exposure in Figure 5 was caused by attempting to get the air temperature back to the required temperature too quickly. In later experiments the temperature was allowed to return normally and this overriding did not occur.

To check the test unit for temperature distribution, thermocouples were taped to the top and bottom of the film holder, to film on the top and bottom of the film holder and also placed in the normal recording position. The thermocouple recording the temperature on the top of the film holder recorded 1° F higher than the bottom thermocouple when measuring a substance of the same temperature. From this it can be seen that the temperature variance between the top and bottom film strips was approximately 1° F.

Chapter III

RESULTS

General

In the first part of this experiment, no humidity control was employed for temperatures of 150° F and greater because at these temperatures the relative humidity within the test unit is estimated to be not in excess of 5%. This is the situation that would exist under actual flight conditions. At temperatures below 150° F concentrated sulfuric acid was used as a dessicant to produce this same condition.

The second part of this experiment dealt with the use of sulfuric acid solutions in an endeavor to produce controlled humidities. It was soon discovered that at temperatures of 150° F and above, the dissociation of the sulfuric acid ($H_2SO_4 \rightleftharpoons H_2O + SO_3$) causes hypersensitization of the emulsions and produces erroneous results. A four hour test at 150° F with a solution of sulfuric acid to give a relative humidity of 75% caused complete blackening of the SO-1213 emulsion. Pinholes were observed in the Plus-X Aerecon emulsion probably due to droplets of sulfuric acid. This restricted the use of sulfuric acid to temperatures of 125° F and below at this relative humidity. Satisfactory results were obtained at 150° F using sulfuric acid solutions to give relative humidities of 25% and 50%.

Effect of Heating Film Before, During, and After Exposure. RH less than 5%.

As was indicated in the experimental procedures, exposures were made at three different times during a test. Figure 7 shows the characteristic curves for Plus-X Aerecon when exposed before and after

heating. Figure 8 shows the characteristic curves for SO-1213 under the same conditions. Each emulsion exhibits a characteristic pattern when compared within itself but a different pattern when compared with another emulsion.

The characteristic curves of Plus-X Aerecon exposed before heating show a shift to the right thus lower speeds but little change in gamma. The characteristic curves of Plus-X Aerecon exposed after heating exhibit this same pattern with a greater spread between the low and high temperatures and a greater decrease in gamma. Fog is not a contributing factor to loss in contrast until temperatures over 200° F are reached. The spread between the low and high temperature characteristic curves is greater for the case of exposure after heating. The characteristic curves for the exposures made at the mid-way point of the run were not included but fall about mid-way between the first and third exposures.

Both speed measured at the point where the density is equal to 1.0 plus fog (Figure 9) and half gamma speed (Figure 13) show almost a linear decrease with increase in temperature for Plus-X Aerecon. The plot of speed (D = 1.0 + fog) is a better portrayal of the actual relative loss in speed because it can be measured more accurately. Half gamma speed requires estimating the gamma of the straight line portion of the H and D curve and then the point of tangency of half the gamma with the toe of the curve. Both of these introduce error. Speed (D = 1.0 + fog) on the other hand is measured from a point on the straight line portion of the curve.

The characteristic curves of SO-1213 (Figure 8) show a shift to the left between exposures made before heating and exposures made after heating. This results in a higher speed for SO-1213 when it is heated for a prolonged period before exposure. This emulsion does not exhibit much change in gamma until temperatures over 200° F are reached. (See Figure 16.) This decrease in gamma above 200° F is due to an abrupt rise in fog level. An almost twofold increase in speed (Figure 10b) at 200° F is occasioned by prolonged heating without a detrimental rise in fog level or appreciable change in contrast. SO-1213 is unusable when heated for four hours or longer at 220° F. It is usable when heated to 220° F for two hours. An emulsion is considered unusable when the fog level density exceeds 0.5. Plus-X Aerecon shows about the same relative decrease in speed with or without the red filter (see Figure 12) whereas SO-1213 shows a slightly greater relative increase in speed when used with a red filter (Figure 13).

Effect of Humidity on Film

In these tests exposures were made in the same manner as in the previous tests but speed vs temperature curves, etc., were plotted only for the case of prolonged heating before exposure. Inasmuch as it took approximately one hour for the temperature of the test unit to come up to the desired value before the first exposure and the last exposure was made four hours later, each sample received about five hours conditioning at the specified humidity. As stated previously, it may be presumed that the emulsion was in equilibrium with its ambient atmosphere as regards relative humidity at the time of the final exposure. Since the same patterns occurred as to speed, gamma, and fog

vs temperature for the four hour runs with the relative humidity less than 5% as those of the two and six hour runs, the first two exposures do not appear on these curves.

Before discussing the effect of humidity on these emulsions, it should be noted that Plus-X Aerecon showed a loss in speed (D = 1.0 + fog) between the start and finish of the testing. The speed of Plus-X Aerecon (Figure 19) dropped over twenty percent during a period of seventy-five (75) days whereas SO-1213 remained constant.

A plot of speed vs temperature (Figures 9c, 11c, 13c) at various humidities for Plus-X Aerecon shows an almost linear decrease in speed with increase in temperature. At all temperatures the higher the relative humidity the lower the speed. At 150° F and 100% RH, Plus-X Aerecon exhibits an increase in speed. This is caused by an increase in gamma. At this temperature, prolonged heating before exposure results in a higher speed than exposure before heating. This is a reversal of the usual situation for this emulsion.

Plus-X Aerecon shows a gain in fog level density with increased humidity (Figure 15c) and at 100% relative humidity an increase in gamma. The decrease in speed with increasing relative humidity for Plus-X Aerecon is shown in Figure 18. Plus-X Aerecon exhibits a rise in gamma and fog level (Figure 15c) with increasing temperature at a relative humidity of 100%. At 75% relative humidity, the fog level is raised but no perceptible change in gamma is occasioned.

Once again SO-1213 exhibits an opposite reaction to adverse conditions when compared to Plus-X Aerecon. The curves of speed vs temperature (Figures 10c, 12c, 14c) for various humidities show an

increase in speed at all temperatures. The inconsistent pattern of these curves suggests that the presence of sulfuric acid in the system has an unpredictable effect at high temperatures. A plot of speed vs relative humidity (Figure 17) shows a gradual increase of speed with increased humidity at 125° F but at 150° F a large increase in speed is observed at 50% and 75% relative humidity with a drop at 100% relative humidity.

SO-1213 shows a slight increase in gamma with increasing temperature at a relative humidity of 75% whereas at 100% a rise is observed up to 120° F with a drop at 150° F. The fog level at 100% relative humidity shows an almost linear rise with temperature; at 75% no increase of fog is observed at temperatures up to 125° F.

Effect of Temperature and Humidity on Filter Factor

The filter factors for Plus-X Aerecon and SO-1213 with a number 25 filter measured at a density of 1.0 are 2.8 and 4.0 respectively. These values were obtained by exposing the emulsions in the test unit. When exposed on the sensitometer in the normal fashion the filter factor for Plus-X Aerecon was 3.3 and for SO-1213 was 4.3.

There was no significant change in the filter factor for Plus-X Aerecon up to temperatures of 150° F for relative humidities between 25% and 100%. Of interest are the low values at 80° F and 100° F for a relative humidity below 5%.

At 100% relative humidity the filter factor for SO-1213 drops to 3.0 with increase in temperature from 80° F to 150° F. At 75% relative humidity it drops to 3.4 at 125° F and to 2.6 at 150°F. The results

at 150° F are probably not reliable. At 50% relative humidity no significant change occurs up to temperatures of 150° F. There was no change in filter factor up to temperatures of 200° F for relative humidities less than 5%. At 220° F the filter factor dropped to 3.5. See Tables 1 and 2 for values of the filter factor at various temperatures and humidities for SO-1213 and Plus-X Aerecon.

Table 1.

Filter Factor for SO-1213 at Various Temperatures and Humidities. Exposure Made Through a Number 25 Filter.

RH / Temp.	0	50	75	100
80	4.0	---	3.8	3.8
100	3.9	4.0	3.8	---
125	---	4.0	3.4	3.0
150	3.9	3.7	2.6	3.2
175	3.7	---	---	---
200	3.2	---	---	---

Table 2.

Filter Factor for Plus-X Aerecon at Various Temperatures and Humidities. Exposure Made Through a Number 25 Filter.

Temp. \ RH	0	50	75	100
80	2.2	---	2.7	2.8
100	2.2	2.6	2.3	3.0
125	2.6	2.4	2.8	2.6
150	2.7	2.5	2.5	3.0
175	2.8	---	---	---
200	3.0	---	---	---

Chapter IV

CONCLUSIONS

Plus-X Aerecon

At humidities lower than 5%, Plus-X Aerecon will give acceptable results up to temperatures of 220° F, and heating periods up to four hours duration. In considering the use of this emulsion at elevated temperatures, the almost sixfold loss in speed must be taken into account. At low humidities, such as would be met in aerial photo reconnaissance, a detrimental rise in fog level and reduction in gamma is not encountered for periods up to six hours until temperatures in excess of 200° F are reached. An increase of humidity definitely accelerates the rise in fog level. Indications are that it would increase gamma.

Increasing temperature and humidity does not cause a significant change in the filter factor. Lowering the relative humidity at temperatures up to 100° F causes a significant lowering of the filter factor.

SO-1213

At humidities less than 5% SO-1213 will give acceptable results at temperatures as high as 220° F for short periods of time (two hours) and for prolonged periods at temperatures as high as 200° F. When heated for six hours at 220° F, complete blackening of the emulsion results with overall density greater than 3.0. At these humidities elevating the temperature causes an increase in speed and gamma. Fog level will not be detrimental to photographic quality until temperatures exceed 200° F. Increasing humidity will increase the speed of SO-1213 and fog level but have little effect on gamma.

Other Considerations

A comparison of the curves of speed (D = 1.0 + fog) versus temperature of the two emulsions tested show that at approximately 175° F with the relative humidity less than 5% the speed of both is the same. In addition, the gamma of Plus-X Aerecon reduces to a value less than 2.0 whereas the gamma of SO-1213 has approached 3.5. Coupled with this is the inherent better resolution of SO-1213 making it a natural choice under these conditions.

Inasmuch as open strips were used in testing these emulsions, no conclusions can be drawn regarding the film being in roll form. It is concurred that the use of film in roll form at low humidities restricts it to temperatures below 180° F[4] and it is axiomatic that increasing the relative humidity will further lower this temperature.

Use of Sulfuric Acid in the Thermosensitometric Test Unit for Humidity Control.

It is questionable that reliable results as to the effect of humidity on the sensitivity of photographic emulsion were obtained. The results obtained with Plus-X Aerecon are considered normal but the erratic results obtained with SO-1213 leaves doubt as to the validity of using sulfuric acid solutions in such close proximity to the emulsion. More work should be done along this line possibly using different salts and sulfuric acid solutions for humidity control and checking the results against the use of an airflow of known humidity such as used by Dimitroff.[1]

