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RETARDANT AIRDROP SIMULATION PILOT STUDY

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INTRODUCTION

Aircraft of several types have been used for nearly 20 years to deliver water or water-based mixtures onto fuel materials in the course of attempts to control or extinguish wildfires. There have been numerous revisions of techniques and changes of mixture composition during the years, most of them being the results of a desire to improve the distribution of the retardant, its wetting or coating action on the fuel, or its actual performance once it had been applied.

For example, it was recognized early that the thickness, or viscosity, of the retardant has some effect on the behavior of a free-falling, coherent mass of liquid (Davis 1959). Full-scale field tests in 1955 to 1959, using simultaneous drops of different compositions, showed by simple comparison that thickened materials reached the ground in a more coherent mass and in a shorter total length of time than water alone.

Other studies (MacPherson 1967) have been directed toward characterizing the performance of particular airplanes (and their tank mechanism). One current project is applying engineering principles to the design of a new load release system (Hawkshaw 1969). There have been several experimental studies (Wilcox et al. 1961) and at least one theoretical study (Garcia and Wilcox 1961) of the behavior of liquid volumes of various sizes falling from rest in still air.

In actual practice, viscosity is the most common, if not the only field measurement used to control the formulation operation. Much more extensive and sophisticated tests should be possible in the context of a fully equipped laboratory. However, there does not seem to be much evidence that there is any systematic attempt being made to use all possible modern instrumentation in relating measurable physical-chemical properties to the quality of full-scale field performance.

The purpose of the work described in this report has been to explore some of the measurements that could be made, and to determine the feasibility and advisability of launching a more detailed study. In the following two sections, the equipment and materials used will be described and their performance qualitatively but critically described.

SUMMARY

Based on the hypothesis that the spatial distribution on the ground of fire retardant materials, dropped from fixed-wing aircraft, must be a result of the physical properties of the retardant, a series of experiments has been run to measure the dispersal patterns obtained with materials of known density, viscosity, yield strength, and surface tension. The objective is the capability of predicting what the dispersal pattern will be from measurements made in the laboratory.

The experiments employed a 40 m.p.h. wind tunnel airstream and 100-ml. samples released 30 inches above the surface. An array of cups recessed into the surface trapped samples for weighing.

Correlation of the data shows that the density (specific gravity) of the mixture has a primary effect on the size of the dispersal pattern. It also shows that as viscosity and yield strength increase, the area covered increases to a maximum value and then decreases at very high values of viscosity (figs. 1 and 2). Surface tension varies considerably among the materials tested, but does not seem to be a major controller of the area covered.

Recommendations are made for future study that includes refined wind tunnel experiments and correlation of these with accurately monitored full-scale field tests.

EQUIPMENT AND MATERIALS

Attapulgite clay--water, Colloid 26--water, and CMC--water mixtures were prepared from material samples supplied by manufacturers from stocks used in blending brand name retardant products. The Fire-Trol sample came from stocks at the Missoula Retardant Base. The Poly-N used was from a test sample of 10-34-0 concentrate supplied by the manufacturer. The Phos-Chek samples also were supplied directly by the manufacturer, the CMC type being a standard product, and the Colloid 26 type being a group of three samples containing amounts of the thickener said to be sufficient to produce Brookfield viscosities of about 800, 1500, and 2200 centipoises. In each case, the formulation was accomplished by placing the indicated amount (table 1) a little at a time over about 1/2 minute of time, into 500 ml. of distilled water contained in a Waring Blender running at its "slow" setting. The blender was left on for a total of exactly 2 minutes. The mixture was transferred to a closed jar and stored overnight before use for wind tunnel tests or for physical property measurements.

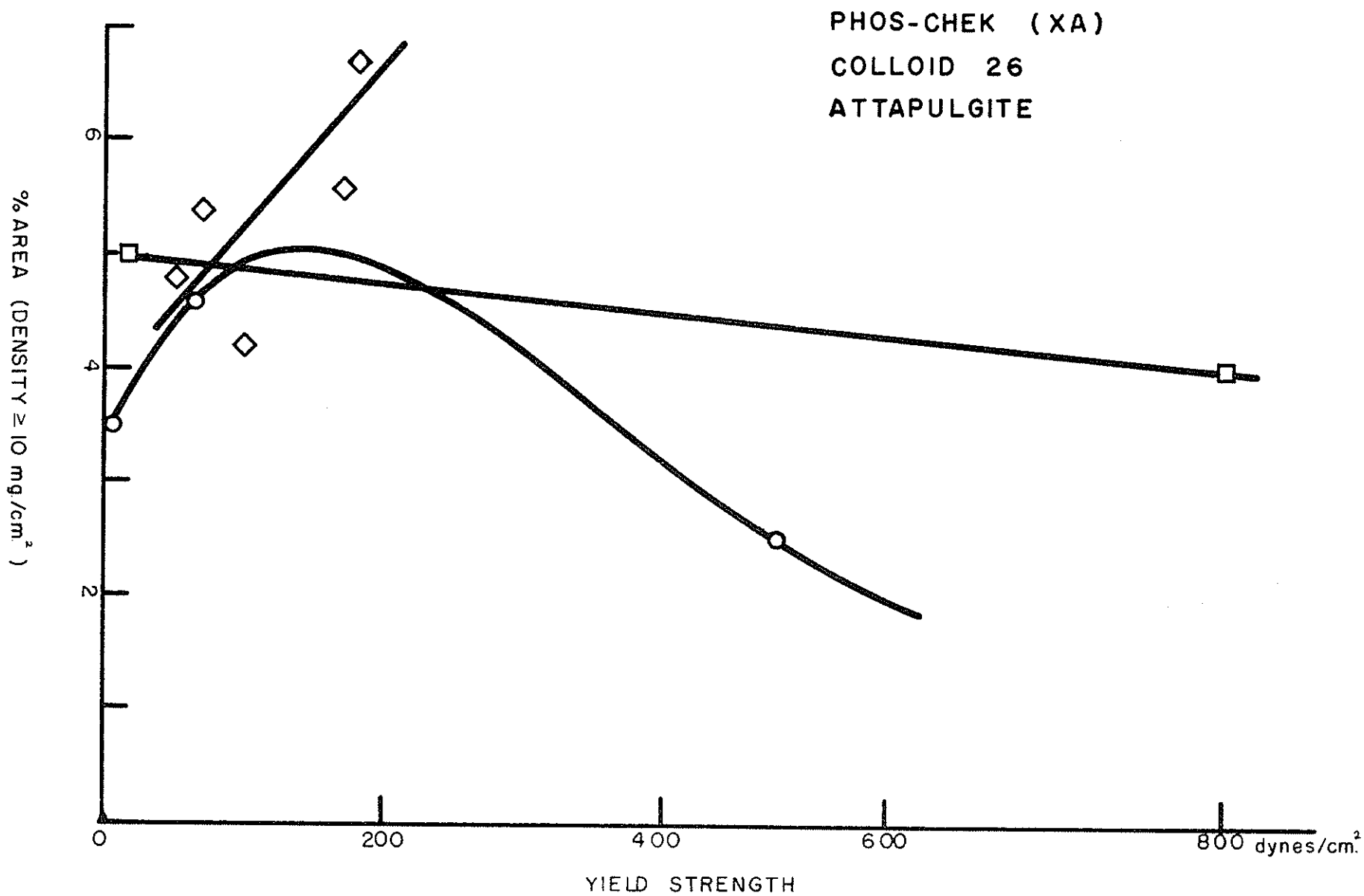
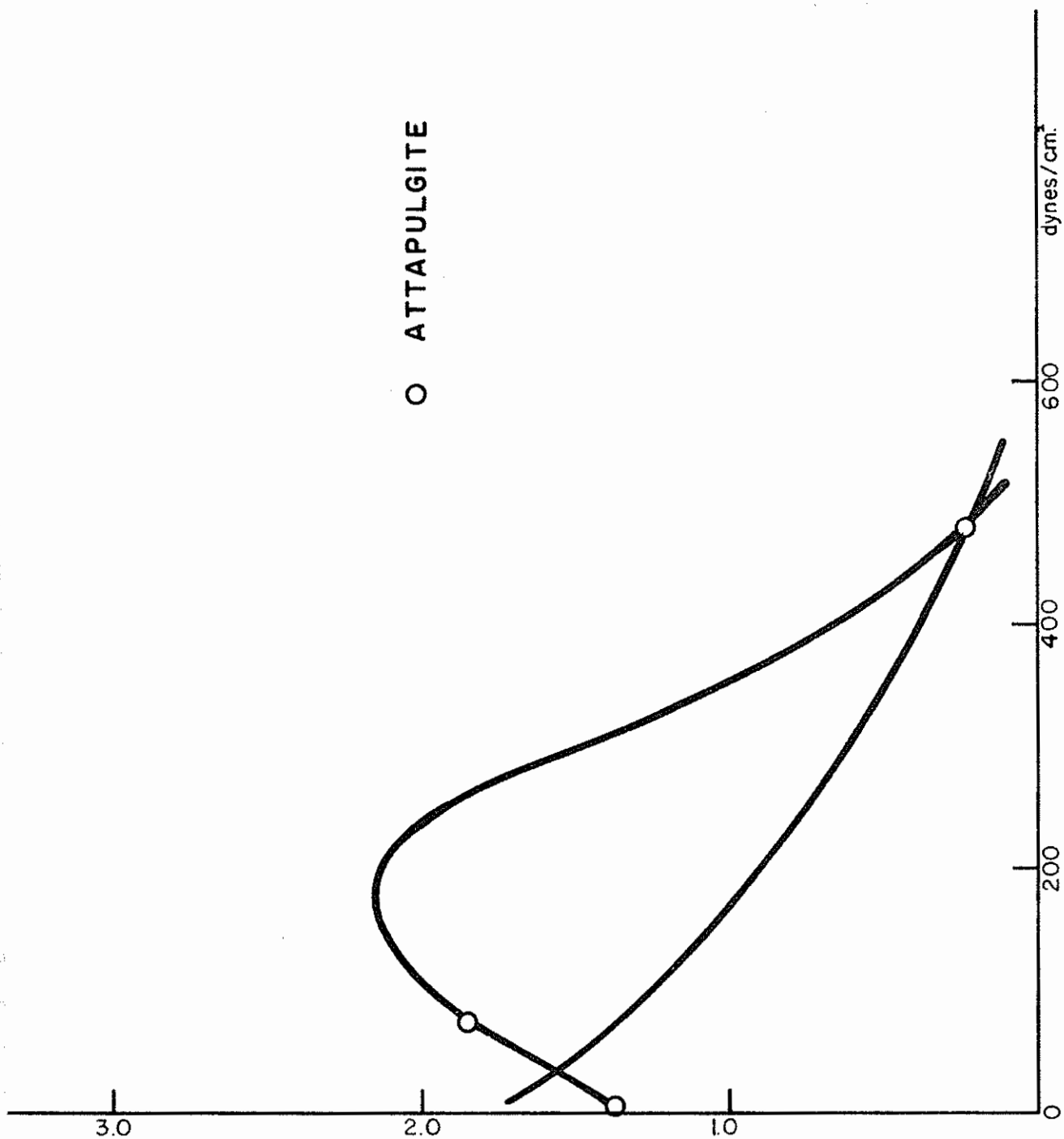

