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Evaporation Reduction Investigations Relating To Small Reservoirs In Arid Regions

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EVAPORATION REDUCTION INVESTIGATIONS RELATING TO SMALL RESERVOIRS IN ARID REGIONS

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SUMMARY

The following statements are based upon a two year evaporation-reduction investigation, 1961 to 1963, relating to small reservoirs in arid regions. The results presented were obtained in the laboratory, from tests made on ten U. S. Weather Bureau Class A evaporation pans, and from tests made on paired plastic-lined 53 by 78 foot reservoirs.

Laboratory Tests

1. The spreading rates of monolayers spread from solids increased with increasing temperature and decreased with increasing chain length of alcohol. The rates attained were too slow to be of practical value in the field. The spreading rates of monolayers spread from both powders and emulsions were essentially independent of the long-chain alcohol used and were approximately equal at the same temperatures, varying from 17.7 feet per minute at 60°F to 33.4 feet per minute at 95°F. The spreading rates of monolayers spread from solutions were only slightly affected by the long-chain alcohol used and independent of temperature. The spreading rates were approximately 21.6 feet per minute for kerosene solutions and 25.6 feet per minute for white gasoline solutions. In order to get comparable spreading rates in the laboratory up to 500 times as much long-chain alcohol in the powdered form had to be used as the long-chain alcohol in the form of a solution or emulsion.

2. Laboratory studies showed that the evaporation-suppression ability of long-chain alcohols increased with increasing hydrocarbon chain length and decreased with increasing temperature. The evaporation-suppression abilities of the long-chain alcohols were not adversely affected by spreading from emulsions and only slightly affected, two to four per cent, by spreading from solutions.

Pan Tests

1. Pan tests showed that there was no difference in the evaporation-suppression ability of powders, solutions and emulsions for a given commercial material provided that sufficient amounts of material are used. In general when water temperatures are less than 70°F, a greater amount of long-chain alcohol in the form of powder is required to achieve the same initial savings* as the alcohol in the form of a solution or emulsion, particularly when using eicosanol and docosanol. During warmer weather the material requirements for equal savings appear to be the same.

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* Initial savings are savings attained within the first twelve hours following application of material. Percentage savings are computed by obtaining the difference between the control pan or pond and treated pan or pond and expressing this difference as a percentage of the total evaporation that occurred on the control pan or pond.

2. The use of the longer chain alcohols, eicosanol and docosanol, in the form of solutions or emulsions resulted in a reduction in evaporation loss up to twice as much as for the shorter chain alcohols, hexadecanol and octadecanol.

Field Tests

1. Tests made on the 53 by 78 foot paired reservoirs showed that solid rings and rafts containing powder, flakes or emulsion, are ineffective methods of maintaining a monolayer on a small reservoir in climatic conditions similar to those in the Southwest.

2. Periodic point applications of powder reduced evaporation on the treated pond up to ten per cent of the evaporation occurring on the control pond. Over a year's time this 10% reduction in evaporation would amount to about a depth of 7.2 inches per acre of water. For greater savings continuous or wind activated dispensing is required. This type of application of powder is complicated because the relatively low melting point of alcohols makes it difficult to keep them in the powder form.

3. Continuous application of solutions from underwater dispensers resulted in savings from 15 to 20 per cent. The use of solutions is not practical where temperatures drop below 65°F as the solubility of alcohols in white gasoline and kerosene are very temperature dependent. The added cost of the solvent may prove to be prohibitive unless material use is minimized with wind activated dispensing.

4. Continuous gravity feed application of emulsion in cold weather during a relatively calm period resulted in a 25 to 30 per cent reduction in evaporation loss. Wind-activated gravity-feed dispensers were developed near the end of the project. Preliminary testing indicates that the dispensers will be reliable and will require very little maintenance. Longer chain alcohols, eicosanol and docosanol, with their high evaporation-suppression ability can be easily applied in the emulsion form with spreading rates comparable to the shorter chain alcohols, hexadecanol and octadecanol.

Wind activated dispensing of long-chain alcohols, eicosanol and docosanol, in the form of an emulsion appear to be the most promising method of maximizing savings on small reservoirs. Further testing is needed, before the above method is ready for wide scale commercial use.

INTRODUCTION

Of all the world's natural resources, water is one of the most essential to man's survival. In the arid regions of the world, water is in very short supply. As the population increases the strain on available supplies is becoming more acute.

One very important source of agricultural water in many arid regions is the farmer's or rancher's individual pond. The value of this water is multiplied many times in isolated areas where other water sources are unavailable. Conservation of this water is of critical importance. In many of these areas, the evaporation loss may amount to as much as a depth of seven feet of water per year. Not only is this water lost, but the water left behind is of lower quality because of the increased concentration of dissolved salts.

A promising method of conserving part of this water is through the suppression of evaporation by means of monomolecular films of long-chain fatty alcohols, such as hexadecanol (C-16) and octadecanol (C-18), spread on the water surface. Films of these materials are not toxic to animals or plants and they offer no appreciable resistance to oxygen or carbon dioxide diffusion. The theoretical amount of this material necessary to form a monolayer on water is quite small, 0.018 pounds per acre. Even at a cost of 50 cents per pound, the economics of evaporation suppression by this method appear to be promising.

Previous Research

The first experiments on the formation of thin films of oil on water were conducted by Benjamin Franklin in 1765. Irving Langmuir was awarded the Nobel Prize in Chemistry in 1932 for research with fatty alcohols. However, field testing of the long-chain fatty alcohols to determine its ability to suppress evaporation has essentially only been under way for the past ten years. In 1955, W. W. Mansfield, of Australia, reported savings up to 30 per cent from areas of water up to ten acres using gauze floats in which he placed flakes of hexadecanol (9). These results from Australia interested other conservation agencies around the world. A 10 to 30 per cent reduction in evaporation loss using solutions of the long-chain alcohols in solvents such as kerosene, were obtained on small reservoirs in Africa (20).

In the United States the following organizations are among those that have been actively engaged in studies of evaporation suppression: U. S. Bureau of Reclamation, U. S. Agricultural Research Service, the Illinois State Water Survey Division, U. S. Geological Survey and the Southwest Research Institute. In addition to these organizations various colleges and universities in the West are studying various phases of the problem of evaporation suppression.

The U. S. Bureau of Reclamation in cooperation with other agencies has made large scale tests on Lake Hefner (1958), Sahuaro Lake (1960), Lake Cachuma (1961), and Pactola Reservoir (1962-1963). On Lake Hefner in Oklahoma, the monolayer was maintained with slurries applied as needed from a moving boat (19).

On Lake Cachuma, the fatty alcohol was largely applied in the form of a molten spray from wind-controlled dispensers (16). At Sahuaro Lake and at Pactola a combination of the molten spray from the fixed dispensers and powder spread from boat mounted agricultural-type dusters was used (15). Reduction of evaporation loss in the above tests ranged from nine per cent over a 12-week period at Lake Hefner to 14 per cent over a six-week period at Sahuaro Lake. In the summer of 1963 preliminary tests using aerial applications were made on Elephant Butte Reservoir by the Bureau in cooperation with Utah State University. These tests demonstrated the possibilities of large scale treatment of reservoirs using the airplane (7) (13).

F. R. Crow of Oklahoma State University testing on paired plastic-lined ponds, reported evaporation reduction up to 25 per cent using slurries continuously applied in accordance with wind speed and direction. When film was applied only during the daylight hours the evaporation reduction dropped to 6.5 per cent (2).

Research conducted by the Southwest Research Institute in collaboration with the U. S. Geological Survey and the Southwest Agricultural Institute, "--has shown that a liquid medium (solution, emulsion, or dispersion) to apply the evaporation retardants offered the most promising method of application, particularly for a small reservoir" (3). In a later publication, it was reported that in nine field tests undertaken on small stock tanks near Laredo, Texas, the best reduction in evaporation, 27 per cent for a two-week period, was obtained using octadecanol in dispersion form and dispensed with a wind-controlled valve and gravity feed system (8).

