

Outdoor Performance of Plastics
I. Introduction and Color-Change

(U.S.) National Bureau of Standards
Washington, DC

Prepared for

Manufacturing Chemists Association
Washington, DC

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IN REPLY REFER TO:

9-24-69

Mr. A. M. Anzalone
Plastics Technical Evaluation Center
Dover, New Jersey 07801

Dear Mr. Anzalone:

Thank you for your recent inquiry requesting further details of our research on weatherability of plastics. There has been considerable interest in our cooperative industry-government program, sponsored by the Manufacturing Chemists Association.

Our ultimate goal is to develop rapid methods to accurately predict outdoor performance of plastics. The article which you read summarizes one step toward that goal; namely, the quantitative characterization of weatherability.

Enclosed are brief reports giving additional details of our measurements on weathered plastics. It should be emphasized that the plastics were selected to provide a broad representative cross section of performance. No attempt was made to select the best plastic of any given type. Therefore, the results should not be taken to mean that the particular plastic tested is the best possible for the polymeric material.

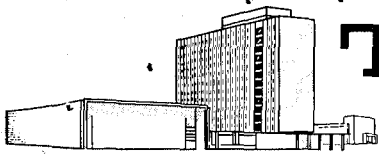
If we can provide more particulars or be of future help, please give us a call.

Sincerely,

Joseph E. Clark, Ph.D.
Research Associate
Manufacturing Chemists Association

Materials Durability and Analysis Section
Building Research Division

Enclosures



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June 1969 - STR-3932

WEATHERING EFFECTS ON PLASTICS

IN BRIEF ... NBS, in cooperation with the Manufacturing Chemists' Association, has completed a two-year study on the outdoor performance of plastics. Changes in appearance have previously been reported. This, the second phase of the program, deals with the physical changes that occur as a result of outdoor weather exposure.

Prediction of a plastic's weatherability is the goal of a current study at the NBS Institute for Applied Technology (U.S. Department of Commerce). The study is being conducted by J. E. Clark and J. A. Slater, NBS Research Associates under sponsorship of the Manufacturing Chemists' Association, in cooperation with G. E. Fulmer of the W. R. Grace and Co., and R. C. Neuman of the B. F. Goodrich Chemical Co. Numerous appearance, physical, and fundamental properties of plastics are being examined in simulated and outdoor exposures.^{1/} This phase of the study deals with the changes in tensile and flexural properties resulting from outdoor exposure.

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To date, measurements have been made on twenty plastics composed of six base polymers that were exposed for 24 months in Arizona, Florida, and Washington, D.C. The plastics include polyethylenes (PE), polymethyl methacrylates (PMMA), polyvinyl fluorides (PVF), polyethylene terephthalates (PETP), glass-reinforced polyesters (RP), and polyvinyl chlorides (PVC).

All 20 plastics were subjected to modified ASTM tensile tests. Five parameters were then obtained from the resulting stress-strain curves. These included Young's modulus of elasticity, yield stress, yield strain, failure stress, and ultimate elongation at break.

The flexural parameters measured were Young's modulus; yield stress; yield strain; rupture stress; rupture strain; and 5 percent stress, or stress at 5 percent strain, if the material did not break at less than 5 percent strain.

The ultimate tensile elongation and 5 percent flexural stress showed the greatest change with time. Ultimate elongation decayed rapidly within one year for most of the plastics. Five percent stress increased substantially in a few months after which there was little or no change. An increase in 5 percent stress was usually accompanied by a decrease in ultimate elongation. These changes indicate a loss of elasticity and flexibility, resulting in increasing stiffness and probably brittleness.

Using ultimate elongation and 5 percent stress, percent retention of initial value was found to be a useful measure for classifying the plastics. Smooth curves fitted for the percent retention of initial ultimate elongation show a definite exponential decrease.

The exponential nature of the curves made possible a mathematically defined failure point. This is reached at 36.8 percent retention of initial value; that is, the point defined by $1/e$, where e is 2.718. Mathematical models using functions of time and weather variables are currently being fitted to the ultimate elongation data.

In general it was found that the plastics performed worst in Arizona, best in Washington, D.C., and intermediate in Florida. Actinic radiation and heat appear to be the primary agents causing physical degradation. Washington, D.C., exposed samples, however, sometimes exhibited a greater loss of physical properties than Florida exposed samples, possibly indicating effects of moisture and air pollution.

1/ Outdoor Performance of Plastics, Nat. Bur. Stand. (U.S.), Tech. News Bull. 53 (5) (1969).

CAPTIONS FOR ILLUSTRATIONS:

Figure 1. Close-up of a flexural measurement being made on a specimen of plastic that has been exposed to outdoor weathering conditions. Such measurements are part of a long-term study by NBS and the Manufacturing Chemists' Association on the effects of outdoor weathering on appearance, physical, and fundamental properties of plastics.

Photo: 69 132-2-3932

Figure 2. G. E. Fulmer, of W. R. Grace and Company, Research Division (left), and J. E. Clark, MCA Research Associate at NBS, examine a specimen of plastic that has been tested to rupture in a study of outdoor weathering effects on plastics.

Photo: 69 132-1-3932

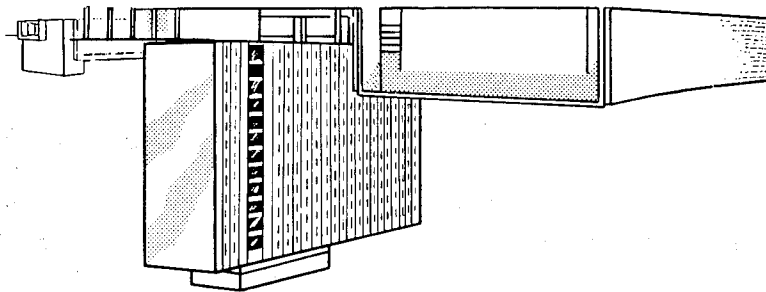
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NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT

4216201-421.04

NBS REPORT

9912

12 September 1968

Not for publication or
for reference.

OUTDOOR PERFORMANCE OF PLASTICS

I. INTRODUCTION AND COLOR-CHANGE

by

Joseph E. Clark*
Nick E. Green*
Paul Giesecke**

Sponsored

by

Manufacturing Chemists' Association

* Research Associate of Manufacturing Chemists' Association

** Group Leader of Appearance Evaluation Group, Central Research Laboratory,
American Cyanamid Company, Stamford, Conn.

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ABSTRACT

This is the first in a series of reports on outdoor performance of 20 plastics, *PMMA, PVC, PVF, PET, FRP/polyester, and Polyethylene.* Computerized analysis and graphs of color data are presented. Reports on physical and other properties important to architectural performance are being prepared.

A coding system is given for computerizing more than 10,000 observations on the 8 properties.

Graphs are presented for Adams color-difference (E) versus time of exposure: 24 months in Arizona, Florida and Washington, D. C. Supporting tristimulus color data (L, a, b) are available on request.

Discoloration "failures" ($E > 25$) occurred only in Arizona, and only for 4 clear PVC's. Two other clear PVC films failed by embrittlement in Arizona. All clear PVC's followed similar patterns of sudden catastrophic discoloration. If any of the clear PVC's were slightly superior, it was PVC-B.

All white-pigmented PVC's discolored only slightly, averaging CLASS "B" color-fastness. If any of the white PVC's were slightly more color-fast, it was PVC-A.

PVF and PMMA were quite color-fast (CLASS "A") as expected. PE film (CLASS "A") and sheet (CLASS "B") did not discolor badly, but PE films embrittled in about a year, beginning in Arizona, then Florida, then Washington, D. C.

RP yellowed to color - CLASS "D" (E between 15 to 20 units) within 2 years. PETP discolored to CLASS "B" (E about 5 to 10 units).

Development of this color-fastness classification system is described. It is based on ranking plastics according to the highest color-difference (E) value attained at any time within a given period at any location.

The CLASS system is now being extended to the other properties.

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12 Sep 68

Joseph E. Clark, Nick E. Green, and Paul Giesecke.

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Sponsored in part by Manufacturing Chemists Association, Washington, DC. Prepared in cooperation with American Cyanamid Co., Stamford, CT. See also Volume 2, PB81-189037, and COM-73-10989. Portions of this document are not fully legible. Also available in set of 9 reports PC E20, PB81-189011.

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KEYWORDS: *Plastics, *Weathering, *Standard reference materials.

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OUTDOOR PERFORMANCE OF PLASTICS

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1. OBJECTIVE

This is the first in a planned series of reports on the outdoor performance of plastics. In this series, data will be graphically presented on 20 plastics exposed in Arizona (A), Florida (F), and Washington, D. C. (W).

Eight properties are being measured periodically. These are appearance, physical, and other properties related to architectural performance.

Computerized presentation and analysis of data will be emphasized.

This report considers the color of plastics. The next report, now in preparation, will concentrate on physical properties.

2. INTRODUCTION

Outdoor exposures have been conducted on 20 plastics formulated from 6 base polymers: polyethylene (PE), polymethyl methacrylate (PMMA), polyvinyl fluoride (PVF), polyethylene terephthalate (PETP), glass-reinforced polyester (RP), and polyvinyl chloride (PVC). Clear and white sheet and film have been exposed in Phoenix, Miami and Washington, D. C. for over 2 years.

This is part of an integrated exposure program in which the same plastics are being exposed to accelerated weathering in laboratory environmental chambers.

The goal is to forecast outdoor performance of plastics, by establishing the relation between such accelerated vs. outdoor exposures.

3. EXPERIMENTAL

Details may be found in our earlier NBS Report 9640, "Correlation of Accelerated and Outdoor Weathering Tests of Plastics" [1]^{1/}. The summaries are given below for convenience of the reader.

3.1 Materials

Table 1 summarizes the 20 plastics formulated from 6 base polymers. These materials were selected and approved by the MCA Plastics Technical Subcommittee.

3.2 Exposures

Specimens were placed on supports at a 45° angle to the horizontal and facing the equator, at

South Florida Test Service Inc.
Miami, Florida

(hot, wet)

^{1/}Figures in brackets indicate the literature references at the end of this paper.

Desert Sunshine Exposure Tests Inc.
Phoenix, Arizona

(hot, dry)

Connecticut and Van Ness Streets
(Old NBS Site)
Washington, D. C.

(temperate)

At regular intervals, samples are removed for testing. Samples are not put back on exposure after removal. Where possible, sufficient replicates were exposed initially to allow for 10-years of sampling.

3.3 Properties Measured

Table 2 lists the most common criteria for evaluation of plastics in architectural outdoor applications: appearance, physical and selected additional properties.

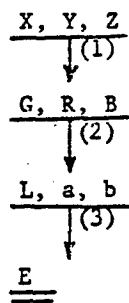
Also listed are member companies of MCA who volunteered to perform the indicated tests.

1. Color

Color of all original and outdoor-exposed specimens was measured under the direction of Mr. Paul Giesecke at American Cyanamid Company, Stamford, Connecticut. A GE spectrophotometer yielded the CIE color values of X, Y, Z.

Calculation of total color difference (E) was done by use of Reilly's modification of Glasser's cube-root formula, which is believed to be the best improvement of Adams chromatic-value formula [2]. This required conversion of X, Y, Z values to G, R, B values [2].

Schematically, this calculation of the Adams Color Difference (E) values plotted herein is:



where

(1) is
$$\begin{aligned} G &= -0.10X + 100.05Y + 0.04Z \\ R &= 110.84X + 8.52Y - 14.54Z \\ B &= -0.62X + 3.94Y + 81.92Z \end{aligned}$$

$$\begin{aligned}
 (2) \text{ is } \quad & L = 25.29 G^{1/3} - 18.38 \\
 & a = 106.0 (R'^{1/3} - G^{1/3}) \\
 & b = 42.34 (G^{1/3} - B^{1/3}) \\
 & (R' = 0.8R + 0.2B)
 \end{aligned}$$

$$(3) \text{ is } \quad E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$$

An added benefit of this method of calculation is direct comparison of tristimulus spectrophotometer readings with Colormaster tristimulus colorimeter readings. The Colormaster colorimeter is used by us at NBS to read color of specimens exposed to accelerated laboratory weathering.

It should be noted that some color-difference (E) values presented in our earlier NBS Report #9640 were given in the Hunter E system. The Hunter equations convert directly from X, Y, Z to L, a, b and complicate comparison with G, R, B colorimeter values. See Reference [2] for correction of the common reference [3] to the Hunter equation.

Calculations and plots were done on the NBS UNIVAC 1108 computer, using both the OMNITAB english-language program and FORTRAN V.

4. RESULTS

4.1 Computerization of Data

Over 10,000 observations now constitute the bank of data on outdoor performance: 20 plastics X 3 sites X 8 samplings, to-date X 22 property-parameters. To efficiently select, plot, analyze and correlate these data, computer handling was found necessary.

To retrieve any individual observation, or set of observations, from the computer memory all data were coded. The code is given in Table 3. Variables coded are type of exposure, time of exposure, plastic, property measured and value of that property.

For example, Arizona exposure for 3 months of plastic PE-60 mil, and the resulting value of color-difference (E) is coded:

1	3	2	111	4.77
---	---	---	-----	------

The unexposed control specimen for this appears as:

0	0	2	111	0.0
---	---	---	-----	-----

The following conventions were adopted for special cases:

Missing data	8888.88	Value
Off-scale reading	9999.99	Value
Repeat exposure of plastic 1	101	Plastic
Repeat exposure of plastic 10	110	Plastic
Second repeat of plastic 10	210	Plastic

All available data can be obtained from the authors. At your request, it can be obtained in the following forms:

IBM punched cards
Computer listing of card-contents
Magnetic Tape

4.2 Color Code for Computer

A 3-numeral code is used for the property of color:

First numeral	1	Color
Second numeral	1	E (Adams color-difference)
	2	L (lightness-darkness)
	3	a (redness-greenness)
	4	b (yellowness-blueness)
Third numeral	1	GE Spectrophotometer
	2	Meeco Tristimulus Colorimeter

Only 111 data are presented in this report: Adams color-difference values calculated from measurements on the GE spectrophotometer.

As mentioned previously, the L, a, b values are available on request.

4.3 Graphic Results

In Figures 1 to 20, following, Adams color-difference (E) is plotted versus time of exposure. There is one graph for each of the 20 plastics. Results are given for exposure in Arizona (A), Florida (F) and Washington, D. C. (W).

Note that: a) Not all plastics are exposed in all locations. b) Color data on a plastic may not continue to 2 years because the plastic has completely deteriorated (e.g., Figure 1) or the supply of replicates is exhausted (e.g., Figure 12). c) For color-difference greater than 25 units (our arbitrary pre-set limit), the following note is printed below the graph: "***NOTE: #POINTS FELL OUTSIDE THE SPECIFIED LIMITS AND WERE OMITTED".

5. OBSERVATIONS

5.1 Effect of Climate

Arizona exposure appeared to produce more discoloration for many plastics (e.g., Figures 2, 7, 8, 9, 11, 14, 15, and 18). This is most noticeable for clear PVC (Figures 7 to 13).

In no case did Washington exposure appear most severe.

In one case (Figure 5) Florida may have consistently caused slightly more discoloration.

5.2 Comparison of Plastics

Figures 21 to 30 group the plastics by discoloration at each site. In plots on which various plastics are compared, plastics are designated by the letter corresponding to their coded numbers.

TABLE 4

LETTER DESIGNATIONS FOR PLASTICS

A	1	PE-1	K	11	PVC-C10
B	2	PE-60	L	12	PVC-C60
C	3	PMMA	M	13	PVC-N
D	4	PVF	N	14	PVC-A4
E	5	PETP	O	15	PVC-A10
F	6	RP	P	16	PVC-A60
G	7	PVC-B4	Q	17	PVC-D4
H	8	PVC-B10	R	18	PVC-D10
I	9	PVC-B60	S	19	PVC-D60
J	10	PVC-C4	T	20	PVC-M

5.2.1 Clear PVC

Figures 21, 22, 23 group the 7 Clear PVC's by discoloration at each site. Three PVC-B's (G, H, I) are shown by solid lines; three PVC-C's (J, K, L) are shown by dotted lines; PVC-N (M) is shown by a dashed line.

All follow similar patterns of discoloration: initial discoloration, slight bleaching, then rapid discoloration. This harmonic (seasonal) behavior does not seem strongly dependent on formulation or thickness.

If any material showed slight superiority, it was PVC-B.

Note that only Arizona exposure failed some materials (color-change greater than 25 units) within 2 years. This is indicated by the "**NOTE" at the foot of Figure 21.

5.2.2 White-pigmented PVC

Figures 24, 25, 26 group the 7 white PVC's by discoloration at each site. Three PVC-A's (N, O, P) are shown by slashed lines; three PVC-D's (Q, R, S) are shown by dot-dash lines; PVC-M (T) is shown by widely-spaced dots.

These show generally similar patterns of mild discoloration. Slightly periodic (seasonal) behavior can be detected in most of the materials. As for Clear PVC's, harmonic behavior does not appear strongly dependent on formulation or thickness.

If any material showed slight superiority, it was PVC-A.