PHOS-CHEK (XA)
COLLOID 26
ATTAPULGITE
% AREA (DENSITY ≥ 10 mg/cm²)
6
4
2
0
200
400
600
800 dynes/cm²
YIELD STRENGTH

Figure 1



YIELD STRENGTH
Figure 2

Table 1

Sample No.	Material	Amount/500 ml. water
Att 1	Attapulgite clay	80.0 g.
Att 2	Attapulgite clay	40.0 g.
Att 3	Attapulgite clay	25.0 g.
Att 4	Attapulgite clay	60.0 g.
FT 1, FT 2	Fire-Trol 100	166.0 g.
CMC 1	CMC	7.0 g.
CMC 2	CMC	3.5 g.
CMC 3	CMC	5.0 g.
CMC 4	CMC	2.0 g.
PC 7	Phos-Chek 202	68.3 g.
PC 6	Phos-Chek 202	68.3 g.
XA 7	Colloid 26	8.0 g.
XA 3	Colloid 26	2.0 g.
PC 3	Phos-Chek 202XA	68.3 g.
PC 4	Phos-Chek 202XA	68.3 g.
PC 5	Phos-Chek 202XA	68.3 g.
PN 1	10-34-0 concentrate (Poly-N)	167 ml.
PN 2	10-34-0 concentrate (Poly-N)	84 ml.
PN 3	10-34-0 concentrate (Poly-N)	125 ml.

Densities were measured with Pyrex pycnometers containing about 25 ml. each.

Viscosity values were obtained from a portable Brookfield Viscometer, using spindle No. 4, and allowing 1 minute of rotation at 60 r.p.m. before making the measurement.

The Haake Rotovisco yields data from which the yield strength can be derived. By varying the speed of rotation of the bob, values of shear stress were observed for a series of values of the rate of shear. When these values are plotted and the curve extended to zero rate of shear, the shear stress axis intercept is defined as the yield strength. A medium viscosity measuring beaker and a MV-1 rotor were used.

In order to measure the surface tension of the liquids, a tensiometer of the "Jolly Balance" type was devised. The sample vessel, a 4-inch Petri dish, rests on a platform about 8 inches long, hinged to a solid support on one end and suspended by a waxed linen cord at the other end. The cord is fastened to the shaft of a synchronous motor. The motor speed and shaft diameter are chosen so that the vertical (downward) rate of motion of the center of the sample is about 12 mm. per minute. A wire ring is suspended in such a way that the plane of the ring is parallel to the surface of the sample, and its weight is borne by a microbalance-arm attachment on a Statham strain gage. The gage has a 60-gram capacity, while the 2-3/4-inch beam arm has a mechanical advantage of 10.

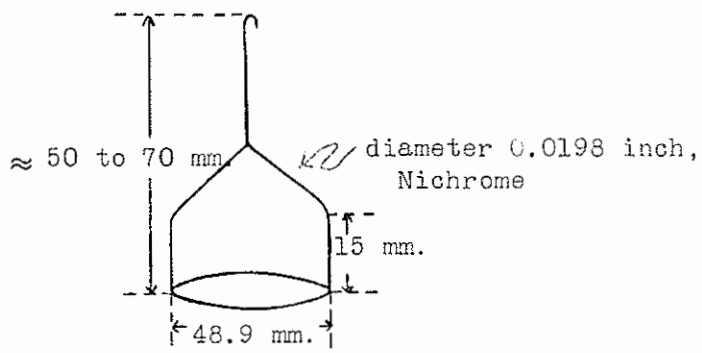


Figure 3.--Tensiometer ring.

The strain gage signal is amplified by a Statham Universal Readout (Model UR5) and recorded by a Bausch and Lomb VOM5 recorder. Calibration is affected by adjusting sensitivity and balance controls until hanging a 3.00-gram weight on the balance hook (the ring already being in place) causes the recorder pen to move from exactly zero to exactly full scale.

Air velocity in the wind tunnel was controlled at 40 m.p.h. (±0.5 m.p.h. estimated fluctuation limit). The conditions of temperature, pressure, and humidity which were not controlled, were in the ranges of 82° to 85° F., 680 to 685 mm. Hg. (total), and 20 to 22 percent relative humidity. The wind tunnel is of square cross section, 36 inches by 36 inches.

The sample release mechanism holds 98.8 ml. (fig. 4). It consists of a spring-actuated cylindrical container which, on release, moves away from a flat, gasketed end plate, sliding over a fixed piston. The liquid contained in the horizontal cylinder and between the end plate and the piston is thus left free to fall with zero initial momentum. Liquid-tight closure is provided by a 1/16-inch by 1-3/8-inch rubber O-ring recessed into the edge of the piston and by a silicone rubber facing (G.E. "RTV") on the end plate. Filling is accomplished through a 1/2-inch hole in the end plate.

The pattern measurement system is an array of 480 poly-lined paper cups (average lip diameter 4.59 cm.) positioned in 1-3/4-inch holes spaced 3 inches center-to-center in 1/4-inch plywood sheets (fig. 5). The array is 10 cups wide and 48 long (parallel to wind direction). The plywood is mounted up on 1-inch blocks to allow the cup rims to be flush with the upper surface of the tray. Masking tape strips are effective in preventing dislodging of cups by holding the upwind edge of the lip against the tray. The vertical distance between the center line of the release mechanism cylinder and the tray surface is 30-1/2 inches.

Photographic observation of the release of liquid in the wind tunnel was conducted using two different camera and light combinations. In order to determine whether the release mechanism functioned rapidly enough, and to observe directly the sequence of motions and shapes during dispersal, a high speed motion picture camera was used (Traid 200). A battery of four floodlights (320 watts each) was located inside the tunnel, downwind, about 6 feet from the release point. Another light (500 watts) was located outside the tunnel, facing inward at the lower left corner of the tunnel window, making an angle of about 60° with the camera's line-of-sight. Camera-to-subject distance was about 10 feet. The film was Kodak High Speed Ektachrome Type B. Four different materials were each dropped twice, once using a 25 mm. lense, and once using a 75 mm. lens: CMC 2, CMC 4, PC 1, and water (see compositions and properties in table 1 and table 2).

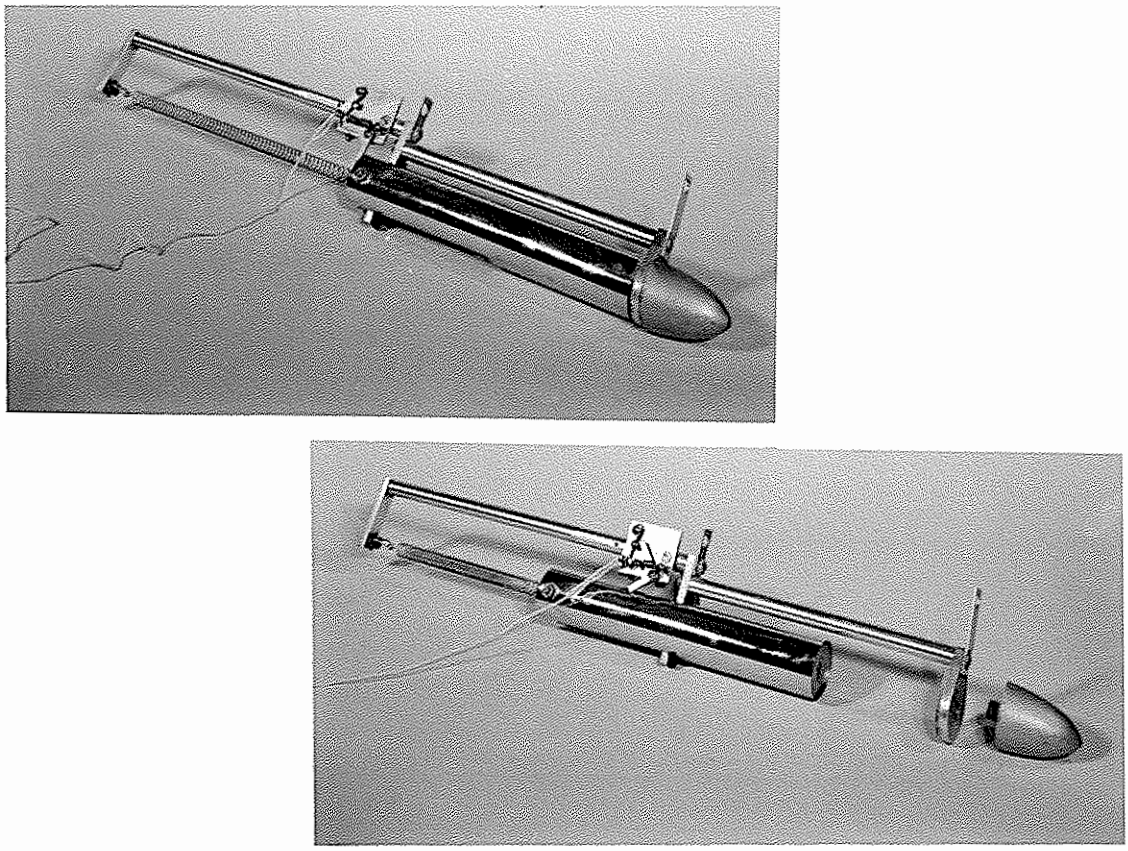


Figure 4.--Sample release mechanism.