Estimates of costs of 27 dollars and 7.5 dollars, for 3.5 and 50 acres approximately circular lakes respectively, for alcohol alone per acre foot of water saved by evaporation suppression have been made by W. S. Chandler and C. O. Reiser (1).

Other cost estimates that have been made range from 4.50 to 300 dollars per acre foot of water saved (4) (2).

Problems Involved

Probably the major problem involved in the suppression of evaporation using long-chain fatty alcohols is wind. Even a gentle wind will move the film across the water surface, and The University of Arizona research program has shown that it is almost impossible to maintain an effective film cover on small reservoirs when the wind speed is above approximately eight miles per hour.

The problem concerning wind becomes more serious as the size of the reservoir decreases. As the size of the reservoir decreases the film is in contact with the water surface for shorter periods of time, therefore the amount of material that needs to be applied per unit area of water surface increases. It has even been stated that the economics of suppressing evaporation on stock ponds are questionable because of the short travel time across the pond by the film (8).

Any type of dispenser developed for a small reservoir must be simple, and require little or no maintenance before evaporation suppression can be economically successful. The type and cost of dispensing equipment as well as the required amount of material per unit area of water surface is dependent upon the physical form of the material used. Thus the determination of the appropriate physical form to use becomes very important as the size of reservoir decreases.

Due to the short length of time the film is on the water, destruction of the film by biological attrition, evaporation, or due to its solubility is not a serious problem on small ponds, if sufficient quantities of materials are applied to keep a film on the water during windy periods. However, if it were decided to apply only sufficient material to obtain "residual savings", i.e., to suppress evaporation only during calm periods, then biological attrition, evaporation and solubility would become more serious problems.

Other problems encountered in evaporation-suppression investigations are the difficulty in detecting the presence of the film on the surface of the water and in determining the amount of water saved. The method of using indicator oils as developed by the U. S. Bureau of Reclamation for detecting the presence and pressure of the film while effective in the immediate area of use, does not provide a complete and continuing history of film presence or pressure for even a small reservoir during windy periods (14). The accuracy of the determinations of the water and energy budget, which are dependent upon reservoir characteristics and instrumentation adequacy are at least at present, not suitable enough for determining the amount of water saved from the average small reservoir.

Other problems involve a firm estimation of cost of water saved. The determination of costs of material, equipment, operations, maintenance, etc., are dependent on physical formulation, type of equipment and methods for applying the chemical. Other factors that will cause the cost to vary from reservoir to reservoir are: (a) climate, (b) size and shape of reservoir, (c) orientation with respect to prevailing winds, and (d) accessibility of the reservoir.

RESEARCH PROGRAM

In July, 1961, the Institute of Water Utilization of The University of Arizona entered into a contract, No. 14-06-D-4012 with the U. S. Bureau of Reclamation to achieve the following objectives:

1. To develop a simple, self-regulating, effective, and reliable apparatus and technique for applying and maintaining an evaporation reducing monolayer of fatty alcohols (hexadecanol and octadecanol) on a small body of water, such as a stock watering pond. The apparatus and technique should be effective on small reservoirs up to approximately ten acres under climatic conditions commonly found in the Southwest.

2. To determine the physical states of fatty alcohols, such as hexadecanol and octadecanol, which are most effective for use in applying and maintaining an evaporation reducing monolayer on small reservoirs.

In order to achieve the above objectives, a coordinated laboratory and field testing program was instituted. Various long-chain alcohols and combinations thereof were screened and tested in the laboratory and on four-foot U. S. Weather Bureau Class A evaporation pans before being tested on paired plastic-lined reservoirs.

Laboratory Tests

In the laboratory phase of the research program the spreading rates and evaporation-suppression abilities of monomolecular films of long-chain fatty alcohols, spread from solids, powders, solutions, and emulsions, were measured as a function of temperature in an effort to determine which chain length or combination of chain lengths and physical formulations should be used during the various seasons of the year. A detailed description of the work performed in the laboratory has been reported in a thesis written by H. E. Goldstein (6). Only a summary of the laboratory work will be presented here.

The spreading-rate apparatus used consisted of an 18 by 36 inch water-jacketed spreading-rate tray, a tray cover, a Whilhelmy-type surface balance, and auxiliary equipment, see Figure 1. The evaporation-rate apparatus, which was patterned after Langmuir's equipment for measuring evaporation rates, consisted of a water-jacketed evaporation dish and a dessicant container with a water-permeable membrane for a bottom mounted on the dish. A schematic of this evaporation rate apparatus is shown in Figure 2.

Solid cylinders, powders, solutions in white gasoline and kerosene, and emulsions of several long-chain alcohols were prepared. The solubility of the long-chain alcohols in white gasoline and kerosene was less than one per cent by weight at temperatures below 65°F.

Most of the emulsions used in the laboratory work were made using EMULSIFIERS 1-3, since EMULSIFIER 4 was available for only the last seven months of the project, see Table 1 for emulsifier specified. EMULSIFIER 4 was available for inclusion in the evaporation-rate tests performed in the laboratory. All field tests using emulsions were made using EMULSIFIER 4; emulsions prepared with EMULSIFIER 4 were found to be the most stable and to have the best viscosity characteristics of the emulsions used.

The various types of emulsions made using EMULSIFIER 4, were prepared by melting a weighed sample of long-chain alcohol and the emulsifier in a beaker and adding this to 140°F water with constant mixing (11). In general, results indicated that using EMULSIFIER 4, a stable emulsion can be easily prepared for an emulsifier to alcohol concentration down as low as one per cent. It was found that viscosity could be controlled by varying the alcohol concentration and/or the emulsifier concentration. By reducing the emulsifier content down to 0.16 per cent, based on the alcohol, a free flowing 30 per cent emulsion was obtained. This 30 per cent emulsion remained stable only for approximately ten days before slowly separating. It was found that as the emulsifier content was reduced the particle size increased with a corresponding decrease in spreading rates. For this reason emulsifier concentrations of ten per cent, based on the alcohol, was generally used both in the laboratory and in the field. The average particle size of this concentration was approximately one micron as compared to an average size of 130 microns for the 30 per cent emulsion. This concentration of emulsion, ten per cent based on the alcohol, required that the alcohol concentration be less than five per cent in order to insure proper flow characteristics. With this concentration, emulsions made over nine months ago are still stable.

The spreading rates and rates at which the surface pressure* increased were measured using monolayers spread from solids, powders, solutions and emulsions at temperatures varying from 50 to 113°F.

Spreading rates of monolayers spread from solids were determined by measuring the change in surface pressure using the Whilhelmy slide, as a function of time and extrapolation of the straight line portion of the surface pressure versus time plot to zero surface pressure. The time determined by this method was assumed to be the time when the water surface was covered by a monolayer of essentially zero surface pressure. The spreading rate was then calculated by dividing the total surface area of water covered by the spreading perimeter of the solid alcohol and the above time.

The spreading rates of monolayers spread from powders, solutions, and emulsions were determined by measuring the rate at which the leading edge of monolayer swept a line of carbon black across the water surface. The rates at which the surface pressure increased for monolayers spread from the above physical formulations were determined by measuring the change in surface tension as a function of time with the Whilhelmy slide surface balance.

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* Surface pressure is the decrease of surface tension of water caused by the monolayer. It was measured using the Whilhelmy type surface balance as shown in Figure 1.

The evaporation rates through monomolecular films of long-chain alcohols spread from powders, solutions in white gasoline, kerosene, absolute ethyl alcohol and petroleum ether, and emulsions were measured as a function of temperature in the range 41 to 113°F. Large excesses of the long-chain alcohols in these physical formulations were applied to the water surface to insure that equilibrium surface pressure monolayers would be formed.

From the spreading-rate data graphical relationships between spreading rate and temperature were plotted for monolayers spread from each of the physical formulations. The spreading rates of monolayers spread from solids increased with increasing temperature and decreased with increasing chain length of the alcohol. For 95+ per cent hexadecanol and 95+ per cent octadecanol the spreading rates were two-tenth and two-hundredth feet per minute respectively at 77°F.