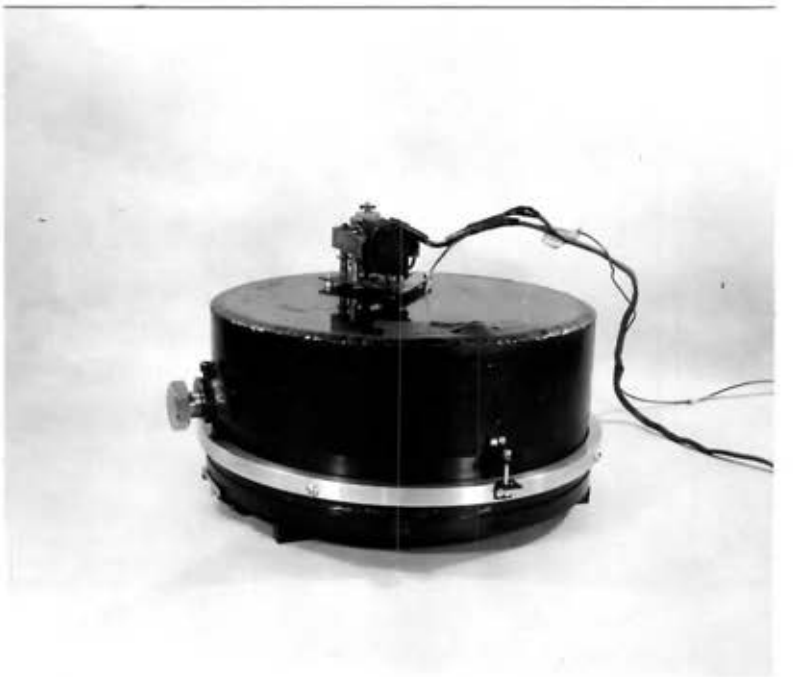

Figure 1. Thermosensitometric Test Unit

Figure 2. Thermosensitometric Test Unit Showing Humidity Test Method

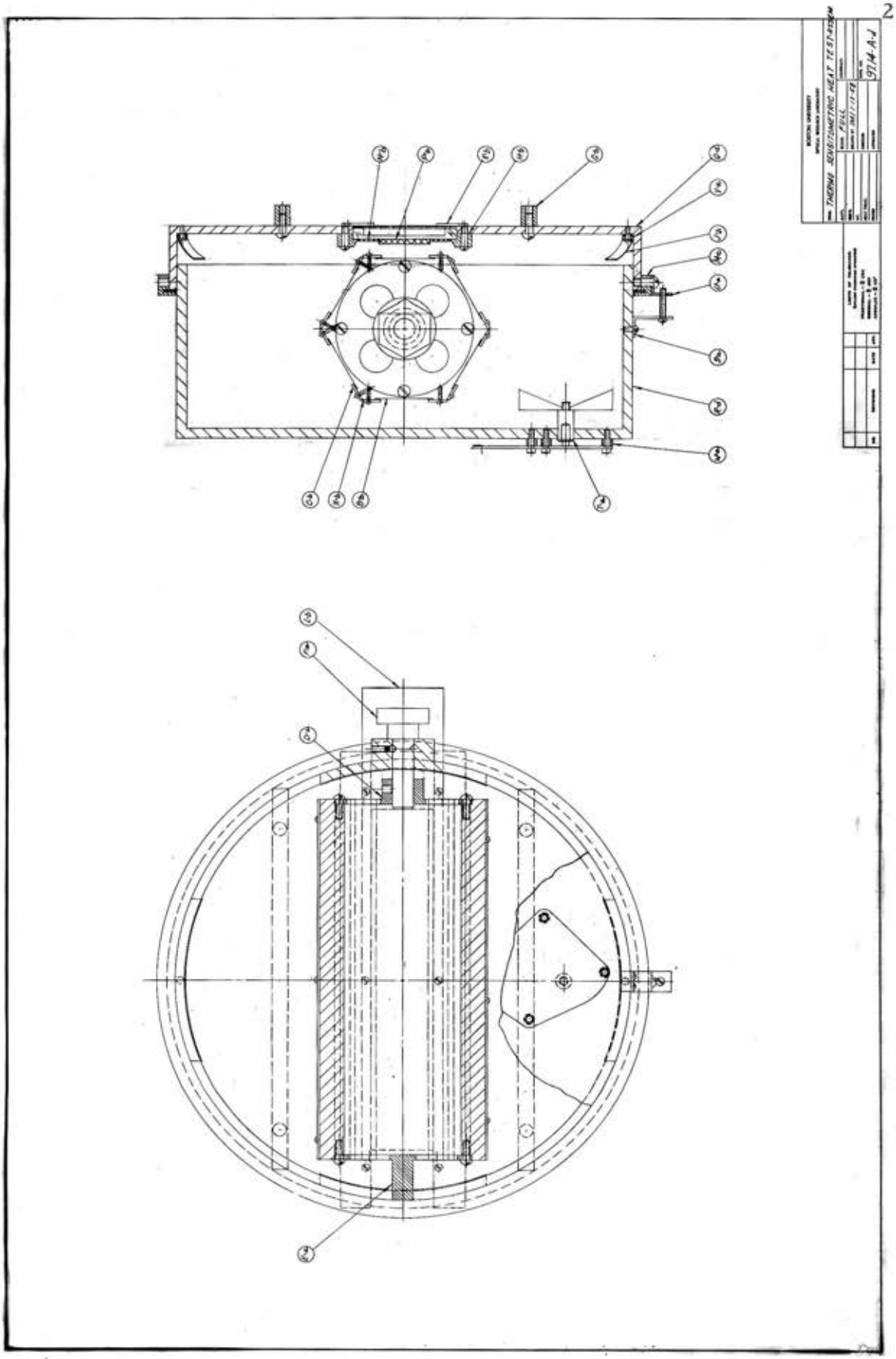

Figure 3. Thermosensitometric Test Unit Assembly

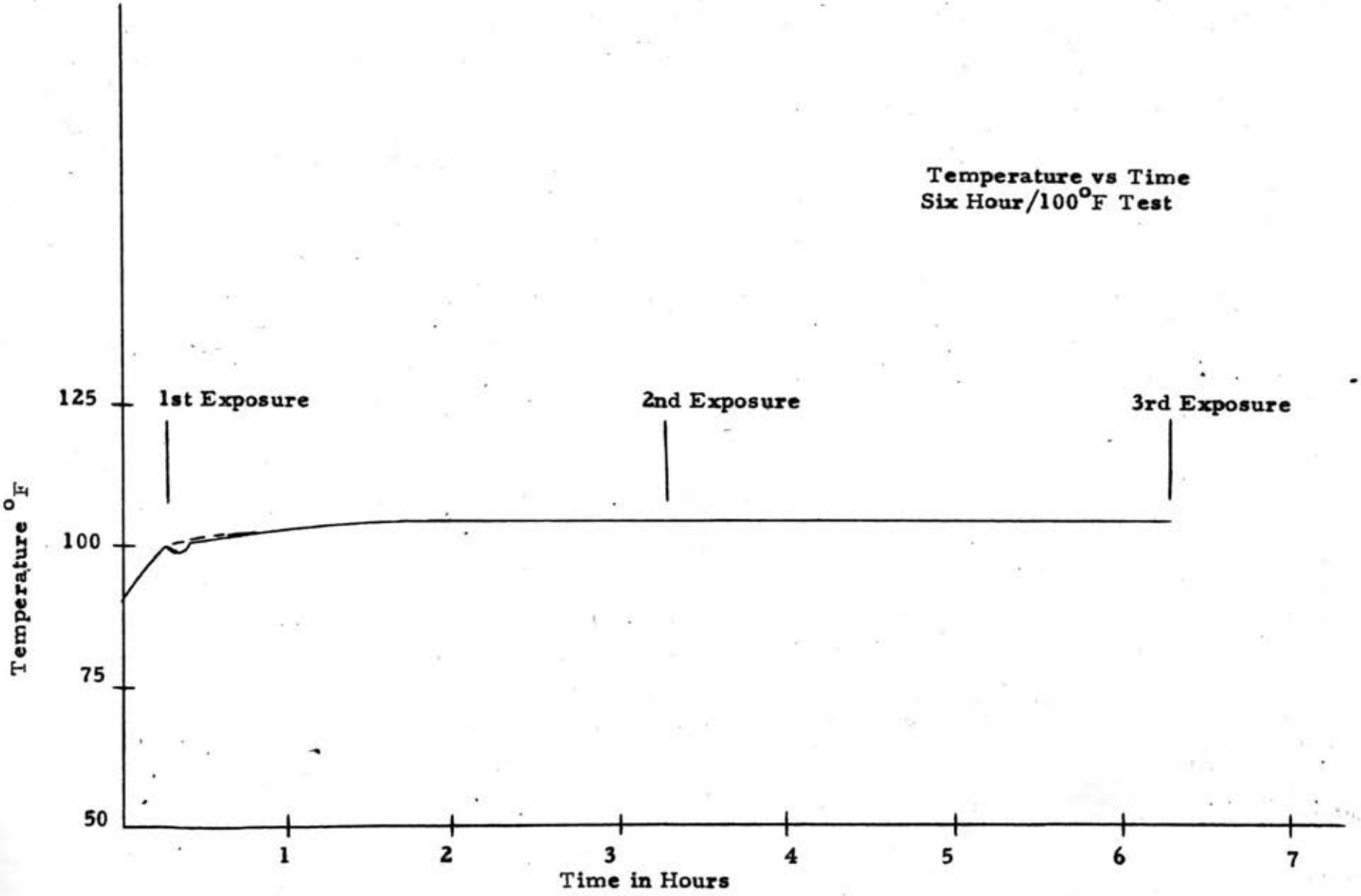

Figure 4. Temperature-Time Curve for 100°F/Six Hour Run

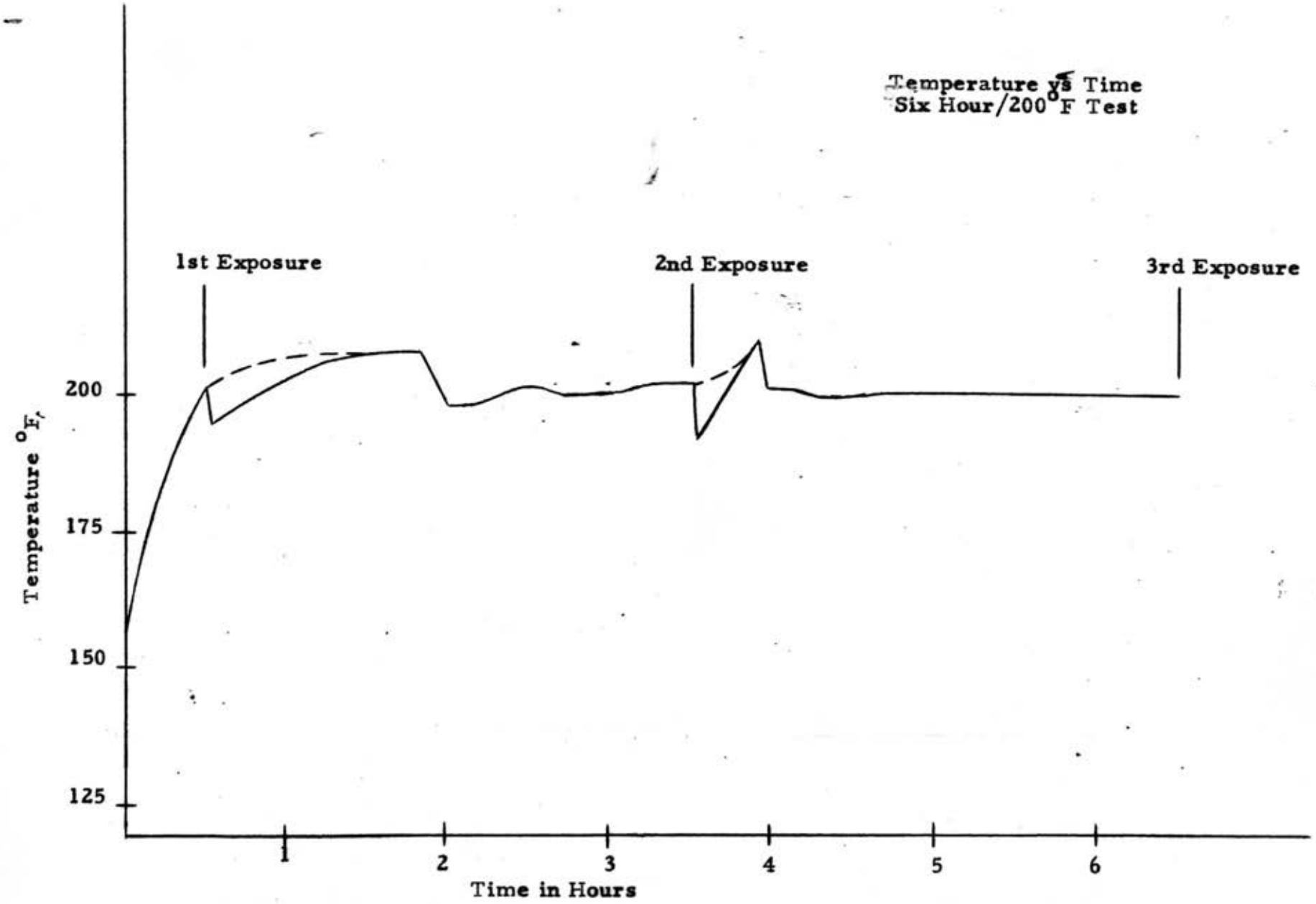

Figure 5. Temperature-Time Curve for 200°F/Six Hour Run

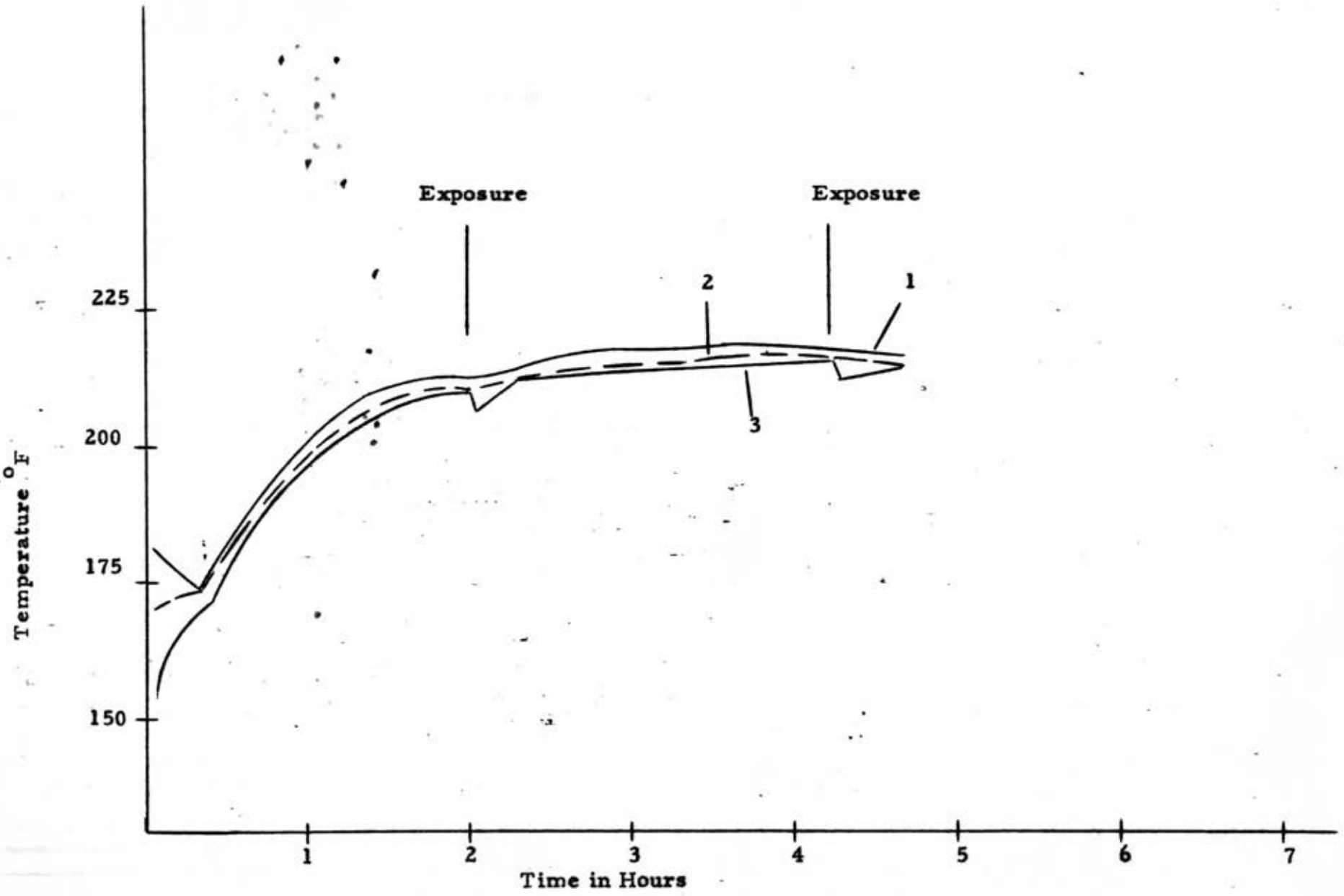

Figure 6. Temperature Check of the Thermosesitometric Test Unit
1. Temperature of the Film on the Top of the Hexagonal Film Holder
2. Temperature of the Film on the Bottom of the Hexagonal Film Holder
3. Temperature of the Air in the Test Unit