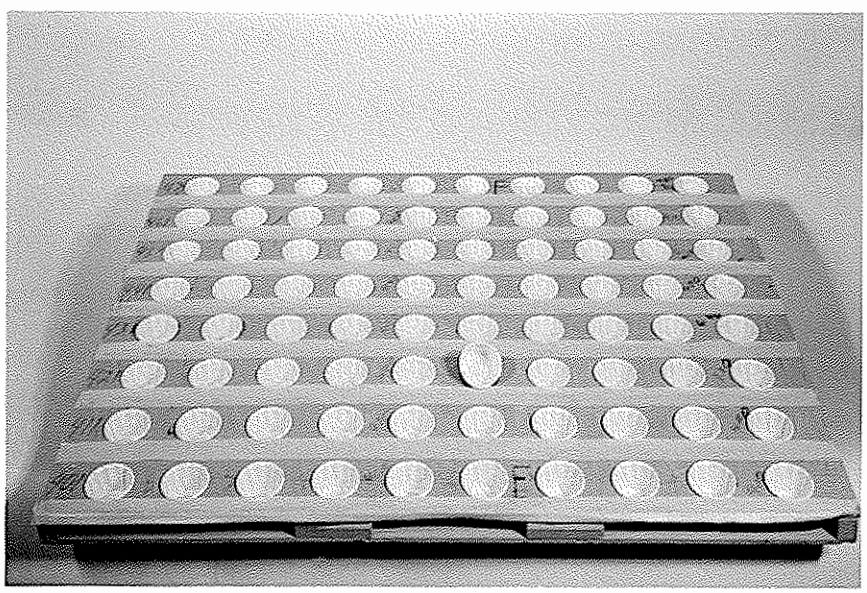


Figure 5.--Sample cup tray (one of six trays that are used simultaneously side by side).

Sample		Date	Composition	d Density G./ml.	n Brookfield viscosity Centipoise	Y Yield strength	S Surface tension Dyne/cm.	Dispersal pattern areas: D ≥ 10 (Percentages)	Dispersal pattern areas: D ≥ 1.8 (Percentages)	Dispersal pattern areas: Total, D ≥ T (Percentages)	Leveling factor percent area divided by average maximum density: D ≥ 1.8	Leveling factor percent area divided by average maximum density: Total, D ≥ T	Average maximum density Mg./cm.^{2}
Attapulgite + water	Att 1A	7/16	13.8 percent clay	1.071	4240	450	73.0	2.3	9.4	37.7			**
	Att 1B	7/29	13.8 percent clay	1.075	*	480	77.2	2.5	9.4	38.8	0.2227	0.937	41.4
	Att 2A	7/15	7.41 percent clay	1.041	490	37	71.6	2.9	11.7	58.8			**
	Att 2B	7/29	7.41 percent clay	1.039	670	72	73.4	4.6	22.7	55.4	1.85	4.50	12.3
	Att 3A	8/1	4.76 percent clay	1.025	190	5	71.9	3.5	18.1	65.4	1.37	4.95	13.2
	Att 4A	8/22	10.7 percent clay	1.046	2865	320	75.1	--	--	--	--	--	--
Fire-Trol 100	FT 1A	7/29	9.0 percent clay	1.144	2240	170	78.3	5.6	36.5	76.5	2.03	4.25	18.0
	FT 1B	8/1	9.0 percent clay	1.140	2415	200	76.7	4.6	29.2	80.4	1.70	4.68	17.2
	FT 2A	8/22	9.0 percent clay	1.147	2850	230	77.8	--	--	--	--	--	--
CMC + water	CMC 1A	7/16	1.38 percent CMC	1.002	780	20	70.5	4.4	11.1	36.5			**
	CMC 1B	7/29	1.38 percent CMC	1.004	1005	20	72.7	4.6	18.8	35.6	1.13	2.13	16.7
	CMC 2A	7/15	0.70 percent CMC	0.999	150	20	72.4	4.2	15.8	37.9			**
	CMC 2B	7/24	0.70 percent CMC	0.999	155	20	72.3	1.9	22.1	69.4	2.21	6.94	10.0
	CMC 3A	8/22	0.99 percent CMC	1.003	260	10	73.1	--	--	--	--	--	--
	CMC 4A	7/24	0.40 percent CMC	0.999	55	30	72.9	4.0	14.6	63.6	0.86	3.75	17.0
Phos-Chek 202 (CMC)	PC 1A	7/24	1.02 percent CMC	1.070	410	5	64.6	3.8	10.2	76.5	0.24	1.89	40.5
	PC 1B	7/30	1.02 percent CMC	1.070	650	20	63.2	4.6	11.7	69.2	0.24	1.41	49.2
	PC 6A	8/22	1.02 percent CMC	1.075	1125	60	70.9	--	--	--	--	--	--
Colloid 26	XA 1A	7/30	1.57 percent XA	0.987	9050	800	*	4.0	5.8	10.0	0.05	0.086	115.8
	XA 3A	8/1	0.40 percent XA	0.999	200	15	71.1	5.0	27.7	61.7	2.77	6.17	10.0
Phos-Chek 202XA (Colloid)	PC 3A	7/30	≈800 cp	1.059	*	50	70.1	4.8	20.6	63.1	0.92	2.82	22.4
	PC 3B	7/31		1.070	1040	70	71.4	5.4	26.1	66.1	1.48	3.73	17.7
	PC 4A	7/31		1.070	1680	120	69.9	5.6	14.6	59.4	0.44	1.78	33.3
	PC 4B	7/31	≈1500 cp	1.071	845	100	70.3	4.2	17.7	66.3	0.78	2.92	22.7
	PC 4C	8/22		1.068	1555	75	67.4	--	--	--	--	--	--
	PC 5A	7/31	≈2200 cp	1.070	2010	180	71.6	6.7	26.5	60.4	1.07	2.45	24.7
Poly-N 10-34-0	PN 1A	7/23	1:3	1.119	25	8	76.6	6.3	36.7	74.0	3.98	8.04	9.2
	PN 1B	7/25		1.118	--	-(8)	79.3	6.3	29.0	66.7	2.40	5.50	12.1
	PN 2A	7/23	1:6	1.069	--	0(4)	74.9	3.5	11.7	68.5	0.72	4.23	16.2
	PN 2B	7/25		1.081	--	-(4)	79.0	1.9	19.8	64.8	2.45	8.00	8.1
	PN 3A	8/22	1:4	1.103	--	-(6)	77.6	--	--	--			
	W 1A	7/22		0.999	0	0	73.2	1.3	8.8	59.2			**
	W 1B	8/1		0.999	0	0	--	3.5	30.6	67.3	3.40	7.48	9.0
	W 2A	7/22		0.999	0	0	--	2.9	18.8	63.8	1.76	5.95	10.7
	W 2B	7/30		0.999	0	0	--	3.3	18.1	63.6	1.97	6.90	9.2

* Value not measured.

** Release mechanism maladjustment.

With the objective of making measurements of the relative distributions of droplet sizes in midair after breakup of the main liquid mass, a Graflex Crown Graphic camera with a Kodak Ektar f4.5 lens was employed at f22. Subject distance was about 3-1/2 feet. Stroboscopic light sources were used, one to the left at about 45° to the camera direction, the other below and slightly to the right (Synctron 200B, Dormitizer Co.). To avoid a highlight reflecting from the back wall of the tunnel, the camera was aimed upward at a slight angle (15 or 20 degrees from horizontal). Film was Polaroid Land Packets Type 55 P/N.

The apparent sizes of droplets, as viewed through the eyepiece reticle of a 12.5x binocular microscope, were compared to that of a 12-inch ruler, photographed suspended under the release mechanism.

EQUIPMENT PERFORMANCE

The measurement of viscosity with the Brookfield instrument has been, and should remain, very popular because it is quite rapid, simple, and reproducible. Since the retardant materials are non-Newtonian in behavior, the viscosity as measured with the Rotovisco can agree with that of the Brookfield at only one rate of shear (for the one chosen Brookfield shear rate).

The use of the Rotovisco to measure yield strength is briefly mentioned by Van Wazer et al. (1963). As described in direct conversation by W. W. Morgenthaler, this method involves rapid engaging and disengaging of the rotor drive gears, producing enough rotation of the drive sahft to give a dynamometer signal (measurement of torque) but not enough to move the rotor very much at all. The yield strength, then, is the maximum force that can be applied to the rotor without causing rotation. In the work being reported here, attempts also were made to measure yield strength by slowly turning the beaker, by hand, and observing the stress produced before any shearing occurred. Neither of these techniques seemed to work well. It is not easy to cause a desired amount of shaft rotation using the gear lever, and duplicate run data did not agree well. The graphs of shear stress against shear rate are smooth enough to be believable, in most cases an extrapolation to zero shear rate does give an intercept on the shear stress axis, and duplicates usually give similar values. Samples having attapulgite clay present in rather large amounts yield more uncertain results because the shearing occasioned by the measuring instrument changes the sample material (increases viscosity and yield strength).