The spreading rates of monolayers spread from both powders and emulsions were independent of the long-chain alcohol used* and were approximately equal at the same temperatures, varying from 17.7 feet per minute at 60°F to 33.4 feet per minute at 95°F. Results indicate that the spreading rates of the pure emulsifiers are higher than the spreading rates measured for the emulsions used in the research indicating that the emulsifier might be spreading ahead of the long-chain alcohols. However, the assumption was made because of the resulting suppression evaporation that the time lag between initial spreading and when the long-chain alcohol in the emulsion becomes the dominant material in the film is negligible. Using this assumption, the spreading rates of the emulsions can be compared to the spreading rates of the other physical formulations.

The spreading rates of monolayers spread from solutions were independent of temperature and were only slightly affected by the long-chain alcohol used. They were dependent on the solvent and in the case of white gasoline on the concentration of the long-chain alcohol. The spreading rates were approximately 25.6 feet per minute for monolayers spread from white gasoline and 21.6 feet per minute for monolayers spread from kerosene.

In order to obtain comparable spreading rates, as much as 100 pounds per acre of powdered long-chain alcohol, as compared to two-tenths pounds per acre of long-chain alcohol in emulsions and solutions, were required. Figure 3 summarizes the spreading rate tests made in the laboratory.

From the evaporation-rate data graphical relationships between the evaporation-suppression ability of the long-chain alcohols and temperature were obtained. Figure 4 contains a summary of the evaporation suppression ability versus temperature tests made in the laboratory. These curves show that the evaporation-suppression ability of the long-chain alcohols increases with increasing hydrocarbon chain length and decreases with increasing

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* Spreading rates for powders were determined using CHEMICALS 1, 2, 4, 6, 7 and 8 whose specifications are given in Table 2. Only CHEMICALS 1, 2 and 8 were used in the spreading rate determinations for solutions and emulsions.

temperature. The highest evaporation-suppression ability of the seven long-chain alcohols tested was exhibited by a commercial sample having 8 per cent octadecanol, 77 per cent eicosanol, and 12 per cent decosanol. Monolayers of this sample prevented 89 per cent of the evaporation at 77.0°F.

The evaporation-suppression abilities of the long-chain alcohols were not adversely affected by spreading them from emulsions or solutions in ethyl alcohol and petroleum ether as compared to spreading them from large amounts of powdered long-chain alcohol. However, the percentage of evaporation saved was lowered by two to four per cent when the long-chain alcohols were spread from white gasoline or kerosene solutions.

Pan Tests

Ten U. S. Weather Bureau Class A evaporation pans were installed at the Institute of Water Utilization Research Center at Tucson, Arizona, see Figure 5 (17). These pans were used to screen powders, solutions, and emulsions composed of combinations of hexadecanol ($^{C}16$), octadecanol ($^{C}18$), eicosanol ($^{C}20$), and docosanol ($^{C}22$). See Table 2 for a list of the commercial materials tested.

Considerable time was spent in the calibration of the ten evaporation pans to insure reliable results. It was found that the difference in albedo between a weathered pan and a shiny new pan caused a difference of ten per cent evaporation. The pans were repainted and during a calibration period of seven days, a deviation of only two per cent between pans was obtained.

Although the results obtained from the evaporation pans cannot be quantitatively applied to a larger reservoir, the pans proved to be of value in comparing physical formulations and types of alcohols under varying weather conditions.

A total of 24 pan tests were made. These tests are reported in detail in the eight quarterly reports submitted to the U. S. Bureau of Reclamation during the investigation. Only a summary of the results obtained from these tests will be presented here. These results essentially show the following:

1. There is essentially no difference in evaporation-suppression ability of powders, solutions, and emulsions for a given commercial material provided sufficient amounts of material are used.

2. Under hot weather conditions the use of the longer chain alcohols, eicosanol and docosanol in solutions and emulsions resulted in somewhat better savings in evaporation as compared with the use of the shorter chain alcohols. In tests conducted during Fall and Winter when using the long-chain alcohols, eicosanol and docosanol in emulsions, the savings were roughly twice those when using hexadecanol and octadecanol. Fall and Winter tests using solutions were not made due to the low solubility of the alcohol in kerosene and white gas below 651°F.

3. When applied in the powdered form* at rates less than 0.20 pounds per acre and the temperature of the water is less than 70°F, the longer chain alcohols, eicosanol and docosanol, spread very slowly taking hours to form a fully compressed film on a four-foot diameter pan. This resulted in reduced savings during the initial period** which is a vital time on a larger reservoir when attempting to maintain a film cover during windy periods.

4. The percentage reduction in evaporation was much greater during the day than during the night time (5). A possible explanation is that with the increase in humidity during the night a greater amount of water is returned to the control pans than to the film-covered pans. This effect of the film retarding the return movement of water molecules from the air to the water has received very little attention from researchers in the field of evaporation suppression (8). Laboratory work is needed to prove or disprove the above explanation.

5. In an earlier report it was stated that the emulsions using approximately one-tenth the amount of alcohol is as effective in the prevention of evaporation as the powders (10). This statement was based on winter tests in which fairly heavy applications of alcohol, greater than 0.4 pounds per acre, were made. Additional tests run during warmer weather using CHEMICAL 6 (4% C-14, 33% C-16, 63% C-18) and CHEMICAL 8 (8% C-18, 77% C-20, 12% C-22), (see Table 2 for complete chemical descriptions) with a lighter application rate, less than 0.4 pounds per acre, showed that equal applications of emulsion and powder produced approximately the same total savings. The lasting qualities of CHEMICAL 6 in the emulsified form was not as good as in the powdered form. This was not true of CHEMICAL 8 where the lasting qualities were about equal. The initial savings of CHEMICAL 8 in the powdered form were much lower than in the emulsified form but the overall savings were about equal. Additional research needs to be done to determine the relative merits of powders and emulsions.

Pond Tests and Development of Dispensers

For field testing purposes, duplicate ponds, 53 by 78 feet in areal extent and with a maximum depth of nine feet, were constructed and lined with vinyl plastic to eliminate seepage. These ponds, located at the Institute of Water Utilization Research Center at Tucson, Arizona, are shown in Figure 2. The testing procedure consisted of applying the film on one pond and comparing the water loss with that of the untreated pond. Water levels in the two ponds were monitored using hook gages having an accuracy of ± 0.001 foot. Readings were taken two or three times a day. The following

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* Commercial powdered material was not available, hence the material was powdered using a small file. The average particle size was approximately 200 microns.

** Initial period is the first twelve hours following application.

climatological data were collected: (a) Wind speed and direction, (b) barometric pressure, (c) air temperature and humidity, and (d) temperature of water in the ponds at the surface measured two or three times a day. In addition to the above climatological data the compression of the monomolecular film was determined on occasions using indicator oils. This determination was facilitated with the use of a portable walkway so that the entire surface of the treated pond was accessible without disturbing the water surface of the pond.

Following are descriptions of the various methods of dispensing used and the general results of the tests made using these methods. Detailed results of these tests have been included in the eight Quarterly Progress Reports submitted to the U. S. Bureau of Reclamation during the investigation.

Screened Rafts. Two screened rafts 17.5 inches by 17.5 inches by 5 inches deep were tested using flakes of hexadecanol and octadecanol. These rafts were constructed of metal screen and floated in the water using styrenefoam floats. The openings in the screen of the raft were observed to plug up after about 48 hours in the water. Little or no savings were achieved using the rafts.

Solid Rings. CHEMICAL 6, in the form of a 6-inch solid ring with a 3.5-inch hole in the center and a 2-inch thickness was tried with little or no savings. Six rings were floated uniformly on the test pond and held in place with nylon string. The evolution rate of the solid material was so slow that the only area of the pond on which maximum film compression was attained was within the center of the rings.

Powdered Packets. CHEMICAL 6 was next tried in the powdered form. One packet of powder containing two ounces of material in a plastic bag which dissolved when in contact with water was applied to the test pond three times daily. The rate of application used, 6.5 pounds per acre per day, was deliberately high in an attempt to get maximum savings from this method. The savings attained during this test were 11 per cent during the treatment period of one week in August and nine per cent during the week following treatement. The percentage savings ranged from 57 per cent during a calm period down to a negative 7 per cent during a windy period. The negative saving during the windy period indicated that a reversal occurred in which more water evaporated from the treated pond than the control pond.