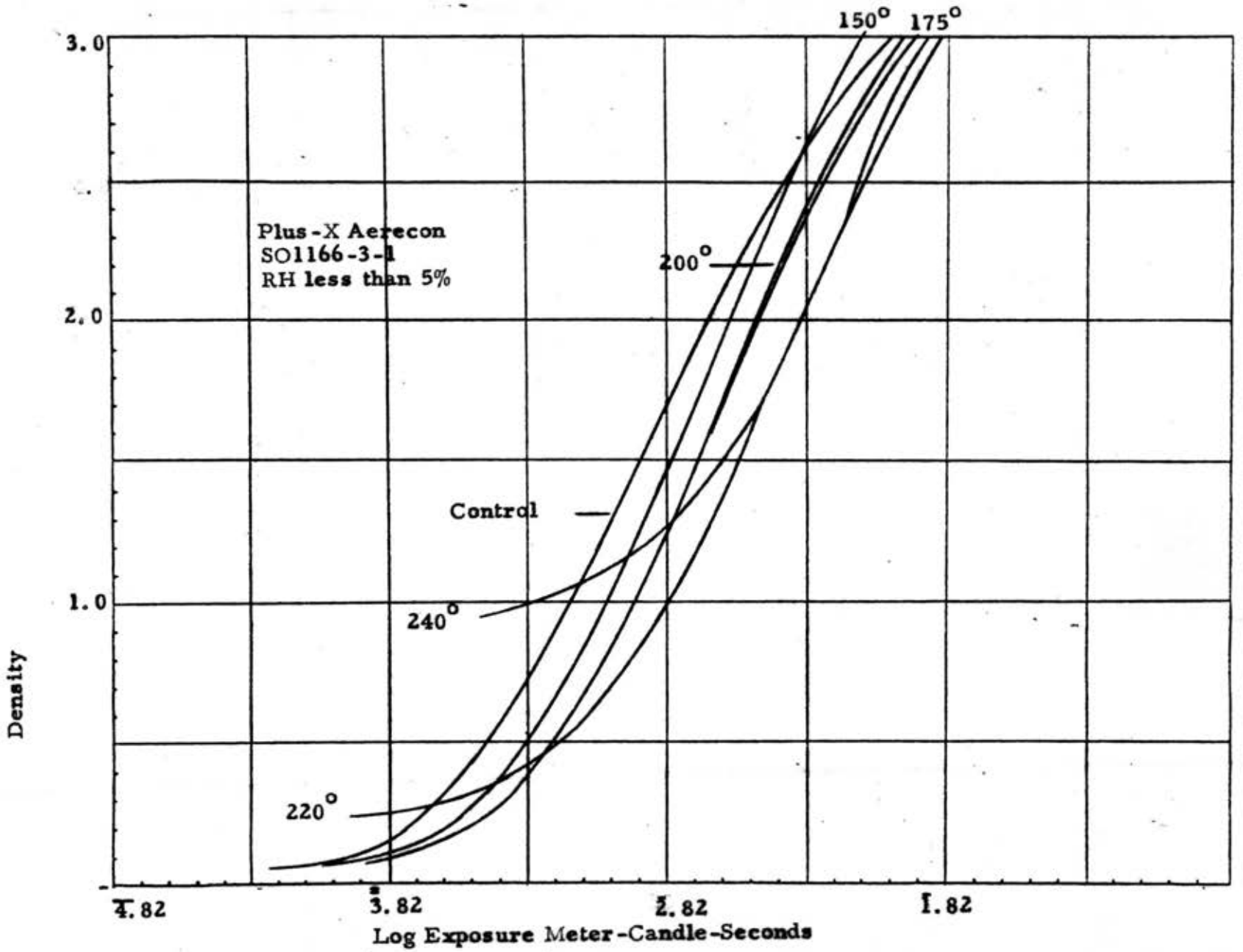

Figure 7a. Emulsion Heated for Two Hours After Exposure

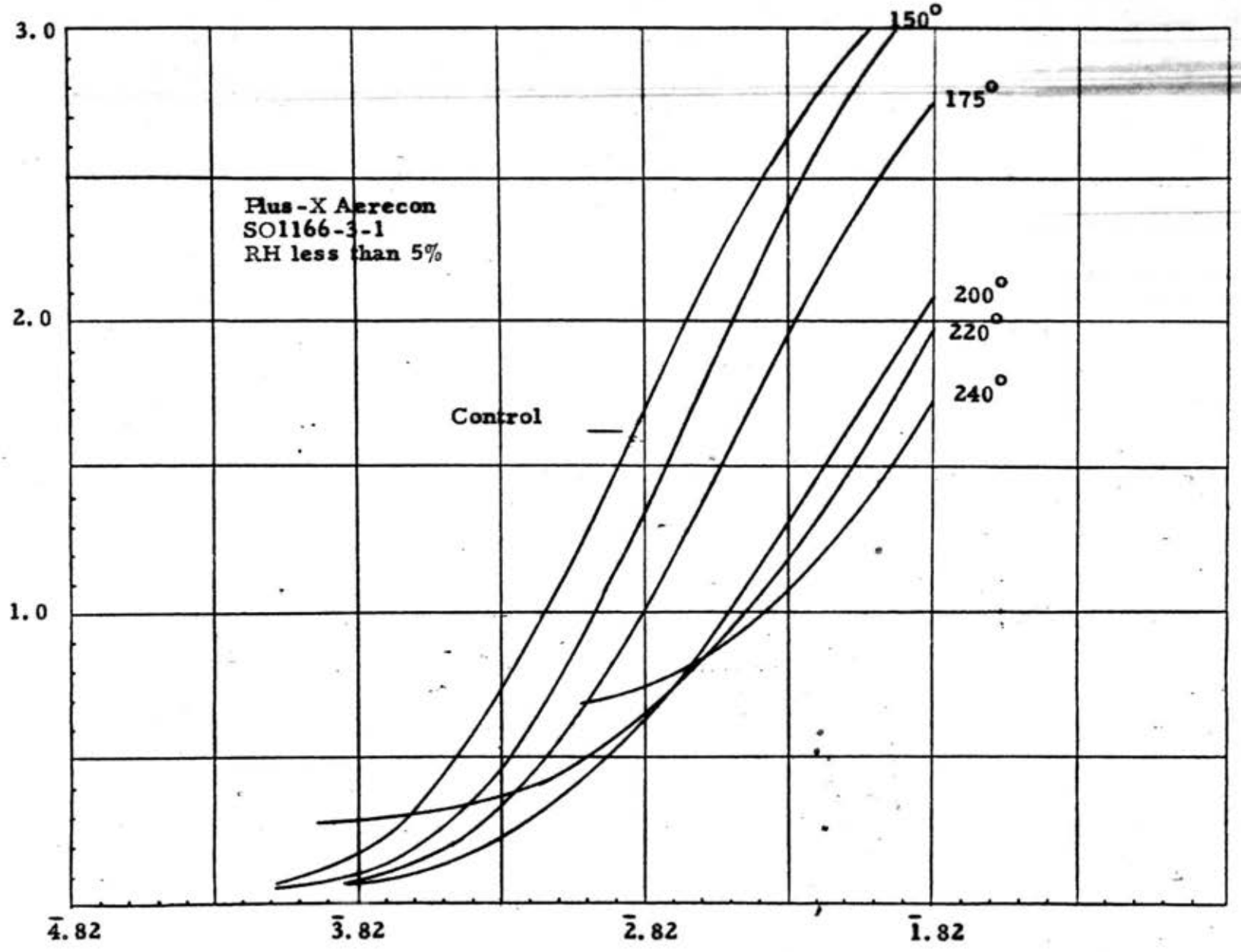

Figure 7b. Emulsion Heated for Two Hours Before Exposure

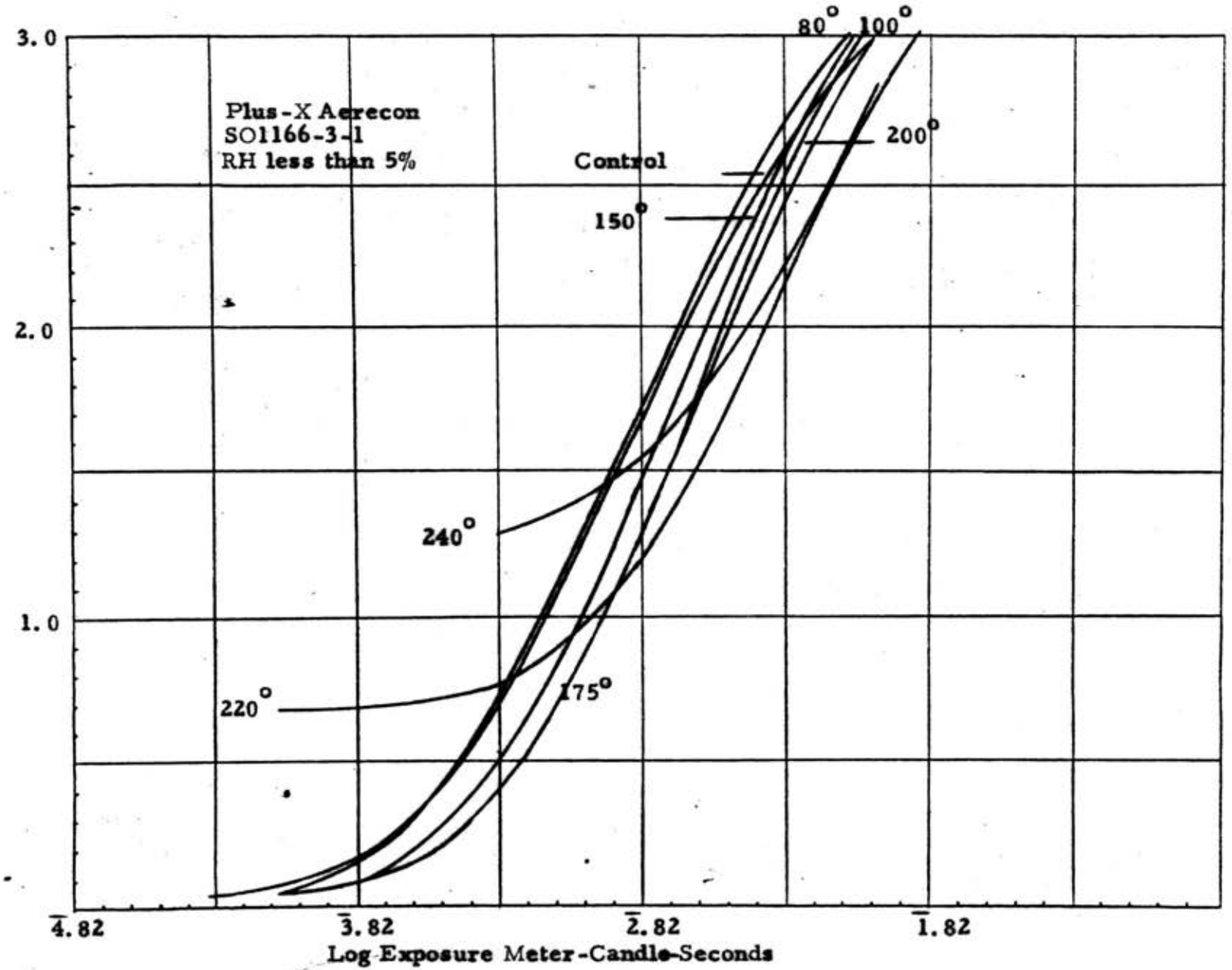

Figure 7c. Emulsion Heated for Four Hours after Exposure

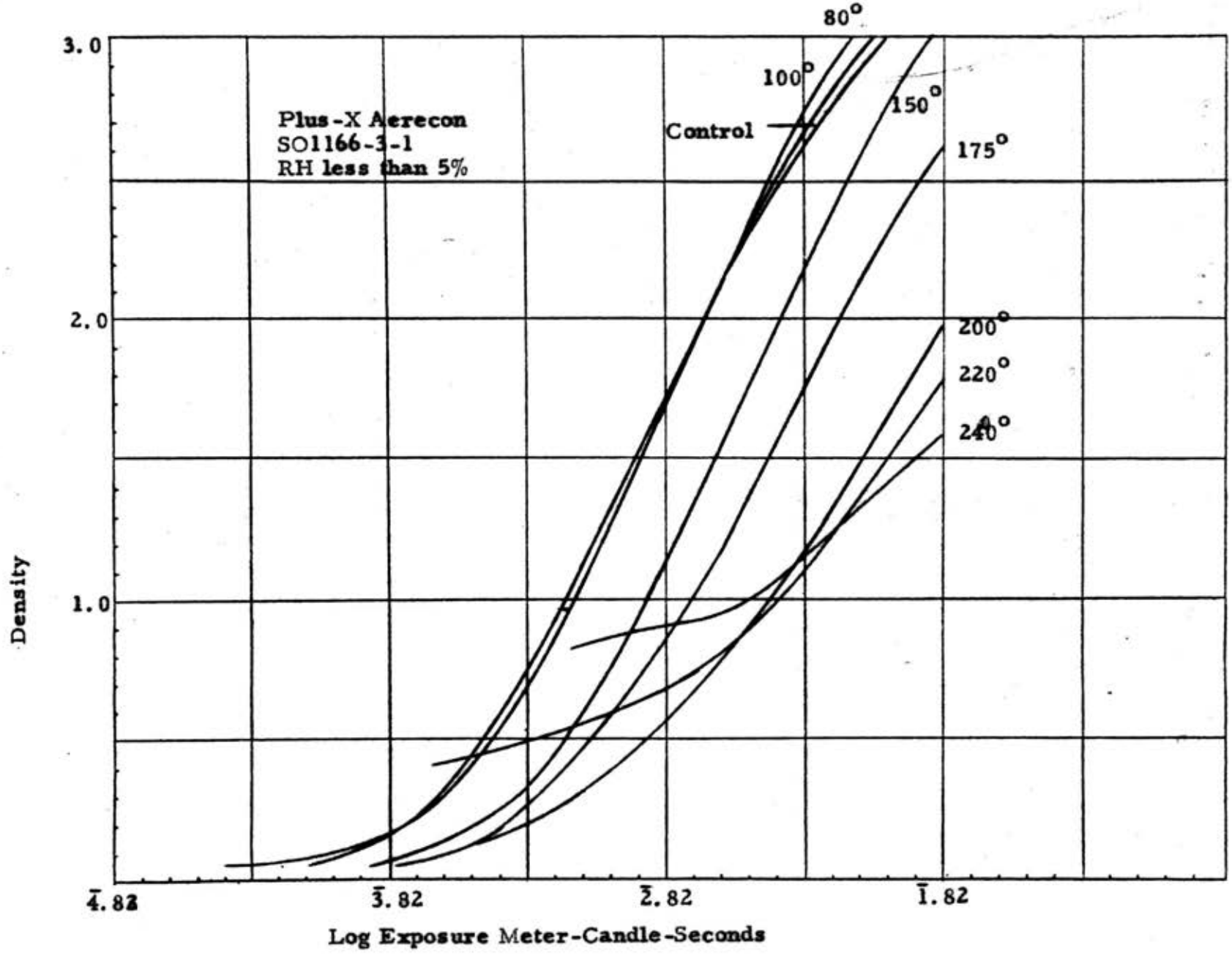

Figure 7d. Emulsion Heated for Four Hours before Exposure

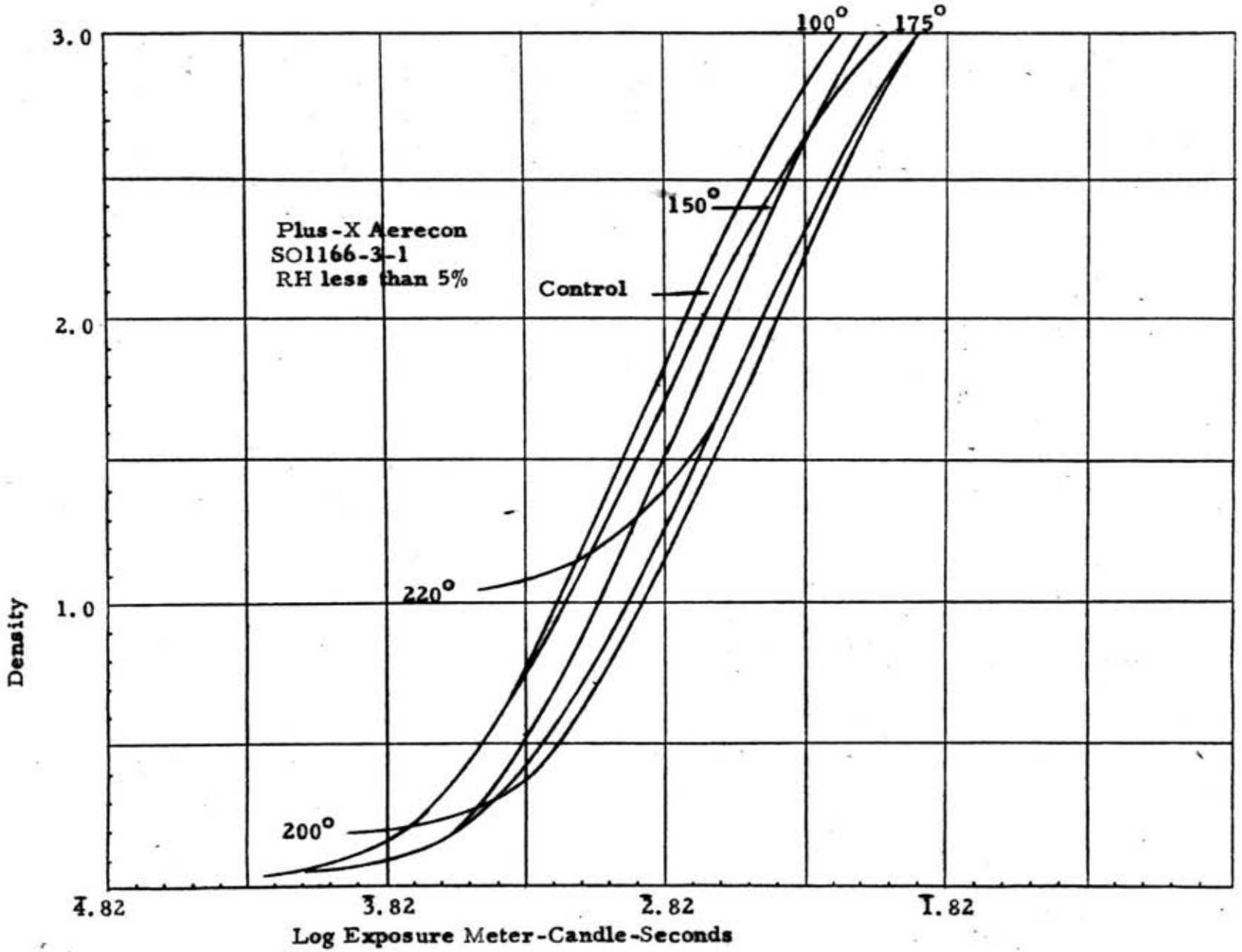

Figure 7e. Emulsion Heated for Six Hours after Exposure

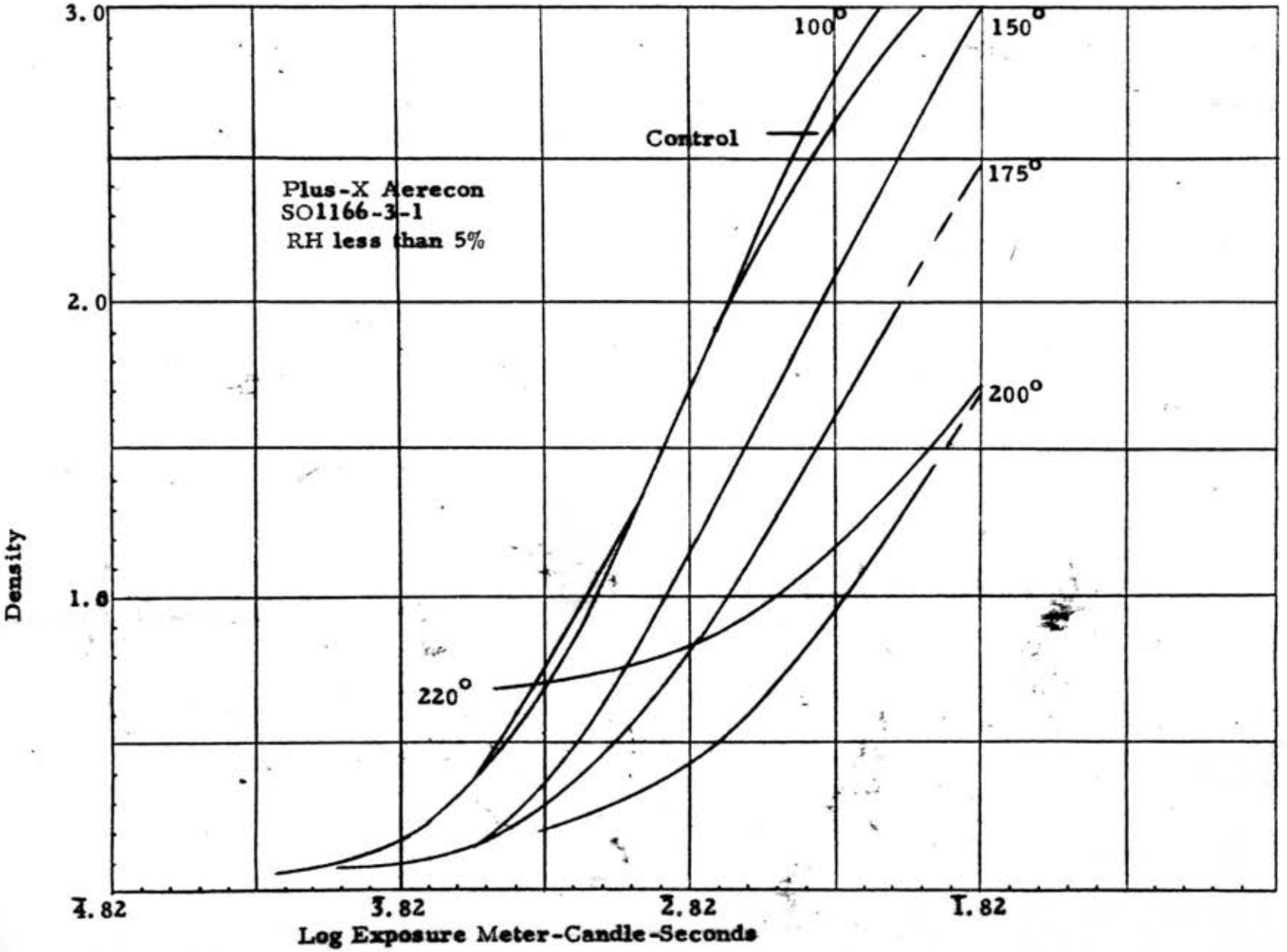

Figure 7f. Emulsion Heated for Six Hours Before Exposure

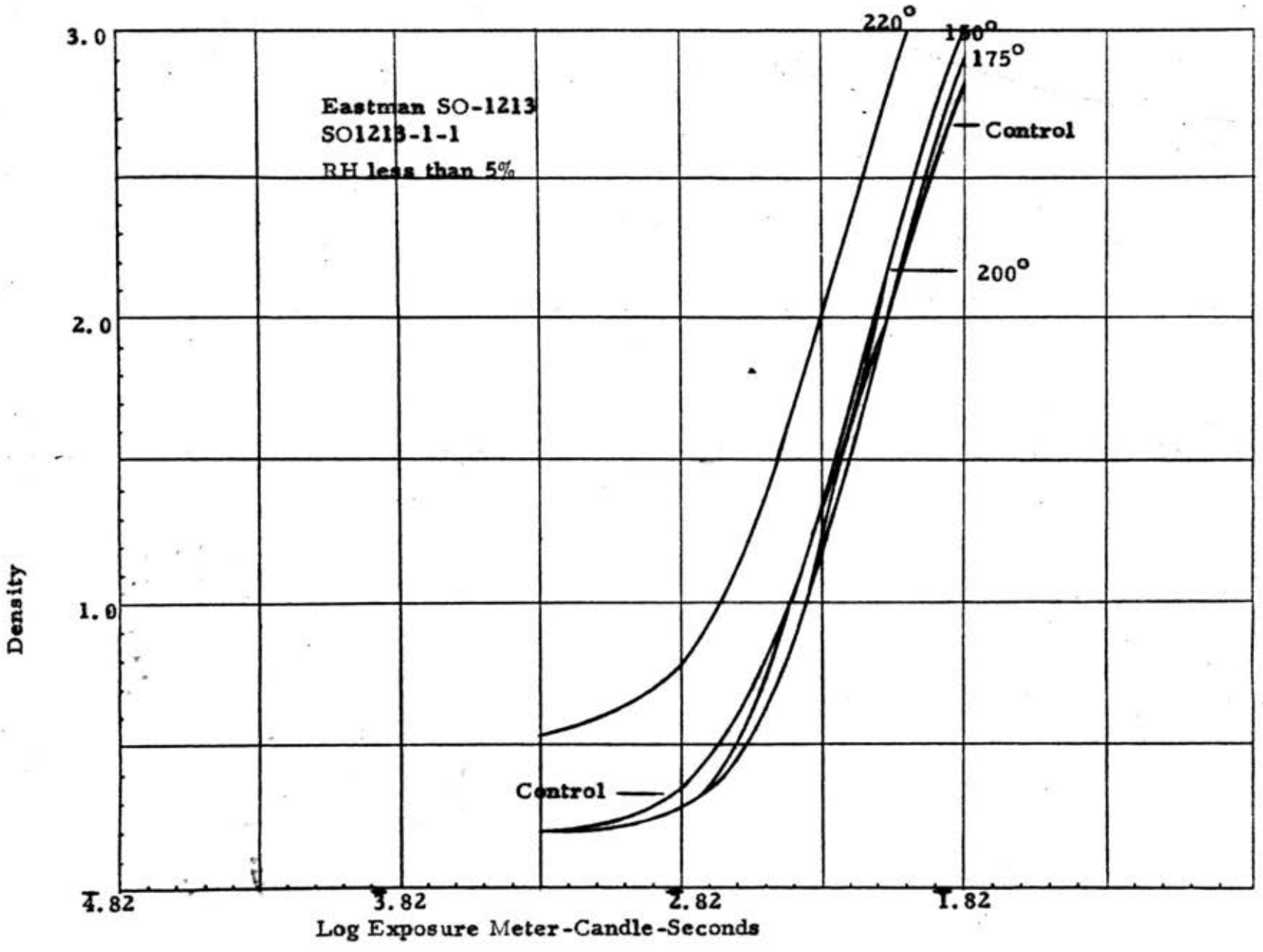

Figure 8a. Emulsion Heated for Two Hours after Exposure

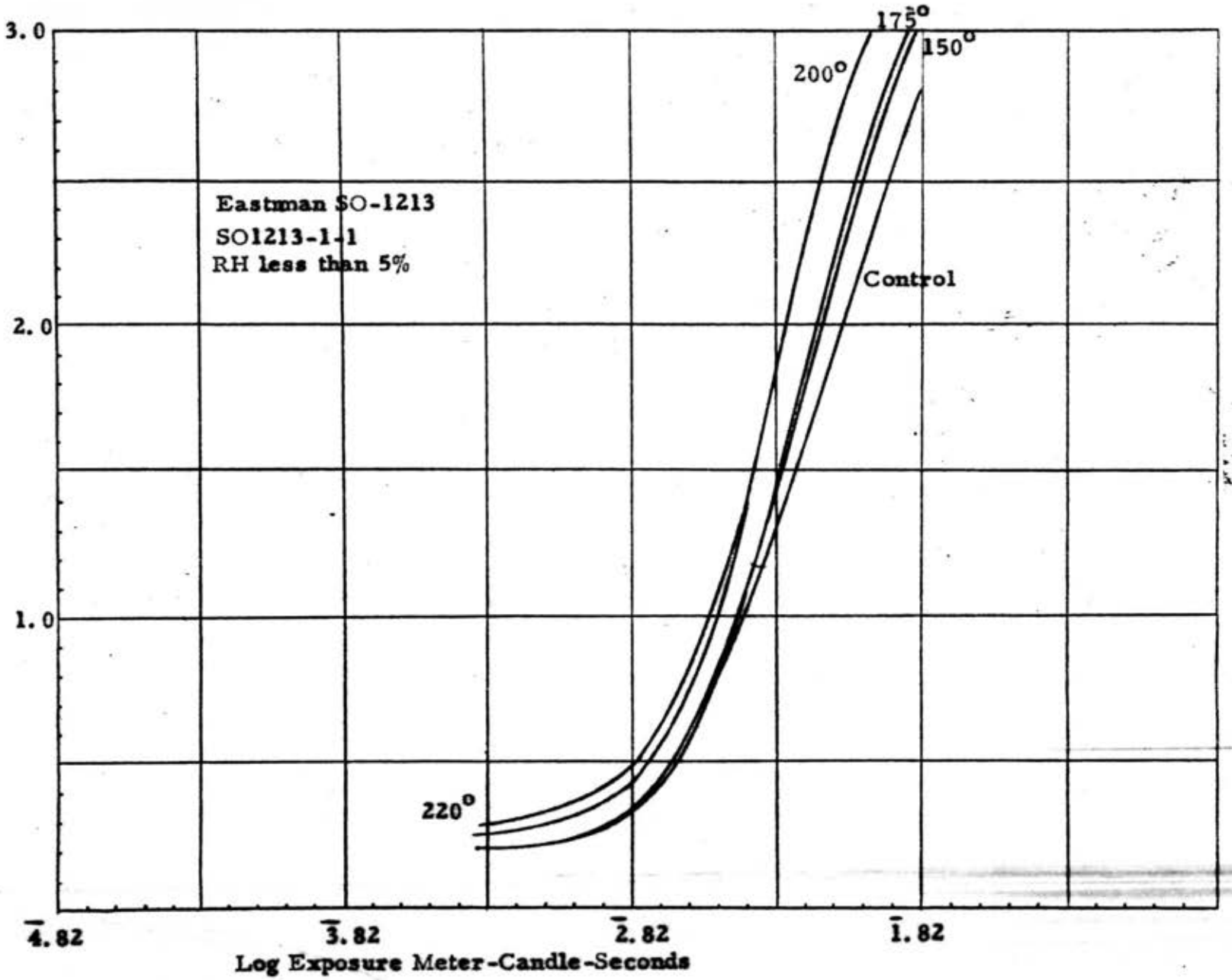

Figure 8b. Emulsion Heated for Two Hours before Exposure

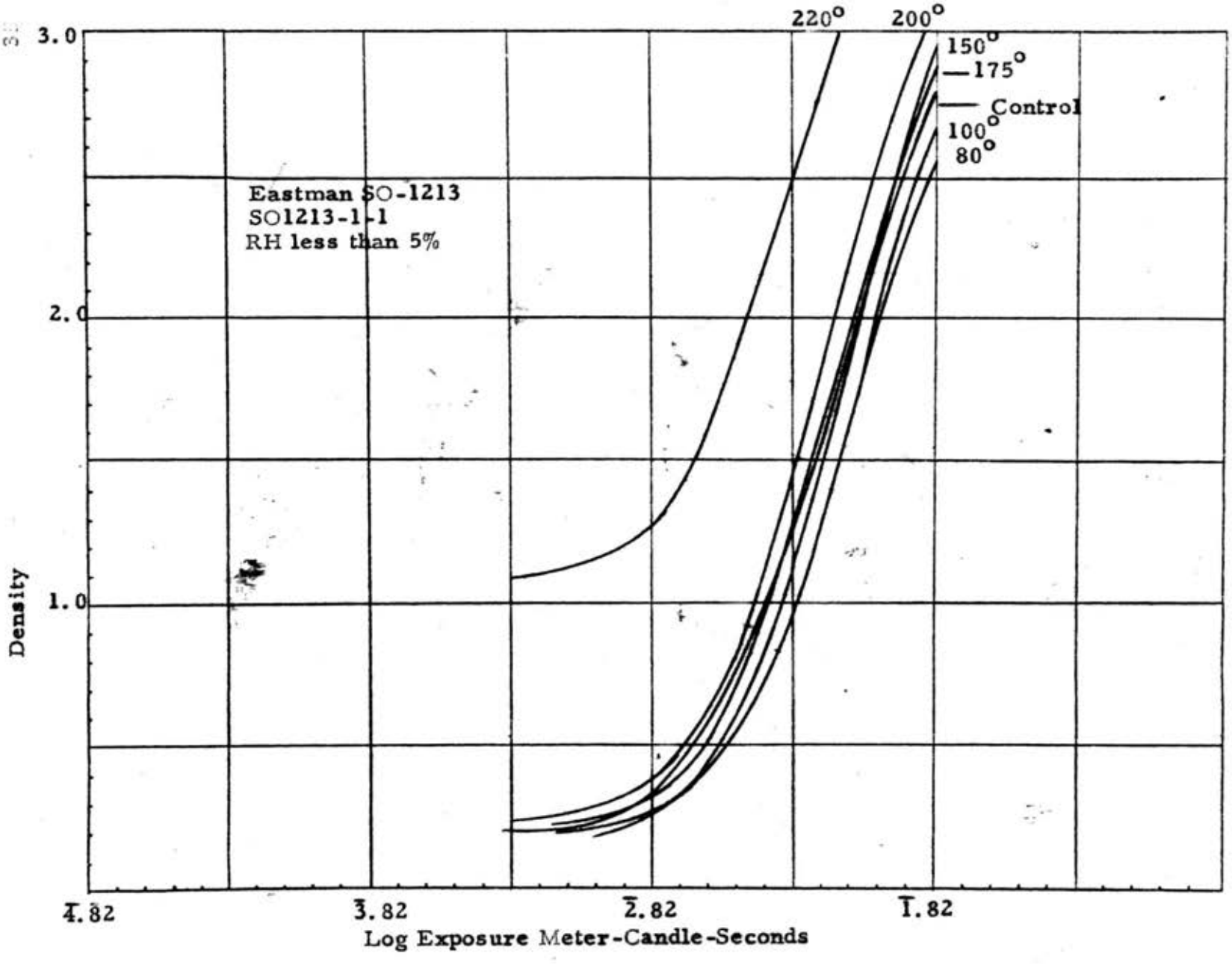

Figure 8c. Emulsion Heated for Four Hours after Exposure

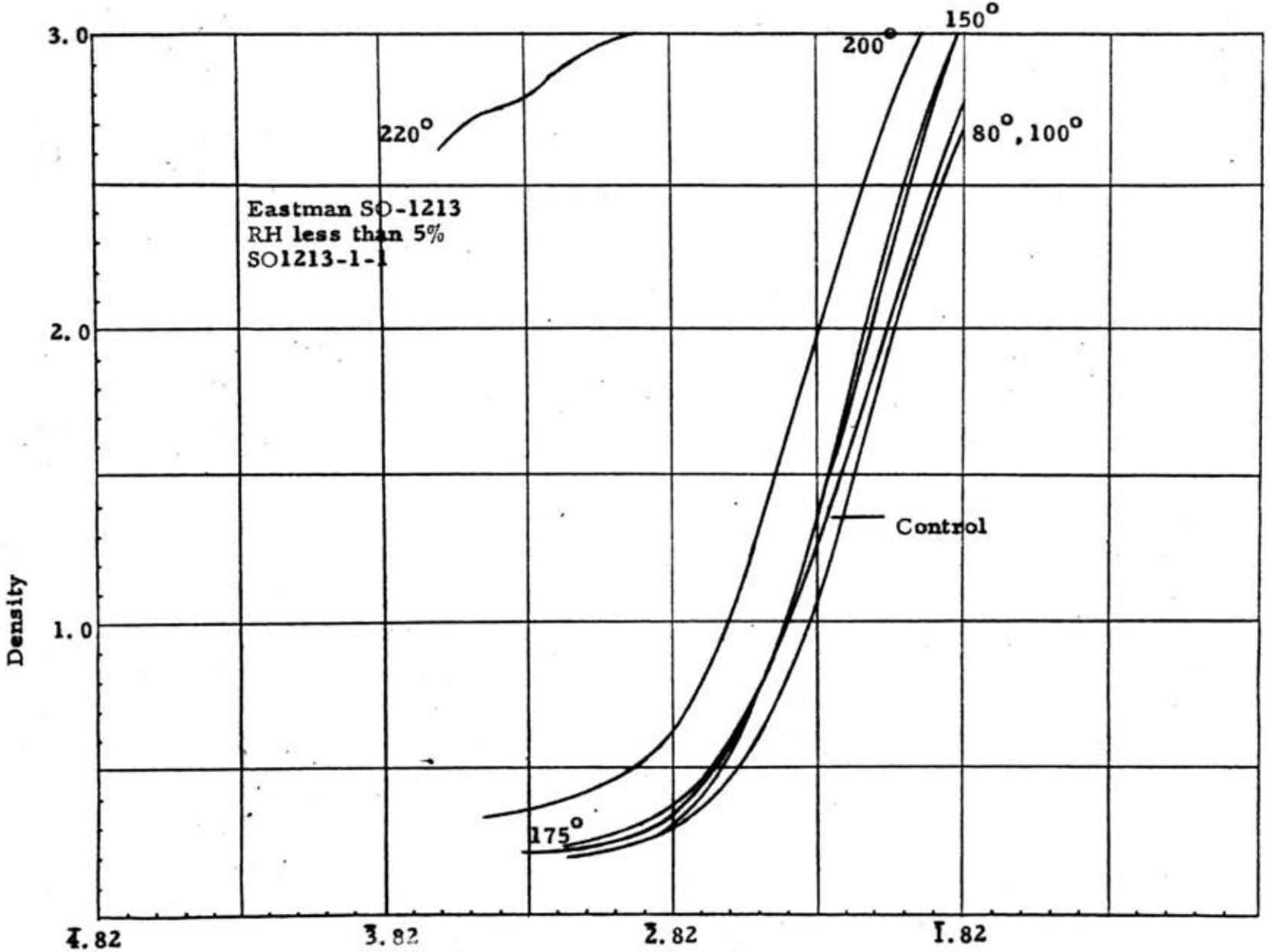

Figure 8d. Emulsion Headed for Four Hours before Exposure