The measurement of surface tension was verified by comparing experimental results on certain pure liquids with values found in standard reference books. For example, the accepted value for water at 25° is 72.3 dynes/cm. The observed value was 73.2 dynes/cm. Similar comparisons were seen for ethanol, chloroform, and acetone. The apparent value was independent of the rate of motion of the sample platform, both for rates somewhat slower and considerably (two or three times) faster than the one used here. The effect of temperature on the surface tension is only a few hundredths of a dyne/cm. over a range of several degrees. This is at least 10x smaller than usual differences between replicate samples. It is quite important, however, to be sure that the sample vessel and the ring are carefully washed and thoroughly rinsed (and then not touched with anything) for each run. It is also true that careful attention must be paid to preserving the shape of the wire ring and its horizontal attitude when suspended from the balance hook. This adjustment also includes achieving, as nearly as possible, simultaneous release from the liquid surface of all parts of the ring at the same time. Accuracy is lost if the ring breaks loose from one side first and swings violently.

To secure dependable operation of the release mechanism, it was necessary to lubricate the O-ring with a few drops of light mineral oil. This was applied to the inside of the cylinder behind the piston. It is likely that the need for lubricant could be eliminated by using an O-ring with slightly larger diameter (3/32 inch or 1/8 inch) and by adjusting the groove depth to cause slightly less pressure against the inner wall of the cylinder.

Because of the adherence of some of the sample material to the end plate and piston of the release mechanism and the spreading of some along the outside of the cylinder by the airstream, the volumn actually released into the air is about 90 percent of the volumn contained. This applies to Phos-Chek and Fire-Trol of nominal viscosities.

The average length of time for complete opening of the sample release mechanism was 0.082 second, as measured from runs 5, 7, and 8 of the motion picture film. This was adequately rapid; motion of the main portion of the sample was negligible during that time. The front portion of the sample, within a centimeter or so of the end plate, had begun to fall and enter the airstream by the time the cylinder reached the end of its travel.

The impact of the cylinder on the recoil pads causes vibration of the whole mechanism. No disturbance occurs at the front, because the sample has moved out of contact with the end plate. At the rear, a small wave or ridge of liquid is sometimes propelled downward by the motion of the piston against the portion of the sample adjacent to it. (See frames 15 to 17 in run 5, and frames 19 and 20 in run 8 of the motion picture film.) This is a fairly small effect, and a firmer mounting of the mechanism to the wind tunnel ceiling should virtually eliminate it.

The handling and weighing of the sample cups was performed as quickly as possible, to minimize error due to evaporation of water. From a few double weighings of cups containing small but measurable amounts of material (greater than "trace"), losses are estimated at 10 to 20 percent (maximum). Loss from larger samples would be a much smaller percentage. The average tare weight was 1.01 ± 0.02 grams per cup. The likely weighing error was ±0.01 grams. Weights less than 0.03 grams were recorded as "trace." Overlays of "Saran Wrap" were used to cover the samples as soon as the cups were removed from the wind tunnel trays.

The cup contents data were reduced to mg. retardant per square centimeter of horizontal surface area and entered on scale drawing plots of the cup array. Contours of equal density were drawn by enclosing all points whose density values fell at or above certain arbitrary values, namely: 1.8, 3, 10, 50, and 200 mg./cm.^{2}. The areas represented within these contours were computed by counting the number of cups involved and dividing by 480, the total number of cups in the trays. The data from one run, FT 1B, were handled in a way that was more time consuming, but conceivably might have been more correct (or at least meaningful). Iso-density contours were located for 1.0, 3.0, 5.0, 10.0, 20, 50, and 100, by interpolating between neighboring cup positions to find discrete points of integral density value. The areas enclosed in these contours were measured with a planimeter. Neither the gross appearance of the dispersal pattern nor the numerical area values were different enough from the more simple method to indicate significant error. The areas were the same within a few percent of their own sizes.

The Traid 200 camera probably yielded photographs as good as it is capable of making. The color film used made the visual presentation of the Phos-Chek release to be quite impressive. The single-frame enlargements suffered some from being made on black-and-white paper.

It is clear that the single exposure photos made with the Graflex camera and stroboscopic light source do reveal much more detail about the configuration of the liquid and the sizes of the drops than any one of the single-frame prints from the Traid 200 film. However, successive events in the dispersal of any one sample are not revealed. Also, only about one-half of 1 percent of a given 100 ml. charge seems to appear, in any one Graflex photo, in the form of droplets that are small enough not to be subject to further breakup before impact. This places drop-size distribution studies on a rather insecure basis.

Synchronization of the Graflex shutter action with the position of the falling liquid must be made independent of the human eye-hand reflex if this technique is used again. None of the photos obtained was really well-centered in the field of view. Correspondence with the Graflex factory might reveal that automatic shutter actuators, and perhaps even photoelectric sensors, are standard items.

The Polaroid Land film was useful in this work because of the time saved in evaluating the photographic setup and determining whether enough of a given sample was in the field to make some drop-size measurements possible. Better control of exposures would make it possible to use ordinary film, chosen for optimum speed and grain size. With the Polaroid film, much of the size estimation data carries an estimated uncertainty of ±10 to ±50 percent of the indicated diameters.

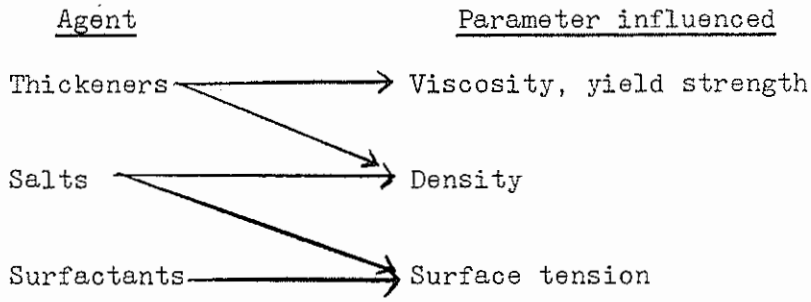
TABULATION

In table 2 are given the measured and calculated values pertaining to the material tested. All quantities are self-evident except perhaps the one termed "Leveling Factor." This quantity may not be better than simple area as a measure of the quality of performance of a retardant mixture but it is intended to be a numerical evaluation that is proportional to the area covered (to any given density) and inversely proportional to the magnitude of the density near the centerline of the pattern. Thus, if a given quantity of retardant spreads out to the maximum area consistent with maintaining some minimum overall density, it will score highest on the leveling factor scale. The opposite is true of a retardant that fails to spread out. The "magnitude of the density" mentioned is evaluated by examining each row of cups perpendicular to the wind direction, noting the size of the largest value of density in that row, and calculating the arithmetic mean of all such largest values for all the rows in the dispersal pattern.

$$\text{Leveling effect} = \frac{\text{Area}}{\text{Average maximum density}}$$

CORRELATIONS

The diagram below indicates some general relationships that are worth noting:



There are three major types of ingredients in one column and three measurable physical properties in the other. Viscosity and yield strength seem always to be related, although not always directly proportional to each other. All of the thickeners have an effect on viscosity (and yield strength). This is hardly a profound observation since that is the purpose of their presence. However, it is not so obvious, but true, that none of them have any effect on the surface tension of the mixture. The polymers and gums have essentially zero effect on density, while the clays have a considerable effect. The concentration of salts (DAP, etc.) effects density and surface tension, but has virtually no influence on viscosity. The presence of any surface active agent has a much more pronounced effect on surface tension than either of the other two ingredient types has on any of the measurable properties.

Distinct differences are indeed observed among the several materials tested, both in the sequence of events in midair during breakup, and in the dispersal pattern on the impact surface. These differences can only be due to mechanical effects (forces) acting between the two fluids as the retardant penetrates the airstream. Thus, it is reasonable to expect variations in physical properties (viscosity, density, etc.) to be associated with changes in dispersal behavior. The simplest of such relationships would be a linear or regular curvilinear trace when numerical values of two such quantities are graphically compared. A considerable number of such relationships have been tried, using data from table 2.

Yield Strength, Viscosity, Surface Tension Versus Area

In figures 6, 7, and 8, the variations of the total area covered with yield strength, viscosity, and surface tension are shown. The data for Colloid 26 are meager, to say the least, and the general shape of the curve is inferred by those of the other materials. The areas plotted in figure 1, those of contour lines for density ≥ 10 mg./cm.^{2}, show that up to a certain point, the area increases with yield strength. The opposite slopes of the Phos-Chek XA lines in figures 1 and 6 are consistent and complementary, not contradictory.

Yield Strength Versus Leveling Factor

Figure 2 indicates the variation of the leveling factor (based on areas where density ≥ 1.8 mg./cm.^{2}) with yield strength. The ranges shown reflect the uncertainty in the leveling factor value caused by the fact that the average deviations, for replicate groups of runs, were ± 14 percent of the measured value for both the areas (≥ 1.8 mg./cm.^{2}) and for the average maximum density. With the limited amount of data available, it is not possible to decide which of the two curves is more reasonable. The peaked shape could be caused by a maximum in the area or a minimum in the average density, as yield strength increases.

Yield Strength Versus Viscosity

Figure 9 reveals that the yield strength is from 6 to 10 percent of the viscosity for water-attapulgite and water-Colloid 26 mixtures, and for Fire-Trol and Phos-Chek (containing Colloid 26). Water-CMC mixtures and Phos-Chek (containing CMC) had uniformly low and essentially constant yield strengths, although the viscosities also were low (1100 cps. or less).