Continuous Powder Application. In order to obtain savings greater than ten per cent, a compressed film must be maintained during the windy periods. For dispensing powdered long-chain fatty alcohols a self-feeding grinder-duster, which is scaled down version of the one the Australians have developed (14), has been built, see Figure 7. The grinder-duster consists of a wire brush driven by a six-volt motor and a self-feed system wherein the solid alcohol is fed into the grinder continuously by means of a weight and pulley. Using this equipment from a moving raft, a 1.5 acre lake was completely covered with a film at maximum compression within approximately five minutes. However, in order to maintain a film during windy weather, many dispersing points would be required and the cost of equipment would probably make this method of application unfeasible for small reservoirs unless satisfactory wind-activated applicators can be developed. For this reason quantitative tests using this dispenser were not made.

Continuous Solution Application. Mixtures of long-chain fatty alcohols from hexadecanol to docosanol in solution using white gasoline as the solvent have been tested in the Fall with savings from 15 to 20 per cent obtained. In applying the alcohol in solution, a simple dispensing system was used, see Figure 8. The two-fold system consists of a bottle containing alcohol dissolved in white gasoline which was placed on the bottom of the reservoir. A glass tube extends to the botton of the bottle allowing water to enter. Due to the difference in specific gravities of the solution and the water, the alcohol in solution will float to the top of the bottle and is forced up through plastic tubes leading to the surface and to the wind vanes which compose the second part of the system. The wind vanes floating on the surface of the water keep the material applied upwind. Needle valves control the rate of flow. The underwater dispensing of the solution is patterned after the method developed and patented by McArthur of England (12).

The use of solutions was found impractical when temperatures drop below 65°F as the solubility of alcohols in white gasoline and kerosene is very temperature dependent.

Continuous Emulsion Application. Continuous application of emulsion to the test pond was attempted using two methods. In one method screened rafts containing the emulsion were placed on the upwind end of each wind vane which was previously used in the dispensing of solutions. The screen openings on the raft became clogged within 48 hours, making the technique ineffective.

In the second method, gallon cans equipped with pressure regulators were mounted on top of the wind vane supports with the flow controlled by adjusting the pressure. The pressure regulator was mounted on top of the gallon emulsion container as shown in Figure 9. The pressure regulator consisted of a copper tube filled with mercury. Inserted into the tube were two glass tubes, one open to the atmosphere and extended through the mercury to the bottom of the copper tube. The second glass tube extended to the void area in the copper tube above the mercury, with the other end of the tube connected to the air tight container holding the emulsion. By adjusting the angle of the copper tube, the depth of mercury and hence the pressure inside the container could be controlled. Adjusting the flow through controlling the pressure rather than restricting the opening reduced the possibility of plugging. Plastic tubing carried the material from the container to the upwind end of the vane. Using the above method of continuous application of emulsions resulted in savings of approximately 30 per cent over a two-week application period and further 25 per cent savings during the two-week period following application. These savings were achieved using a mixture of alcohols containing 33 per cent hexadecanol and 63 per cent octadecanol.

These rather favorable savings were made during a relatively calm period. An additional test conducted in March showed that in order to get savings greater than ten per cent using reasonable application rates, less than 0.5 pounds per acre per day, wind activated dispensers would need to be developed.

Wind Activated Emulsion Application. In order to maintain a film cover during windy periods and avoid wasting material during the calm periods, a wind-activated dispenser for emulsions was developed. The dispenser consisted of a brass screw encased in a plexiglass housing. The screw was activated in the first model by wind cups. The emulsion was fed to the screw by gravity through a plastic tube leading from a gallon can. The emulsion was then metered through the screw according to wind speed. An attempt was made to design the system so that it would dispense material according to the formula of material requirements developed by F. R. Crow of Oklahoma (2). This formula is as follows:

$$R = 0.0000093U^{2.02}$$

where, R is the required application rate in pounds per hour per foot of upwind shore line normal to the wind and U is the wind speed in miles per hour at a point two meters above the water surface. An attempt was made to design the dispenser so that the maximum application rate would be sufficient to cover a 30 foot width of water surface in an eight mile per hour wind using a two per cent emulsion. Under these conditions an application rate of long-chain alcohol of approximately .018 pounds per hour would be needed. Using a 2% emulsion, the application rate would be approximately one-tenth gallon per hour. The rate achieved in the pilot model was approximately linear with respect to wind speed varying from 0.047 gallon per hour at a wind speed of four miles per hour to .095 gallon per hour at a wind speed of eight miles per hour. This rate was not attained in the initial testing due to restriction to flow caused by the long plastic tube leading to the upwind end of the wind vane. Because of this restriction the application rate was so low that there were very little savings achieved in the initial testing of the wind-activated emulsion dispensers. Modifications were made on the dispenser in that the screw was activated by an 18-inch, 8-bladed propeller as shown in Figure 10. This model was then unidirectional and could be placed on the shore, thus increasing its applicability to the larger reservoirs. The propeller activated dispenser was developed too late to test under this contract but will be thoroughly tested in the future.

DISCUSSION AND CONCLUSIONS

In this investigation results from the laboratory and pan tests were used qualitatively to screen various long-chain alcohols and physical formulations on the basis of spreading rate and evaporation suppression ability. The field tests with the test ponds were used primarily to study the relative ease and effectiveness of application for the various physical formulations.

The laboratory and pan tests have indicated that the use of a combination of long-chain alcohols having high percentages of eicosanol and docosanol rather than hexadecanol and octadecanol result in higher evaporation savings. The physical formulation used does not apparently affect the resulting evaporation saving once a monolayer is formed, but it does affect the spreading rate, the material requirements for maintaining an effective monolayer and ease of application in accordance with wind speed. The relative merits of the physical formulations as determined from this investigation will be discussed in terms of the spreading rate, the material requirements and ease of wind activated application, keeping in mind that the use of the longer chain eicosanol and docosanol results in higher evaporation savings.

Dispensing of Long-Chain Alcohol in the Solid Form

Although easy to apply, the spreading rate of solid material is too slow to be of practical value in the formation of an effective monolayer. This was verified both in the laboratory and in the field tests. The spreading rate of solid material decreases with increasing chain length and increases with increasing temperature.

Dispensing of Long-Chain Alcohol in the Powdered Form

When excess material was used in the laboratory the spreading rates of powders were independent of the long-chain alcohol used. At reasonable application rates of powder, less than 0.5 pounds per acre, and at temperatures under 70°F the spreading rate of eicosanol as observed in the pan tests is noticeably less than that for hexadecanol and octadecanol. In order to get comparable spreading rates in the laboratory up to 500 times as much long-chain alcohol in the powder form had to be used as the long-chain alcohol in the form of an emulsion or solution.

In field tests using an excessive application of powder three times a day, average savings up to ten per cent were attained. To achieve higher savings wind-activated dispensers are needed. The development of this type of dispenser is complicated by the failure of the presently available powders to remain in the powdered form at temperatures encountered in the field. Power requirements for powdering the solid material in the field are high enough to require either some type of electrical or gas motor or if wind driven, a fairly large propeller with a relatively expensive gear reduction system.

In summary it may be stated that the advantage of using long-chain alcohol in the powdered form rather than in the solution or emulsion form on small reservoirs is that the powdered form does not require the use of any additives which may increase the cost and/or may be toxic to fish and animal life.

The disadvantages are: (a) excessive point application of powder is required to achieve the same spreading rate as emulsions and solutions, particularly for the longer chained eicosanol and docosanol, and (b) the problems encountered in the development of a simple wind-activated dispenser of powder within the economic range for use on a small reservoir appear to be insurmountable.