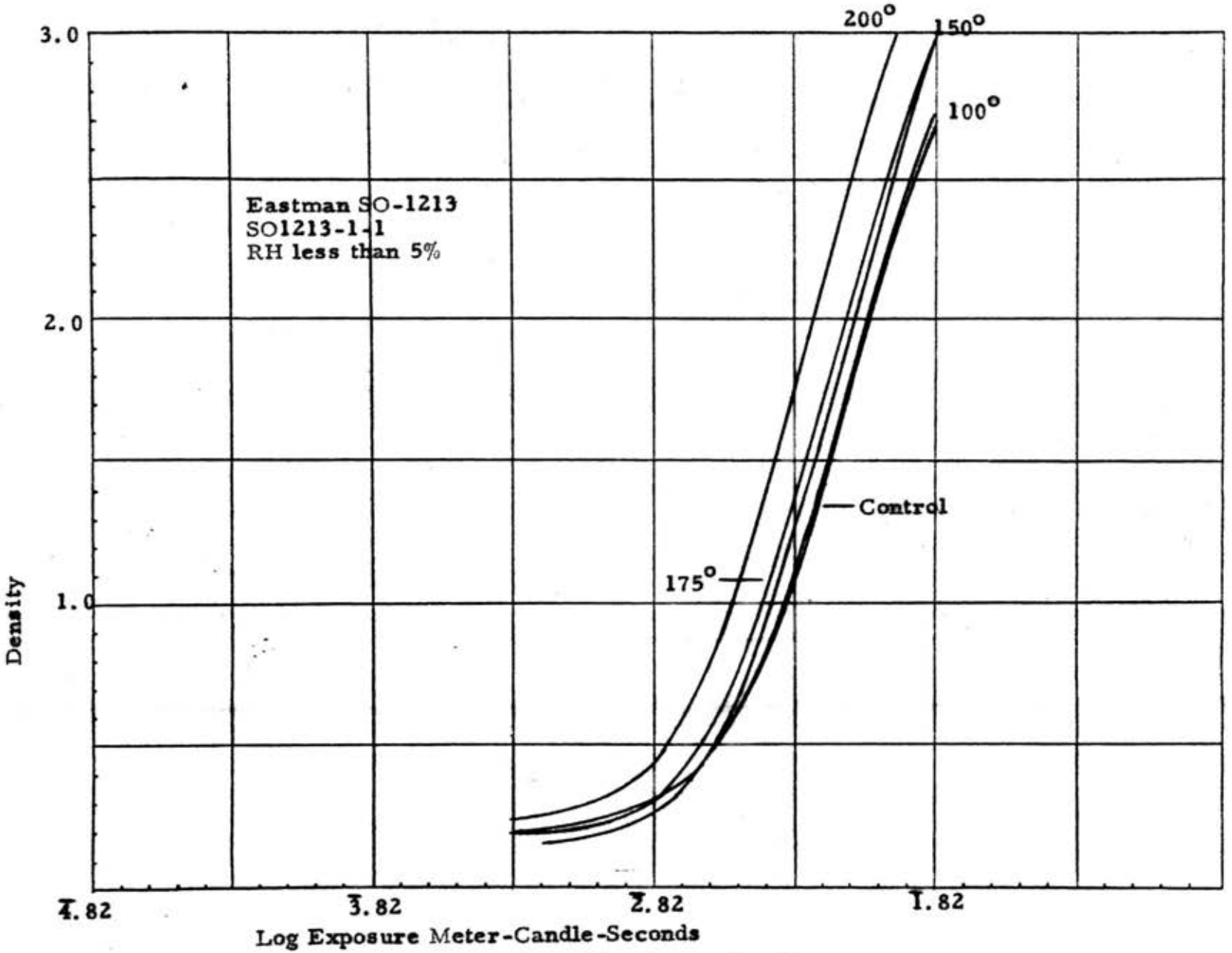

Figure 8e. Emulsion Headed for Six Hours after Exposure

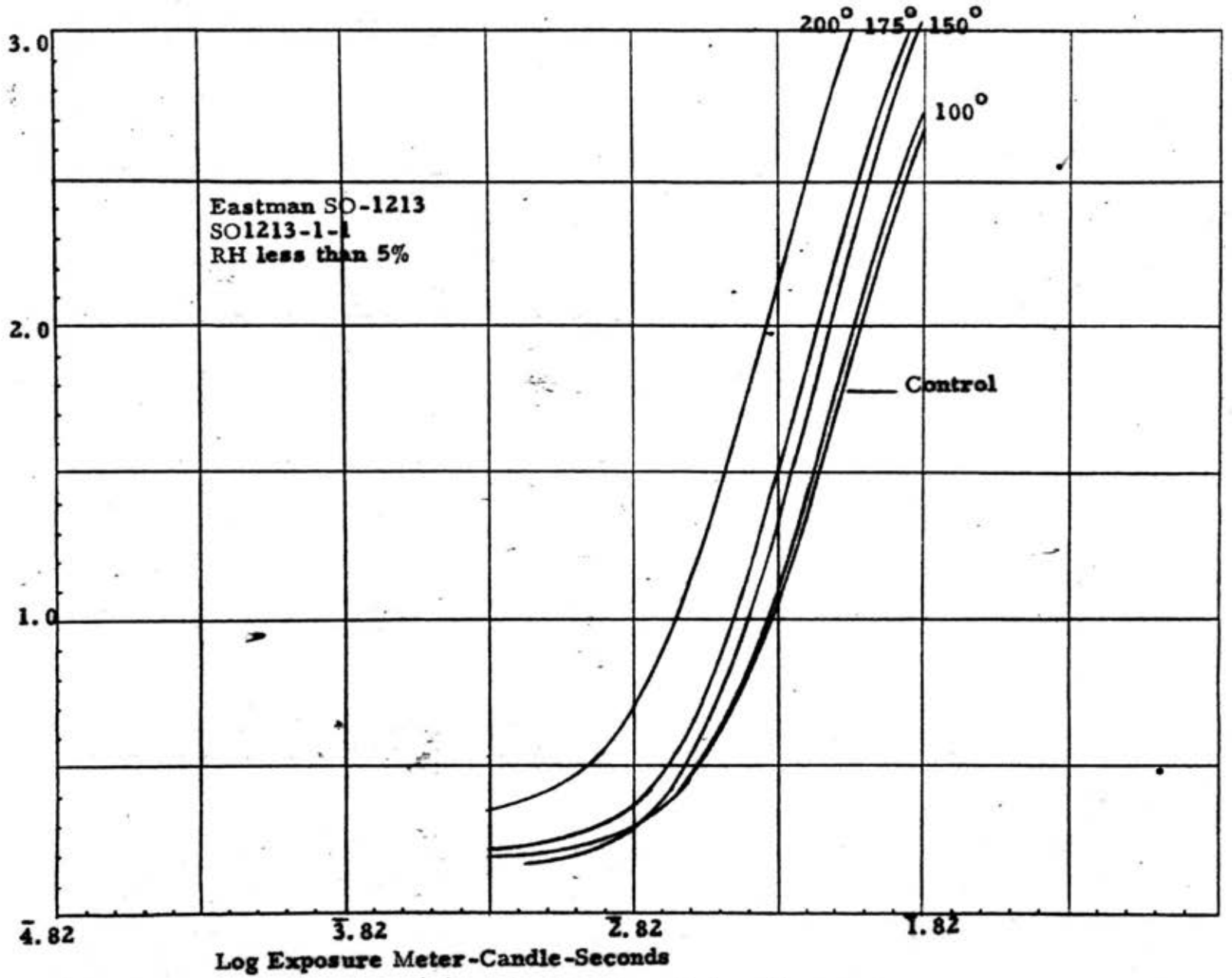

Figure 8f. Emulsion Heated for Six Hours before Exposure

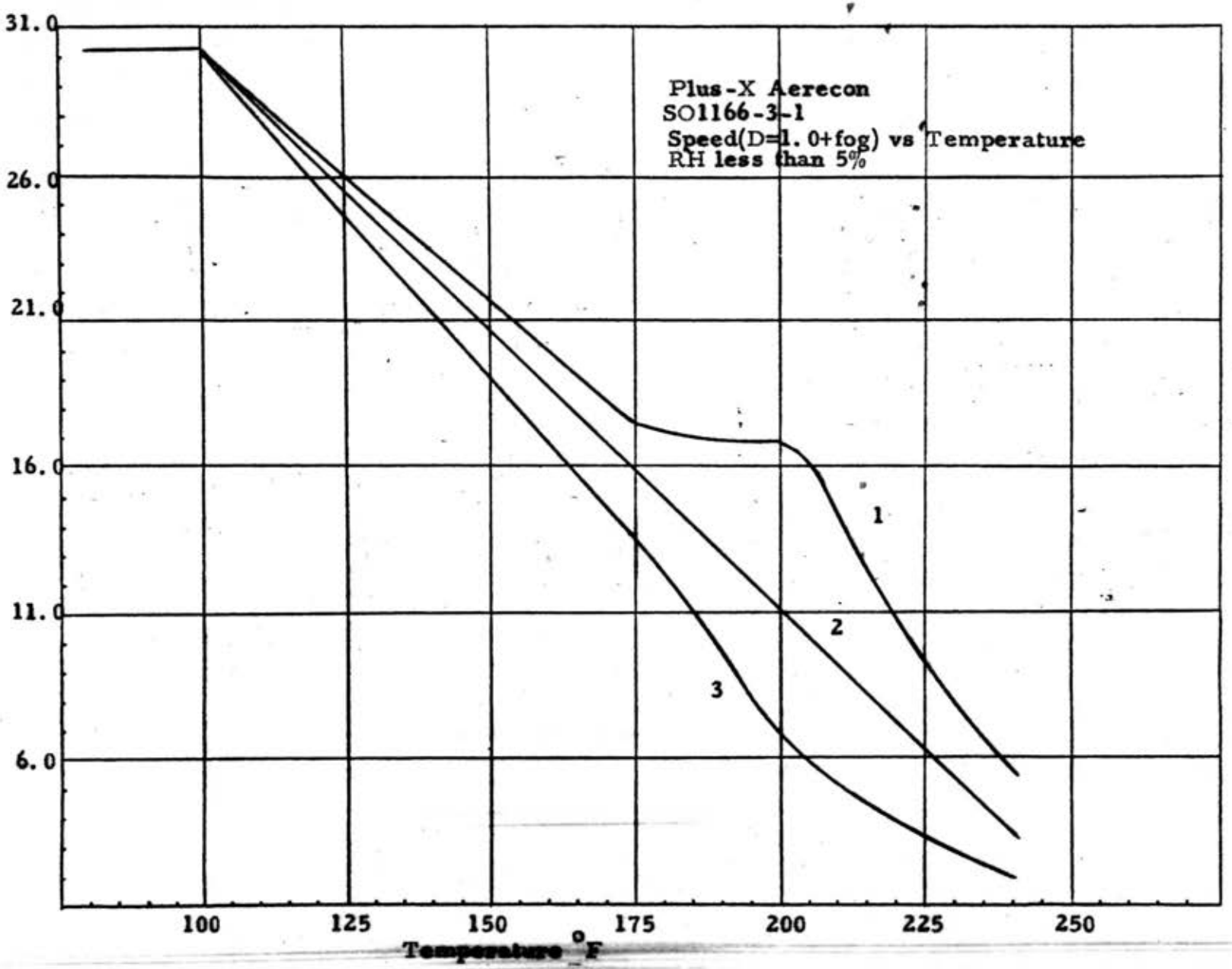

Figure 9a. 1. Emulsion Exposed--Heated Two Hours
2. Emulsion Heated one Hour--Exposed--Heated one Hour
3. Emulsion Heated Two Hours--Exposed

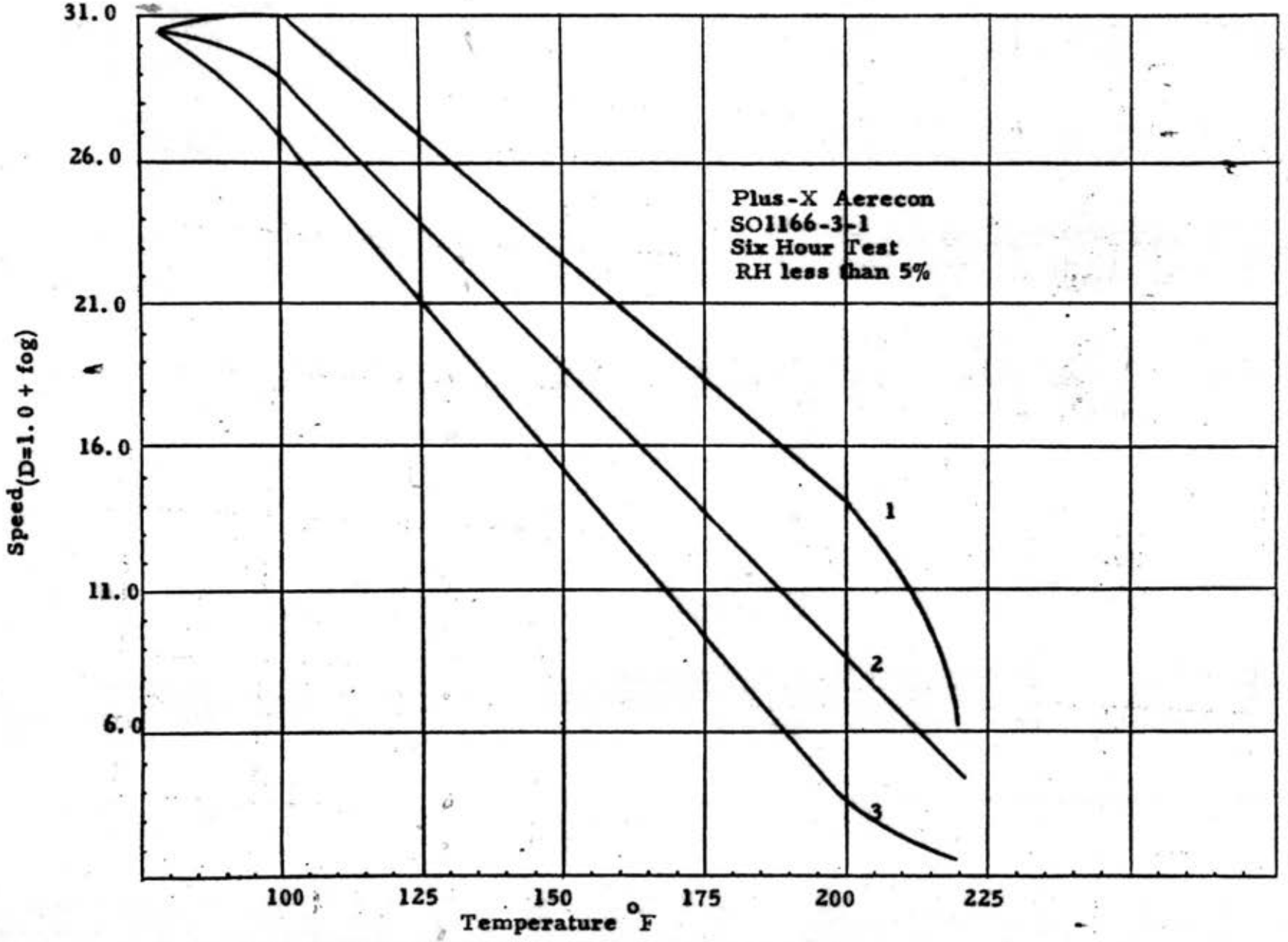

Figure 9b. Plot of Speed vs Temperature
1. Emulsion exposed and then heated for six hours
2. Emulsion heated for three hours-Exposed-Heated for three more hours
3. Emulsion heated for six hours before exposure

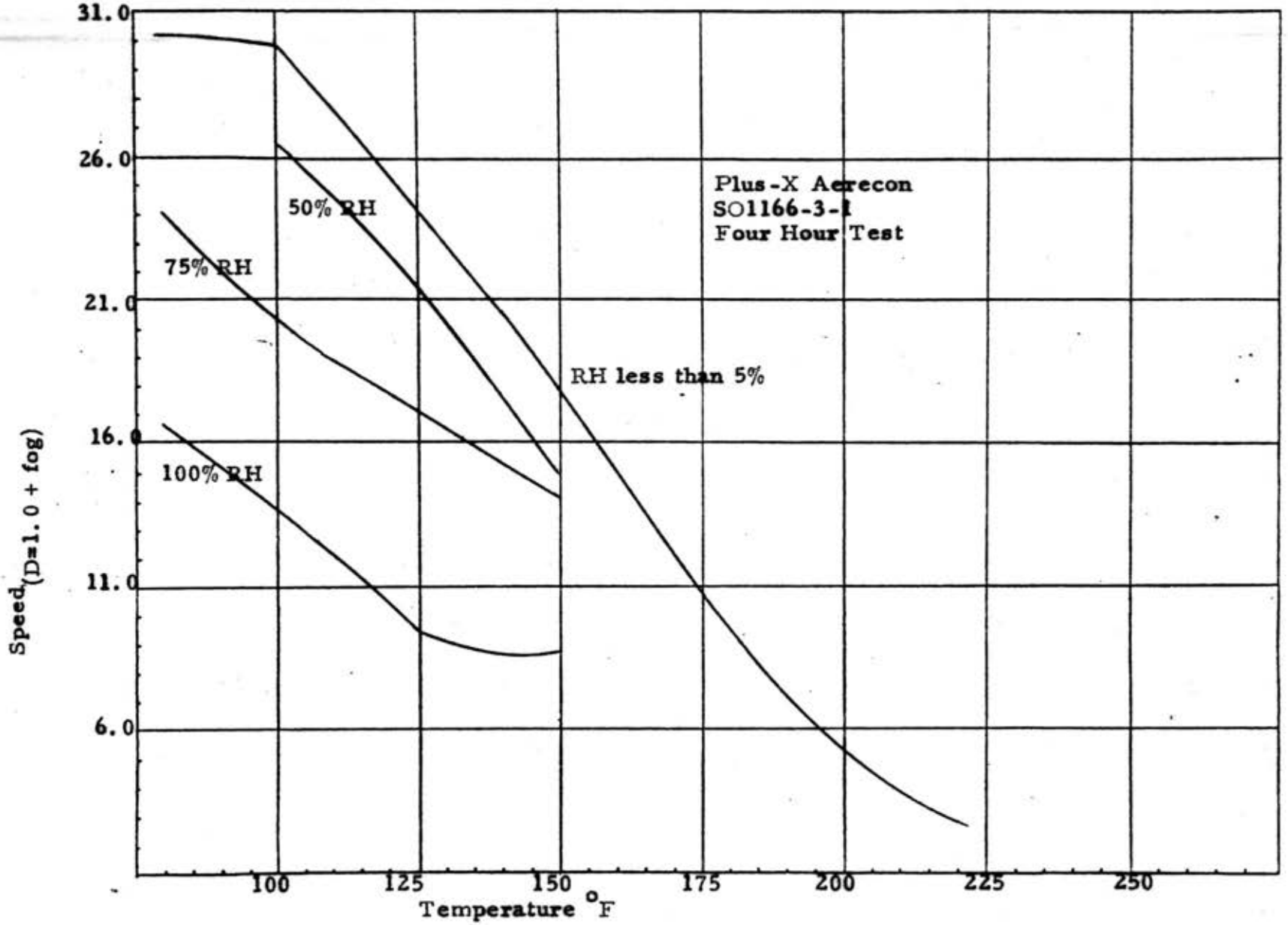

Figure 9c. Speed vs Temperature for various Humidities. Emulsions heated for four hours before exposure.

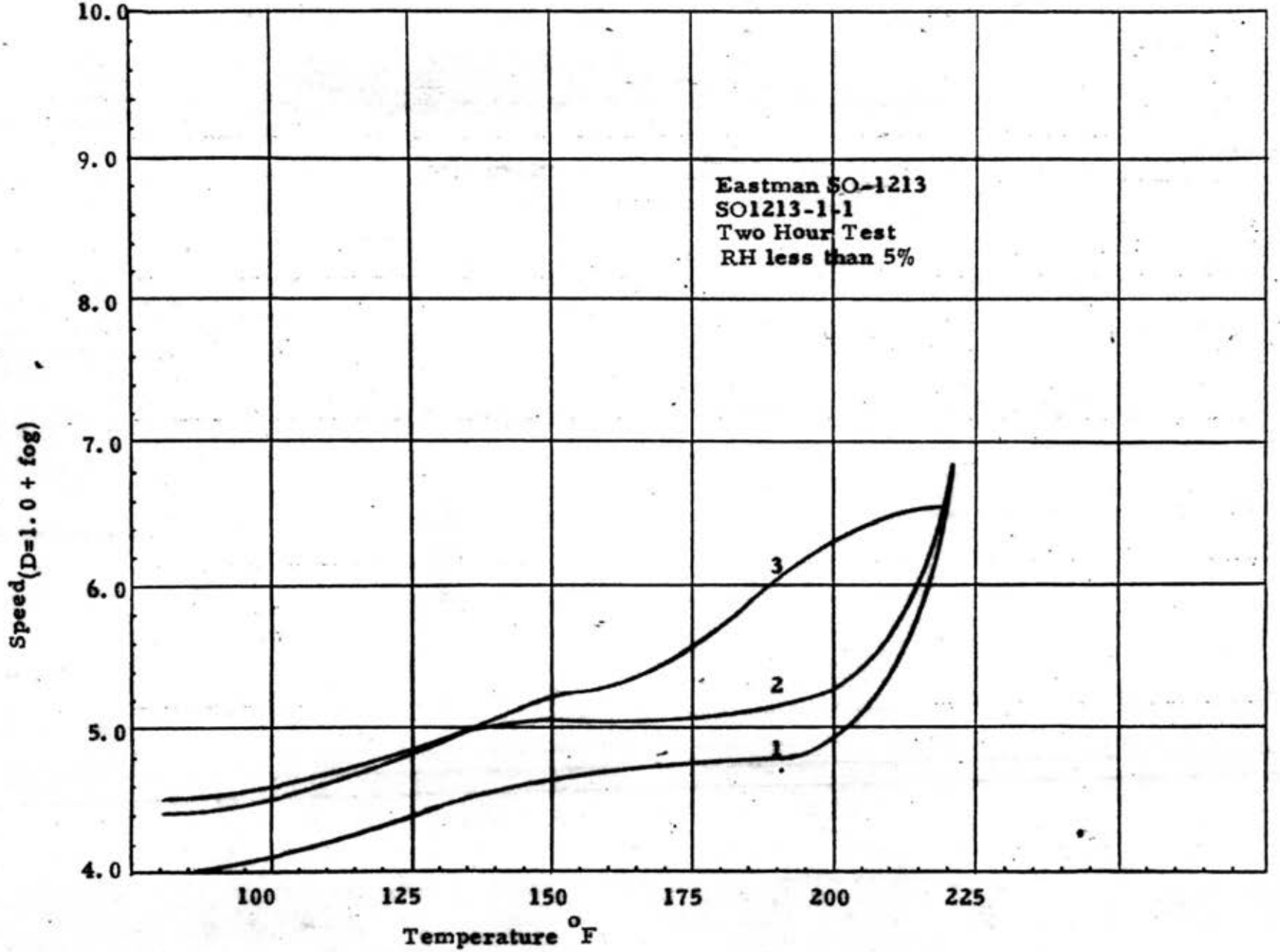

Figure 10a. Plot of Speed vs Temperature

1. Emulsion exposed and then heated for two hours
2. Emulsion heated one hour-Exposed-Heated one more hour
3. Emulsion heated for two hours before exposure