5.2.3 PVF and PMMA

Figure 27 is a composite comparison of two very good polymeric materials. Based on the polymer structures of polyvinyl fluoride and polymethyl methacrylate, their resistance to weathering should be excellent. These results, and industrial experience with these materials, confirm this prediction.

Both materials performed equally well, and were not affected by location.

5.2.4 Other Plastics

Figures 28, 29, 30 group the various plastics (except PVF and PMMA) by discoloration at each site.

Three white PVC's (N, O, T) were selected for comparison with the clear RP (F), polyethylene (B), and PETP (E). Glass-reinforced polyester (F) consistently discolored most in this group. In comparison, all three white PVC's did not discolor greatly.

Moderate effects of season and location were noted. In PE-60 (B) and RP (F), peaks occur around August in the period of maximum sunlight, and lows occur around January.

6. RANKING OF PERFORMANCE

It is highly desirable to be able to objectively rank the performance of architectural materials. The following section is a first step toward that goal.

6.1 Failures

Plastics with greater than 25 units of color-difference from the original were arbitrarily designated "failures". In fact, visual examination of such specimens confirms that they all discolored greatly.

Table 5 shows that discoloration "failures" to-date have occurred only in Arizona, and only for 4 clear PVC's. After 20-24 months, PVC-B4, B10, C10 and N60 severely discolored.

6.2 Classification

Of course, the acceptable degree of discoloration varies with application. For that reason, a performance ranking rather than a "pass-fail" designation is needed. Unfortunately, it is much more difficult to satisfactorily classify performance.

One system under trial is to arbitrarily create the classification:

<u>Class</u>	<u>Adams (E) Color-Difference</u>
A	0-5
B	5-10
C	10-15
D	15-20
E	20-25
F	Greater than 25

However, the performance rank of a plastic may change significantly with location and time selected for ranking. In fact, not only may a CLASS "A" material fall to lower class, but lower class materials may rise to higher class.

Table 6 presents the results of one solution to this problem. Plastics were ranked according to the highest E-value attained at any time (within 1 year, column 1 or within 2 years, column 2) at any location.

A weakness of this system is that it may lead to over-design (and probably higher cost) of plastics for less-demanding applications. However, small additional cost may be acceptable at this time to improve the "image" to the consumer of plastic construction materials.

Accuracy and precision of color-difference (E) values herein is about ± 1 unit. Therefore, borderline cases were given the better of the two ranks in question, in view of the above-described tendency to "over-design".

6.2.1 Classes of Plastics

A study of Table 6 shows that most of the plastics performed well, in color stability, for 1 year in all locations. Of the 20 plastics, 18 were CLASS "A" or "B" for 1 year. Over half were CLASS "A".

At 2 years, only 4 remained CLASS "A". Of the twenty, 13 were CLASS "A" or "B" for 2 years.

Furthermore, none were "failures" at 1 year, but 4 failed with 2 years.

Thus, 2-year exposure definitely separated the very good materials from the very bad. One-year exposure was much less effective in classifying the plastics.

6.2.2 Changes in Class

No material could better its class, with this system. Thus, the "bleaching" obstacle to ranking was overcome.

Some of the clear PVC's showed a drastic change in classification from 1 to 2 years:

PVC-B4	A to F
PVC-B10	A to F
PVC-B60	B to E
PVC-C10	A to F
PVC-N60	B to F

Of all the plastics exposed, only the clear PVC's have shown this exponential discoloration. Two clear PVC's remain, which are not in the above list: PVC-C4 and PVC-C60. As noted in Table 6, failure of PVC-C60 was likely at 24 months, but the supply of replicates for observation was exhausted. This leaves PVC-C4, which behaved similarly to PE-1: good color retention but total embrittlement of the film in about a year in Arizona and Florida. The Washington specimen of PVC-C4 was intact at 2 years. Thus, almost all clear PVC's failed by either discoloration or embrittlement within about 2 years.

Such examples of catastrophic failure are those which are most difficult to predict. Our other mathematical approaches to this forecasting problem may provide a solution.

7. SUMMARY

This is the first in a series of reports on outdoor performance of 20 plastics. Computerized analysis of color data and graphs are presented. Similar reports are underway for 2 physical properties and 5 other properties related to outdoor architectural performance.

A coding system is given for computerizing more than 10,000 observations on the 8 properties.

Color of all original and outdoor-exposed specimens was measured on a GE spectrophotometer, which yielded CIE color values of X, Y, Z. Total color-difference between original and exposed replicates was calculated in the Adams system from the computed L, a, b values.

Graphs are given of Adams color-difference (E) versus time of exposure: 24 months in Arizona, Florida and Washington, D. C. Supporting tristimulus color data (L, a, b) are available on request on magnetic tape, punched cards or computer listing.

Development of a weatherability classification system is described. This classifies performance as CLASS "A", "B", "C", "D", "E", or "F". It is based on ranking plastics according to the highest property value attained at any time within a given period at any location. Its successful application to the color-difference (E) data is presented. The CLASS system is now being extended to the other properties.

Discoloration "failures" (E>25) occurred only in Arizona, and only for 4 clear PVC's. Two other clear PVC films failed by embrittlement in Arizona.

All clear PVC's followed similar patterns of sudden catastrophic discoloration: initial color change, slight bleaching, then rapid discoloration. All but 1 of 7 clear PVC's failed by discoloration (E>25) or embrittlement (of films) within about 2 years. If any of these clear vinyls were slightly superior over the others, it was PVC-B.

All white-pigmented PVC's showed somewhat periodic slight discoloration. They averaged CLASS "B" color-fastness. If any of the white vinyls were slightly more color-fast, it was PVC-A.

For both clear and white PVC's, periodic discoloration does not appear strongly dependent on formulation or thickness.

PVF and PMMA were quite color-fast, as expected. Both materials performed equally well (CLASS "A"), and were not affected by location.

PE film (CLASS "A") and sheet (CLASS "B") did not discolor badly, but PE films embrittled in about a year, beginning in Arizona, then Florida, then Washington, D. C.

PETP discolored to CLASS "B" and RP yellowed to CLASS "D" within 2 years. In comparison with other intermediate-class plastics, RP consistently discolored most.

Moderate effects of season and location were usually noted, especially for PE-60 and RP.

In overall perspective, most of the plastics were fairly color-fast for 1 year in all locations, but by 2 years varying degrees of significant discoloration were measured. At 2 years, there were:

- 4 CLASS "A"
- 9 CLASS "B"
- 0 CLASS "C"
- 2 CLASS "D"
- 1 CLASS "E"
- 4 CLASS "F"

In CLASS "A", one of the four was PE-1 which retained good color but totally embrittled. Another was white PVC-A60 which was only exposed in Washington, D. C.; Arizona exposure would probably lower its assigned CLASS. Thus, the only 2 truly comparable members of CLASS "A" at 2 years were PVF and PMMA.

8. RECOMMENDATIONS

This series of reports should be completed, to record and summarize the bank of observations.

Graphic and mathematical analysis of the data should be continued and refined. Promising classification systems such as that described herein should be developed further, as an aid in objectively and simply comparing performance of new products.

MCA sponsor-companies should avail themselves of the data bank in the appropriate forms. With the aid of MCA Plastics Technical Subcommittee members, these data can provide a sound base for development of improved plastics.

9. ACKNOWLEDGMENTS

We gratefully acknowledge the help of Dr. J. L. Herndon, for his help in caring for exposed samples and in reducing raw data;

W. C. Cullen, V. E. Gray and the staff of the National Bureau of Standards, Materials Durability and Analysis Section, for always lending helping hands when they were needed;

Dr. W. F. Bartoe, F. H. Carman and the MCA Steering Committee, for guidance toward our goals;

R. Saxon and the American Cyanamid Company, Central Research Laboratory staff, for helping us to obtain the color data on which this report is based.

10. REFERENCES

- [1] "Correlation of Accelerated and Outdoor Weathering Tests of Plastics", J. E. Clark, NBS Report #9640, Second Printing, Dec. 1967.
- [2] "Significance of Recent CIE Recommendations for Color Measurement", F. W. Billmeyer, Color Engineering 6, No. 1, 36, Jan.-Feb. 1968.
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TABLE

- 1 Twenty Plastics for Exposure Program
- 2 Evaluation Criteria for Architectural Plastics
- 3 Computer Code for Weathering Data
- 4 Identification Letters for Graphs of Plastics
(see Text on page 5)
- 5 Discoloration "Failures" by 24-Months
- 6 Color-CLASS of Weathered Plastics

TABLE 1

TWENTY PLASTICS FOR EXPOSURE PROGRAM

<u>BASE POLYMER</u>	<u>PLASTIC</u>	<u>DESIGNATION</u>
Polyethylene	Translucent - 1 mil	PE-1
	- 60 mil	PE-60
Poly (methyl methacrylate)	Clear - 60 mil	PMMA-60
Poly (vinyl fluoride)	Clear - 1 mil	PVF-1
Poly (ethylene terephthalate)	Clear - 5 mil	PETP-5
Polyester/ x-linked	Clear - 60 mil	RP-60
Poly (vinyl chloride)	B-C { Clear - 4 mil - 10 mil - 60 mil	PVC-B4
		-B10
		-B60
	S _n { Clear - 4 mil - 10 mil - 60 mil	PVC-C4
		-C10
		-C60
	Clear - 60 mil	PVC-N60
	B-C { White - 4 mil - 10 mil - 60	PVC-A4
		-A10
		-A60
	S _n { White - 4 mil - 10 mil - 60 mil	PVC-D4
		-D10
		-D60
	White - 60 mil	PVC-M60

TABLE 2EVALUATION CRITERIA FOR ARCHITECTURAL PLASTICS

<u>PROPERTY</u>	<u>COMPANY</u>
Color	American Cyanamid
Haze	Monsanto
Gloss	Hercules
Surface Roughness	Union Carbide
Tensile Properties	W. R. Grace B.F.Goodrich
Flexural Properties	W. R. Grace
Electrical Properties	Firestone Plastics
UV Spectra	E.I.duPont

TABLE 3

COMPUTER CODE FOR WEATHERING DATA

<u>EXPOSURE</u>	<u>TIME</u>	<u>PLASTIC</u>	<u>PROPERTY</u>	<u>VALUE</u>
<u>0 Control</u>	0	1 PE-1 mil	<u>1 Color</u>	#
1 Arizona	3 <u>Months</u>	2 PE-60	111 E (Adams)	
2 Florida	6 "	3 PMMA	121 L	
3 Wash. D.C.	9 "	4 PVF	131.a	
	12 "	5 PETP	141 b	
<u>4 Atlas Xe</u>	16 "	6 RP		
41 dry	20 "	7 PVC-B4	<u>2 Haze</u>	
42 spray	24 "	8 - 10	21 T at 420nm	
	30 "	9 - 60	22 T at 550nm	
	36 "	10 PVC-C4		
<u>5 Xenotest</u>		11 - 10	<u>3 Gloss</u>	
51 dry, 30% RH, Light		12 - 60	31 45°	
52 wet, 30% RH, Light		13 PVC-N		
53 dry, 30% RH, Lt/Dk		14 PVC-A4	<u>4 Surface Rough.</u>	
54 wet, 30% RH, Lt/Dk		15 - 10	41 AA	
55 dry, 90% RH, Lt/Dk		16 - 60	42 Peaks/inch	
56 wet, 90% RH, Lt/Dk	5 <u>Hours</u>	17 PVC-D4		
	10 "	18 - 10	<u>5 Electrical</u>	
<u>6 Enclosed Carbon</u>	25 "	19 - 60	51 D.C.) at 1 KC	
61 dry	50 "	20 PVC-M	52 D.F.)	
62 spray	100 "			
	500 "			
<u>7 Sunshine Carbon</u>	1000 "		<u>6 Tensile</u>	
71 dry	5000 "		61 Modulus x 10 ⁵	
72 spray			62 Y Stress x 10 ³	
			63 Y Strain %	
<u>8 FS/BL</u>			64 Tensile x 10 ³	
			65 Ult. Elong. %	
<u>9 Brucksch Device</u>				
91 13,000 ppm SO ₂			<u>7 Flex</u>	
92 18 ppm SO ₂			71 Modulus x 10 ⁵	
93 1400 ppm SO ₂			72 Y Stress x 10 ³	
			73 Y Strain x 10 ⁻²	
			74 R Stress x 10 ³	
			75 R Strain x 10 ⁻²	
			76 5% Stress x 10 ³	
			<u>8 UV Spectra</u>	
			81 Peak wavelength	
			82 Peak height	

TABLE 5

DISCOLORATION "FAILURES" BY 24 MONTHS*

<u>PLASTIC</u>	<u>TIME OF OBSERVATION</u>	<u>ADAMS (E) COLOR-DIFFERENCE</u>
PVC-B4	24 Months	28.32
-B10	24 Months	42.03
-C10	20 Months	26.59
-C10	24 Months	47.59

*ARIZONA only. No E-values greater than 25 were found in this period in Washington, D. C. or Florida

TABLE 6

COLOR-CLASS OF PLASTICS

<u>CLASS</u>	<u>AT 1 YEAR</u>	<u>AT 2 YEARS</u>
<u>A</u>	PE-1 (1) PMMA-60 PVF-1 PVC-B4 -B10 -C4 -C10 -A4 -A10 -A60 (2) -D60 -M60	PE-1 (1) PMMA-60 PVF-1 PVC-A60 (2)
<u>B</u>	PE-60 PETP-5 PVC-B60 -N60 -D4 -D10	PE-60 PETP-5 PVC-C4 -A4 -A10 -D4 -D10 -D60 -M60
<u>C</u>	RP-60 PVC-C60	-
<u>D</u>	-	RP-60 PVC-C60 (3)
<u>E</u>	-	PVC-B60
<u>F</u>	-	PVC-B4 -B10 -C10 -N60

(1) Film embrittled completely at all sites in 1/2 - 1 1/2 years.

(2) Washington, D. C. data only.

(3) Data to 16-months only. Based on comparison with others of its type, the 24-month prediction would be CLASS "E" or "F".

GRAPHS OF COLOR-DIFFERENCE VS. TIMEFIGUREINDIVIDUAL PLASTICS

1	Polyethylene (1 mil)
2	Polyethylene (60 mil)
3	Polymethyl methacrylate (60 mil)
4	Polyvinyl fluoride (1 mil)
5	Polyethylene terephthalate (5 mil)
6	Glass-reinforced Polyester (60 mil)
7	Polyvinyl chloride -B (4 mil)
8	" " -B (10 mil)
9	" " -B (60 mil)
10	" " -C (4 mil)
11	" " -C (10 mil)
12	" " -C (60 mil)
13	" " -N (60 mil)
14	" " -A (4 mil)
15	" " -A (10 mil)
16	" " -A (60 mil)
17	" " -D (4 mil)
18	" " -D (10 mil)
19	" " -D (60 mil)
20	" " -M (60 mil)

INDIVIDUAL LOCATIONS

21	Arizona	)	
22	Florida	)	7 Clear PVC's
23	Washington, D. C.	)	
24	Arizona	)	
25	Florida	)	7 White PVC's
26	Washington, D. C.	)	
27	A, F, W		Exposures of PVF and PMMA
28	Arizona	)	
29	Florida	)	PE, PETP, RP, White PVC-A
30	Washington, D. C.	)	