Dispensing of Long-Chain Alcohol in the Solution Form

Laboratory tests indicated that the spreading rates of monolayers spread from solutions were only slightly affected by the long-chain alcohol used and were independent of temperature. In the field using continuous underwater dispensing of solutions of eicosanol and docosanol up to 20 per cent savings were attained. However, the solubility of alcohols in white gasoline and kerosene are very temperature dependent, making the use of these solutions impractical when the temperature drops below 65°F. This would prevent the use of solutions from about October 15 to May 15 in climates similar to those of Tucson, Arizona. The continuous underwater dispensing of the solution was relatively trouble free but had the disadvantage of not being controlled by wind speed, thereby wasting material during calm periods and not having sufficient material available to maintain a compressed monolayer during windy periods. Attempts to develop wind-activated dispensers are complicated by the volatile nature of the solutions.

In summary the advantages of the use of solutions are: (a) the spreading rate is relatively fast, is independent of temperature, and is only slightly affected by the long-chain alcohol used, (b) relatively small amounts of long-chain alcohol are needed to generate a film, and (c) being in a liquid form, continuous application is simplified. The disadvantages are: (a) the solution could not be used in the late fall, winter and spring and (b) the cost of the solvent would be prohibitive unless suitable wind-activated dispensers could be developed.

Dispensing of Long-Chain Alcohol in the Emulsion Form

As for the powders, the spreading rate of emulsions is independent of the long-chain alcohol used and both are about equal at the same temperatures. The flow characteristics of the emulsions used in this investigation are such that a relatively large diameter of tube is required for even a small rate of flow but the viscous nature of the emulsion makes it relatively easy to use a screw type metering device for dispensing.

In summary the advantages of using long-chain alcohol in the form of an emulsion are: (a) the longer chain alcohols, eicosanol and docosanol, can be easily utilized in the form of an emulsion to give a physical formulation with a satisfactory spreading rate and a high evaporation-suppression ability, (b) the unit material cost is much lower than for solutions using white gas and kerosene, while the alcohol requirements are much lower than for the powdered form and, (c) the material can be easily dispensed in accordance to wind speed using a wind-activated screw dispenser. The disadvantages of using long-chain alcohol in the form of an emulsion are: (a) the emulsifiers used in this project, although believed to be non-toxic have not been cleared by the proper health agencies, and (b) total cost of material and transportation might be higher than for the powdered forms. However this cost can be greatly reduced if the alcohol is emulsified in large quantities at central locations in concentrated form and diluted by the rancher in the field. Preliminary testing has shown that this is possible.

In conclusion it appears that wind-activated dispensing of the long-chain alcohols, eicosanol and docosanol, in the form of an emulsion appears to be the most promising form of maximizing savings on small reservoirs at the present time.

SUGGESTIONS FOR FUTURE RESEARCH

There is a need to determine the optimum concentration of long-chain alcohols both in solutions and emulsions. There are limitations which are imposed by solubility in the case of solutions and viscosity in the case of emulsions, but there is considerable latitude remaining that needs to be investigated.

Although at the present time it appears that emulsions have the advantage both in ease of dispensing and economics, there is a need for further evaluation of the relative merits of powders, solutions, and emulsions.

Additional research is needed to determine the optimum spacing and rate of dispensing of solutions and emulsions through both gravity-flow type and pressure type dispensers as a function of wind speeds and reservoir area.

The possible toxicity of the more promising emulsifiers should be further studied. EMULSIFIER 4 now being used at The University of Arizona is believed to be non-toxic, but has not received clearance from the Food and Drug Administration of the U. S. Department of Health, Education and Welfare.

New methods of estimating evaporation savings are needed. Infrared techniques as well as commercial humidity transducers should be tested in the field.

Additional studies are needed regarding the storage of energy aspect of the evaporation suppression problem. Does the energy retained due to the reduction of evaporation at one time show up at a later time in the form of increased evaporation? Based upon the pond testing program to date, indications are that the effects of stored energy on small reservoirs will be small compared to other climatic and biological effects. For instance, studies showed that the albedo change resulting from algal growth had a greater effect on water temperatures than evaporation reduction. On larger ponds and reservoirs the situation might be different.

As suggested by the results of the pan tests, research is needed to determine the effect of humidity on evaporation-suppression ability of monolayers.

Additional research is needed in the laboratory to determine the specific resistance to evaporation at various film pressures using monolayers formed from emulsions. Laboratory results obtained during this investigation indicated that at maximum compression there was no apparent decrease in specific resistance due to the emulsifier. However, the emulsifier may contaminate the film at pressures less than maximum.

Additional work urgently needs to be done to determine the time lapse, if any, between the passing of the film front and the establishment of a compressed monolayer, particularly in the case of emulsions and solutions where surface-active emulsifiers and solvents are used.