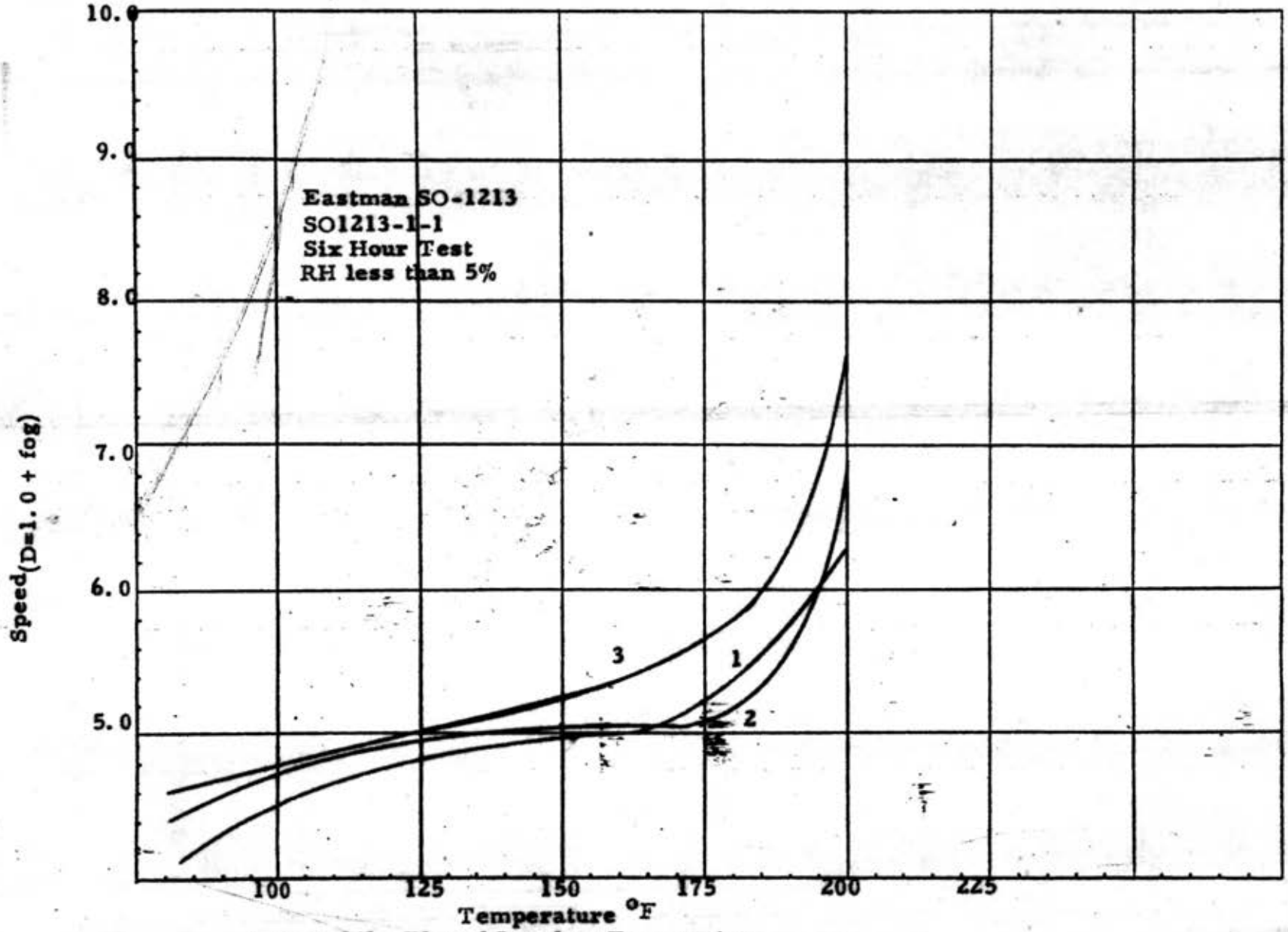

Figure 10b. Plot of Speed vs Temperature
1. Emulsion exposed and then heated for six hours
2. Emulsion heated for three hours-Exposed-Heated for three hours
3. Emulsion heated for six hours and then exposed

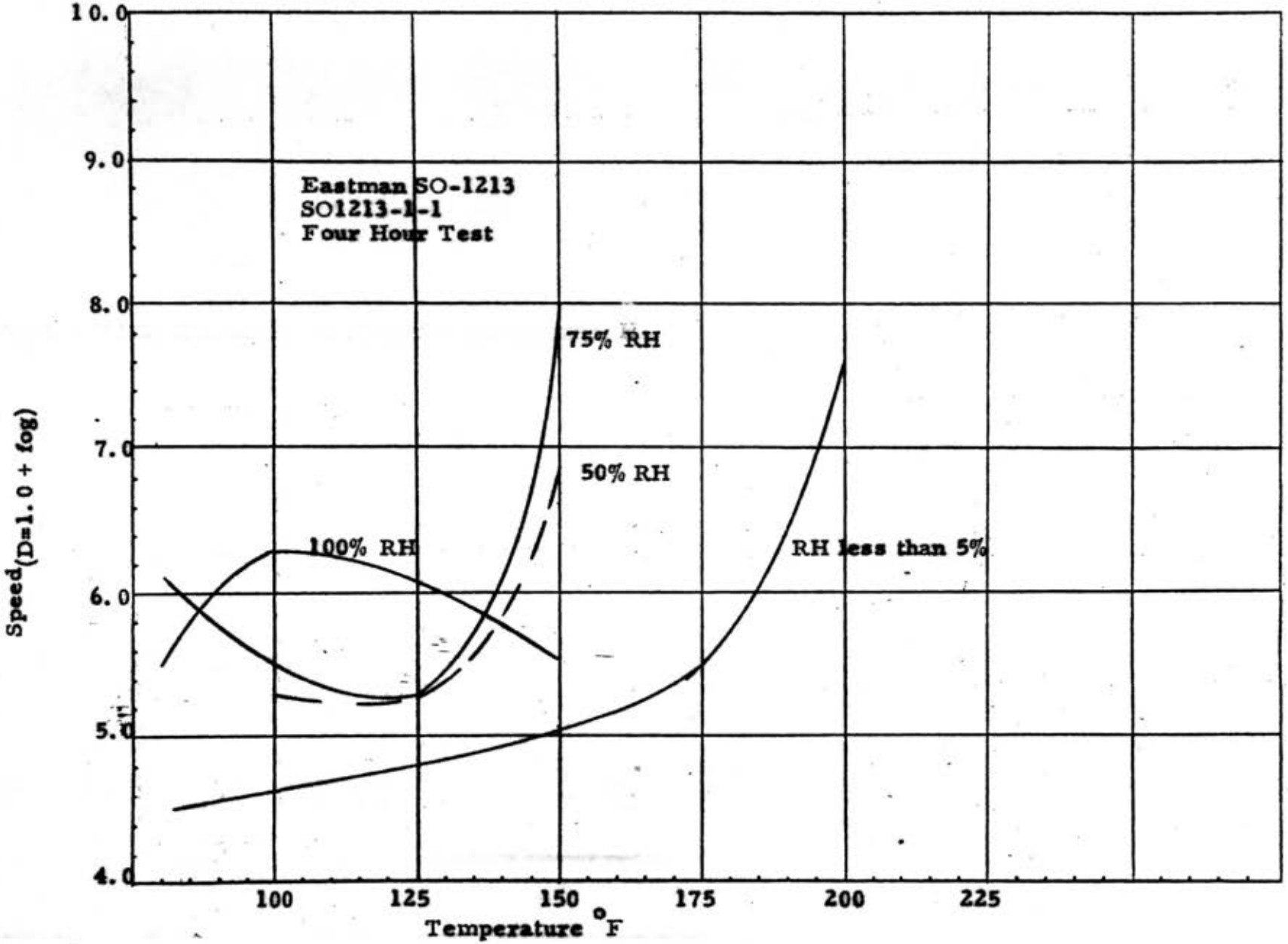

Figure 10c. Speed vs Temperature for various Humidities. Emulsions heated for four hours before exposure.

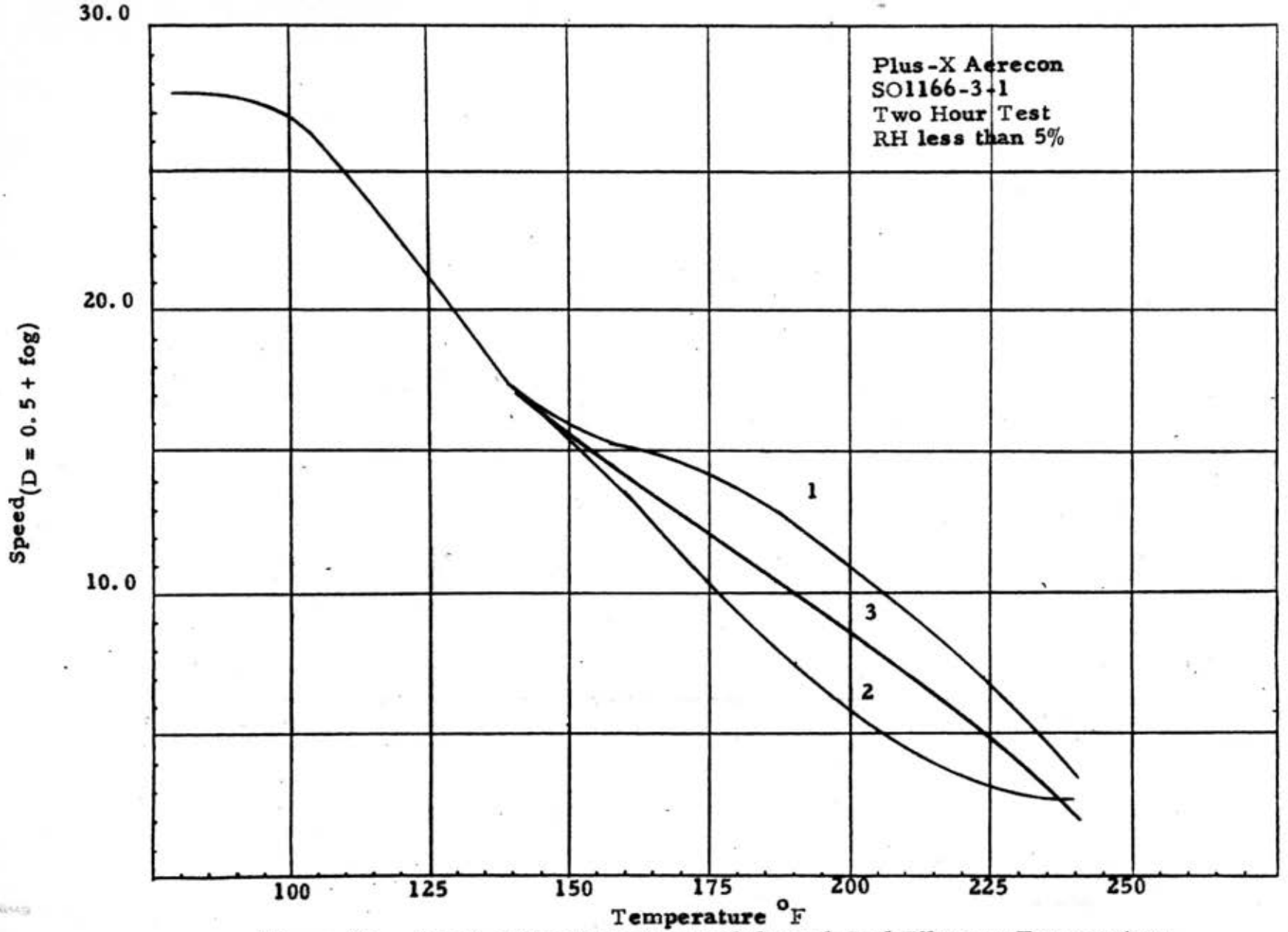

Figure 11a. Speed of Emulsion Exposed through Red Filter vs Temperature
1. Emulsion Exposed--Heated for Two Hours
2. Emulsion Heated One Hour--Exposed--Heated One Hour
3. Emulsion Heated for Two Hours--Exposed

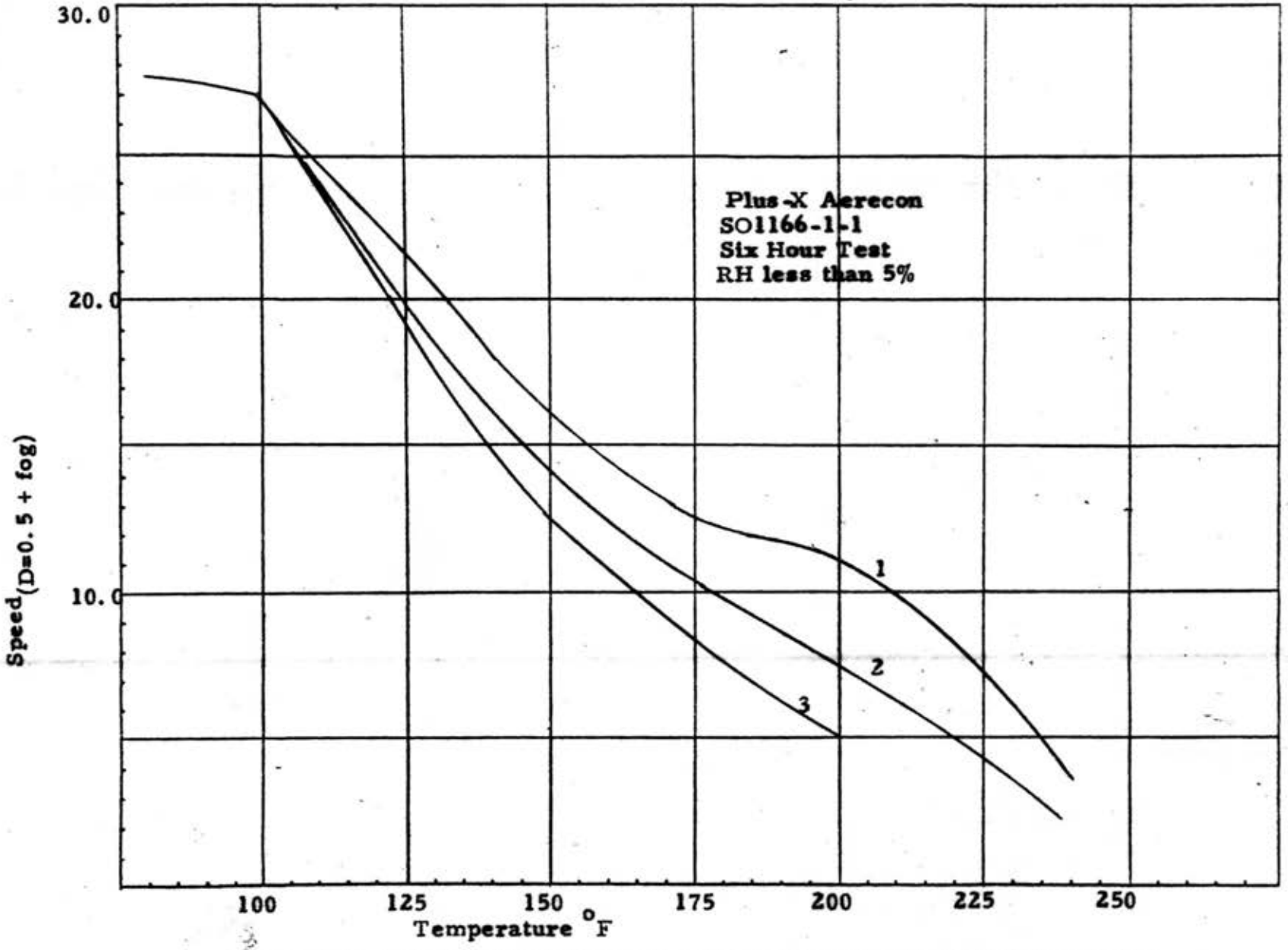

Figure 11b. Speed of Emulsion Exposed through Red Filter vs Temperature

1. Emulsion exposed and then heated for six hours
2. Emulsion heated for three hours-Exposed-Heated three hours
3. Emulsion heated for six hours before exposure

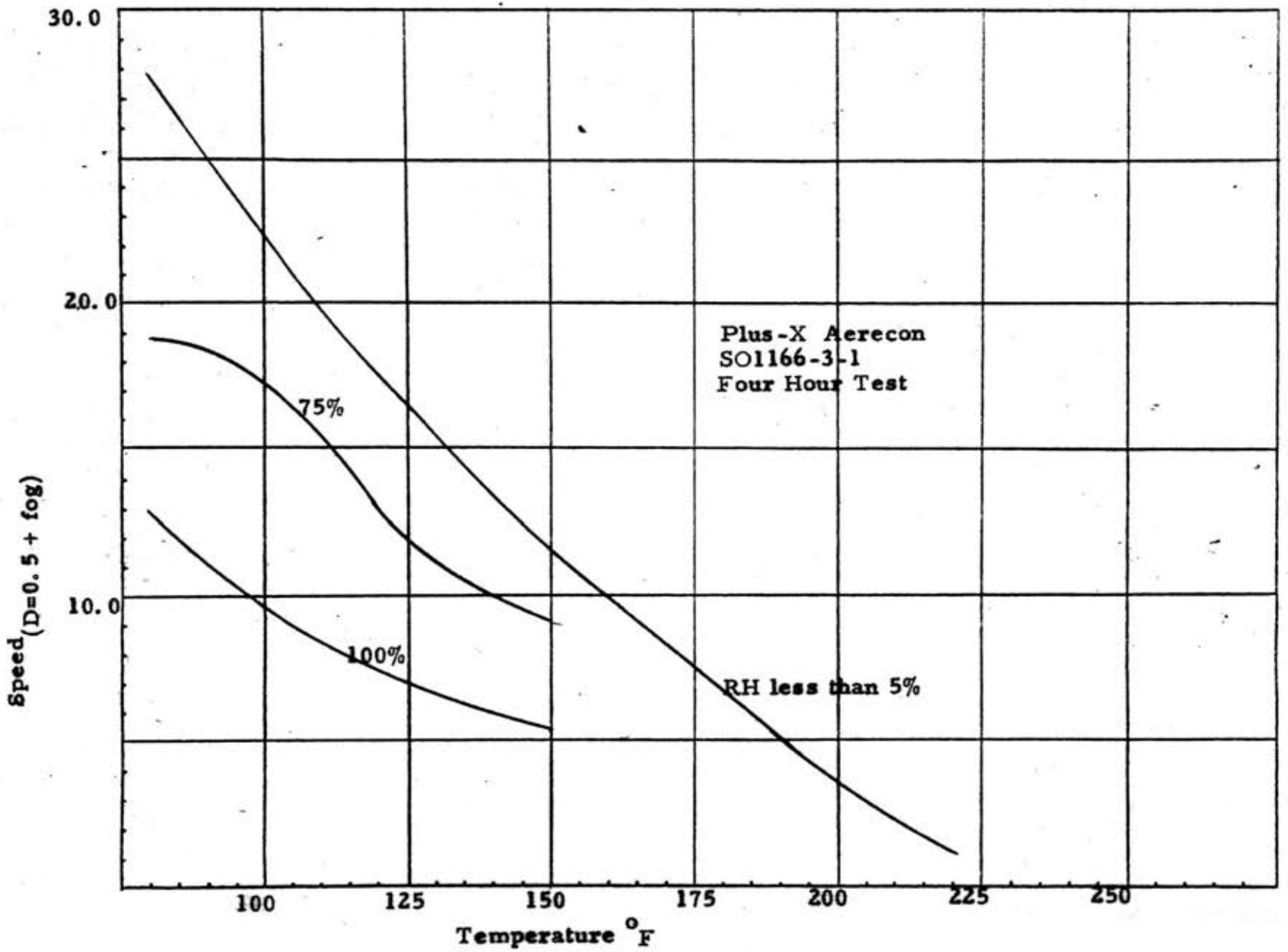

Figure 11c. Speed of Emulsion Exposed through Red Filter vs Temperature for various Humidities. Emulsions heated for four hours before exposure.

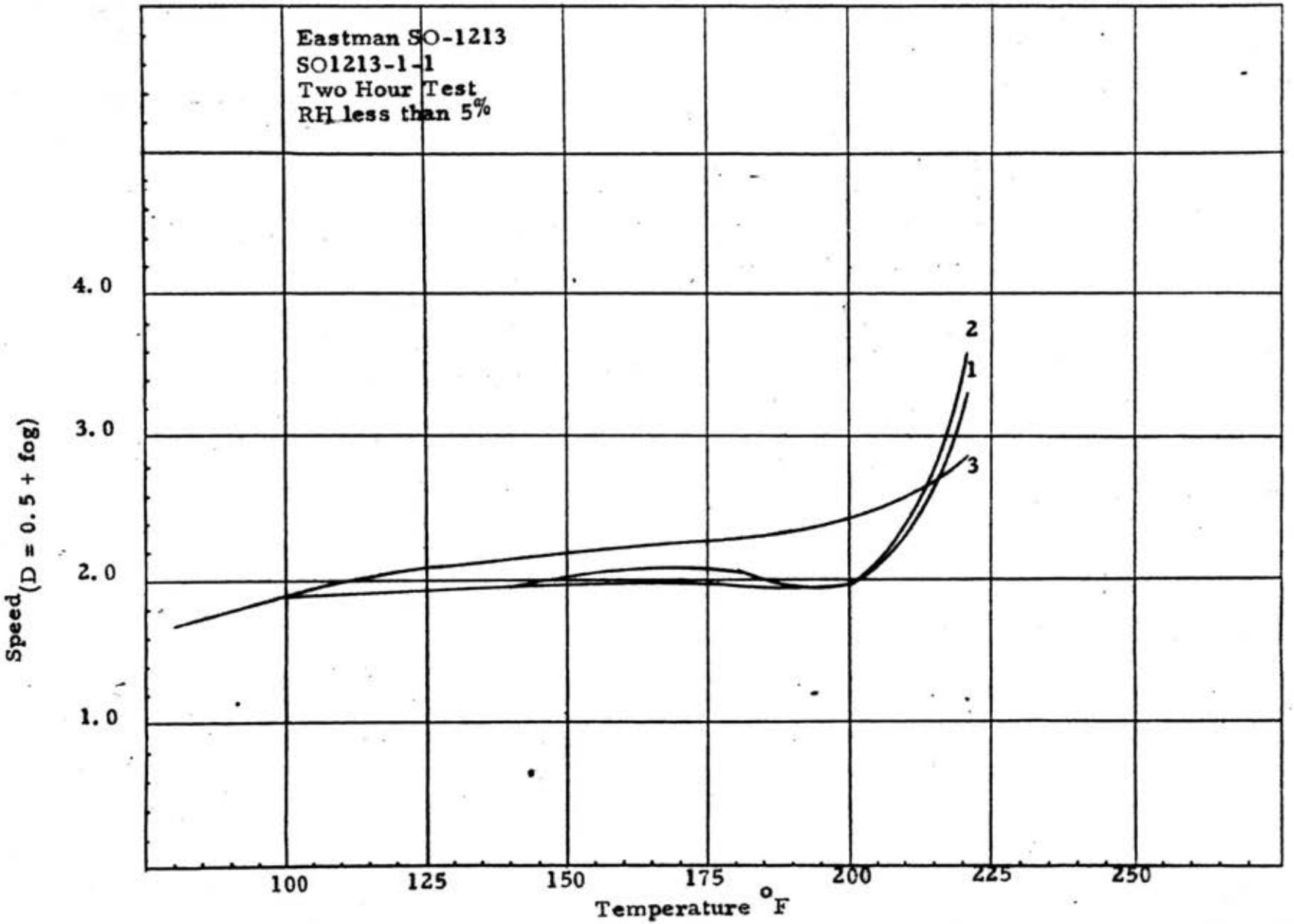

Figure 12a. Speed of Emulsion with Red Filter vs Temperature
1. Emulsion Exposed--Heated for Two Hours
2. Emulsion Heated for One Hour--Exposed--Heated for One Hour
3. Emulsion Heated for Two Hours--Exposed