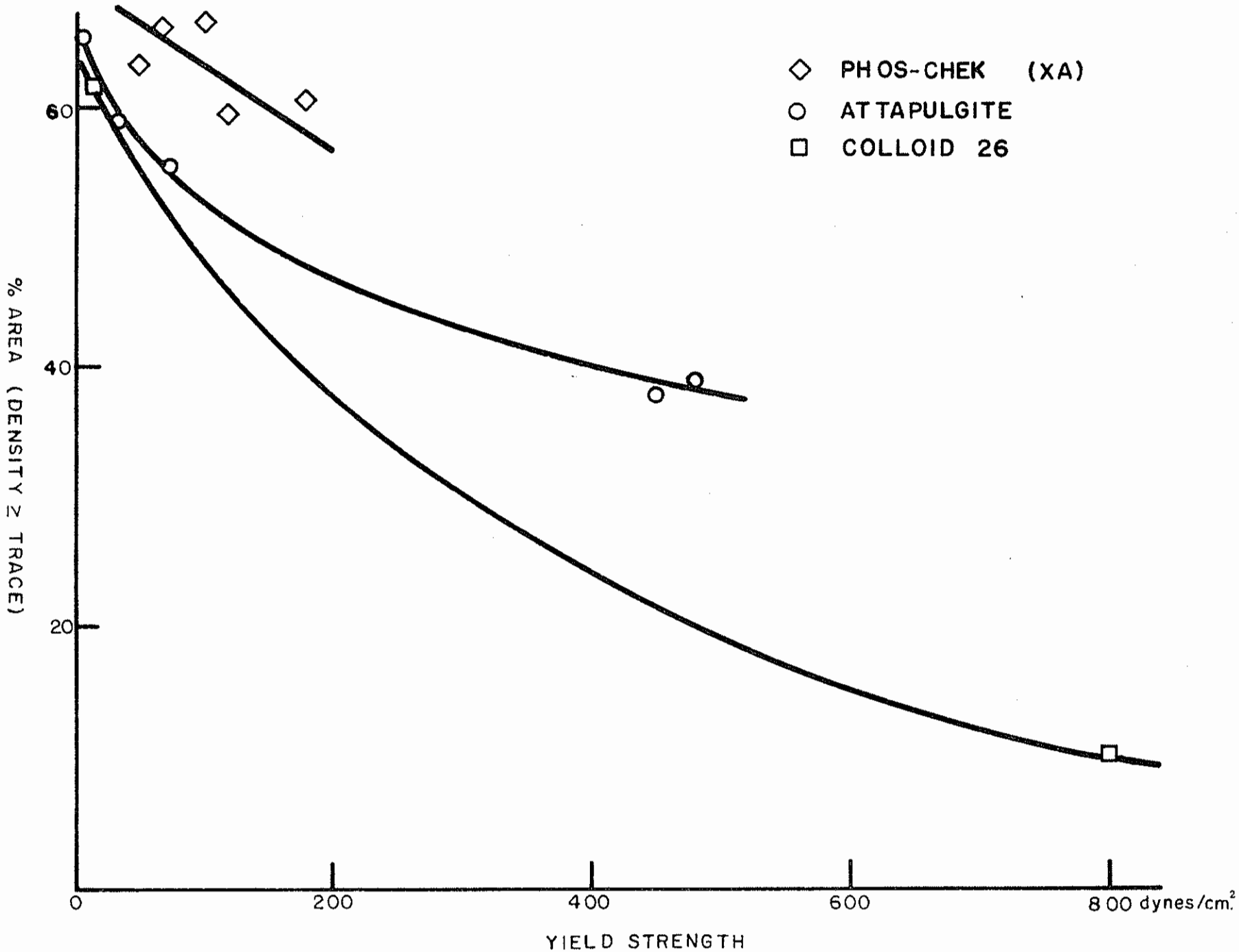

PHOS-CHEK (XA)
ATTAPULGITE
COLLOID 26
% AREA (DENSITY ≥ TRACE)
60
40
20
0
200
400
600
800 dynes/cm.²
YIELD STRENGTH

Figure 6

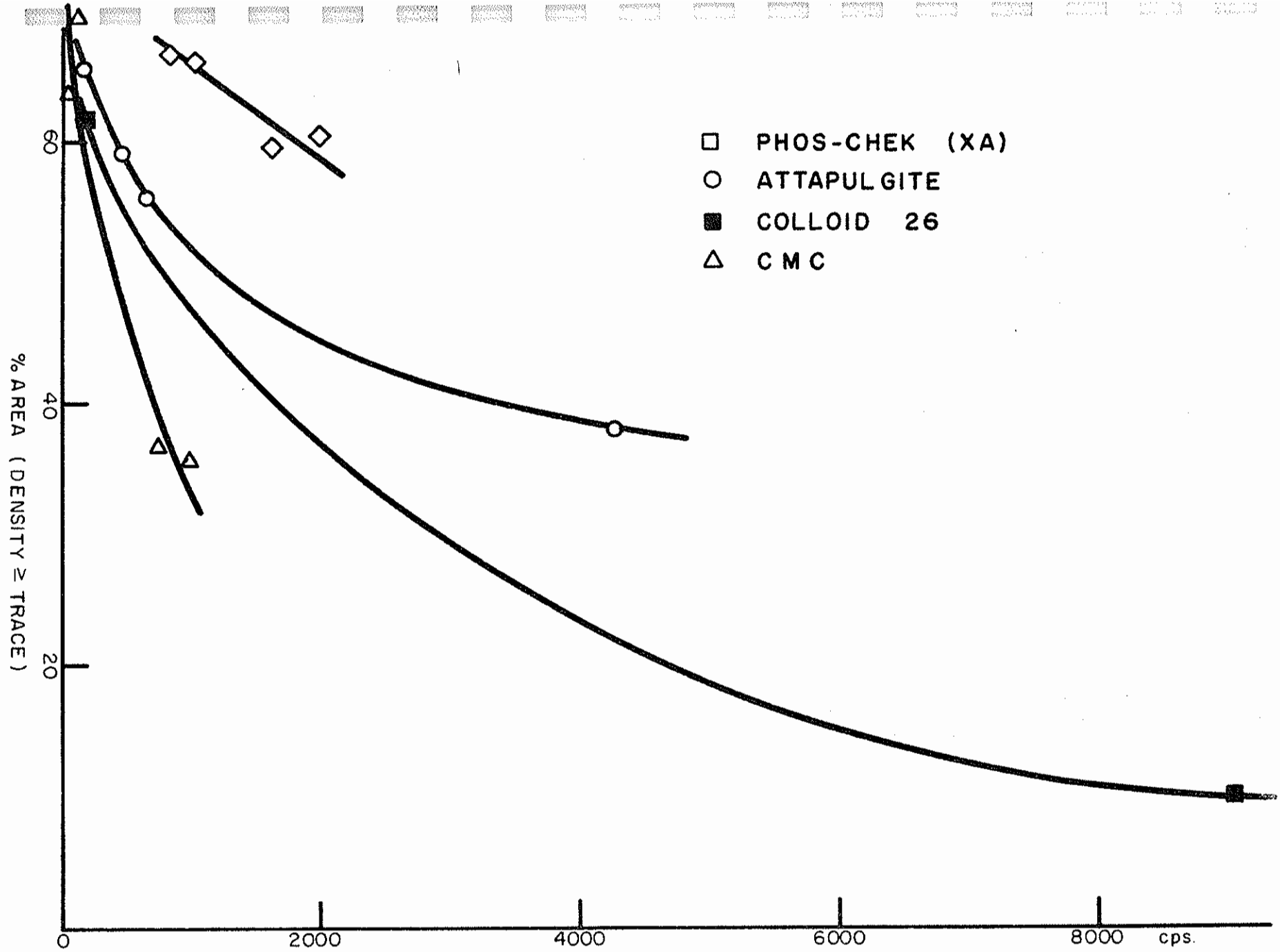

PHOS-CHEK (XA)
ATTAPULGITE
COLLOID 26
CMC
% AREA (DENSITY ≥ TRACE)
60
40
20
0
2000
4000
6000
8000
cps.
VISCOSITY

Figure 7

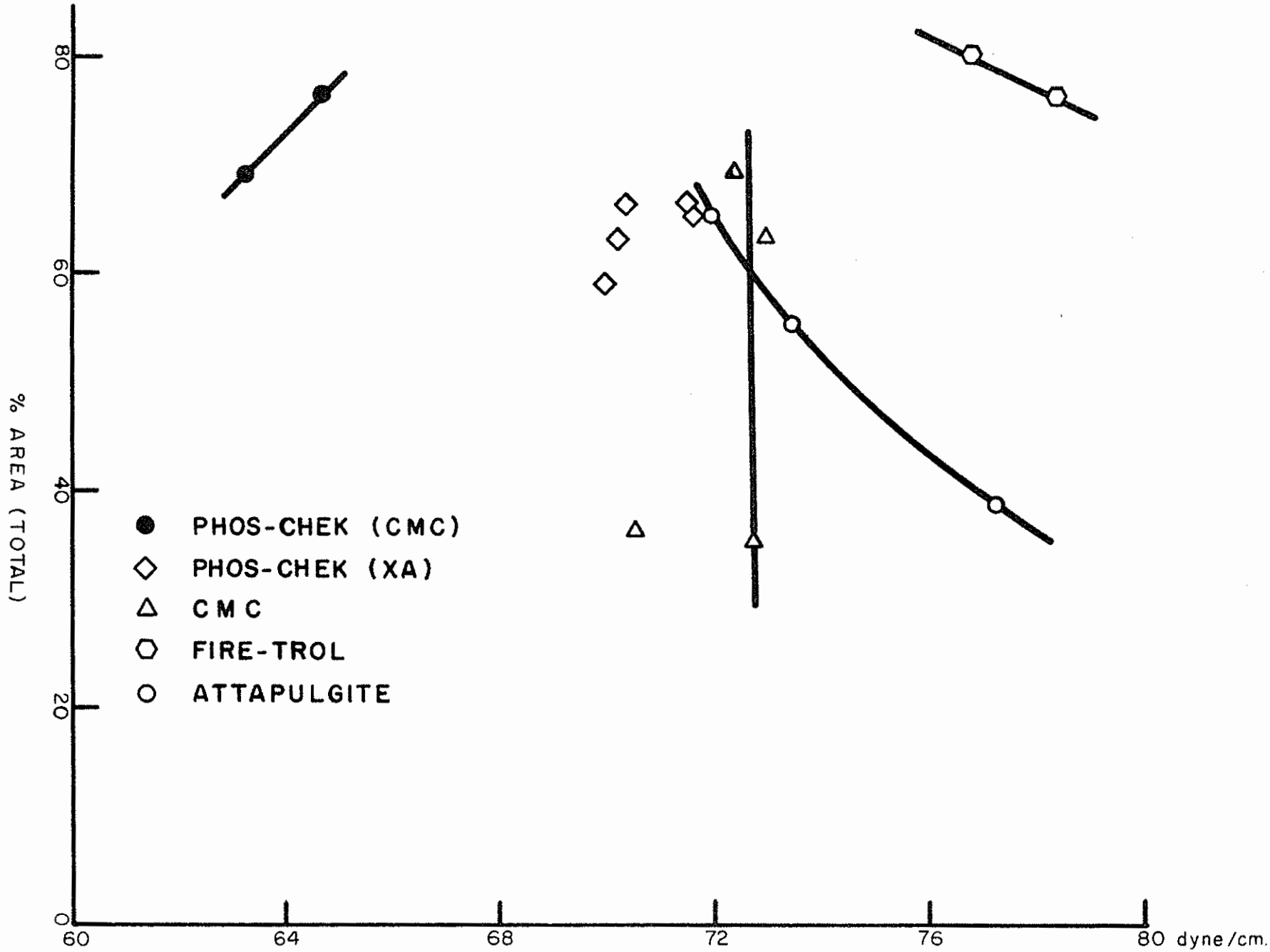
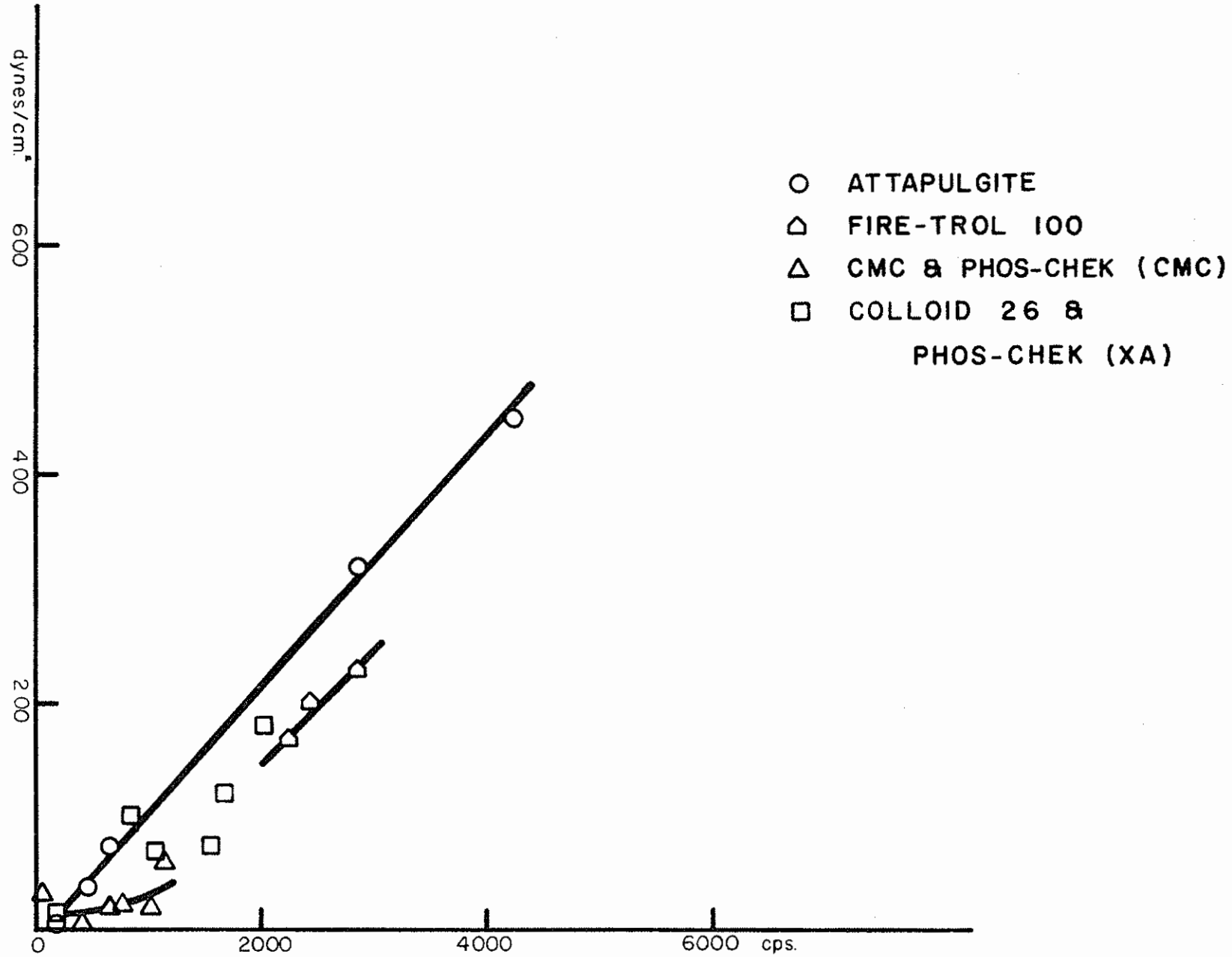

% AREA (TOTAL)
0
20
40
60
80
60
64
68
72
76
80 dyne/cm.
SURFACE TENSION
PHOS-CHEK (CMC)
PHOS-CHEK (XA)
CMC
FIRE-TROL
ATTAPULGITE

Figure 8



YIELD STRENGTH

VISCOSITY

Figure 9

Surface Tension

When all the samples run were considered in the order of their surface tensions, a significant grouping appears (fig. 10). The precision of the measurement is felt to be in the order of ±2 dyne/cm. Nearly all of the values for the two component mixtures (water and one of the three: CMC, attapulgite clay, or Colloid 26) lie within ±2 dynes/cm. of the value for water alone, 73.2 dynes/cm. When ammonium phosphate alone is present (as in 10-34-0) the surface tension is high. When clay is present with the salt (Fire-Trol), it does not prevent the salt from having the same effect that it has when alone. The marked depression of the surface tension in Phos-Chek mixtures cannot be logically ascribed to the CMC and Colloid 26; they have no effect alone. The corrosion inhibitor in all Phos-Chek formulations has a chemical identity that should cause it to have considerable potency as a surface active agent. None of that particular substance was available for test, but the addition of 0.5 volume percent as a liquid detergent (a "Bestline" cleansing agent) caused the observed surface tension of distilled water to fall to 32 dynes/cm.

Droplet Size Distribution

The measurement of the size distribution of droplets during the breakup process produced the graphs shown in figure 11. A high, narrow peak would indicate that the material tended to produce a uniform spray, with many of the drops being of about the same size. The highest frequency observed was for 1.4 mm. drops of pure water. However, two other materials showed values nearly as high, and the difference may not be significant. It is clear that a trend exists, with high viscosity in the absence of salt (Att) producing the widest range of sizable frequencies. As salt content is increased, or as viscosity is decreased, the shape and position of the drop size distribution curve approaches that of water.

There is an apparent relationship between the leveling factor and the most probable drop diameter. The samples actually used for the drop diameter measurements were not also subjected to dispersal pattern determinations. The leveling factors used in figure 12 were observed for samples nominally identical to the droplet size samples, or were obtained by interpolation from the trend of leveling factors with percentage composition. This correlation should be regarded as quite tentative; there are only a few data points, and both it and the droplet size distribution curves themselves are derived from measurements made on less than 1 percent of the sample in each case. The general shape of the distribution may reflect only the fact that the Phos-Chek

SURFACE TENSION

THE RECTANGLES INDICATE THE PRIMARY INGREDIENTS PRESENT AND THE RANGES OF SURFACE TENSION VALUES OBSERVED.