LEGEND - FIGURE 1

a - Spreading Rate Tray

b - Water Jacket

c - Constant Temperature Bath and Pump

d - Surface Pressure Balance

e - Spreading Rate Tray Cover

f - Heat Exchanger

g - Thermocouples

h - Windows

n - Application Port

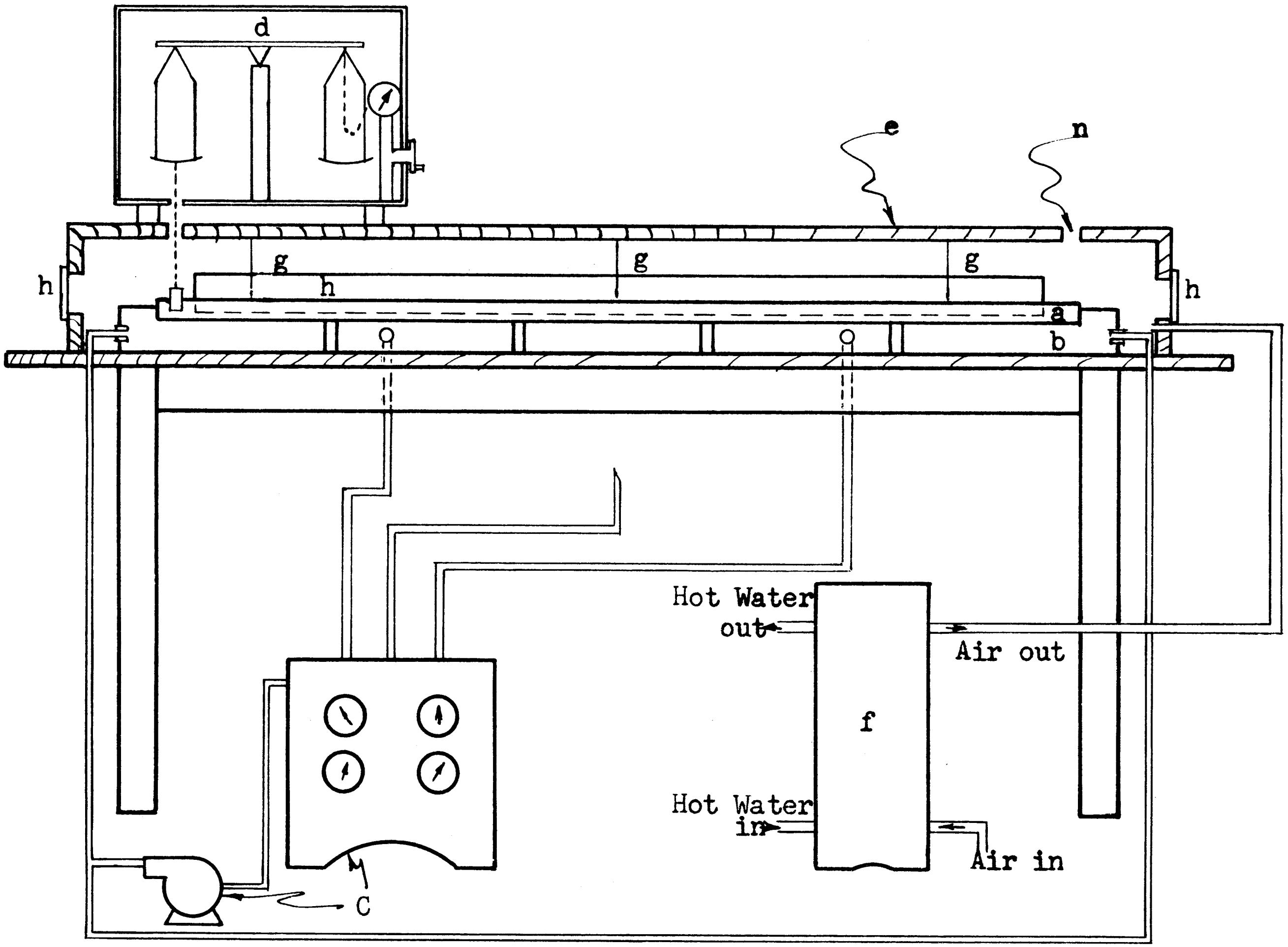

FIGURE 1. SCHEMATIC DIAGRAM OF SPREADING-RATE APPARATUS

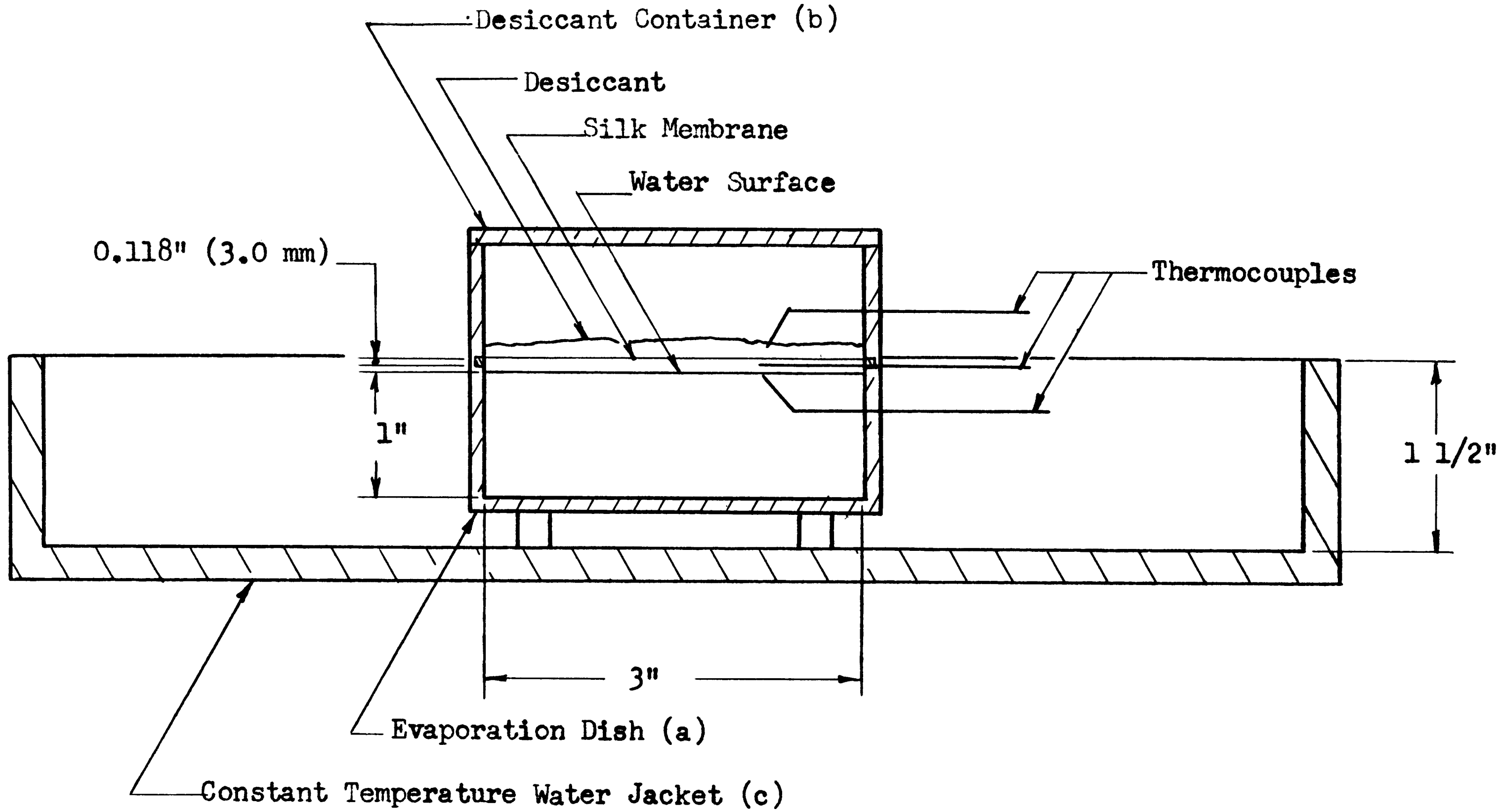

FIGURE 2. SCHEMATIC DIAGRAM OF EVAPORATION-RATE APPARATUS

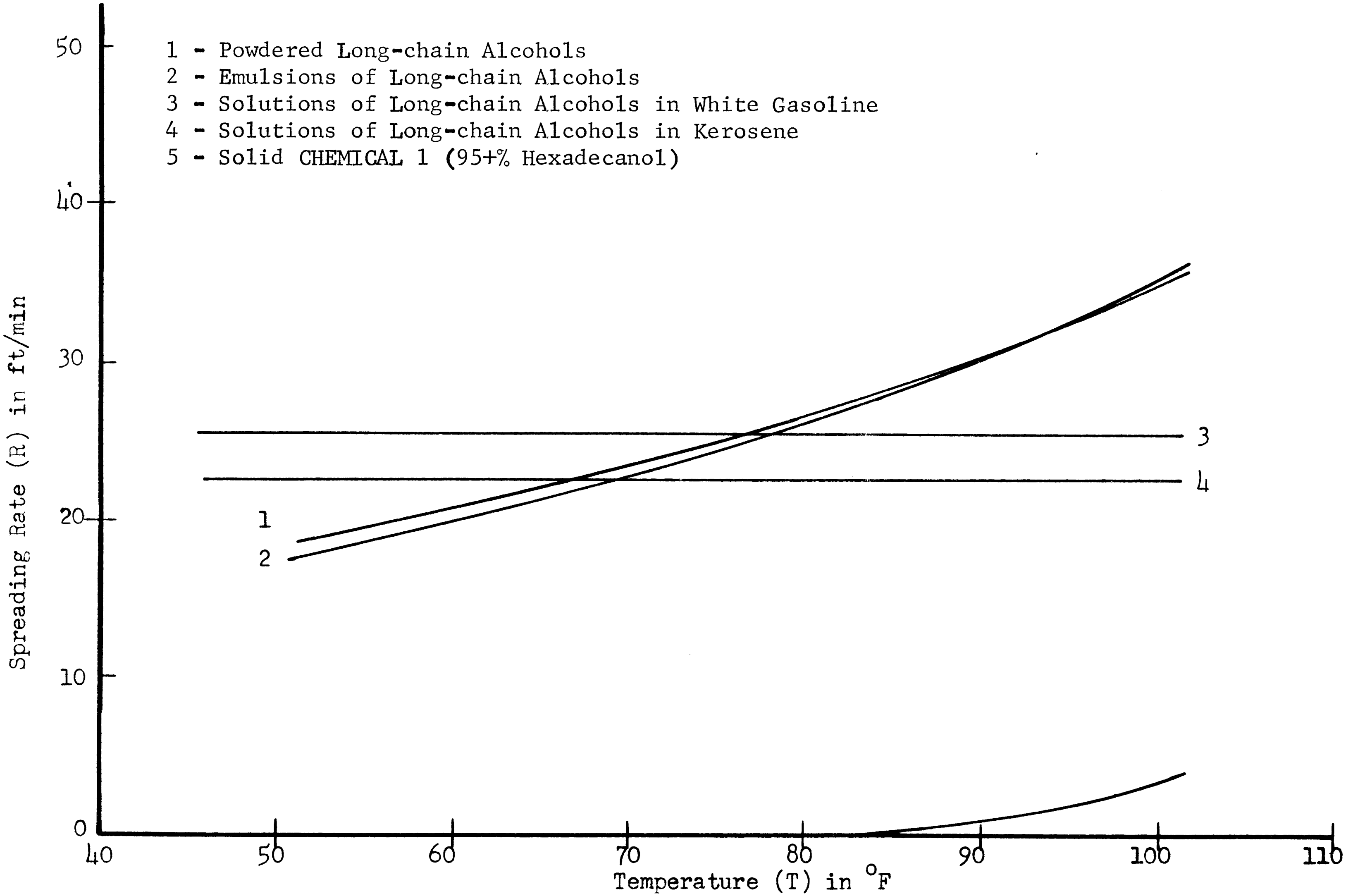

FIGURE 3. SPREADING RATES VERSUS TEMPERATURE OF MONOMOLECULAR FILMS SPREAD FROM DIFFERENT PHYSICAL FORMULATIONS OF LONG-CHAIN ALCOHOLS