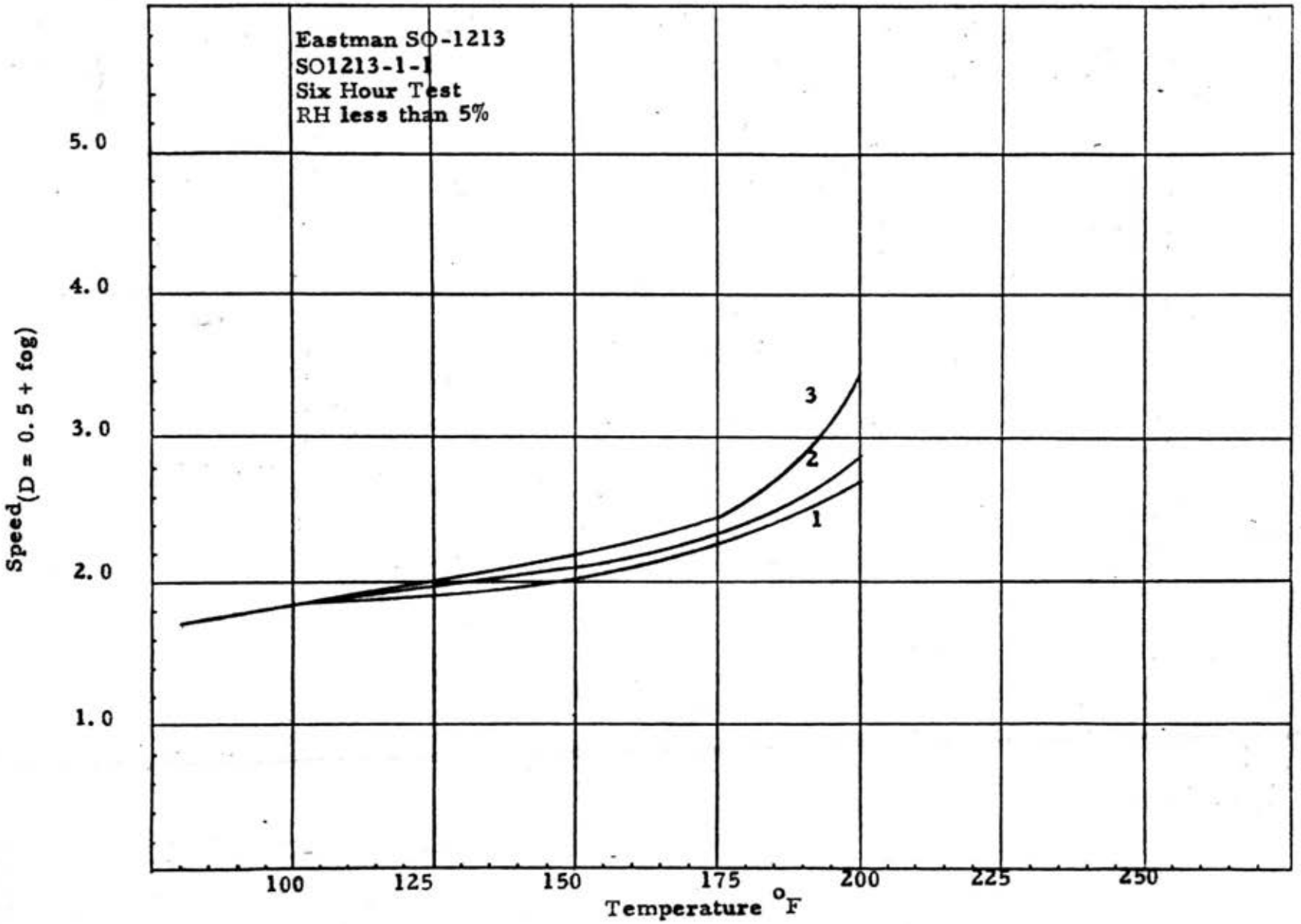

Figure 12b. Speed of Emulsion with Red Filter vs Temperature
1. Emulsion Exposed--Heated Six Hours
2. Emulsion Heated Three Hours--Exposed--Heated Three Hours
3. Emulsion Heated Six Hours--Exposed

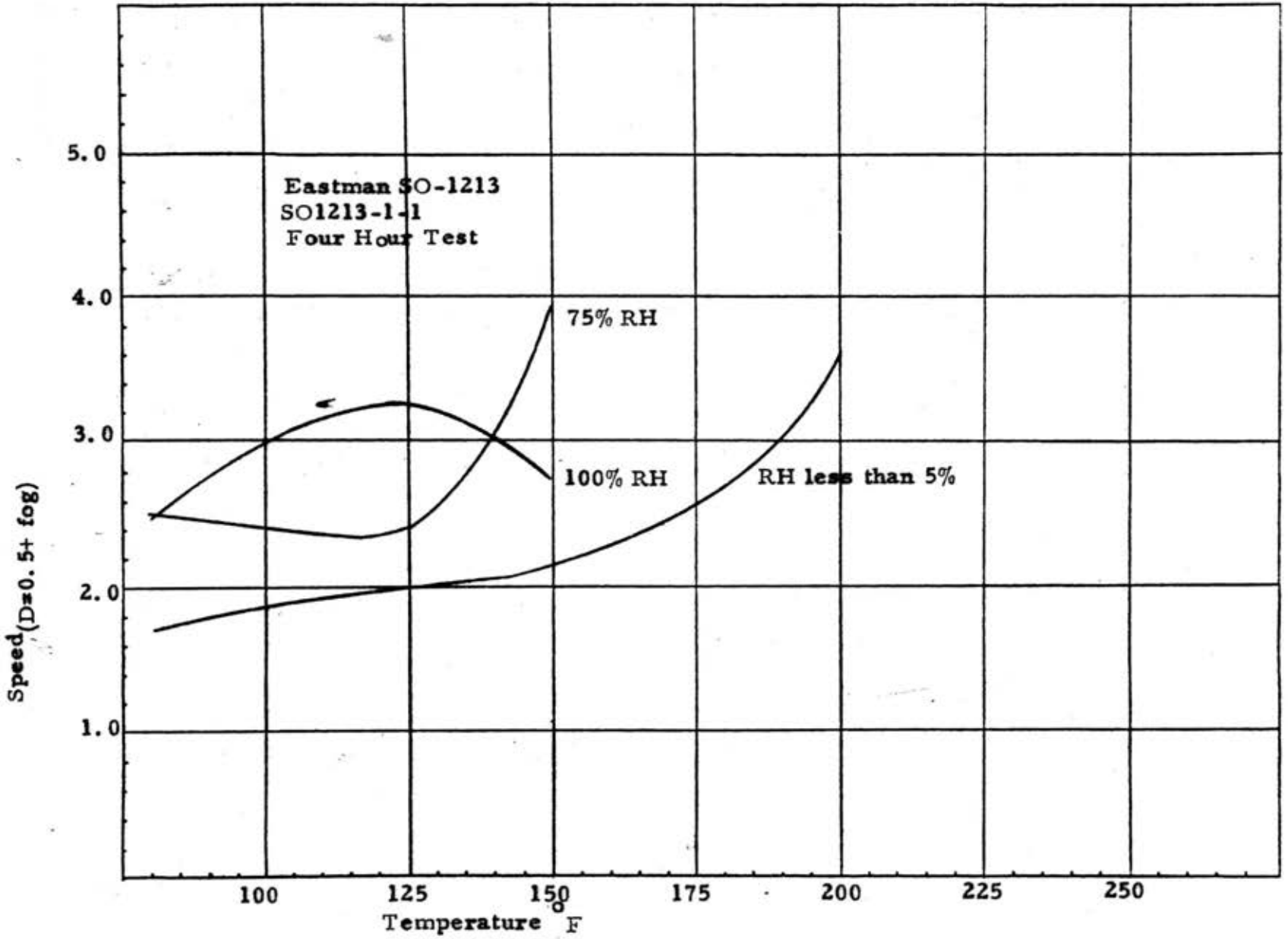

Figure 12c. Speed of Emulsion Exposed with Red Filter vs Temperature for various Humidities. Emulsions heated for four hours before exposure.

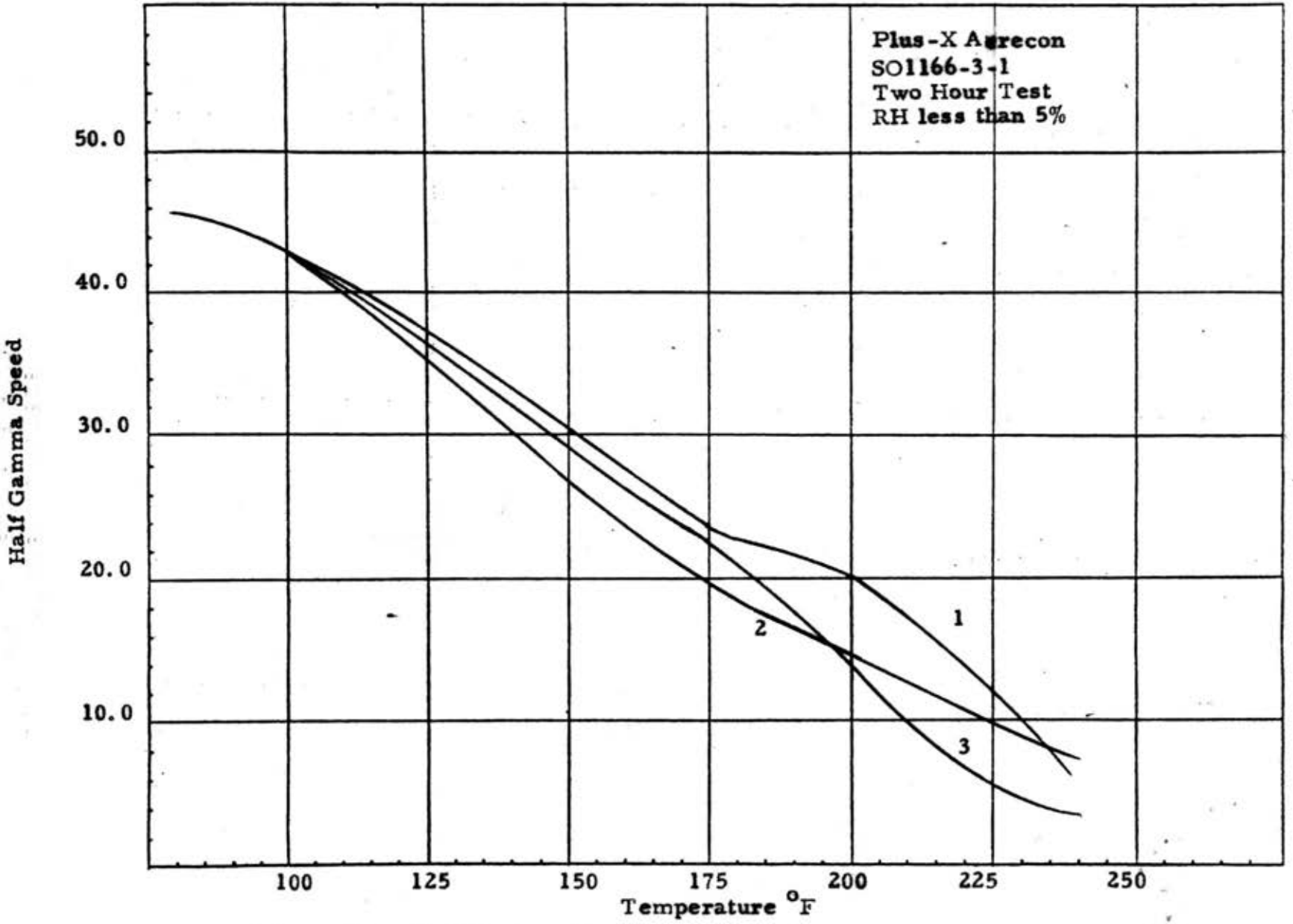

Figure 13a. Half Gamma Speed vs Temperature

1. Emulsion Exposed--Heated for Two Hours
2. Emulsion Heated One Hour--Exposed--Heated One Hour
3. Emulsion Heated Two Hours--Exposed

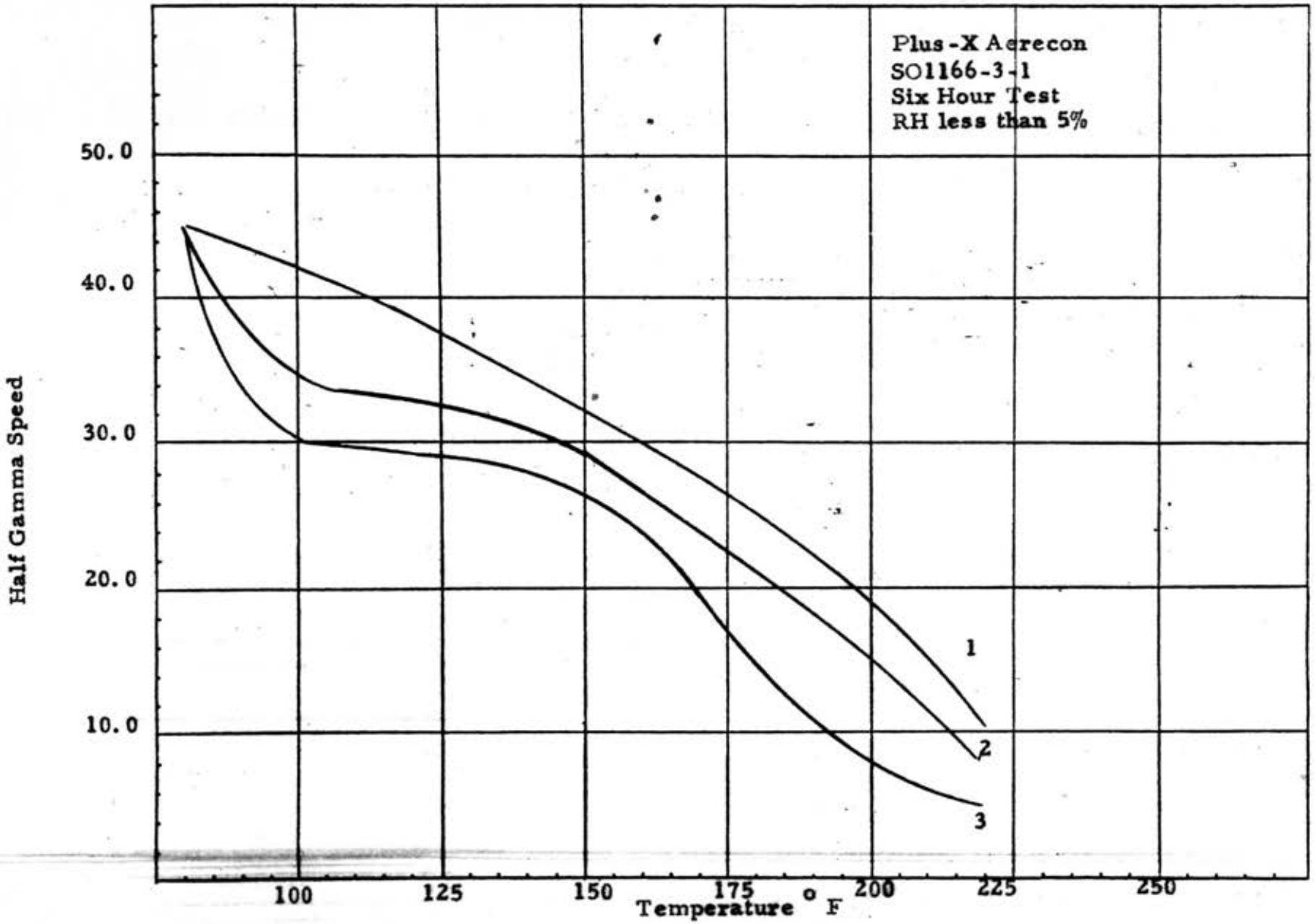

Figure 13b. Half Gamma Speed vs Temperature
1. Exposed--Heated Six Hours
2. Emulsion Heated Three Hours--Exposed--Heated Three Hours
3. Emulsion Heated Six Hours--Exposed

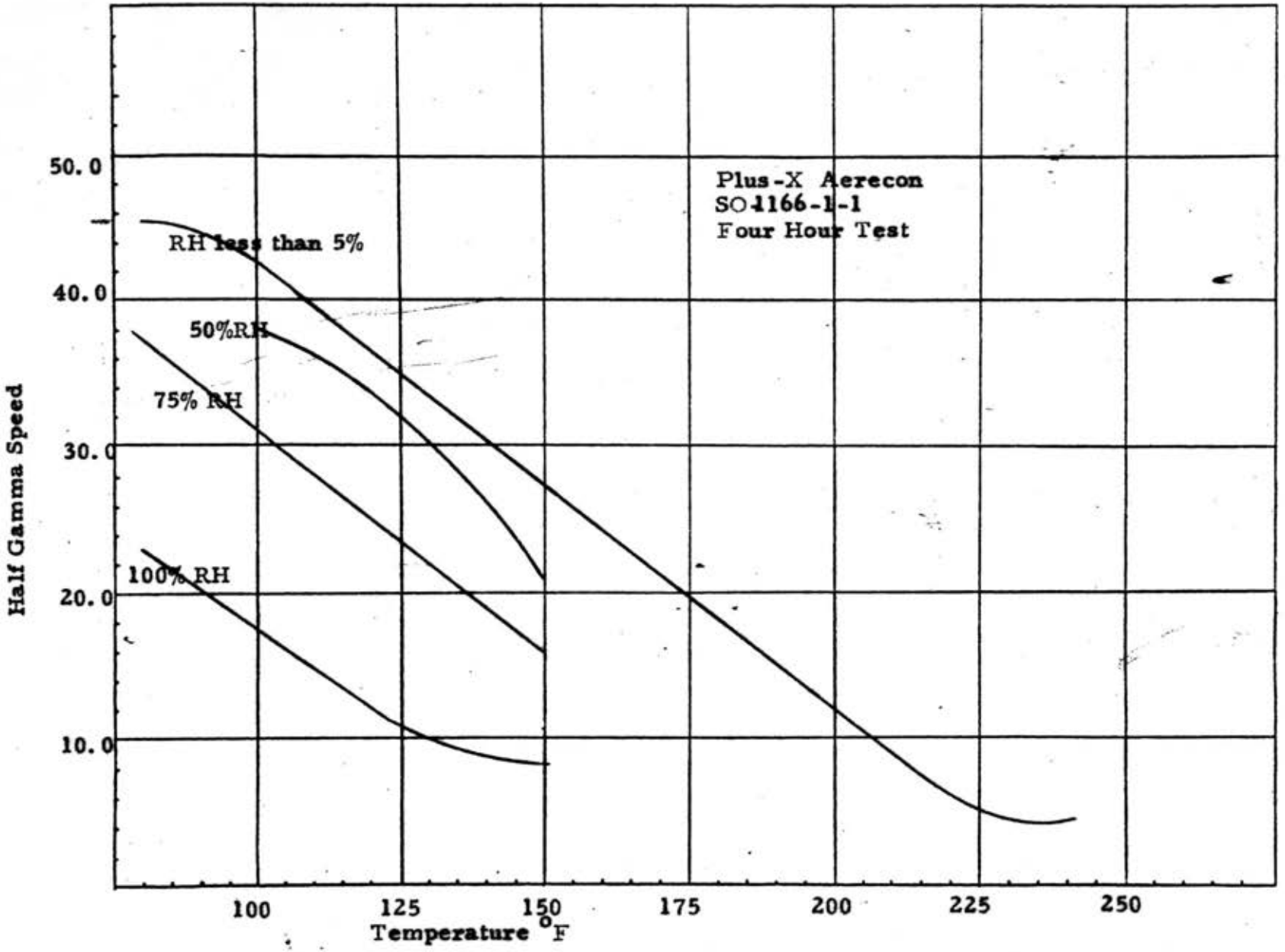

Figure 13c. Half Gamma Speed vs Temperature for various Humidities. Emulsions heated for four hours before exposure.