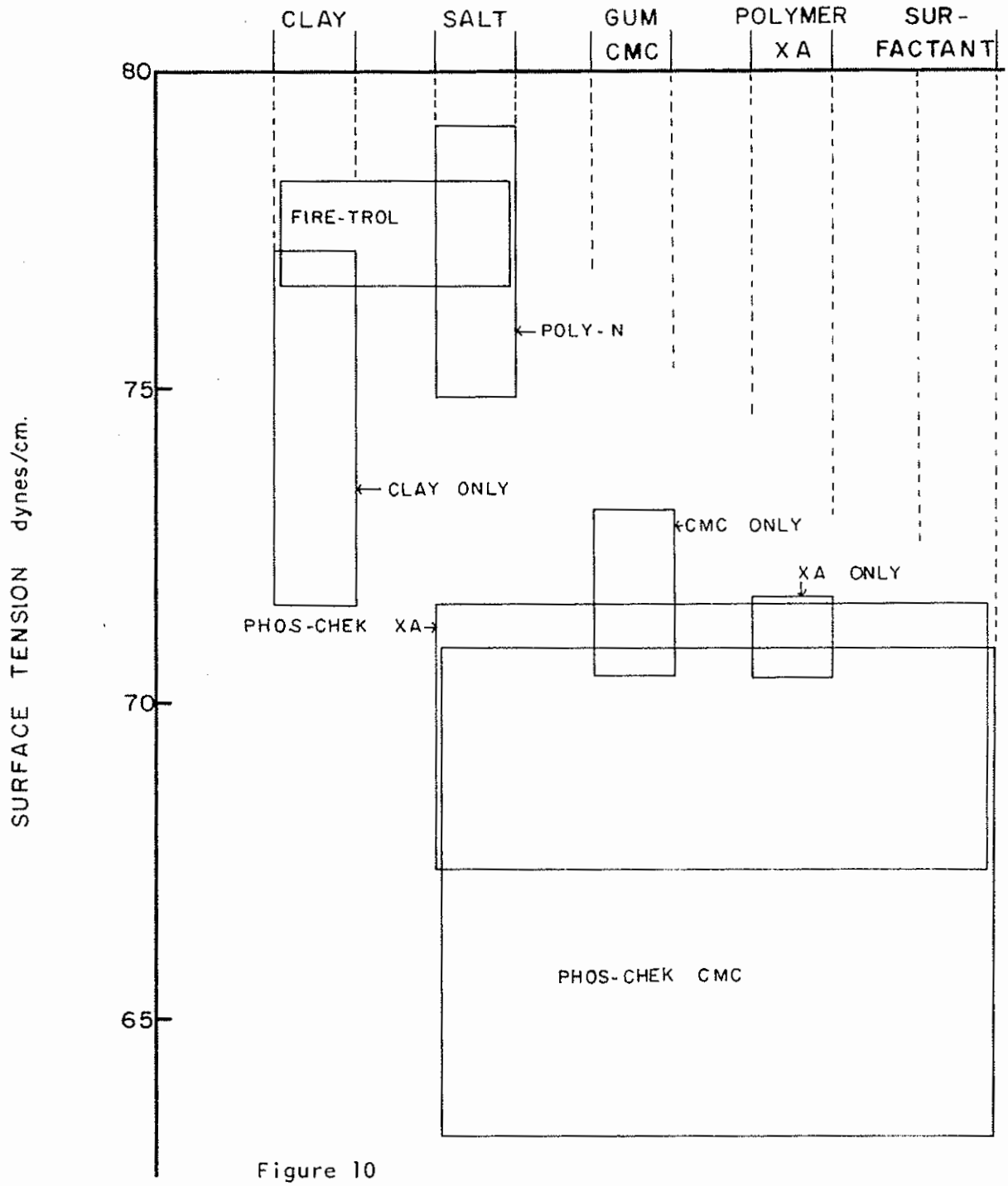


Figure 10

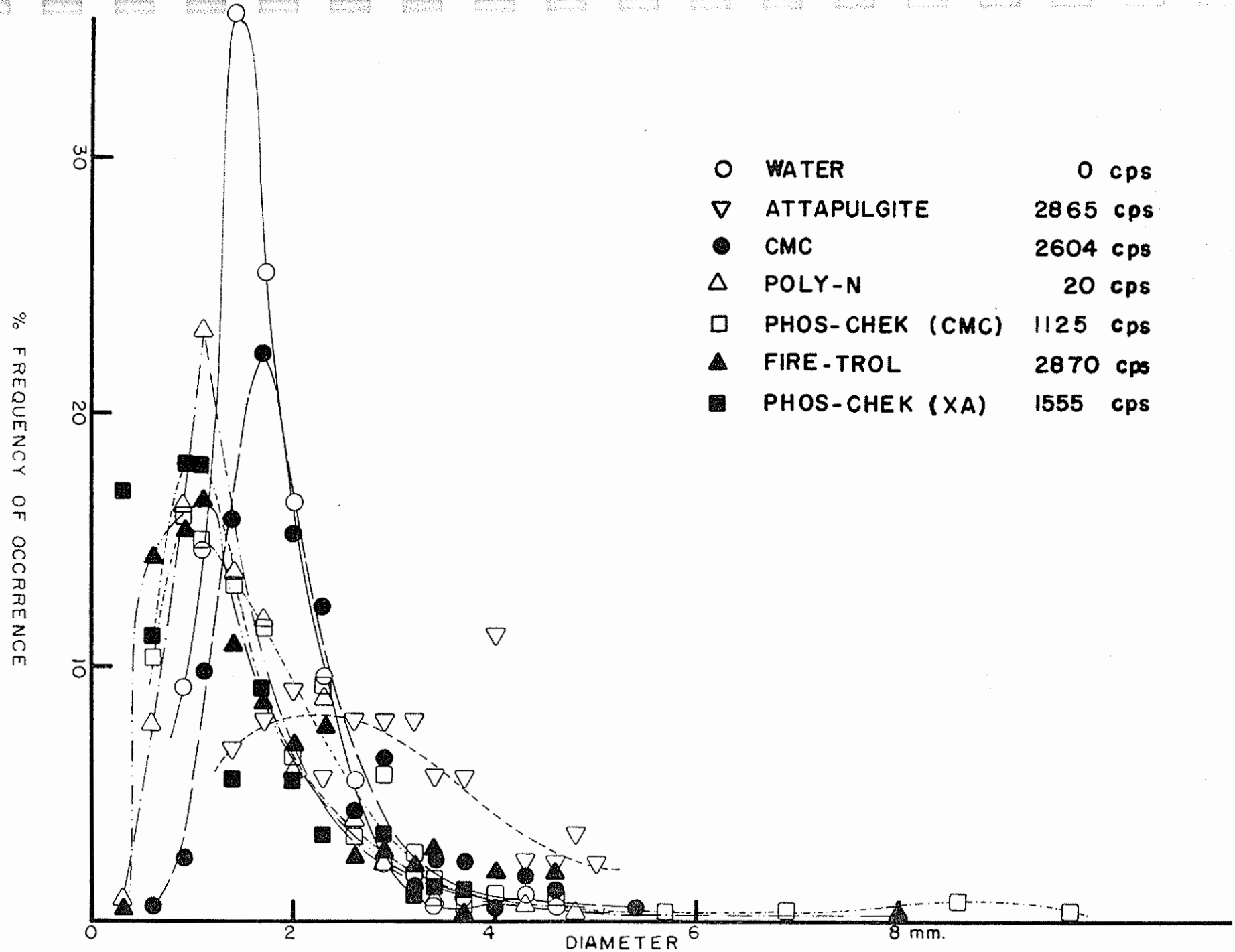

WATER 0 cps
ATTAPULGITE 2865 cps
CMC 2604 cps
POLY-N 20 cps
PHOS-CHEK (CMC) 1125 cps
FIRE-TROL 2870 cps
PHOS-CHEK (XA) 1555 cps
% FREQUENCY OF OCCRRENCE
30
20
10
0
2
4
6
8 mm.
DIAMETER

Figure 11

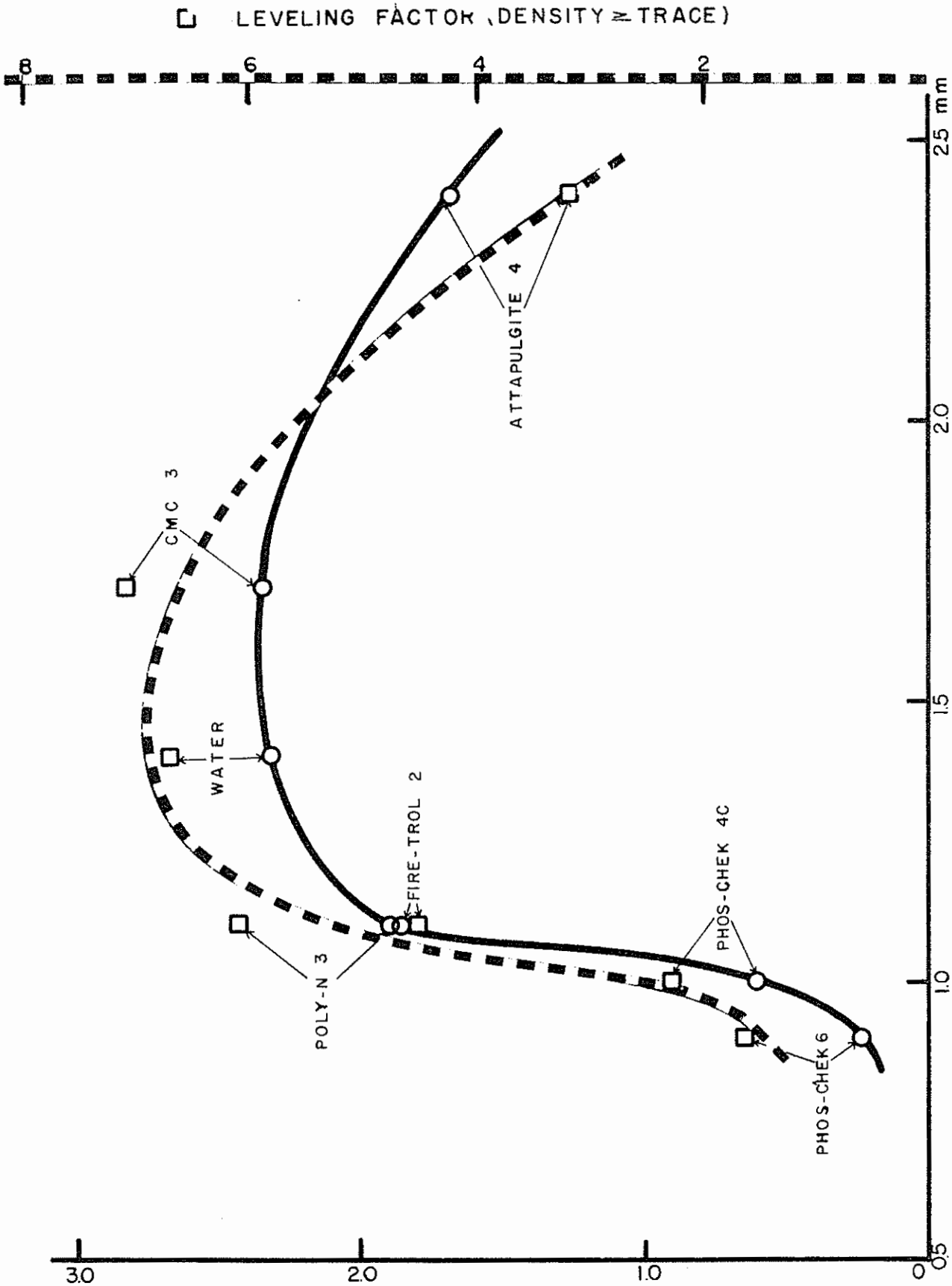

LEVELING FACTOR (DENSITY ≥ TRACE)
8
6
4
2
2.5 mm
2.0
1.5
1.0
.5
0
1.0
2.0
3.0
ATTAPULGITE 4
CMC 3
WATER
FIRE-TROL 2
PHOS-CHEK 4C
POLY-N 3
PHOS-CHEK 6
DIAMETER
LEVELING FACTOR (DENSITY ≥ 1.8 mg./cm.²)

Figure 12

materials are "stringy," tending to form long tendrils of liquid between drops, and the attapulgite seems to break up more quickly and completely than other mixtures of the same viscosity. The Phos-Chek probably generates relatively more smaller droplets, while attapulgite thickener would favor a higher population of larger drops.