LEGEND - FIGURE 4

a - CHEMICAL 1 (Powder)
95+% Hexadecanol

b - CHEMICAL 2 (Powder)
95+% Octadecanol

c - CHEMICAL 3 (Powder)
50% Hexadecanol
50% Octadecanol

d - CHEMICAL 6
63% Octadecanol
33% Hexadecanol
4% Tetradecanol

e - CHEMICAL 7
80% Octadecanol
8% Eicosanol
8% Hexadecanol

f - CHEMICAL 8
77% Eicosanol
12% Docosanol
8% Octadecanol

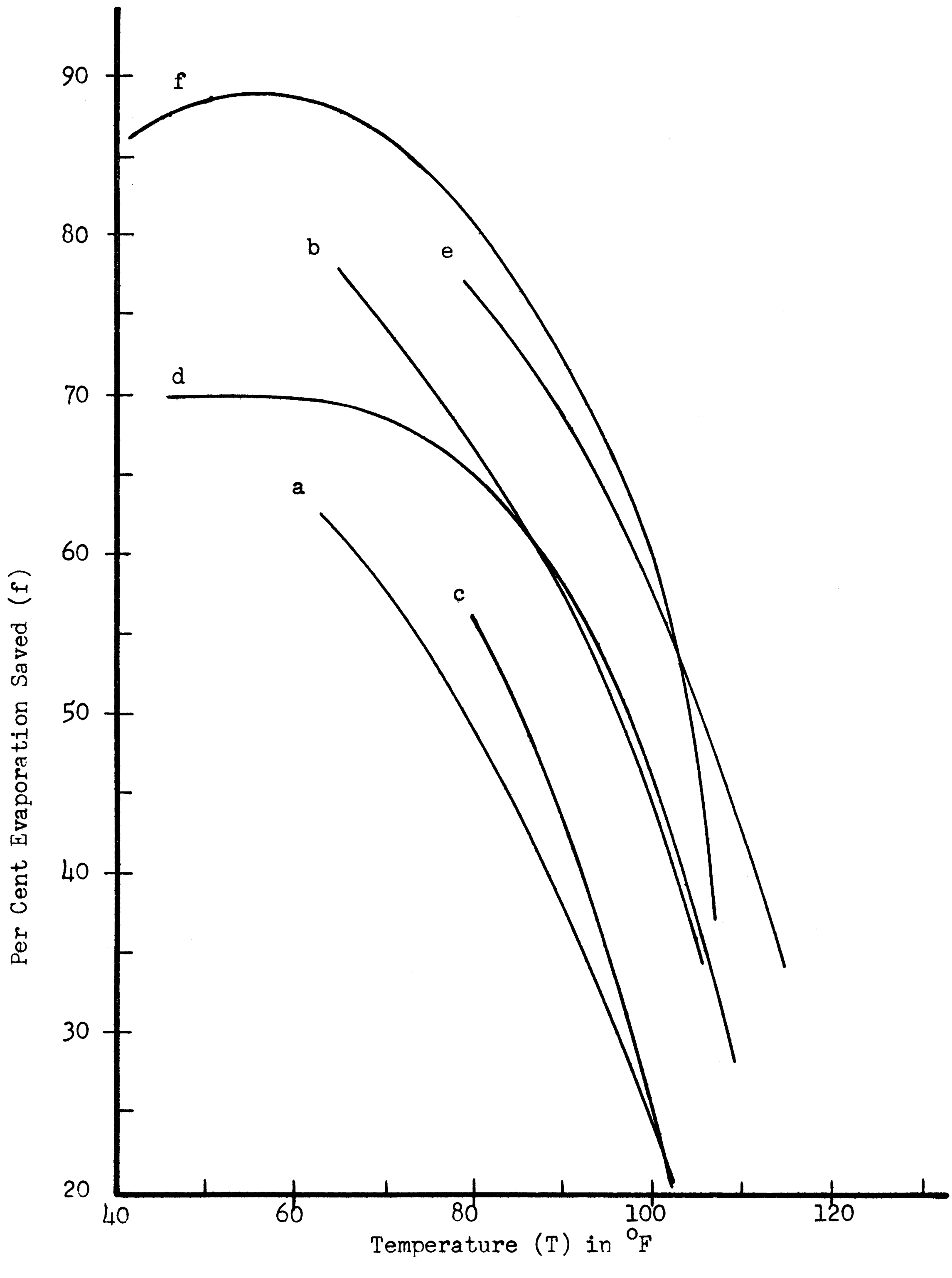

FIGURE 4. PERCENTAGE OF EVAPORATION SAVED VERSUS TEMPERATURE FOR MONOMOLECULAR FILMS SPREAD FROM LONG-CHAIN ALCOHOLS

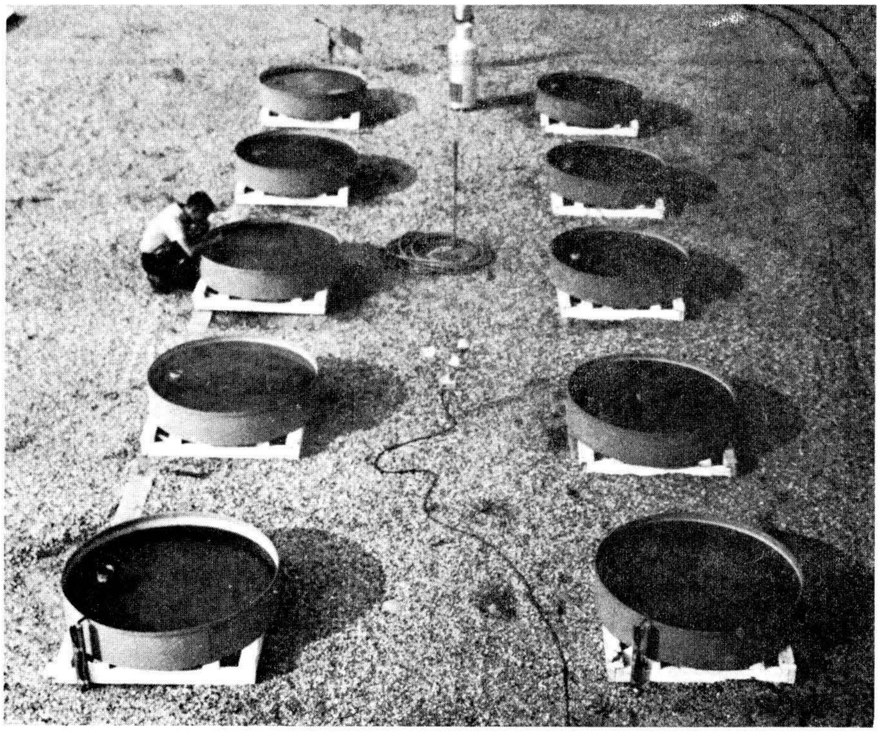

FIGURE 5. U. S. WEATHER BUREAU CLASS 'A' EVAPORATION PANS USED TO SCREEN LONG-CHAIN ALCOHOLS AND PHYSICAL FORMULATION.