FIGURE 1

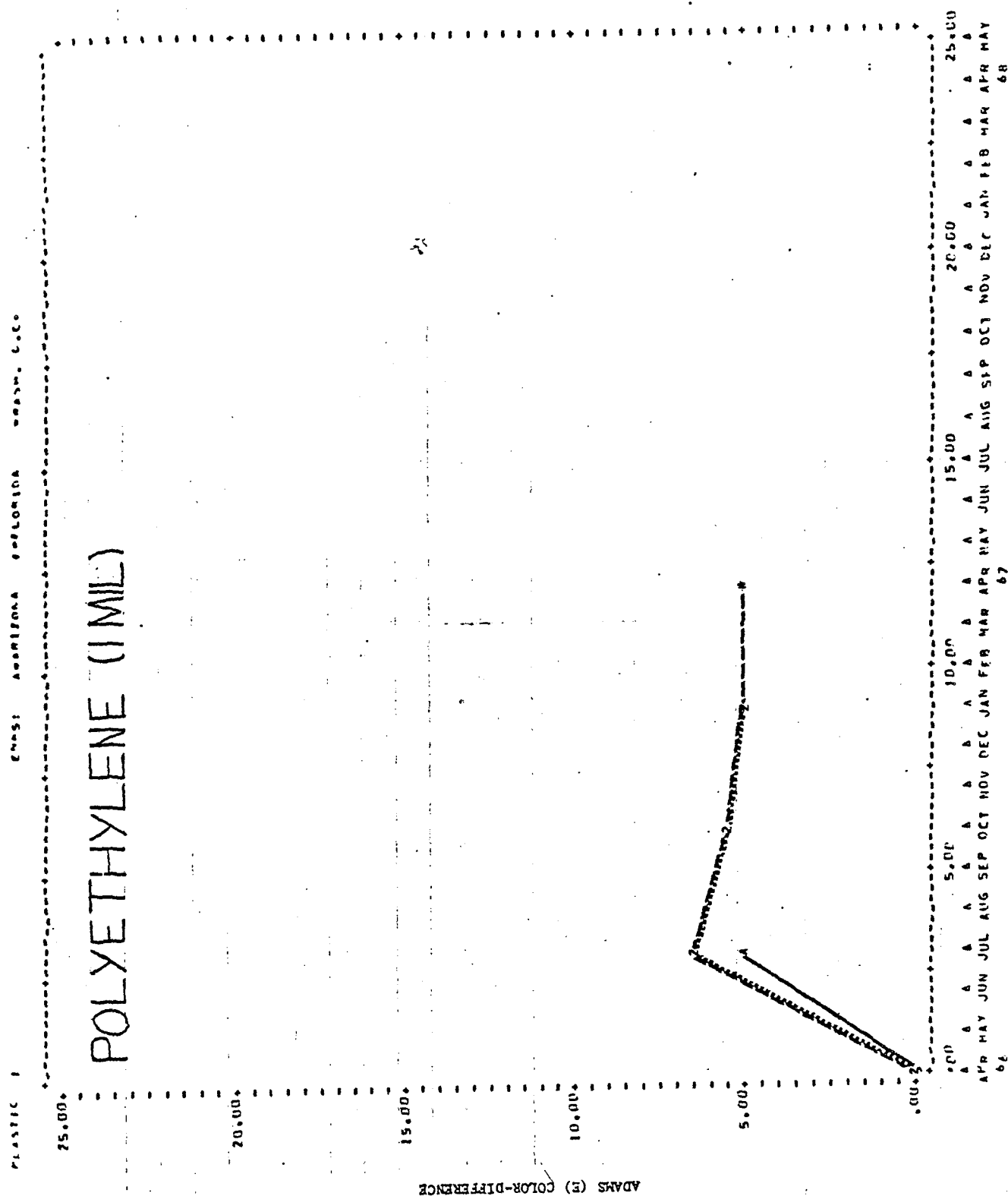


FIGURE 2

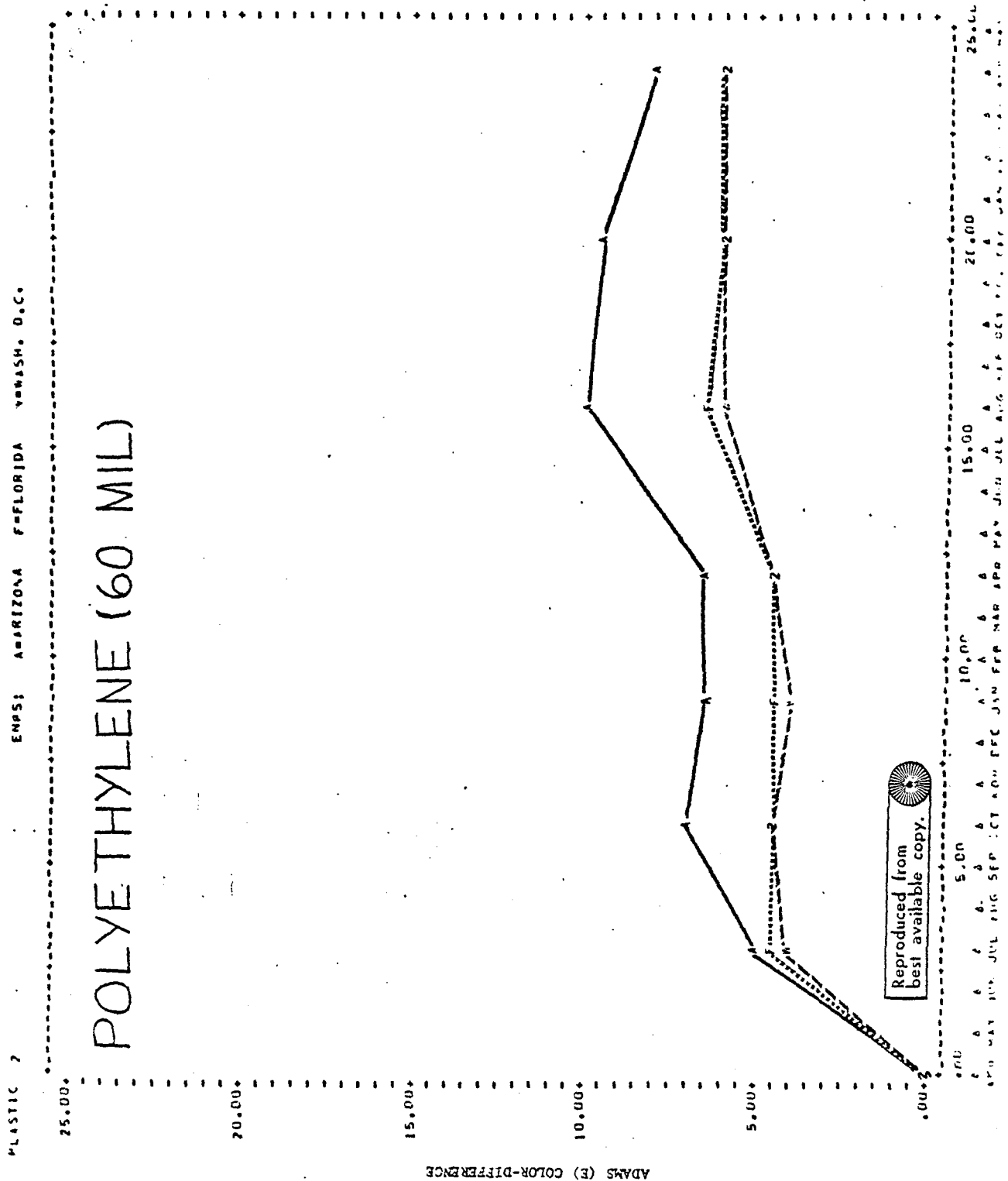


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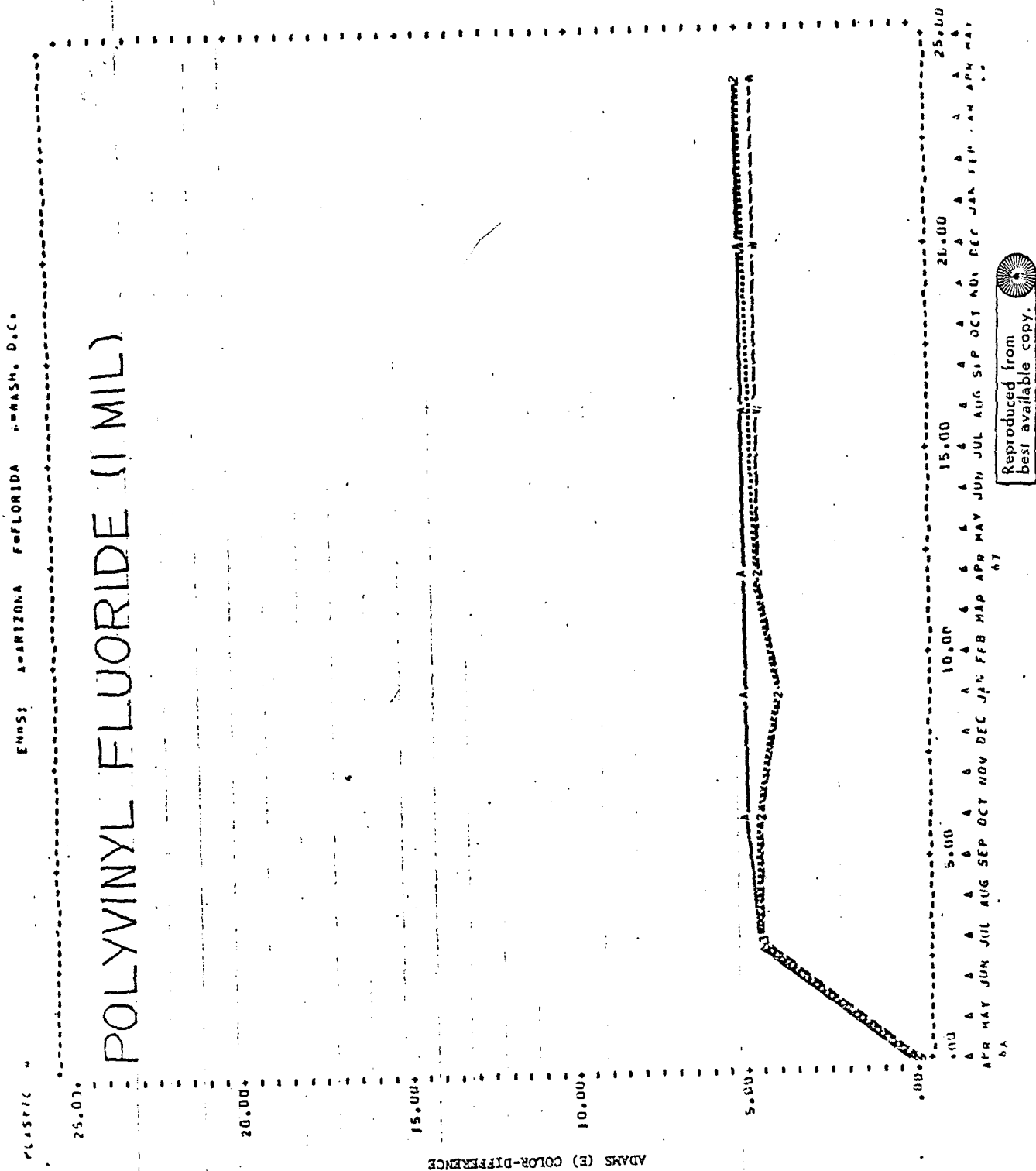


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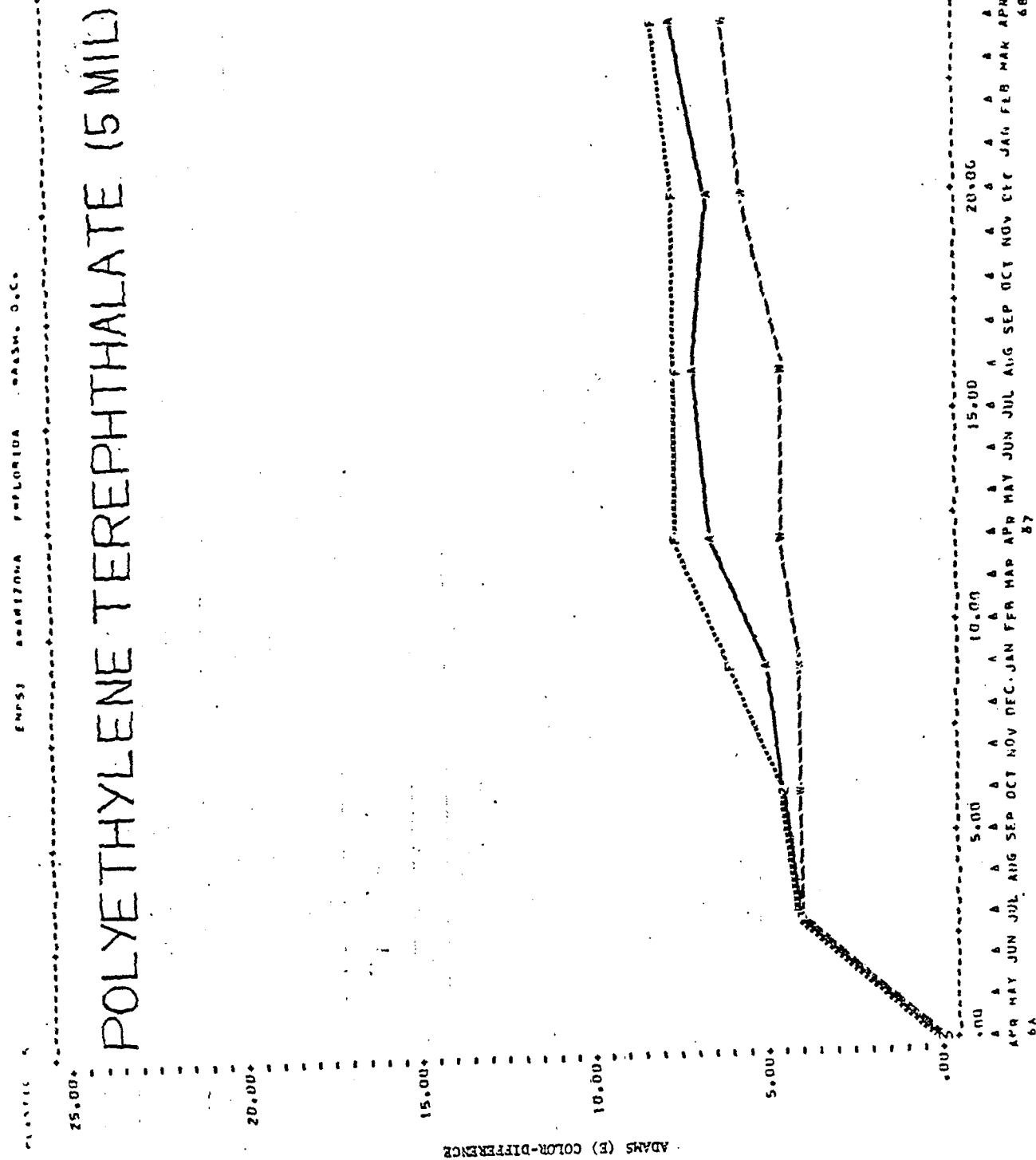
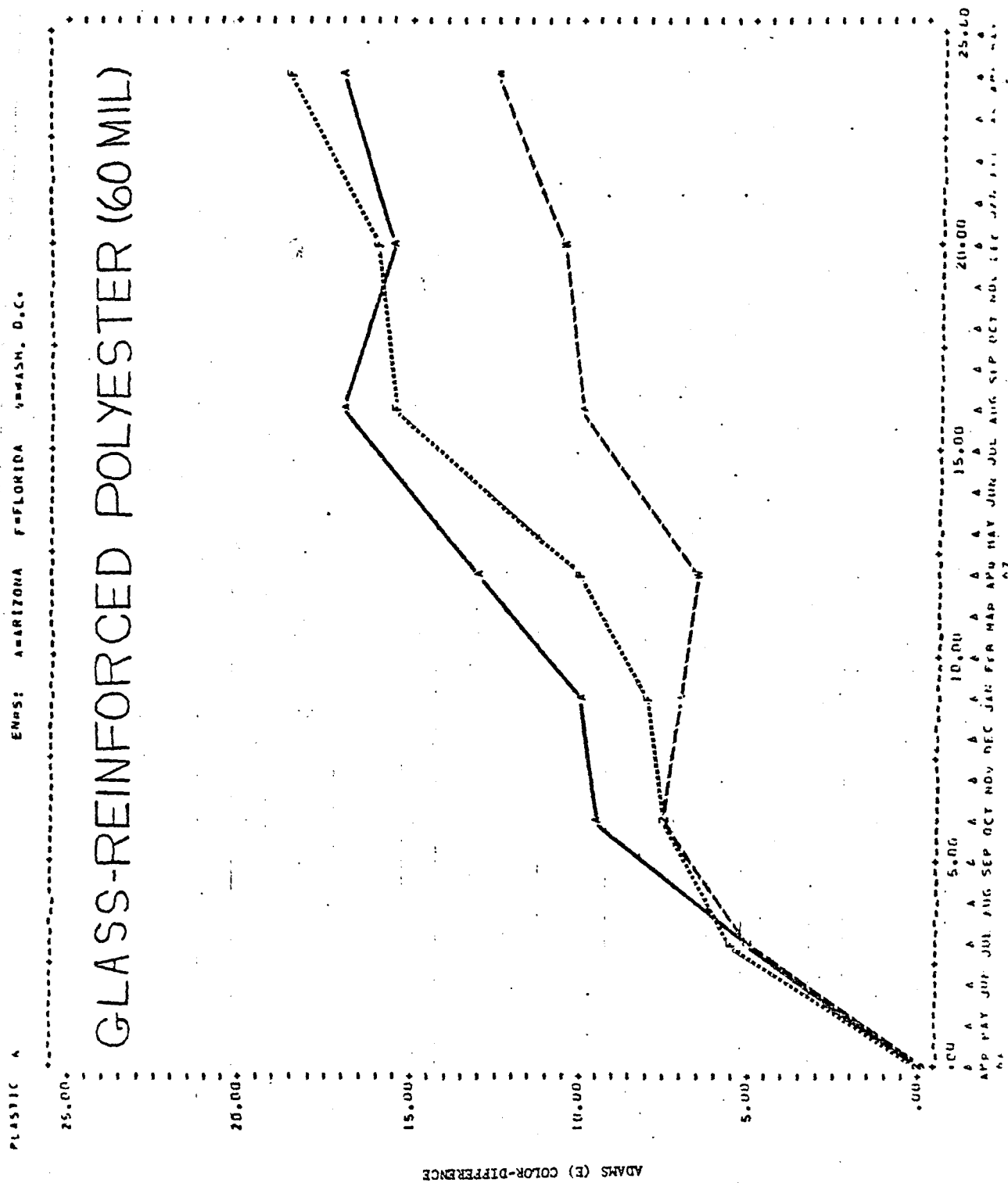