Pattern Area Prediction

In order to compare the performance of one type of mixture with that of another type, a single mathematical expression will need to be found that will adequately relate the performance (area or leveling factor) to the easily measurable physical properties. A first attempt by manual, intuitive means, has had an encouraging result.

It has been noted that attapulgite clay mixed with water can be made to have a wide range of yield strength while surface tension is practically the same as that of pure water. The two variables considered are density and yield strength. On the other hand, Phos-Chek mixtures show yield strength and surface tension values different from water, but have constant density values. Four equations were set up using data values from runs Att 1A, Att 2B, PC 3 (average of two replicates), and PC 5A.

$$\text{Area (density} \geq \text{trace)} = x\,(\text{density}) + y(\text{yield strength}) + z\,(\text{surface tension}) + a$$

$$37.7 = 1.071x + 450y + 73.0z + a$$
$$55.4 = 1.039x + 727y + 73.4z + a$$
$$64.6 = 1.065x + 60y + 70.8z + a$$
$$60.4 = 1.070x + 180y + 71.6z + a$$

Simultaneous solution yields $x = +511$, $y = -0.0706$, $z = +1.93$ and $a = -612$. The equation producing figure 11 is:

$$A = 511d - 0.0706Y + 1.93S - 612$$

where:

A = area of dispersal pattern, density $\geq$ trace
d = density of sample, g./ml.
Y = yield strength, dynes/cm.^{2}
S = surface tension, dynes/cm.

This represents an empirically derived relationship that will allow the prediction of the dispersal pattern area from measurement of the three physical properties. Future work will incorporate two factors which should make for an improvement in figure 13, i.e., a better fit of experimental data points to a common line drawn through them. First, more careful attention will be given to providing adequate numbers of replication runs. Second, the coefficients in the equation will be evaluated by computer processing of many data, rather than by manual calculation from a few values.

CONCLUSIONS

The question must be considered as to whether it is reasonable to expect tests carried out in a wind tunnel to be useful in predicting and understanding full-scale field operations. The vertical distance of fall is but 30 inches, and the air velocity only 40, perhaps 50 miles per hour. However, the fundamental processes occurring are the same, as the airstream abrades the liquid surface and subdivides the original single volume into smaller portions. Whenever one effect is linked to a cause in laboratory tests, the nature and direction of that effect will surely be the same on a large scale.

It is apparent that there is no single "good" or "best" dispersal pattern. Maximum coverage at a useful density is obviously desirable, but a higher priority is exercised by the needs of the field situation. Enough knowledge of the airstream-retardant system must be provided to allow the choice of the proper material. It will then give the desired amount of coverage under the limits imposed by the size of the fire target, the amount of upper story vegetation cover, and the altitude and airspeed of the aircraft.

As a measure of how well a retardant performs we have used the size of the area covered by at least a minimum loading of 1.8 mg./cm.^{2}. The actual size of this loading, in gal./100 ft.^{2} is not, and need not be, the same as values used to achieve useful effects in firefighting. It has been chosen for comparison of wind tunnel tests with each other. It seems, from figures 1, 2, 6, and 7, that the area covered decreases as viscosity and yield strength become very large. But there is an apparent optimum yield strength value in the region of 200 dynes/cm.^{2}. This latter value is usually associated with a viscosity in the region of 2,000 centipoise (fig. 9).

Surface tension alone does not seem to affect strongly the area covered. The empirical equation seems to indicate that density is by far the most important factor, with surface tension and yield strength each having roughly one-tenth as much an effect.

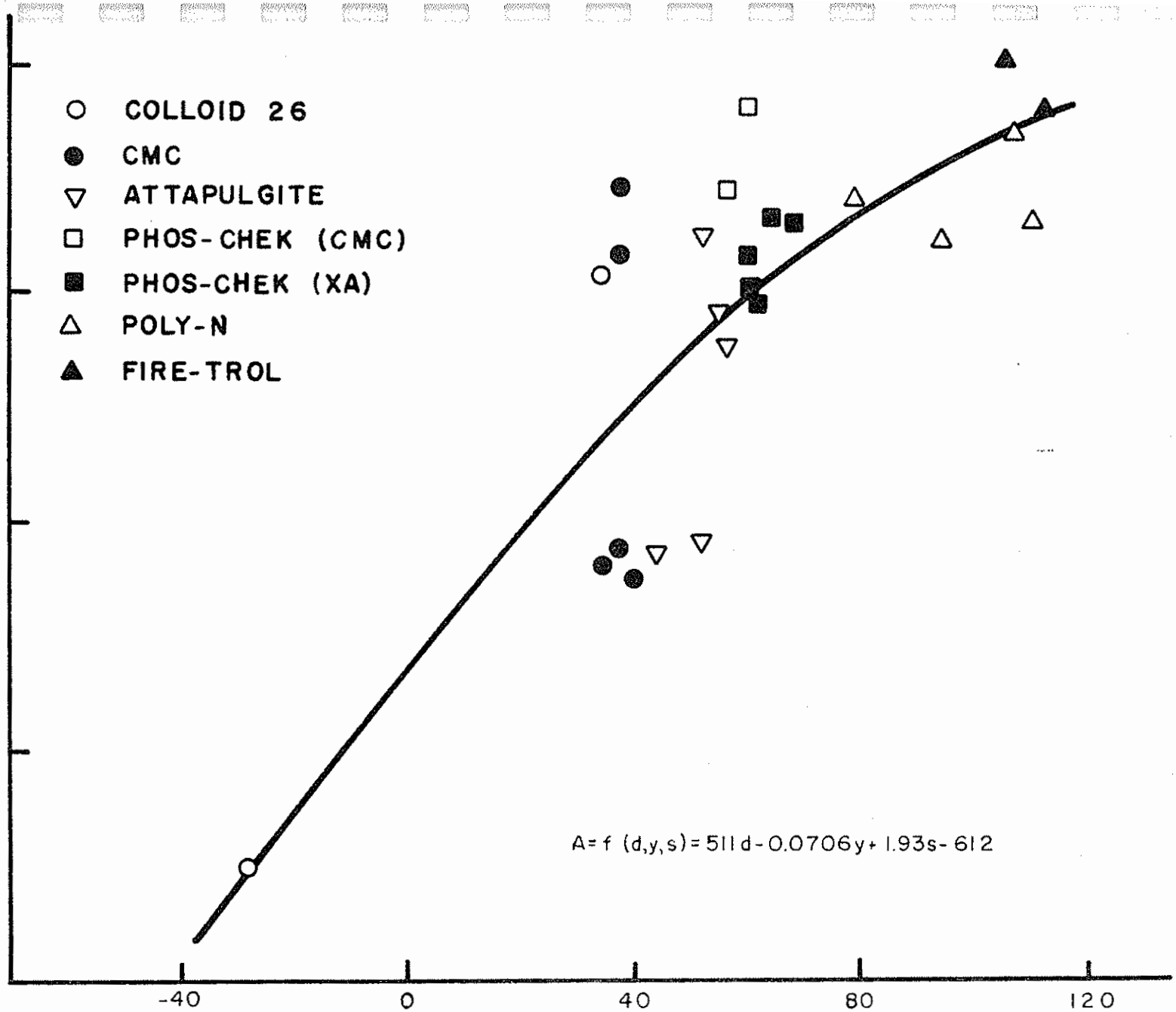

COLLOID 26
CMC
ATTAPULGITE
PHOS-CHEK (CMC)
PHOS-CHEK (XA)
POLY-N
FIRE-TROL
A = f (d,y,s) = 511d - 0.0706y + 1.93s - 612
-40
0
40
80
120
f (d,y,s)
A AREA (DENSITY ≥ TRACE)

Figure 13

RECOMMENDATIONS

Additional study should be directed along two general lines. First, determine the exact effects of known causes in a single type of mixture. For example, it would be possible to cause a controlled range of surface tension values in a series of samples containing only water, Colloid 26, and traces of a surfactant, while maintaining constant values of density, viscosity, and yield strength. A number of other such studies are possible. Second, as a matter of practical importance, more data should be collected on the behavior of the brand name products now in use. A reliable performance graph, similar to figure 13 should be developed for each of them. They might all be expected to obey the same correlation, but higher accuracy might be achieved separately.

As this study develops, it would be highly significant to have data on full-scale field tests where the rheological properties of the actual materials dropped are measured, at the same time, in the laboratory. Field tests should be made on several materials that would, based on the work described in this report, produce clear variations in dispersal patterns. These drops should be instrumented well enough to provide accurate knowledge of the windspeed and direction and the altitude, velocity, and track of the aircraft relative to the sampling grid. This will insure that the model (or models) produced by wind tunnel tests will be based on factors that are the important ones in full-scale operations.

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