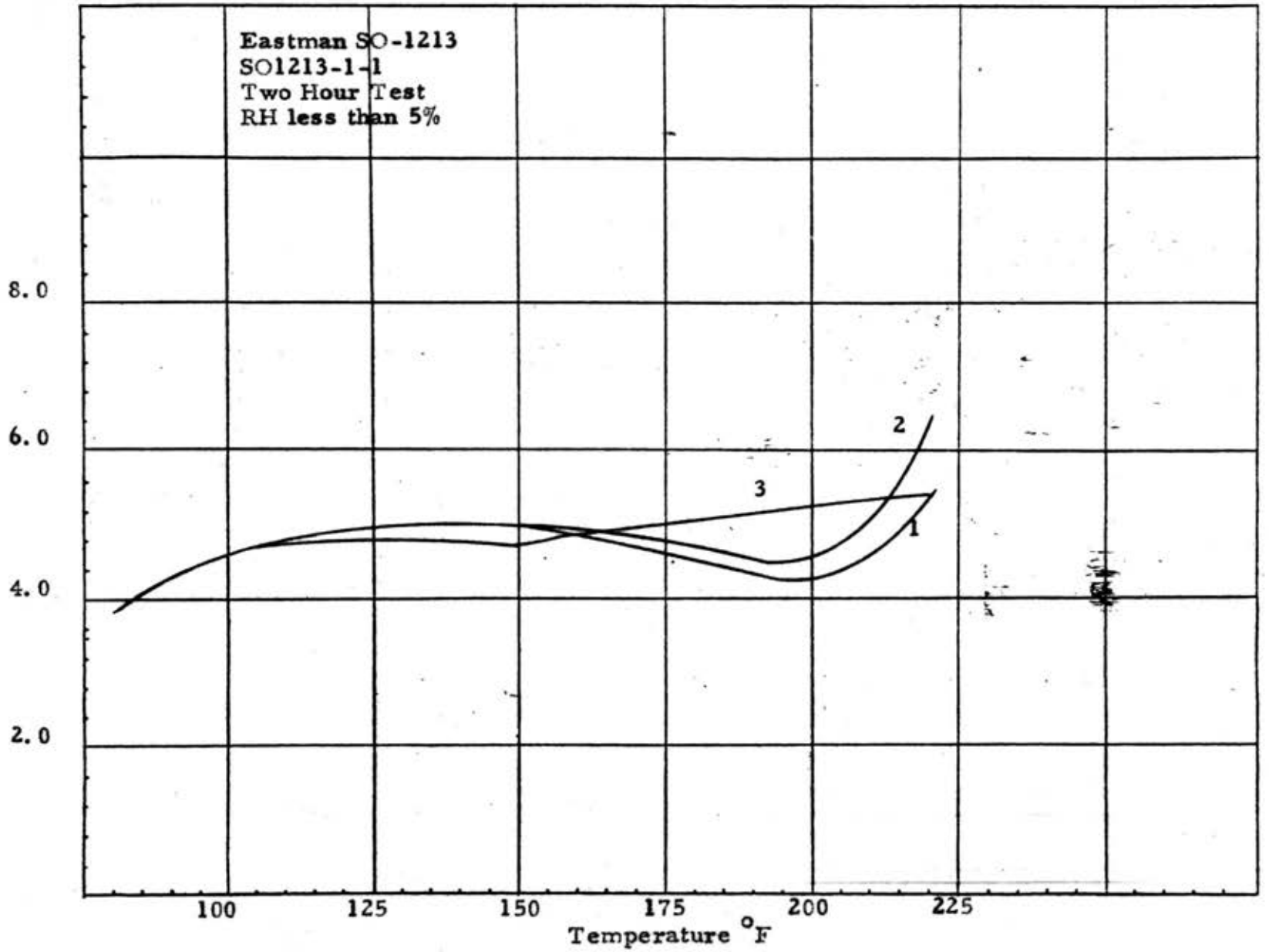

Figure 14a. Plot of Half Gamma Speed vs Temperature
1. Emulsion Exposed--Heated for Two Hours
2. Emulsion Heated One Hour--Exposed--Heated for One Hour
3. Emulsion Heated for Two Hours--Exposed

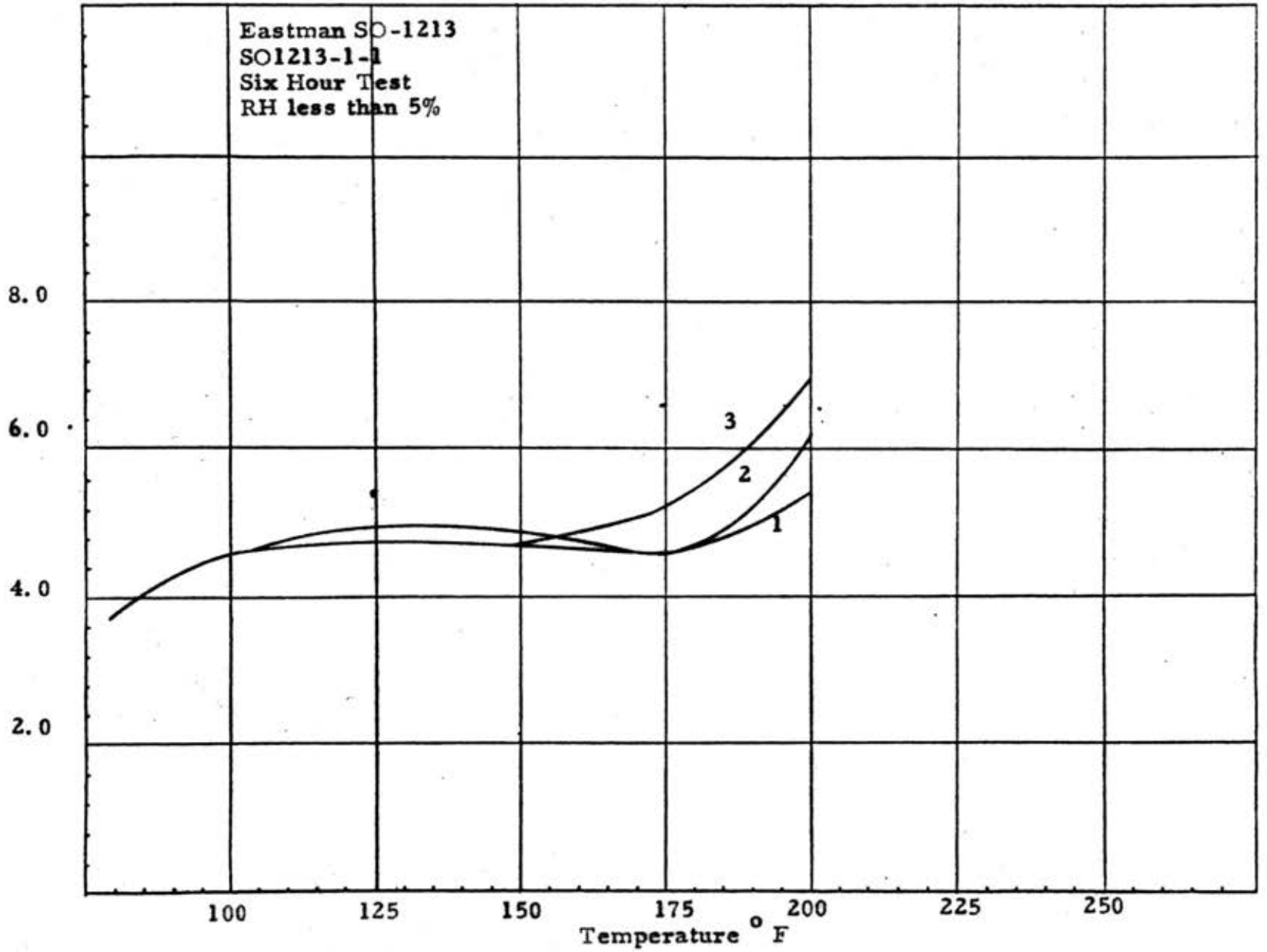

Figure 14b. Half Gamma Speed vs Temperature
1. Emulsion Exposed and Heated Six Hours
2. Emulsion Heated Three Hours--Exposed--Heated Three Hours
3. Emulsion Heated Six Hours--Exposed

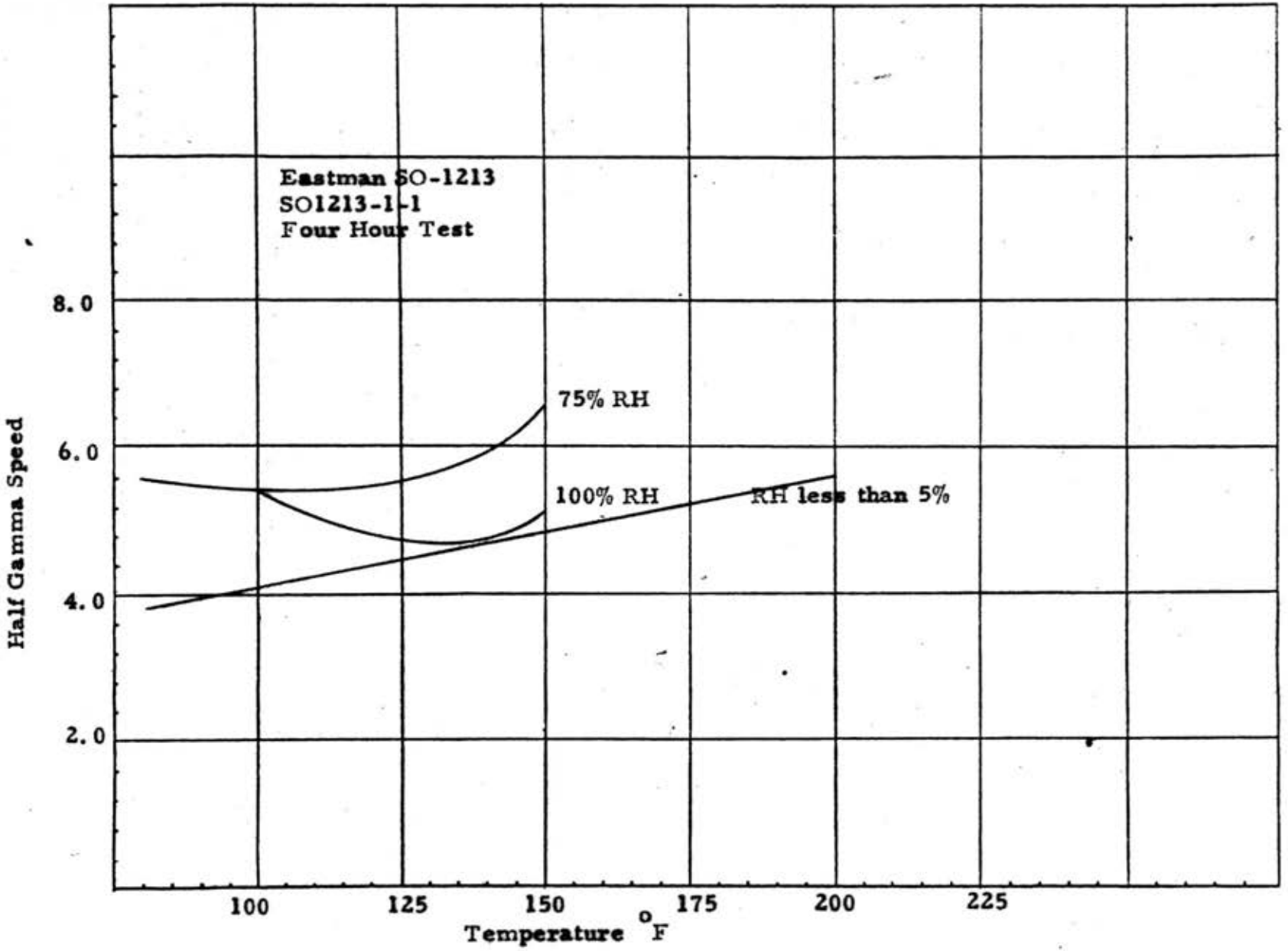

Figure 14c. Plot of Half Gamma Speed vs Temperature for various Humidities. Emulsions heated for four hours before exposure.

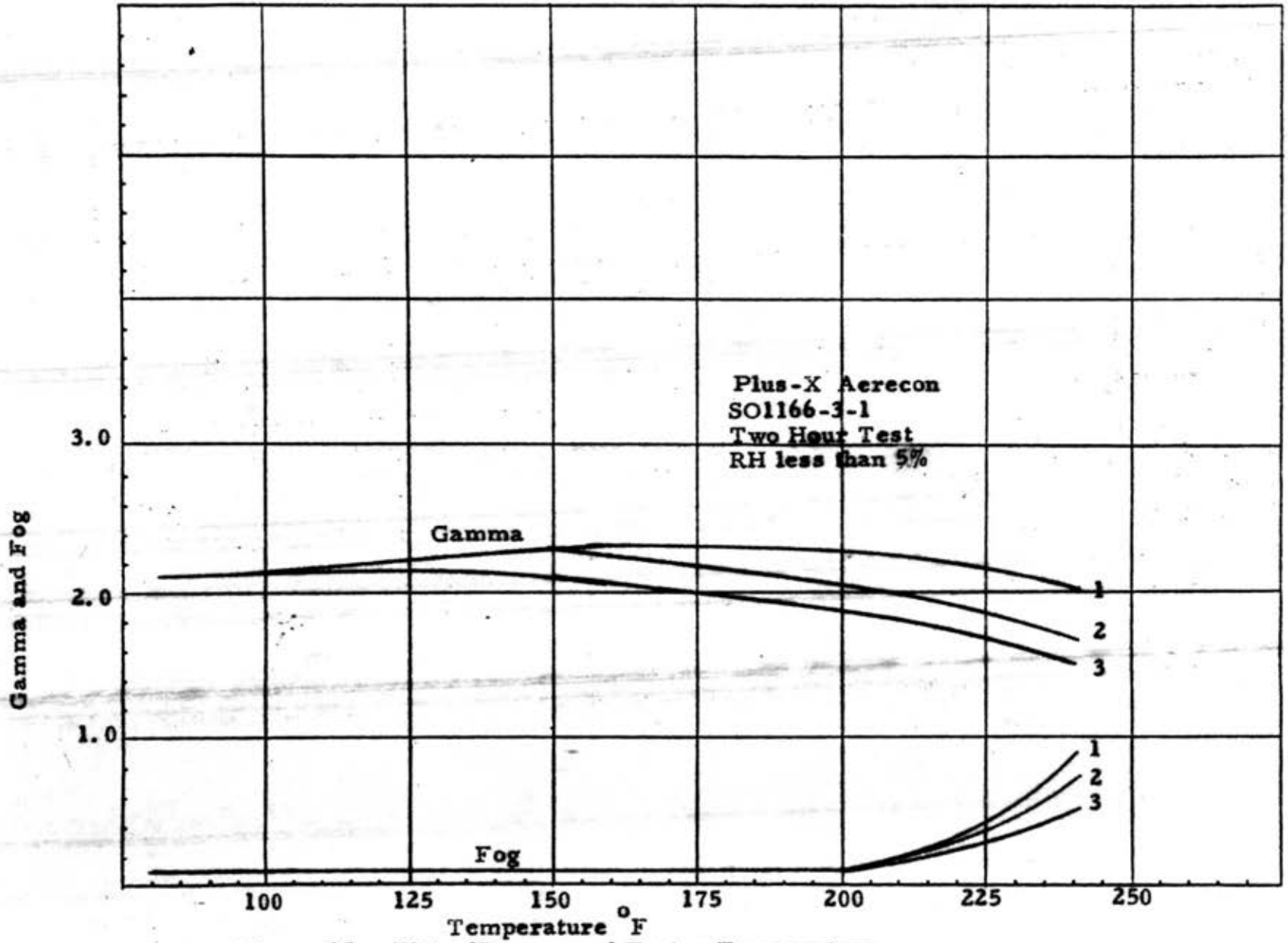

Figure 15a. Plot ofGamma and Fog vs Temperature

1. Emulsion exposed and then heated for two hours.
2. Emulsion heated for one hour-Exposed-Heated for one more hour.
3. Emulsion heated for two hours and then exposed.

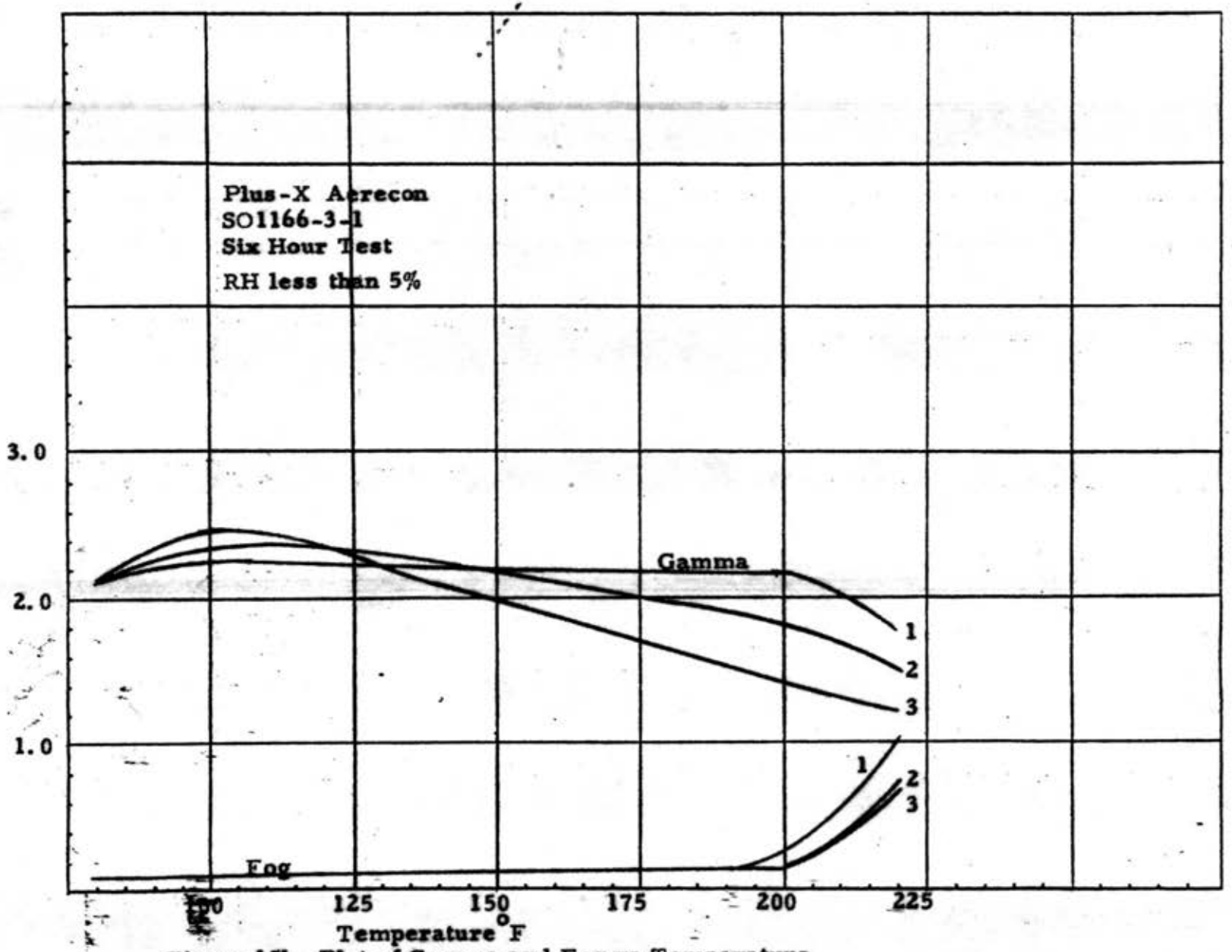

Figure 15b. Plot of Gamma and Fog vs Temperature
1. Emulsion heated for six hours after exposure.
2. Emulsion heated for three hours-Exposed-Heated three more hours.
3. Emulsion heated for six hours before exposure.

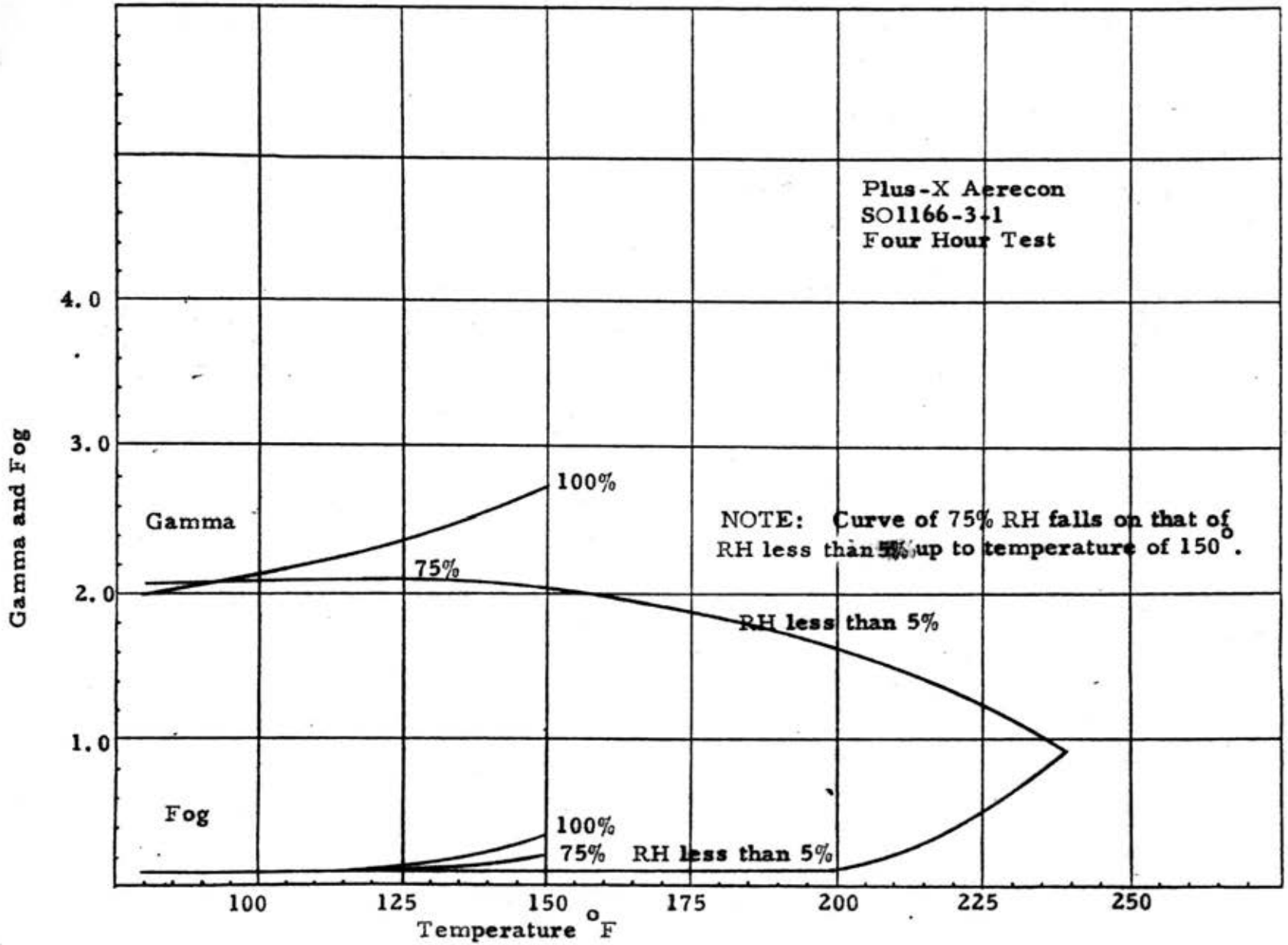

Figure 15c. Plot of Gamma and Fog vs Temperature at various Humidities. Emulsion heated for four hours before exposure.

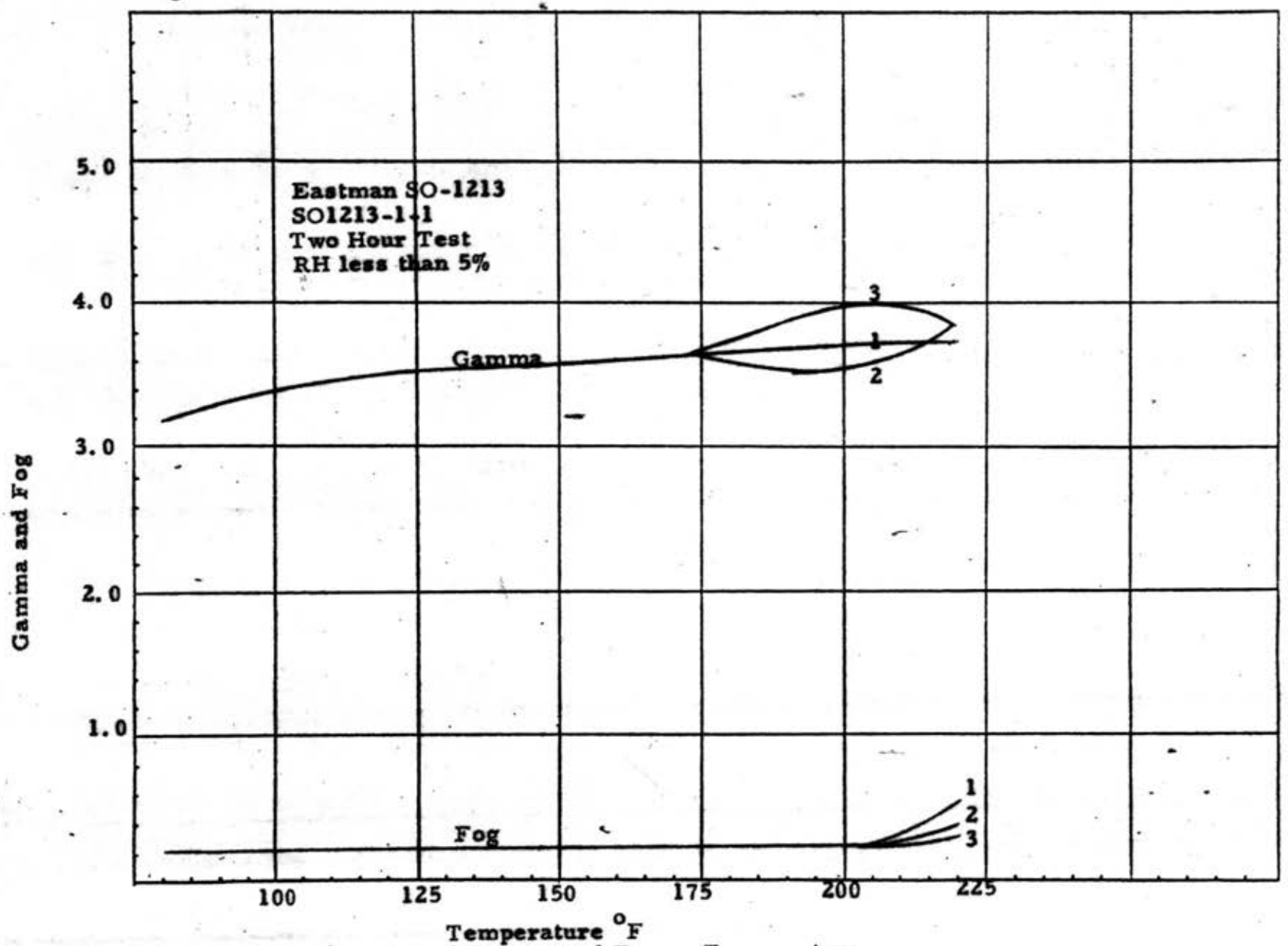

Figure 16a. Plot of Gamma and Fog vs Temperature

1. Emulsion exposed and heated two hours.
2. Emulsion heated one hour-Exposed- Heated one more hour.
3. Emulsion heated two hours before exposure.