FIGURE 6



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FIGURE 7

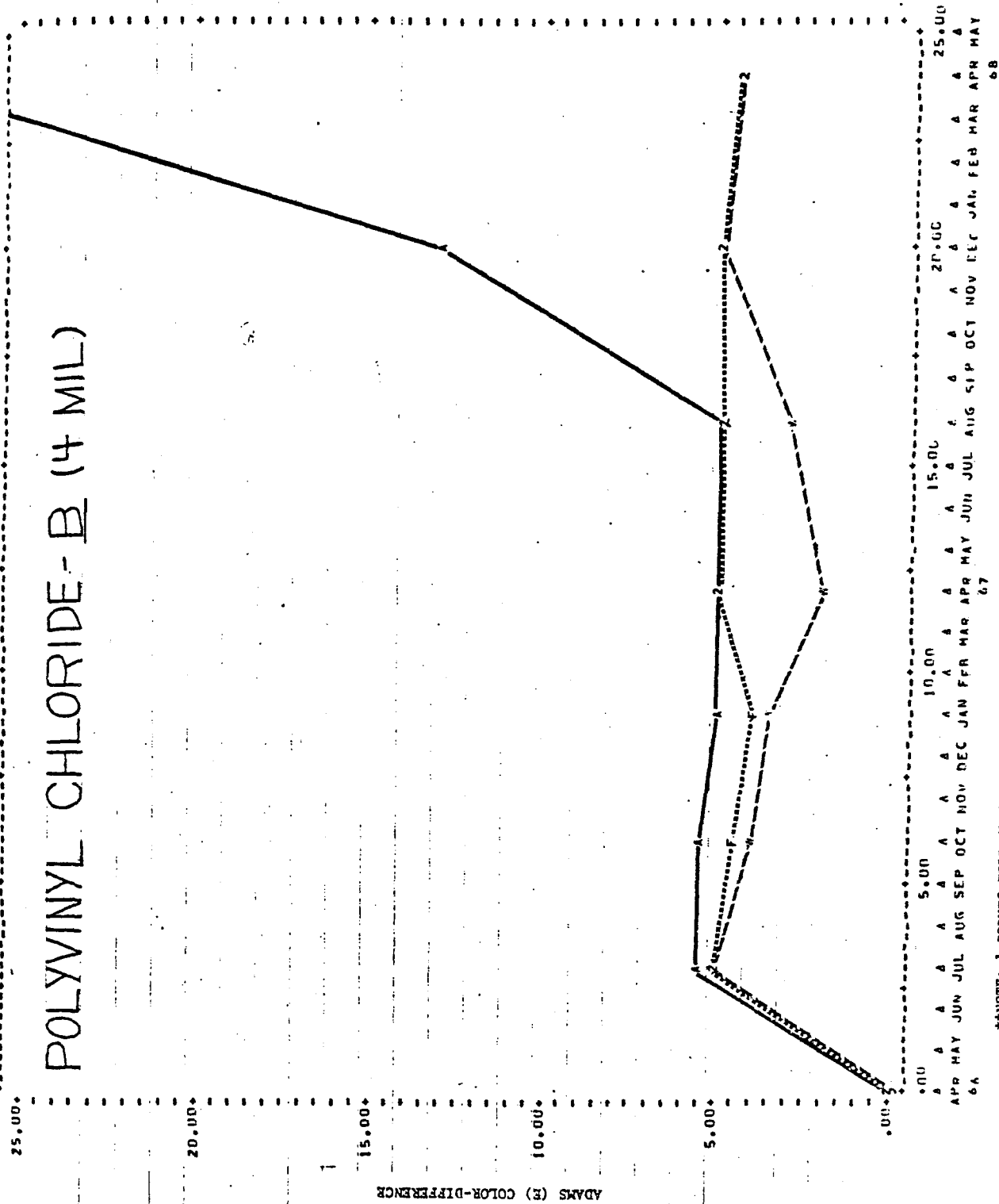


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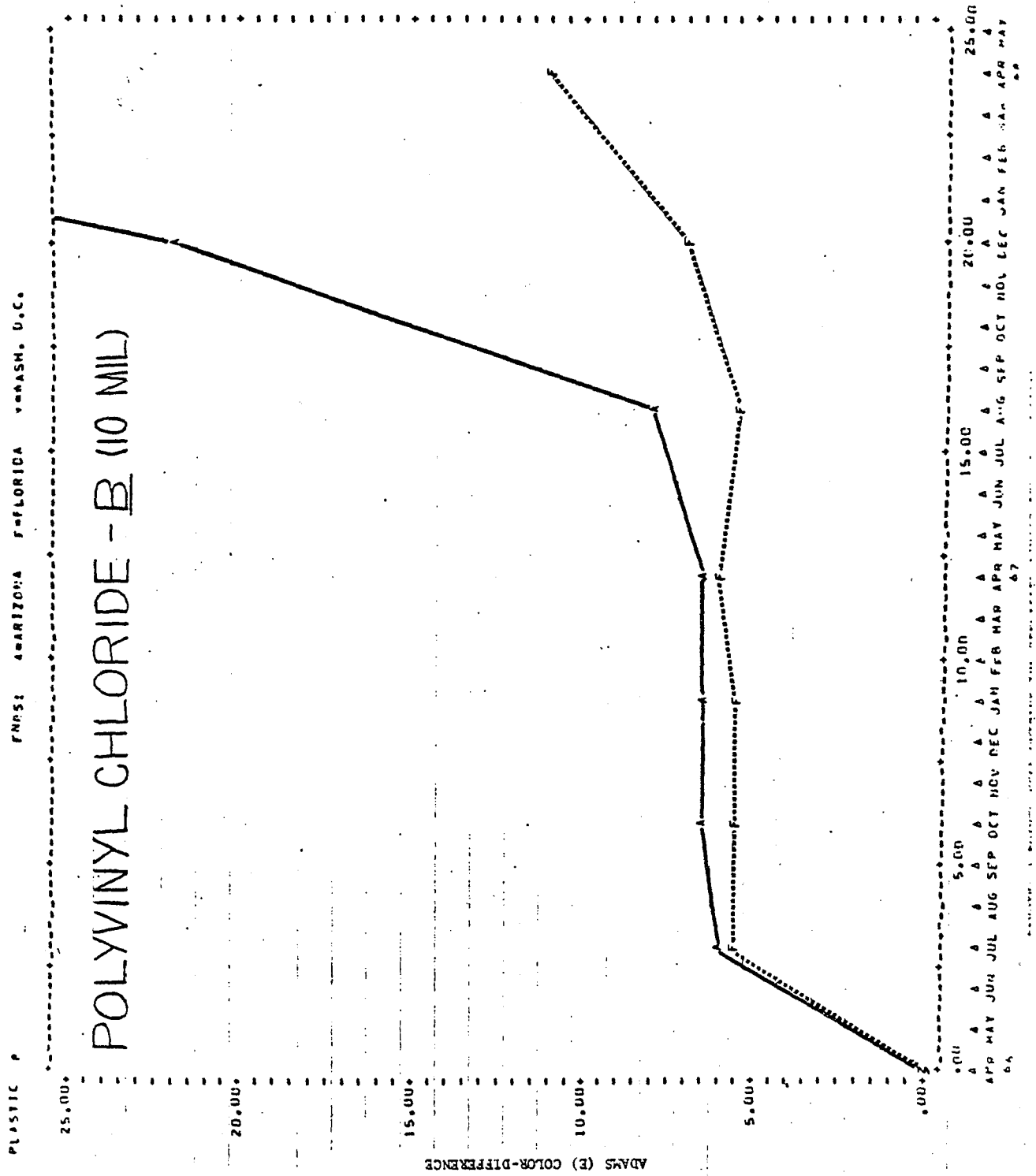


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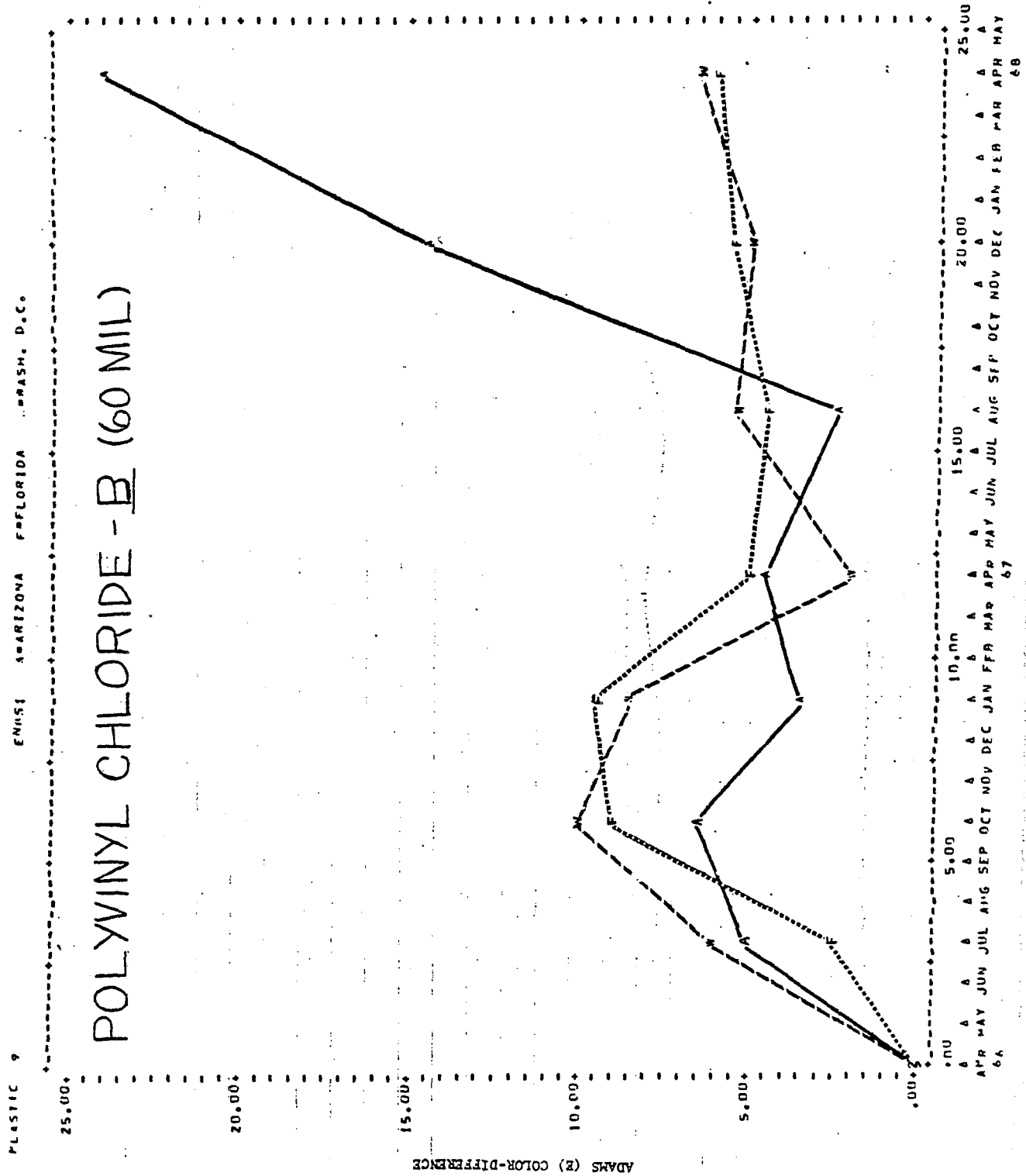
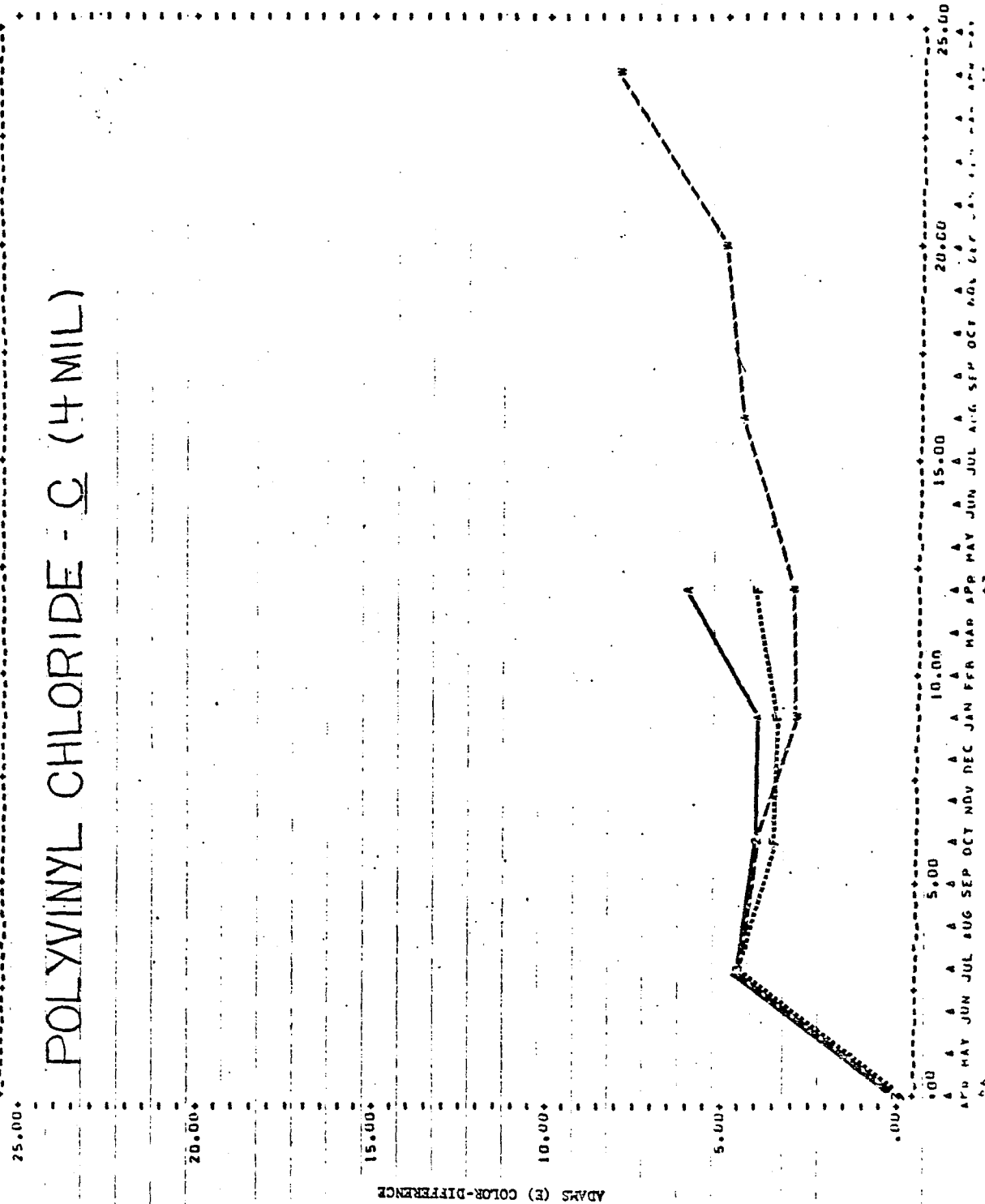


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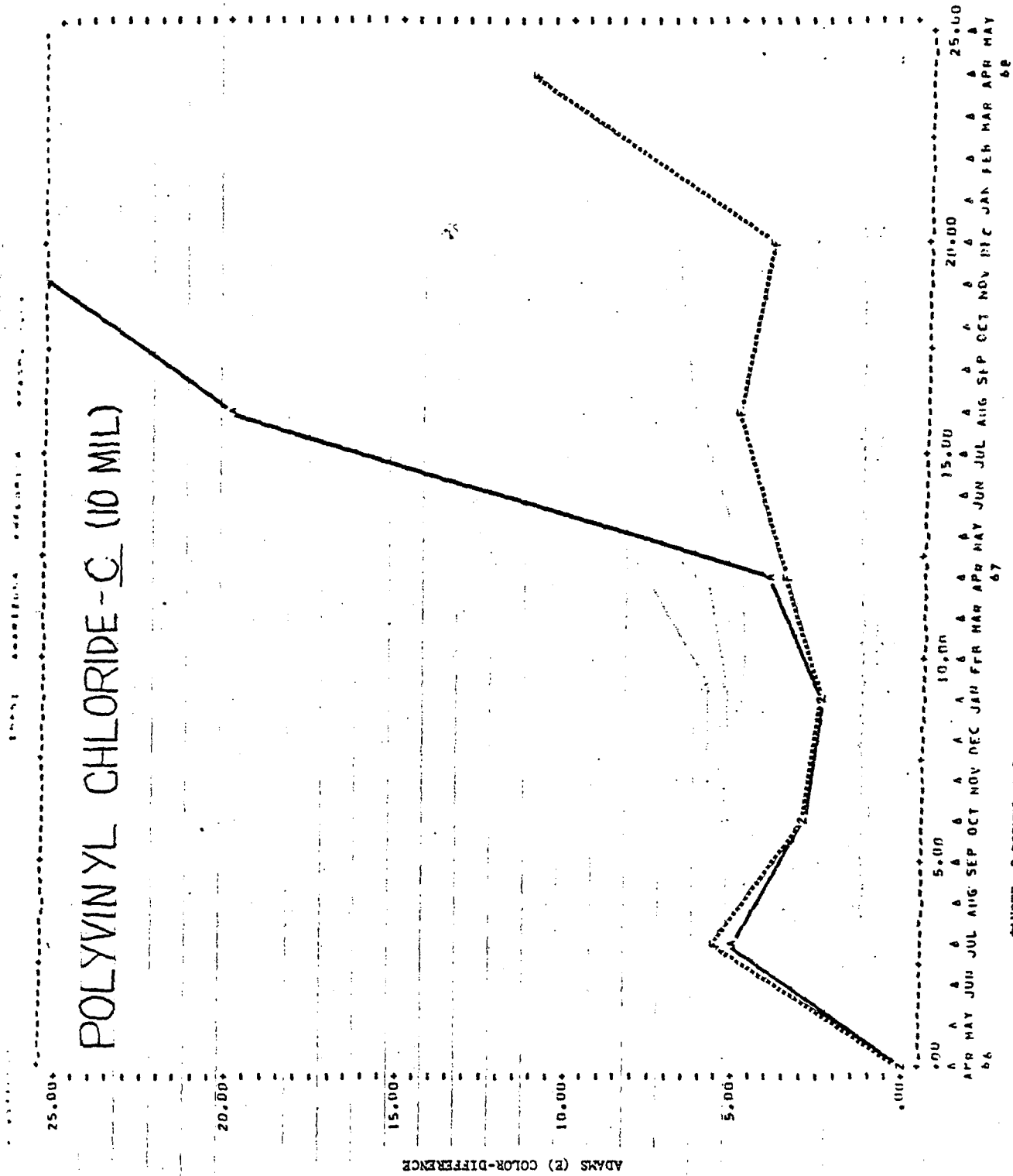
PLASTIC IN ENPS: ARIZONA FLORIDA WASH. D.C.

POLYVINYL CHLORIDE - C (4 MIL)



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FIGURE 11



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FIGURE 12

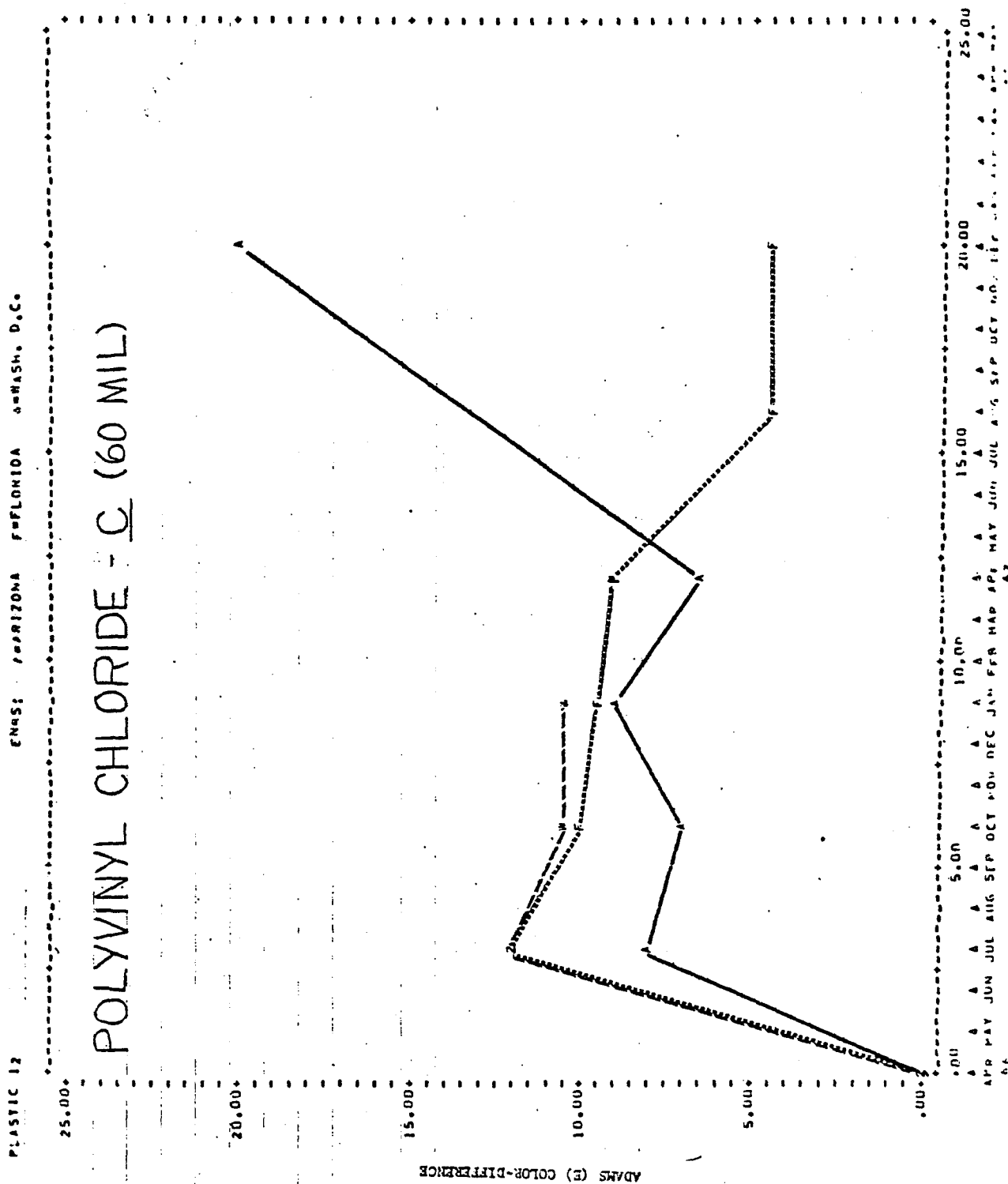


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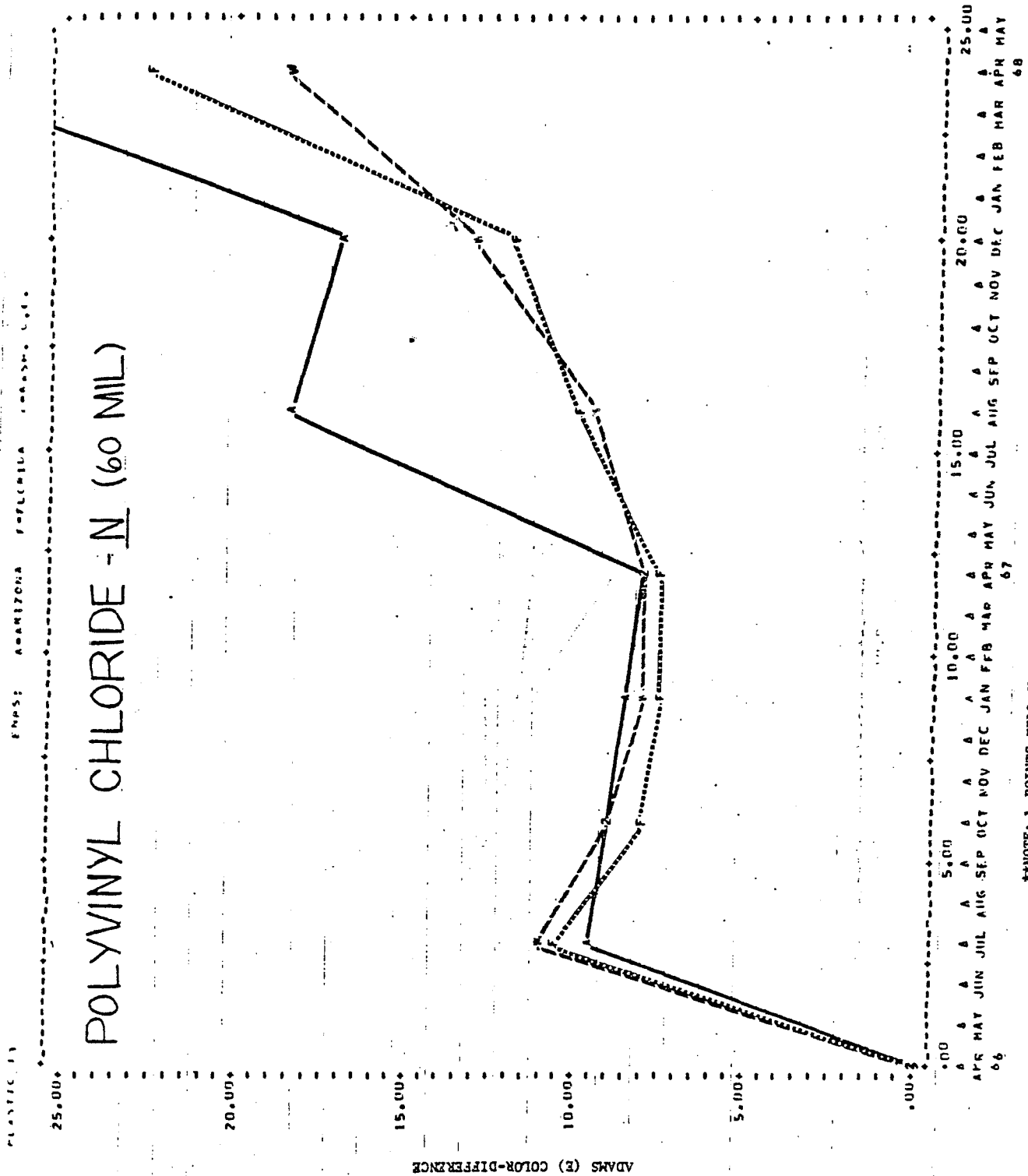


FIGURE 14

ENDS: ARIZONA F-FLORIDA AMASH, D.C.

PLASTIC IN

POLYVINYL CHLORIDE - A (4 MIL)

ADAMS (E) COLOR-DIFFERENCE

25.00
20.00
15.00
10.00
5.00
0.00

APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
64 67

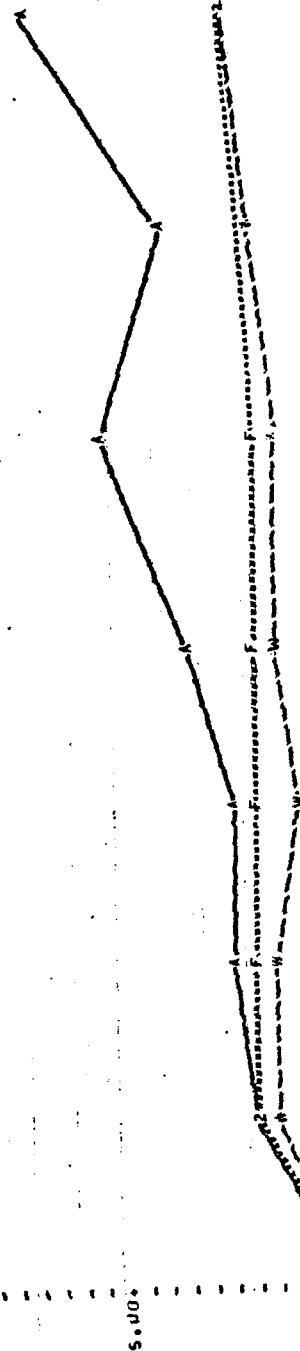


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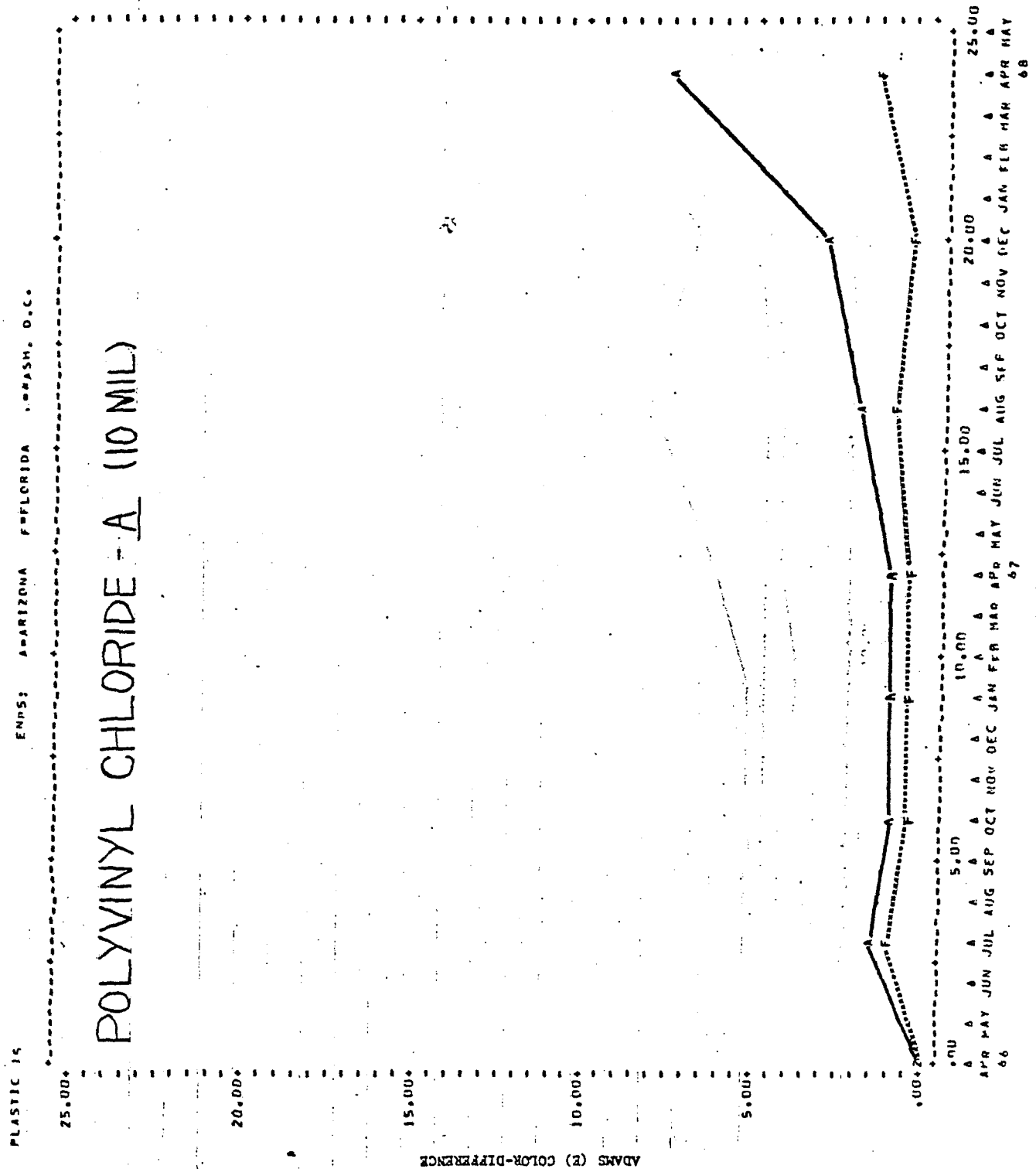
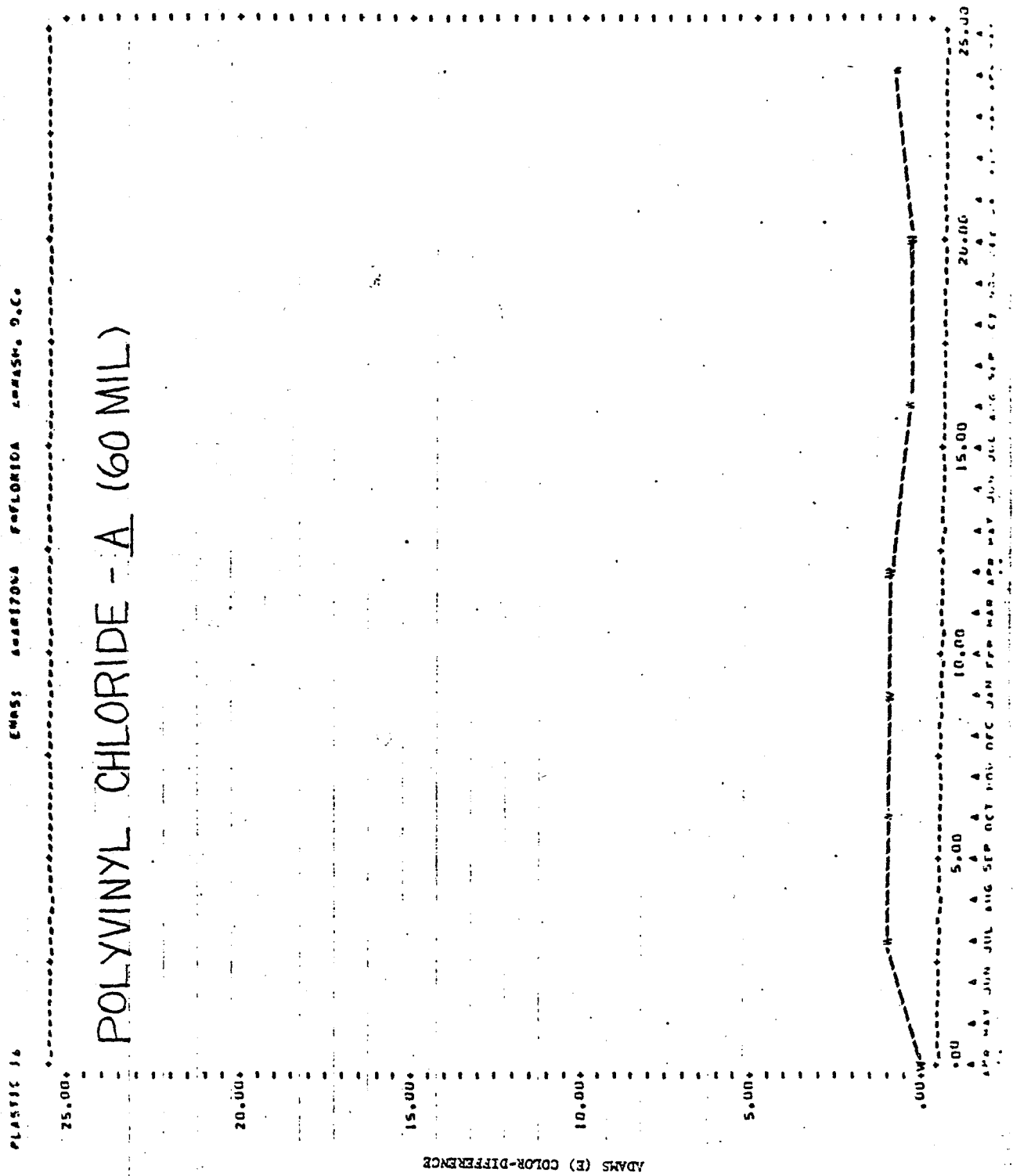