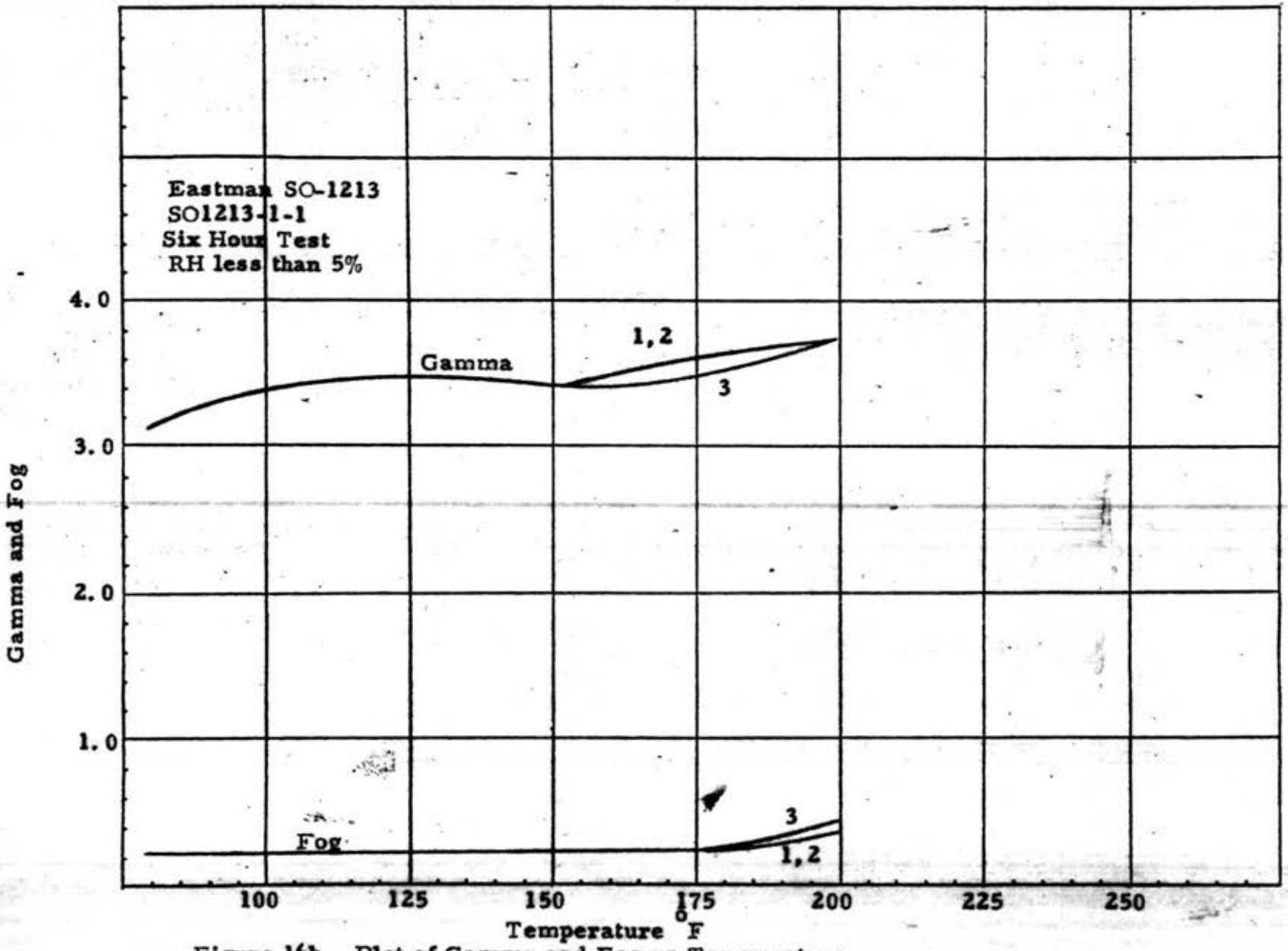

Figure 16b. Plot of Gamma and Fog vs Temperature
1. Emulsion exposed and then heated for six hours.
2. Emulsion heated for three hours-Exposed-heated for three hours.
3. Emulsion heated for six hours before exposure.

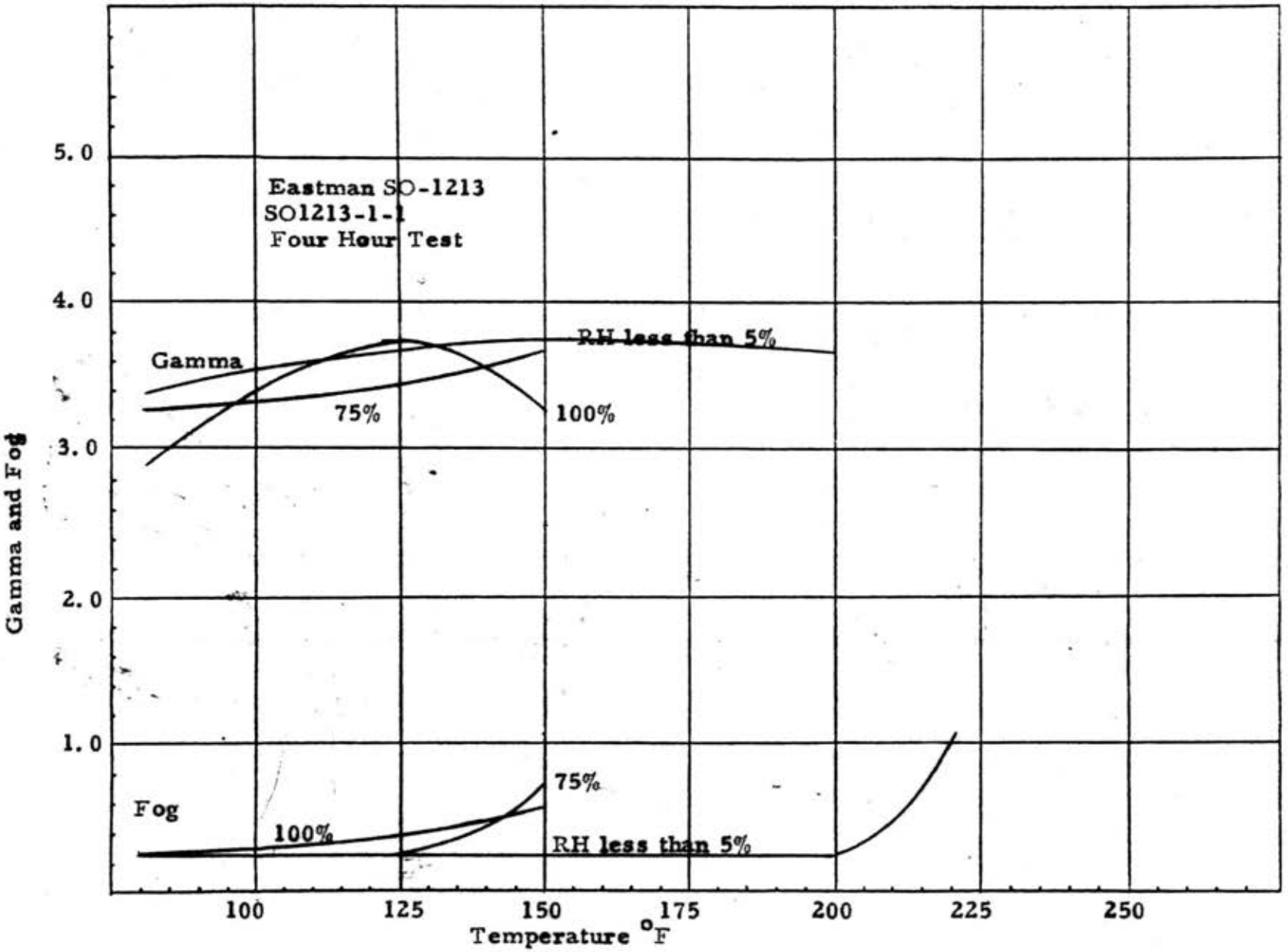

Figure 16c. Gamma and Fog vs Temperature at various Humidities. Emulsions heated for four hours before exposure.

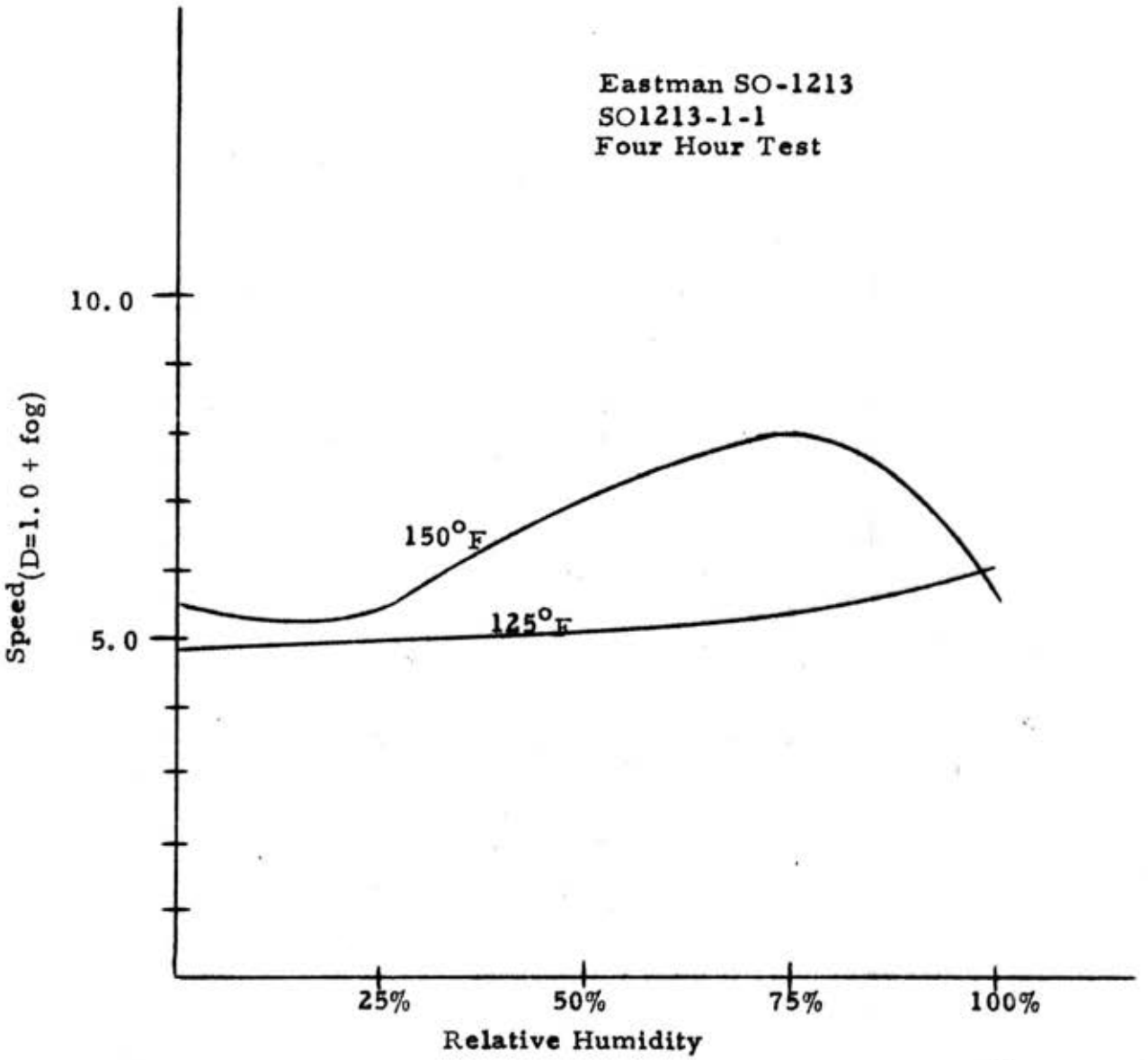

Figure 17. Speed vs Relative Humidity for 125°F and 150°F

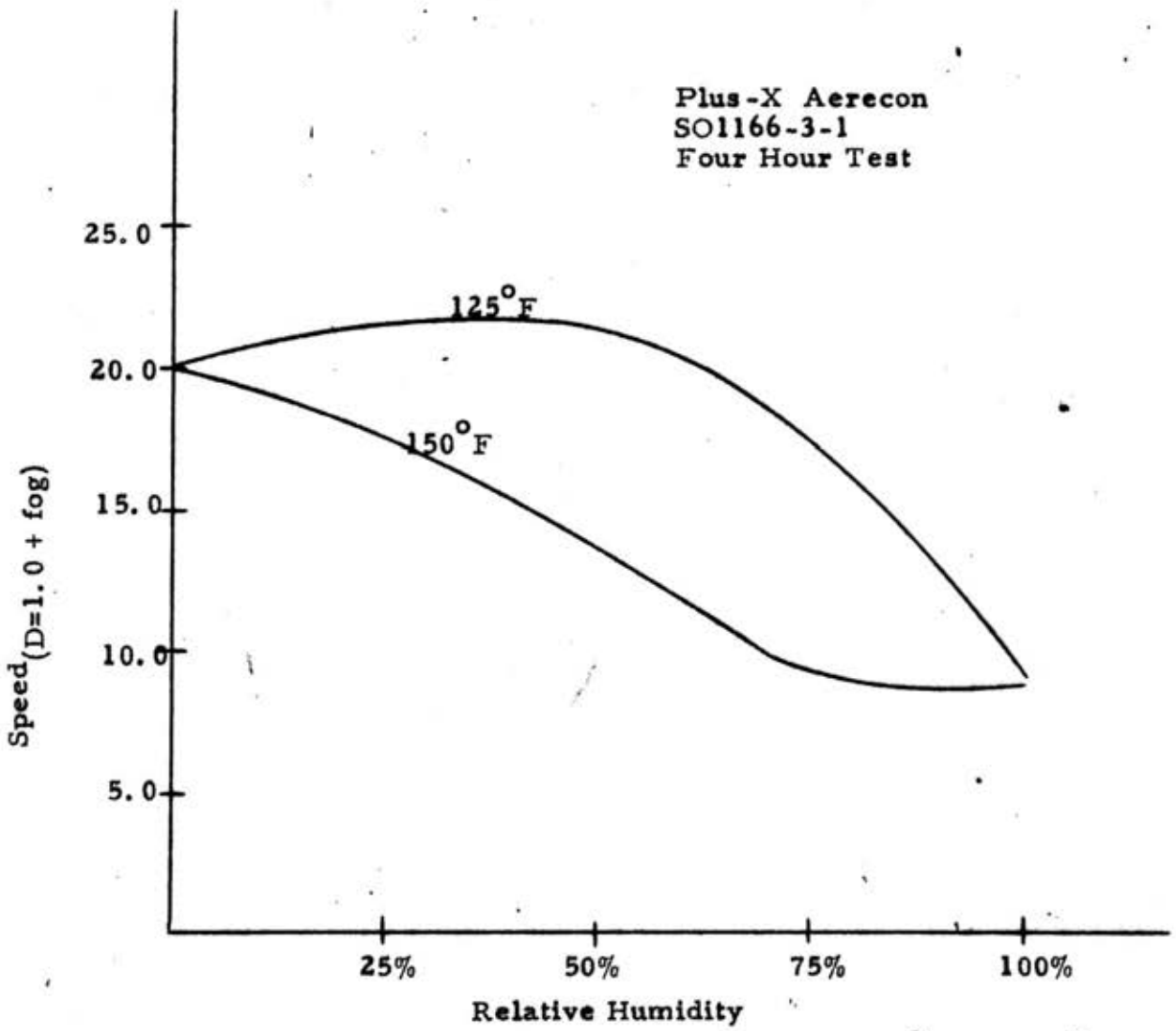

Figure 18. Speed vs Relative Humidity for 125°F and 150°F

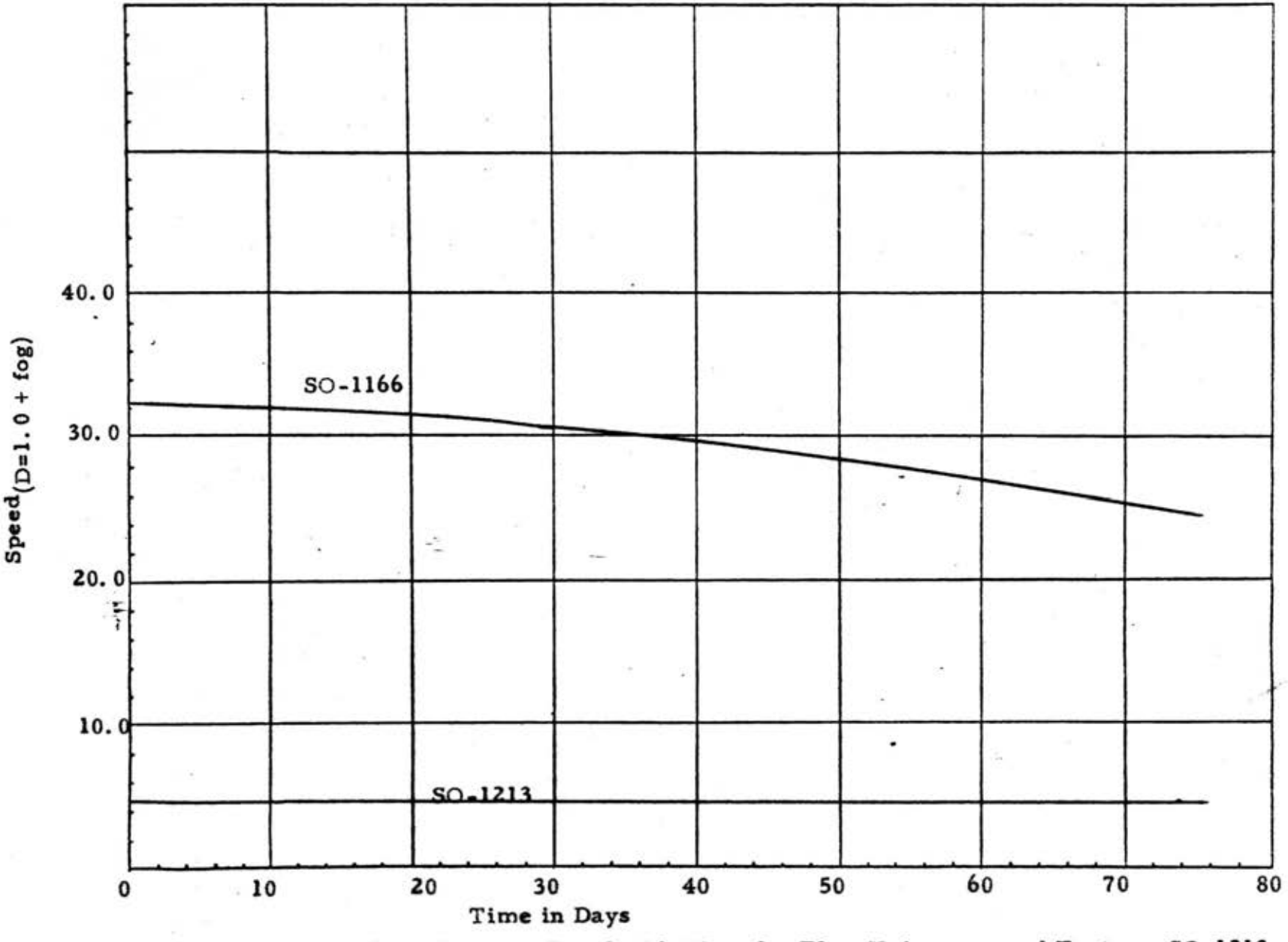

Figure 19. Change in Speed with Time for Plus-X Aerecon and Eastman SO-1213

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ABSTRACT

The high speed of present day and future reconnaissance vehicles brings to the fore the problem of the effect of heat on the components of the reconnaissance system. This thesis presents an investigation of the effect of heat upon the photographic emulsion, considered by some the weakest link in the reconnaissance system in this regard. In addition, the effect of humidity on the photographic emulsion is studied.

In order to provide a suitable system for carrying out the experimental work, a thermosensitometric test unit was designed and built. This test unit, coupled with a controlled heat electric oven, made it possible to heat emulsions for any duration of time at elevated temperatures and expose them at specified time intervals on the Eastman IB Sensitometer. The combination of this test unit and the Eastman IB Sensitometer made it possible to make careful determinations of sensitometric properties, in particular, gamma and speed.

Two emulsions, Plus-X Aerecon and Eastman SO-1213, were tested at temperatures up to 240° F. at very low humidity levels. Solutions of sulfuric acid were used for humidity control with temperatures up to 150° F.

The results of this experiment showed that the speed of Plus-X Aerecon decreases almost linearly with increasing temperature. An increase in humidity caused a greater decrease in speed. On the other hand, SO-1213 showed an increase in speed with higher temperatures and also a slight increase in speed with greater humidities.

The use of sulfuric acid solutions for humidity control in open receptacles within the test unit may have been responsible for some

questionable results. Other means for humidity control need to be considered. In summation, equipment and techniques are described by means of which the reaction of two aerial photographic emulsions to the heat environment of a reconnaissance system may be predicted.