FIGURE 16



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FIGURE 17

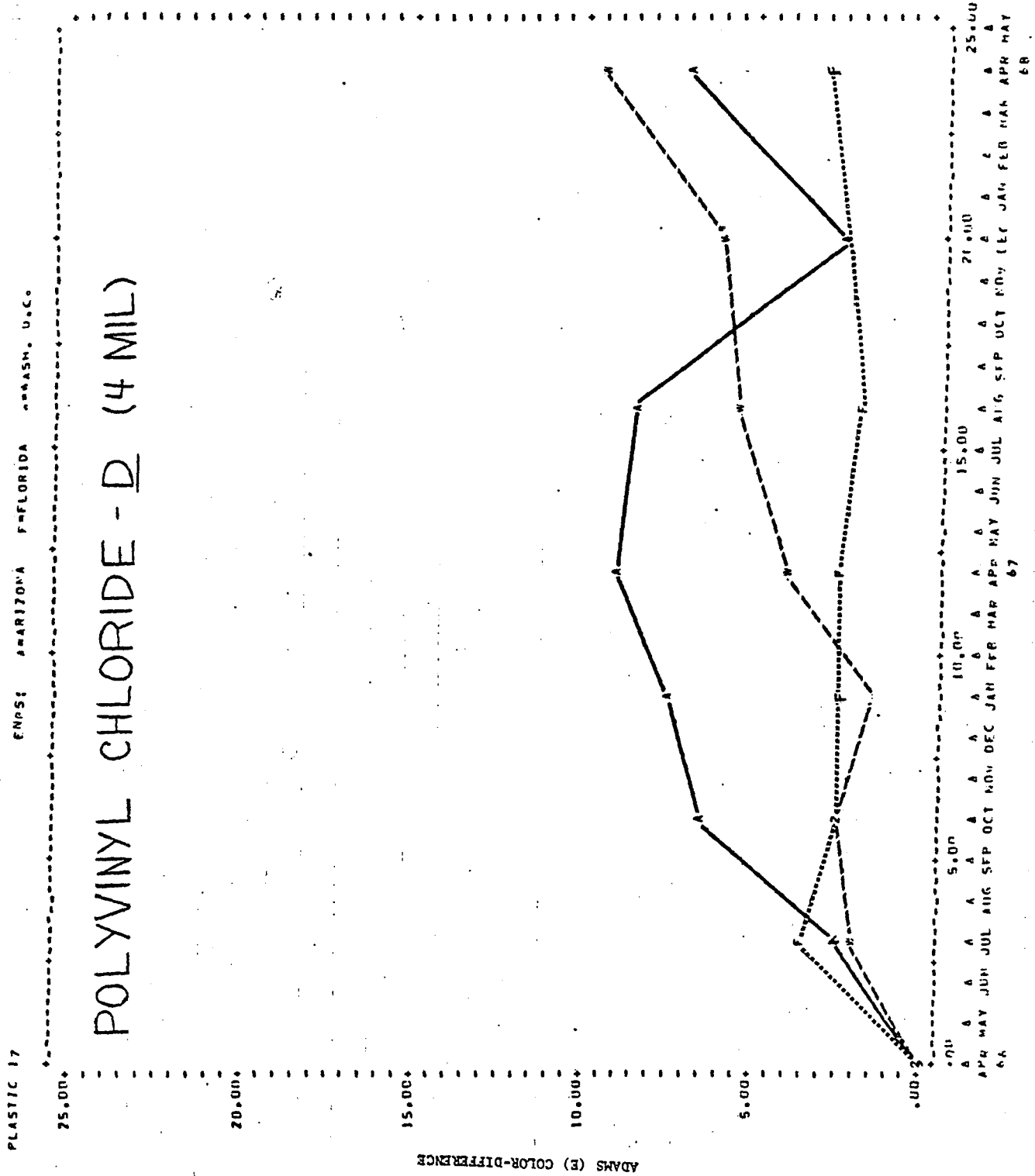


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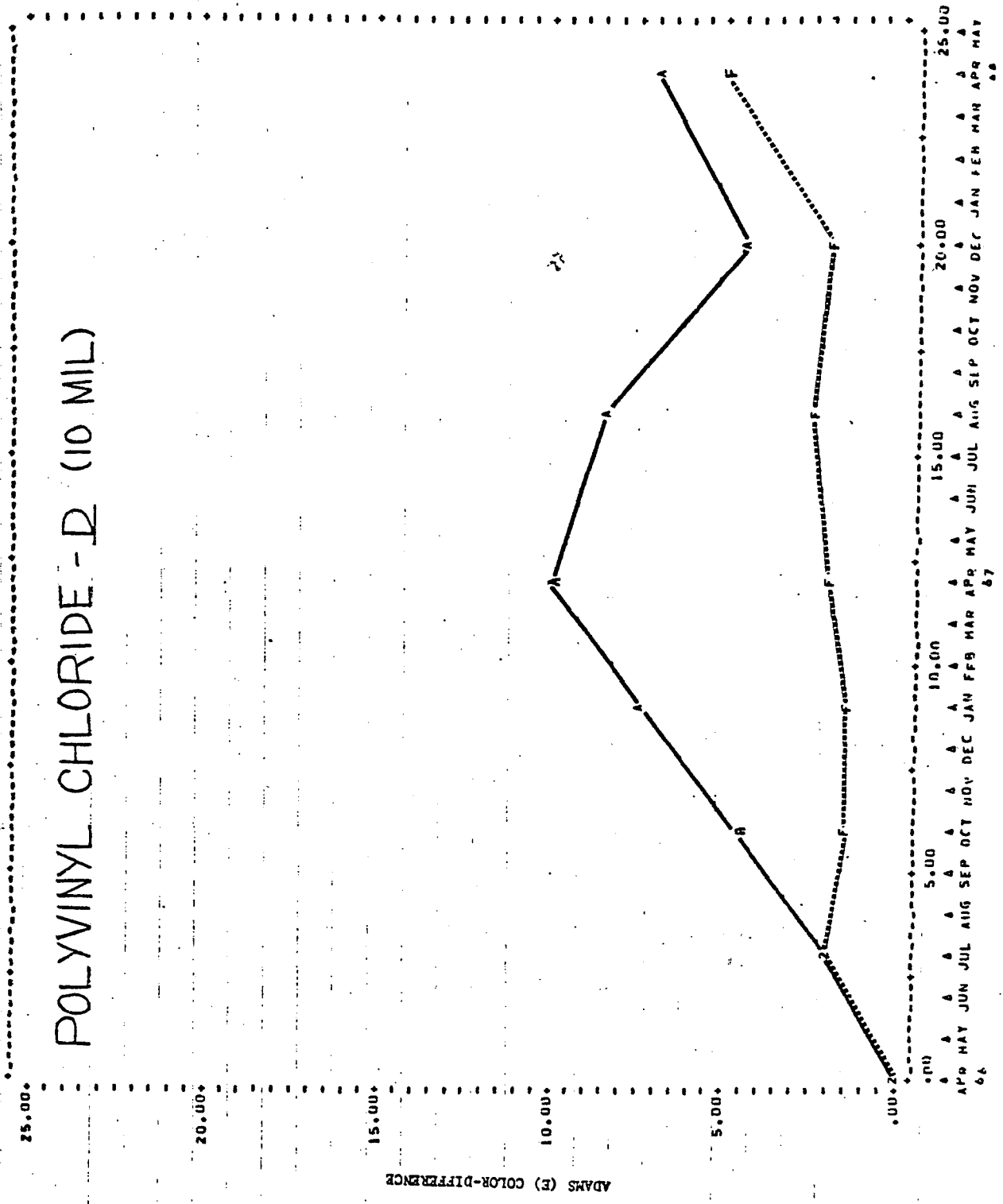


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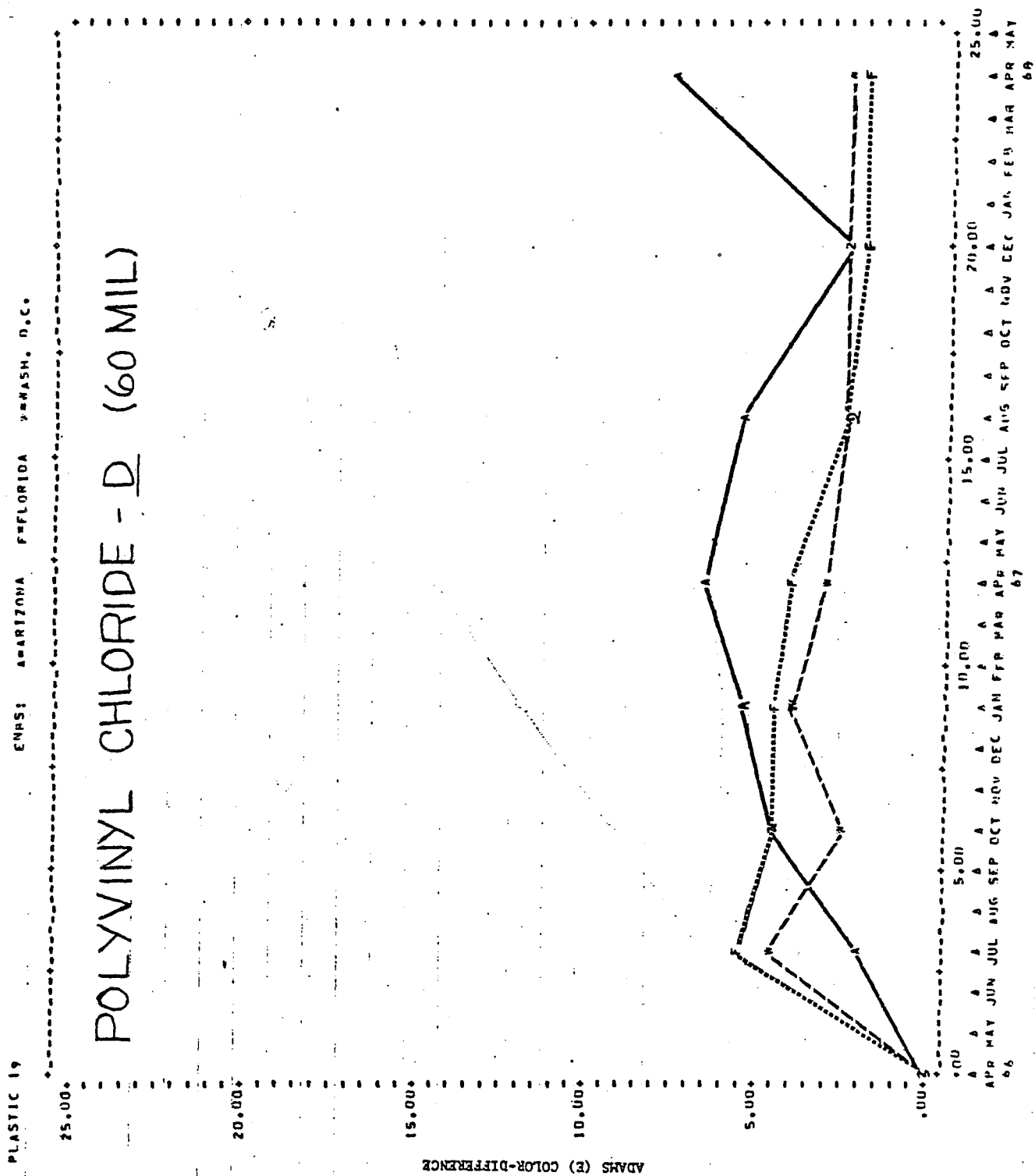


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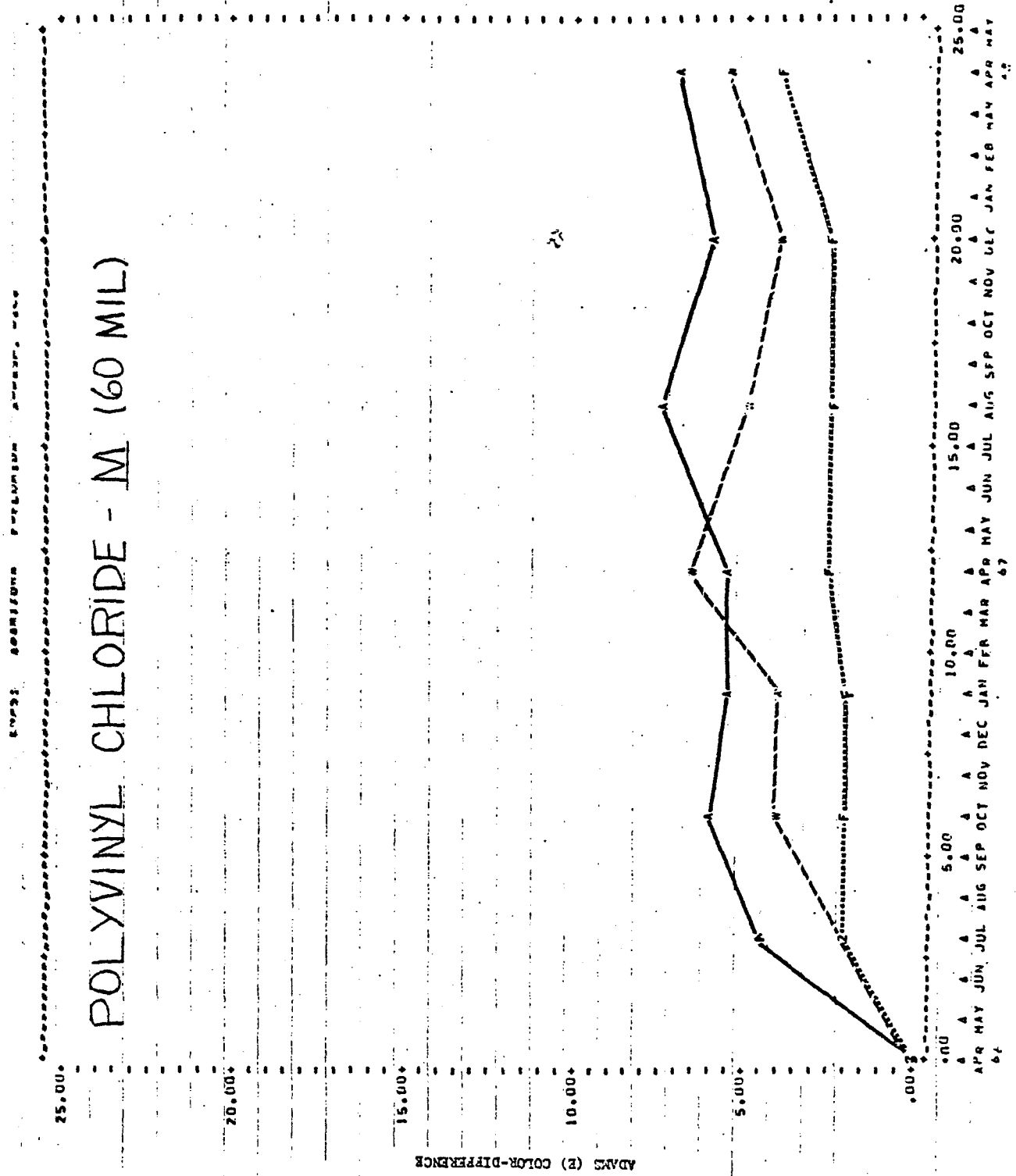


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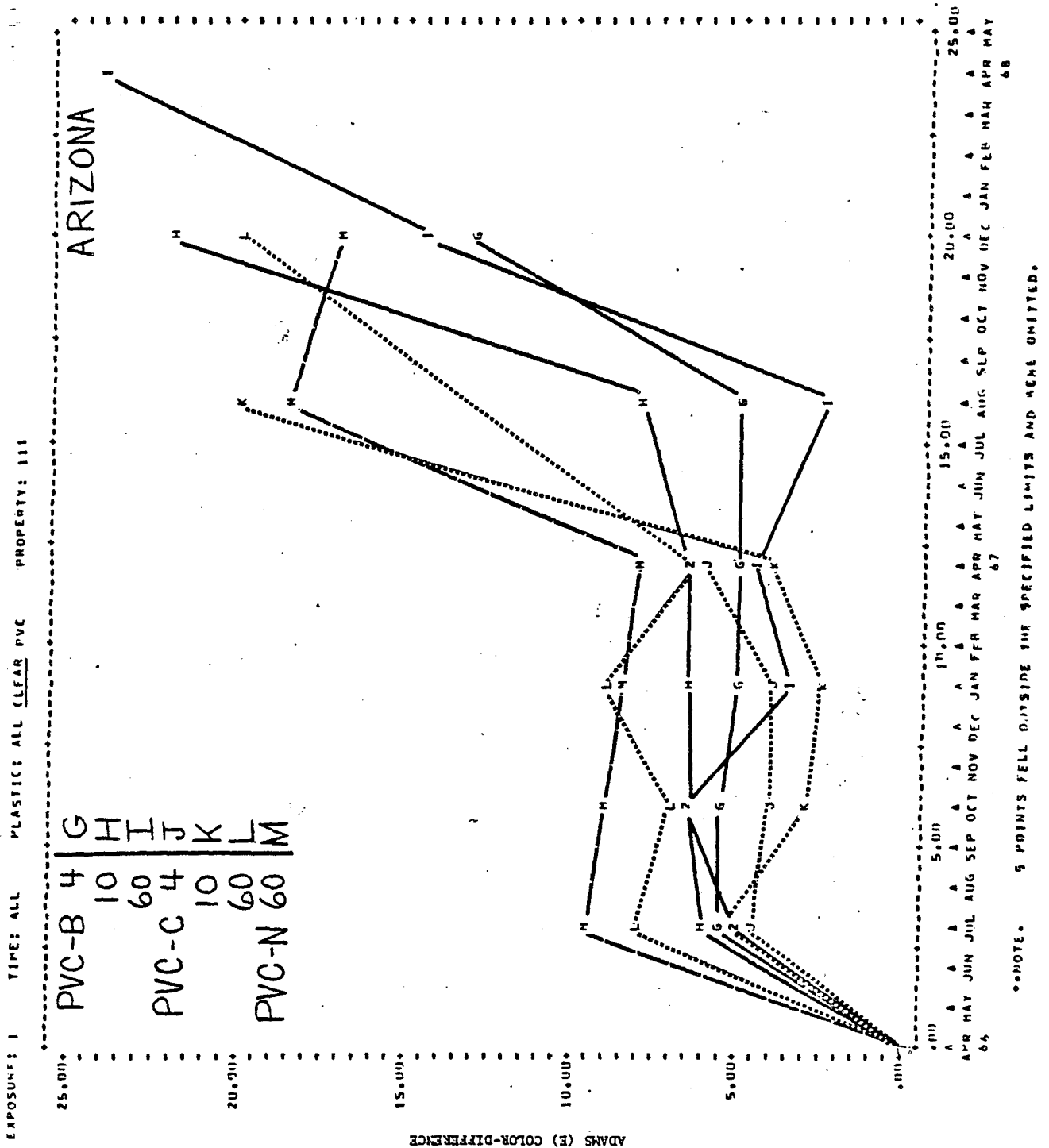


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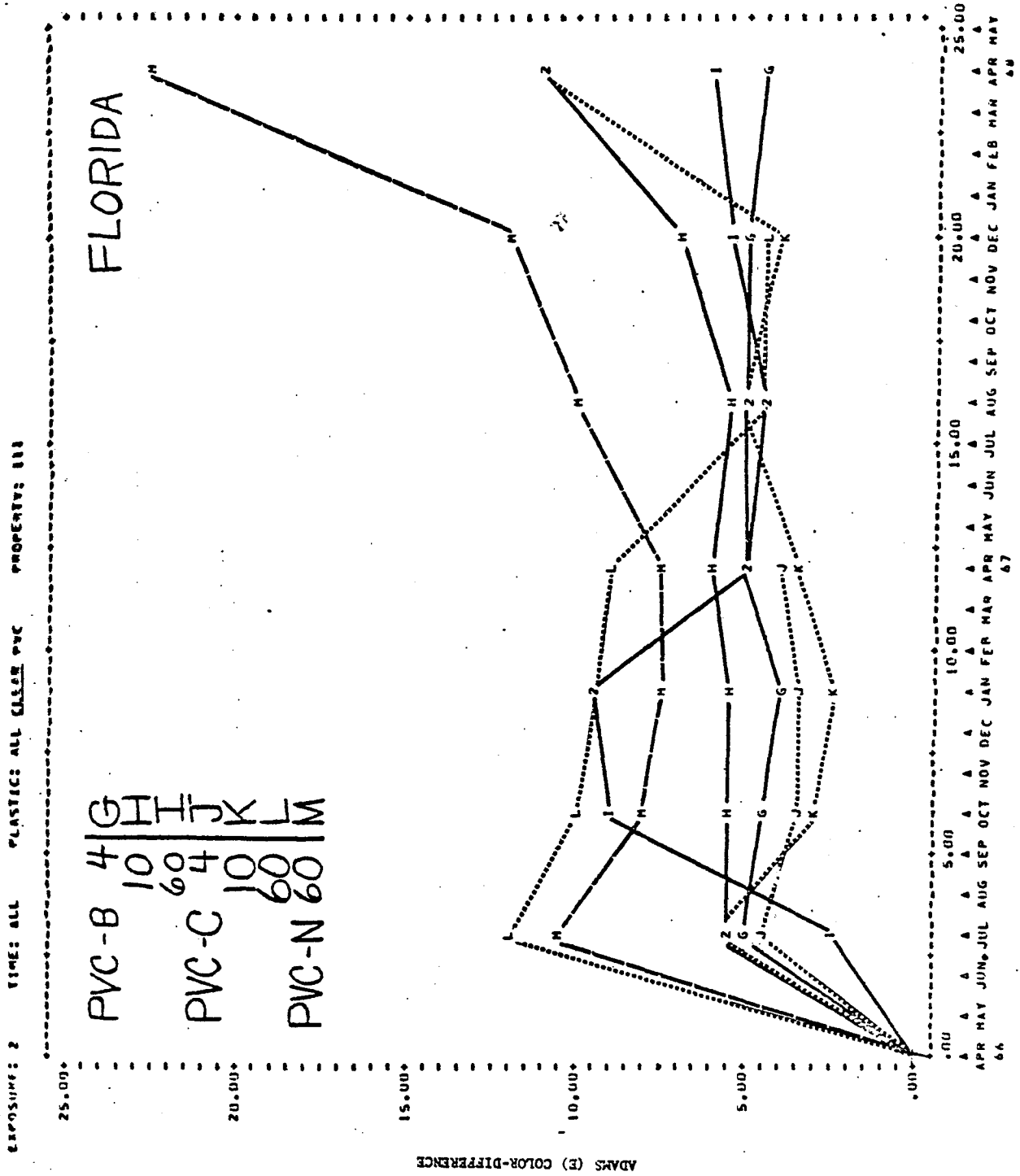


FIGURE 23

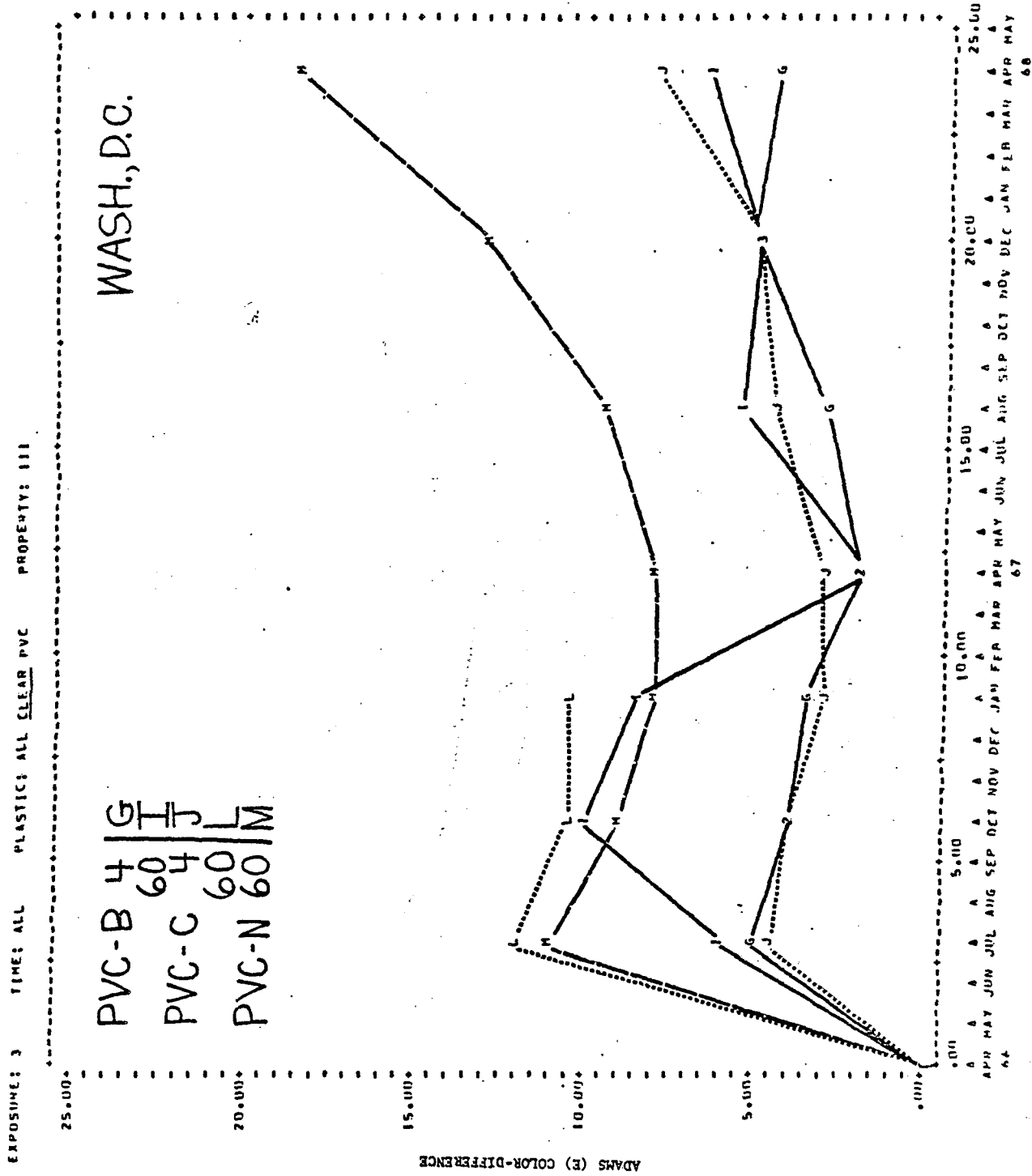


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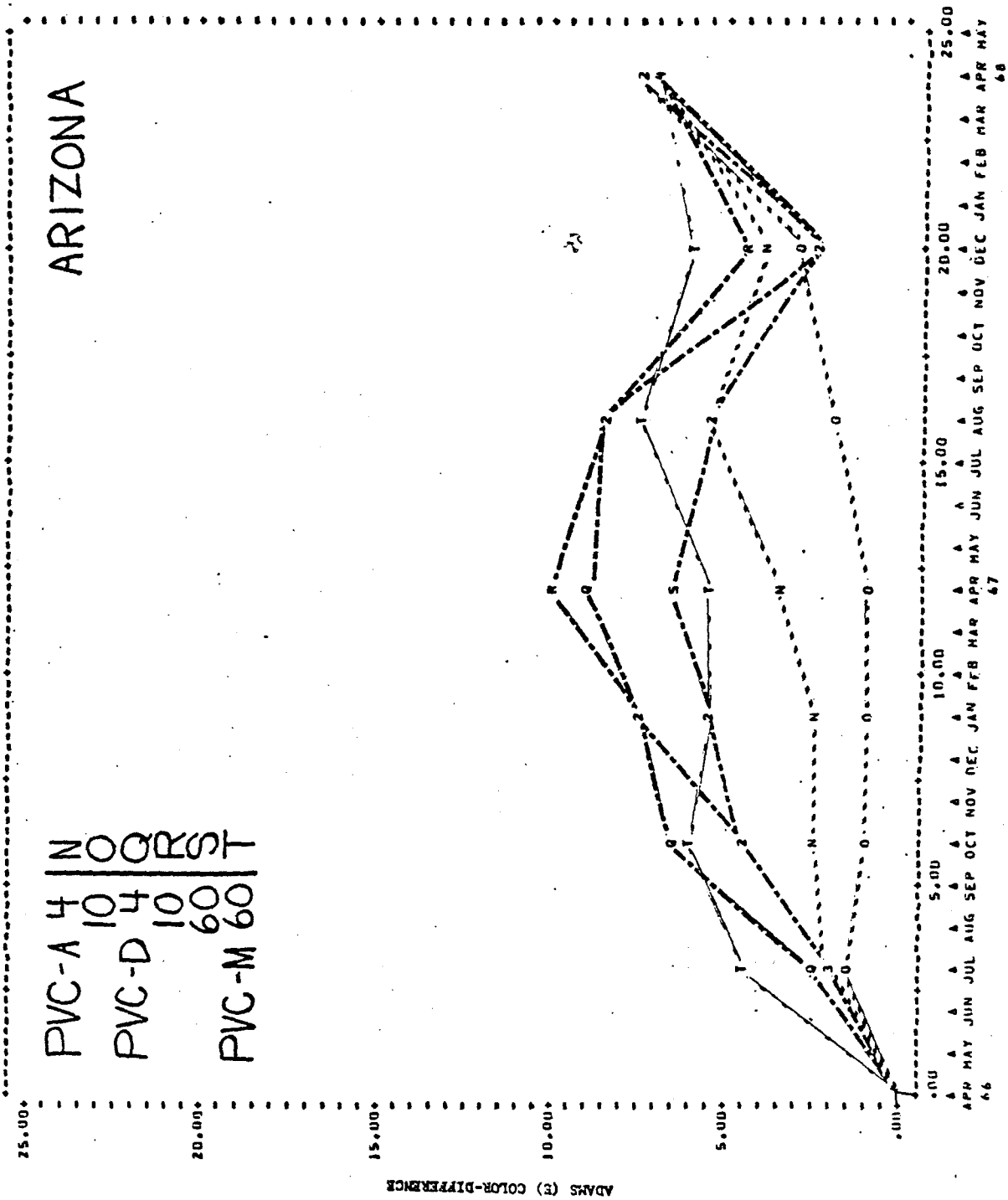


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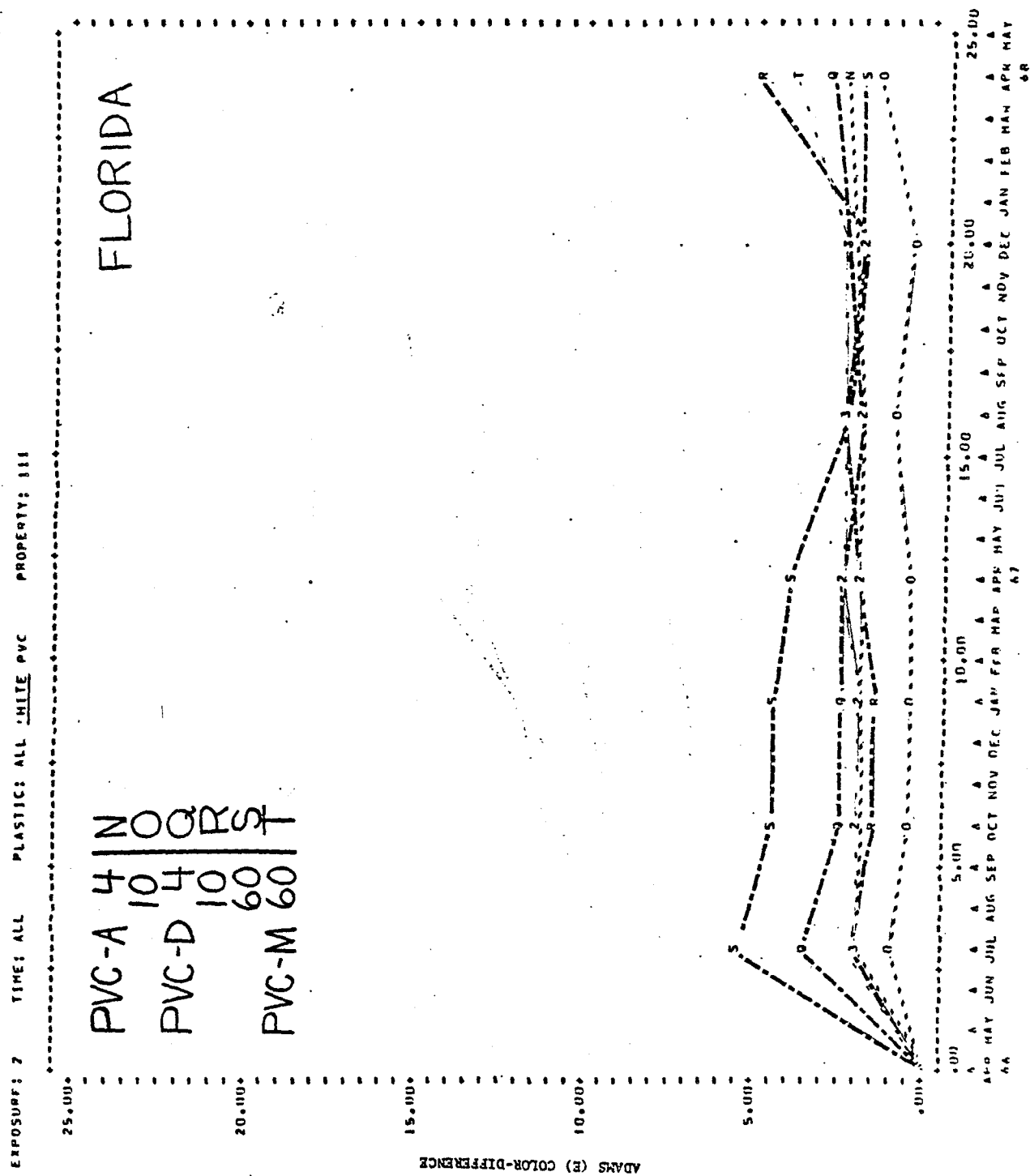


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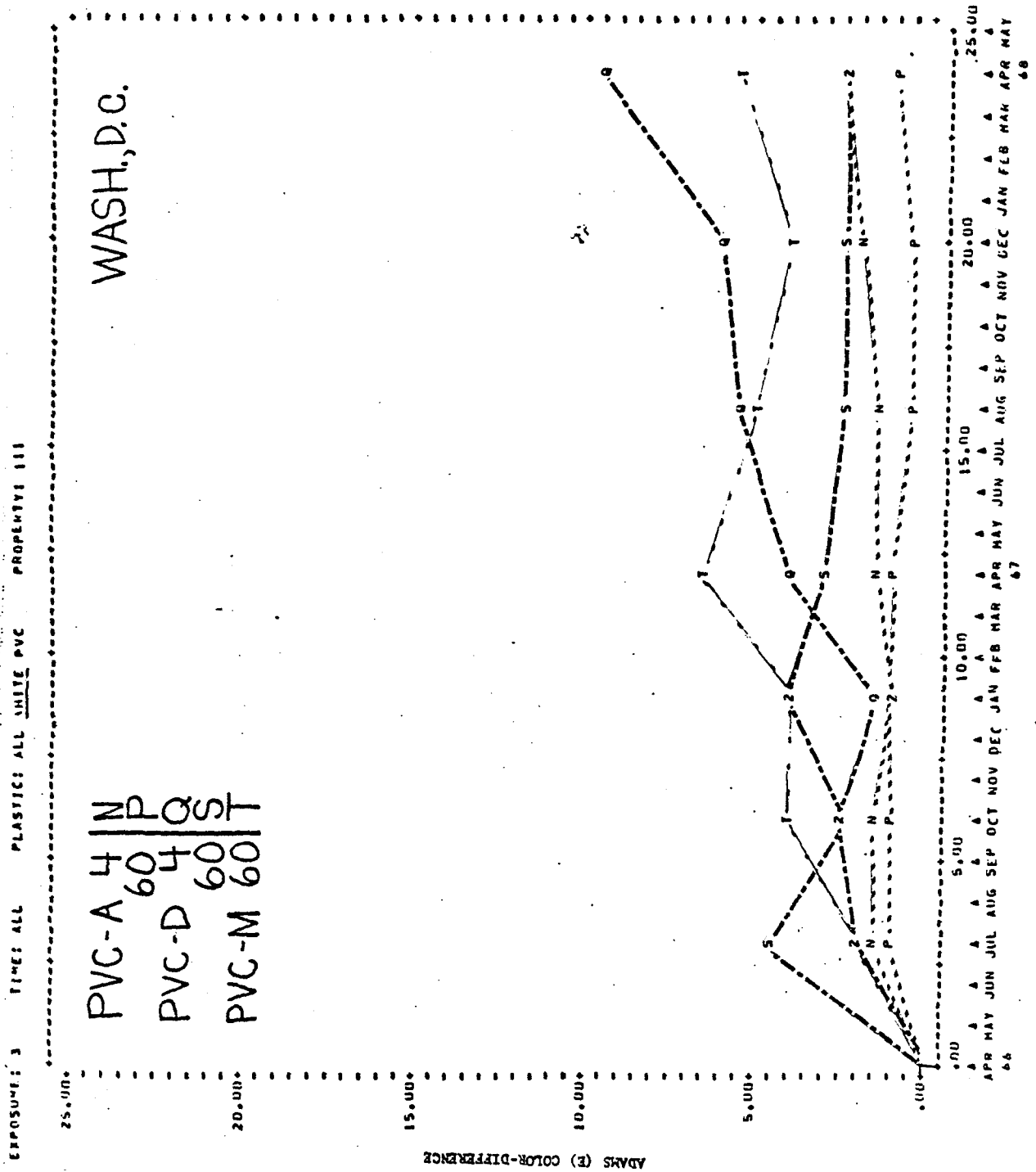


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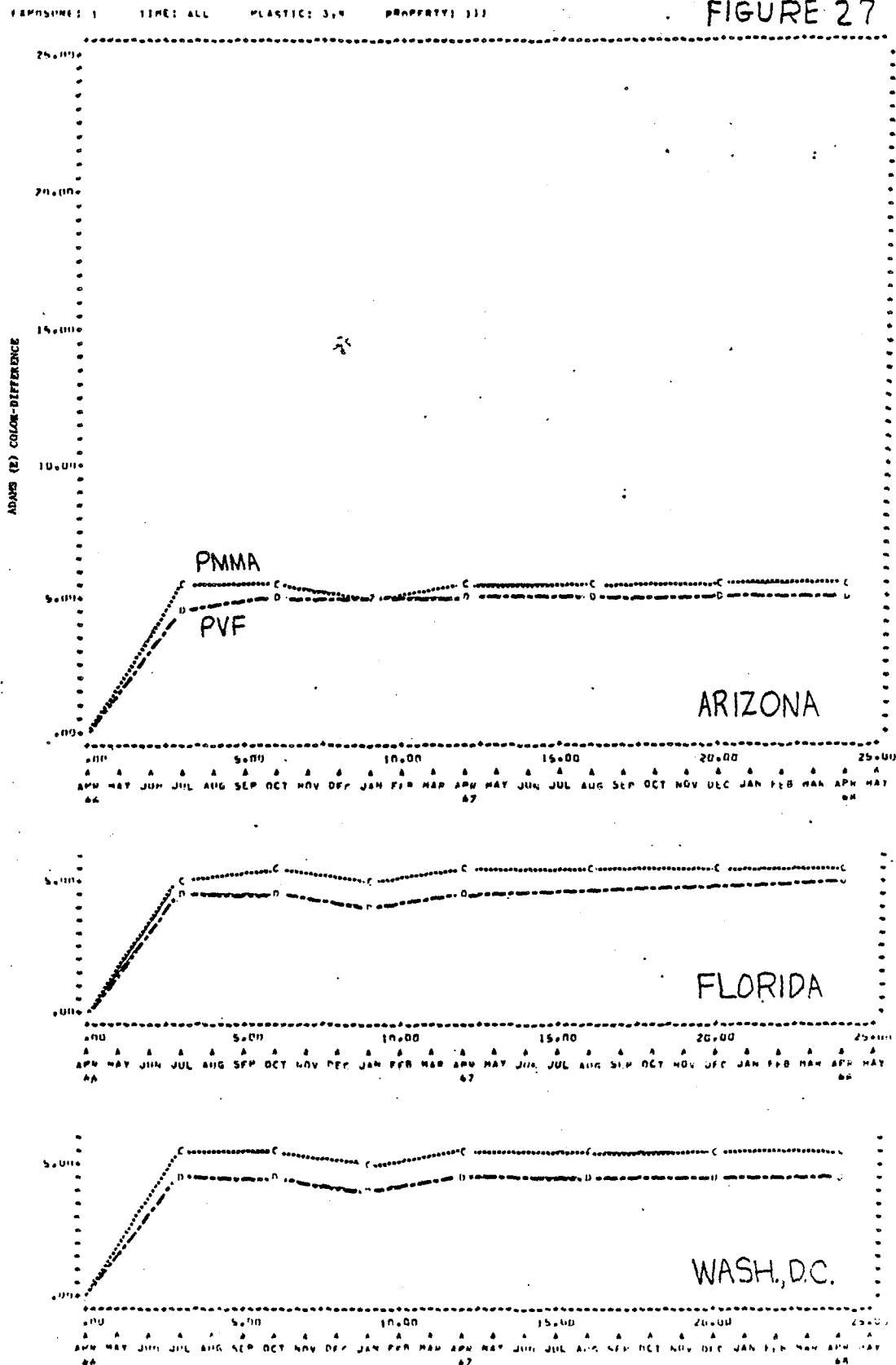


FIGURE 27



FIGURE 28

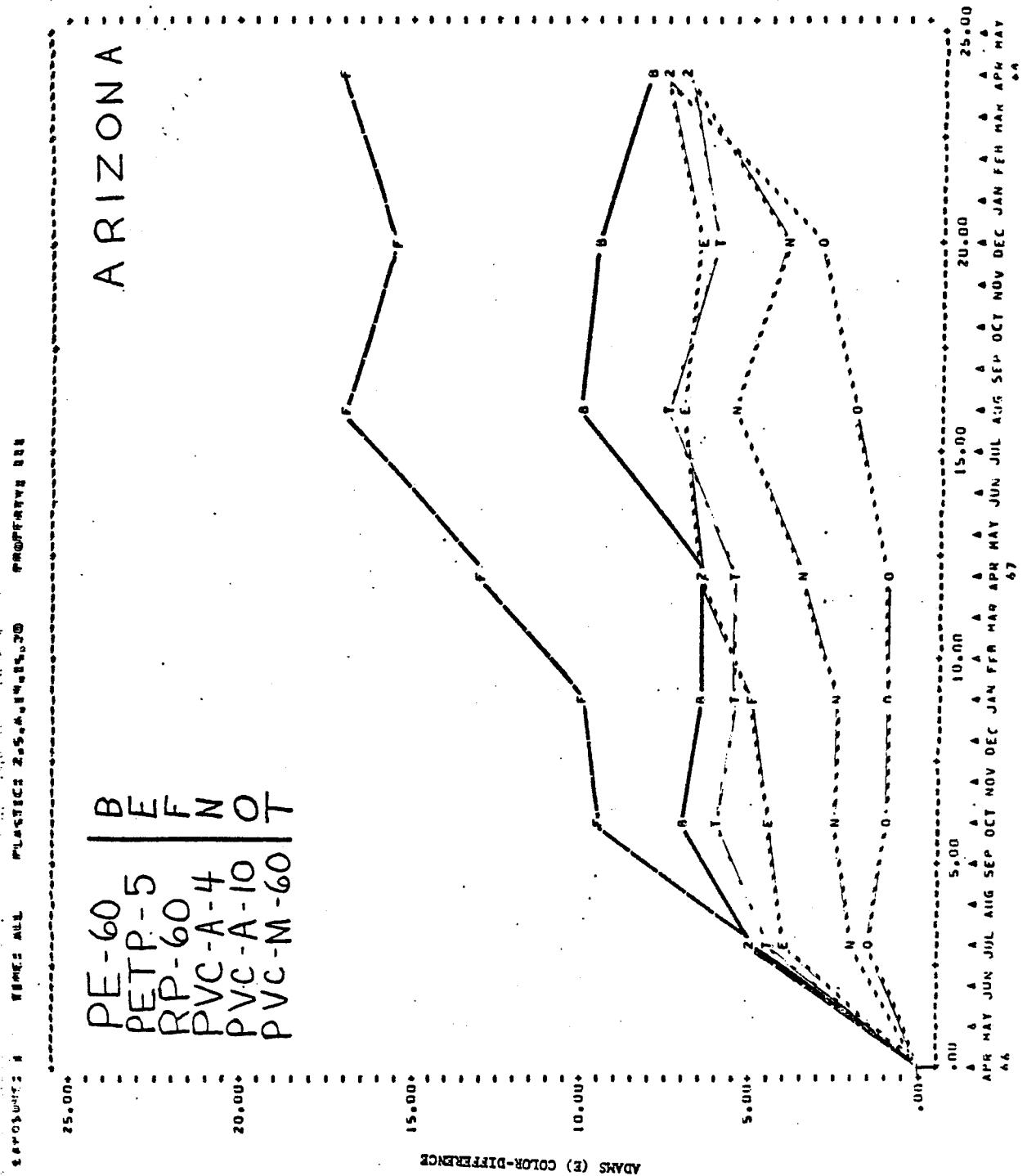


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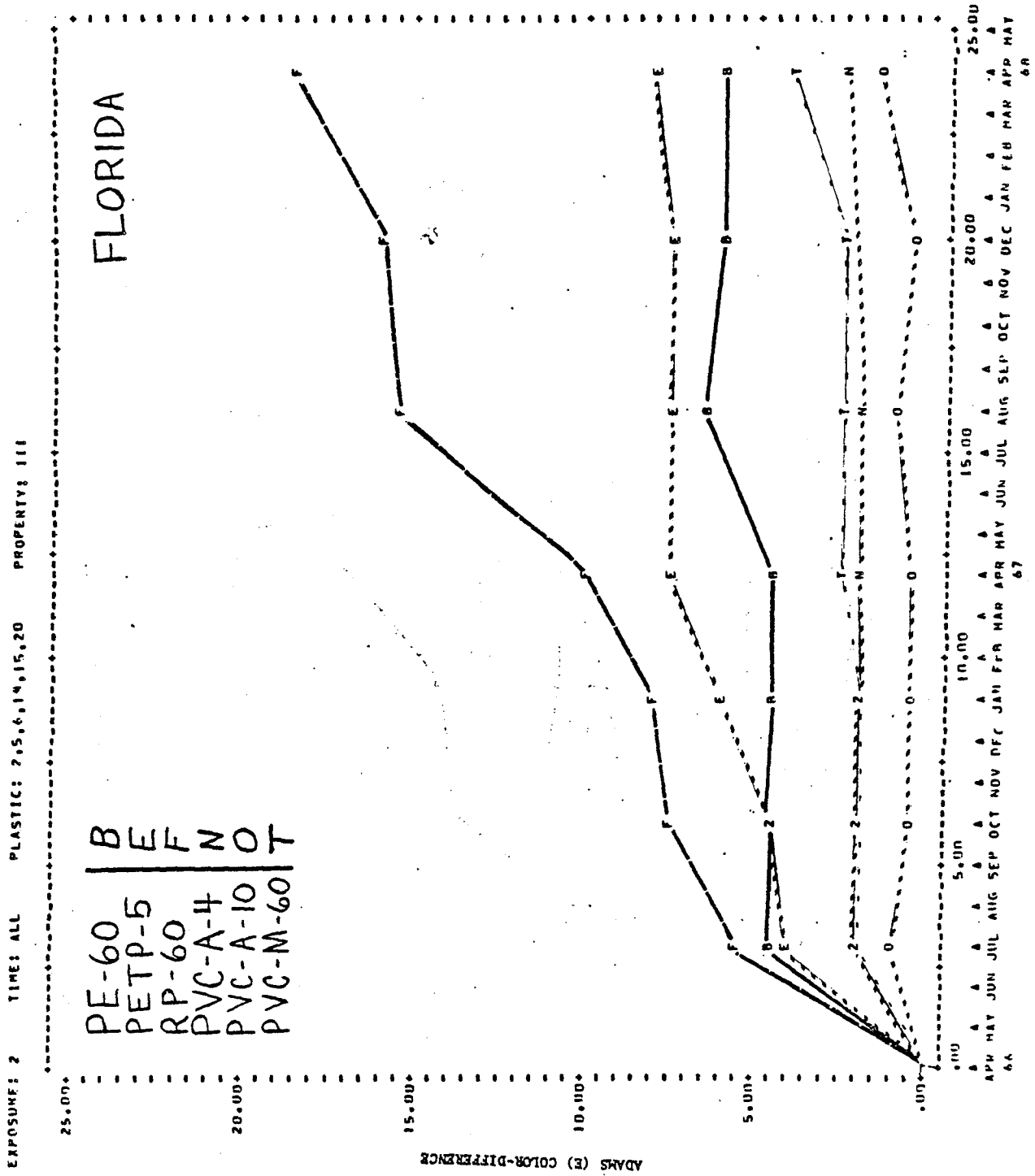


FIGURE 30