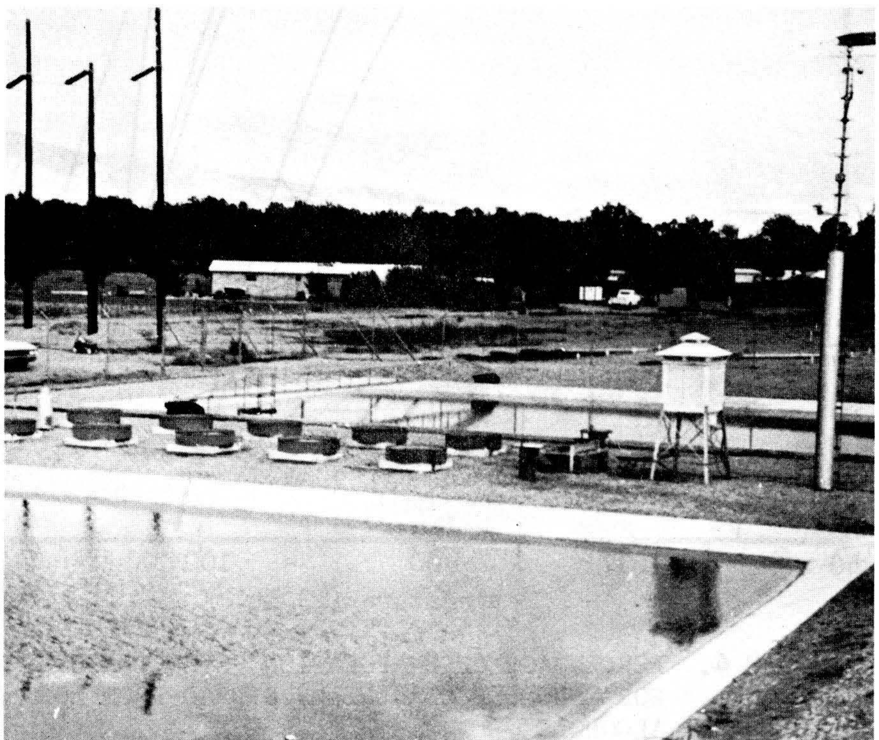

FIGURE 6. EVAPORATION-SUPPRESSION TEST PONDS AND EVAPORATION PANS.

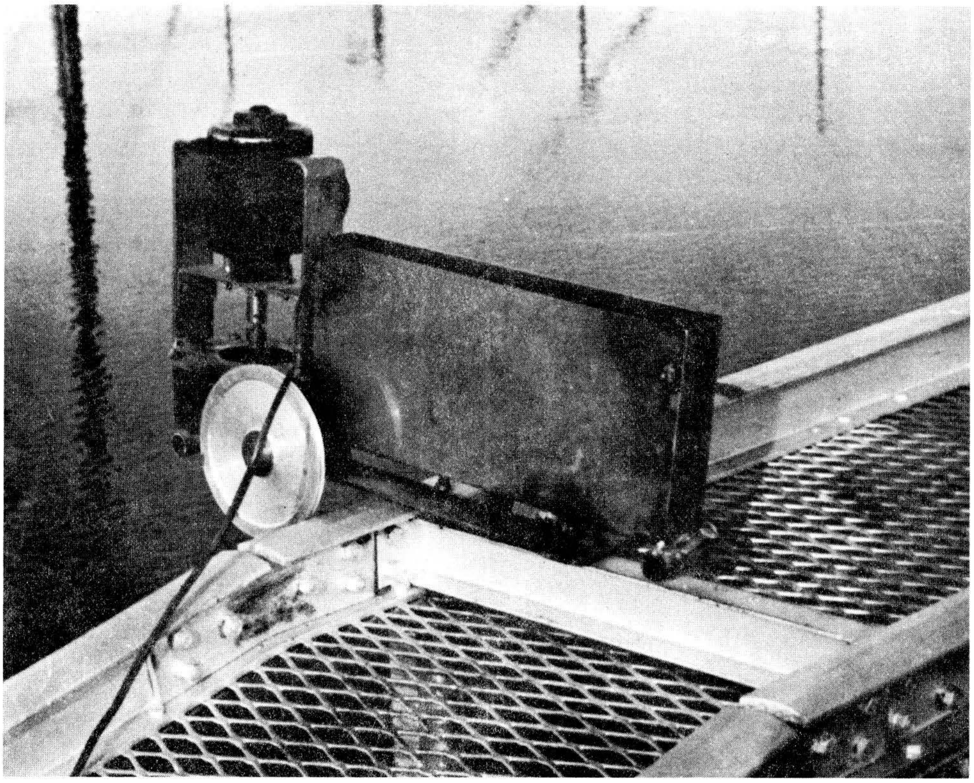

FIGURE 7. SELF FEEDING GRINDER-DUSTER FOR DISPENSING POWDERED LONG-CHAIN ALCOHOLS.

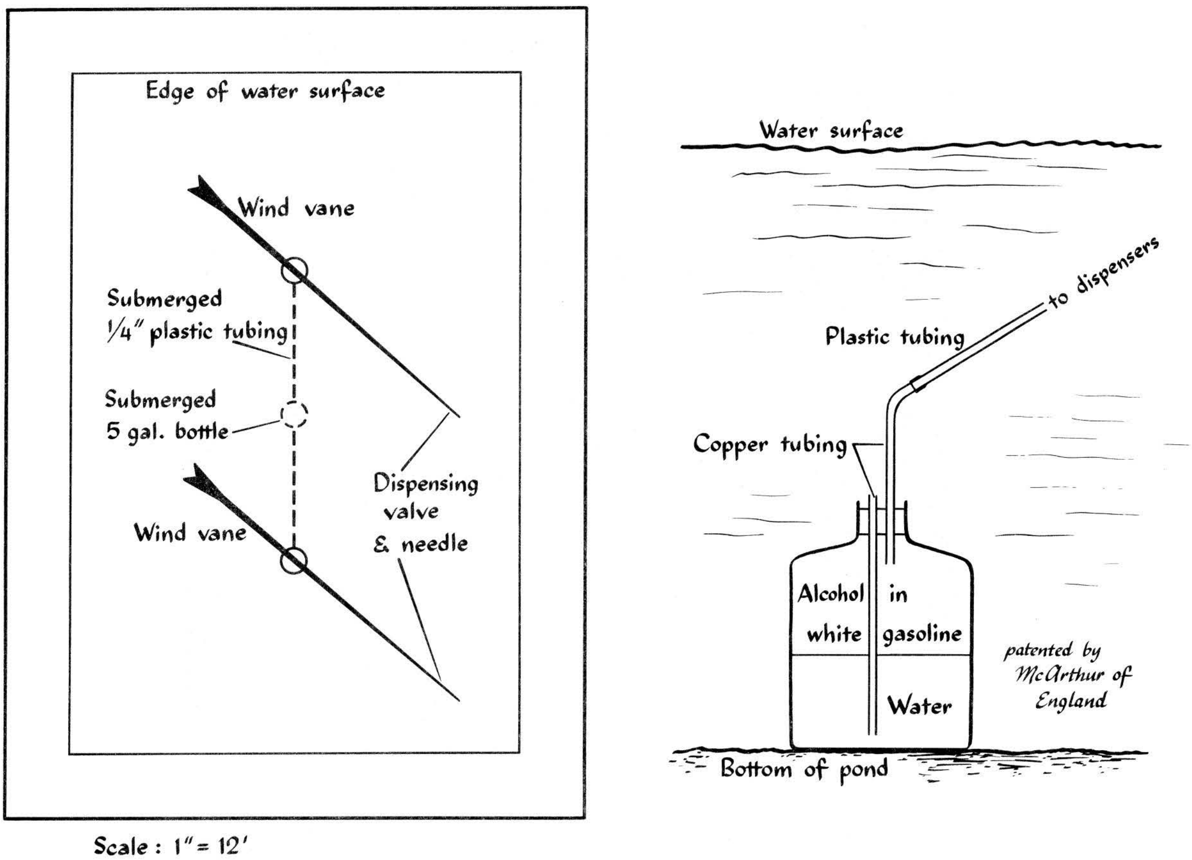

FIGURE 8. SCHEMATIC DIAGRAM OF DISPENSING APPARATUS FOR LONG-CHAIN ALCOHOLS IN SOLUTIONS.

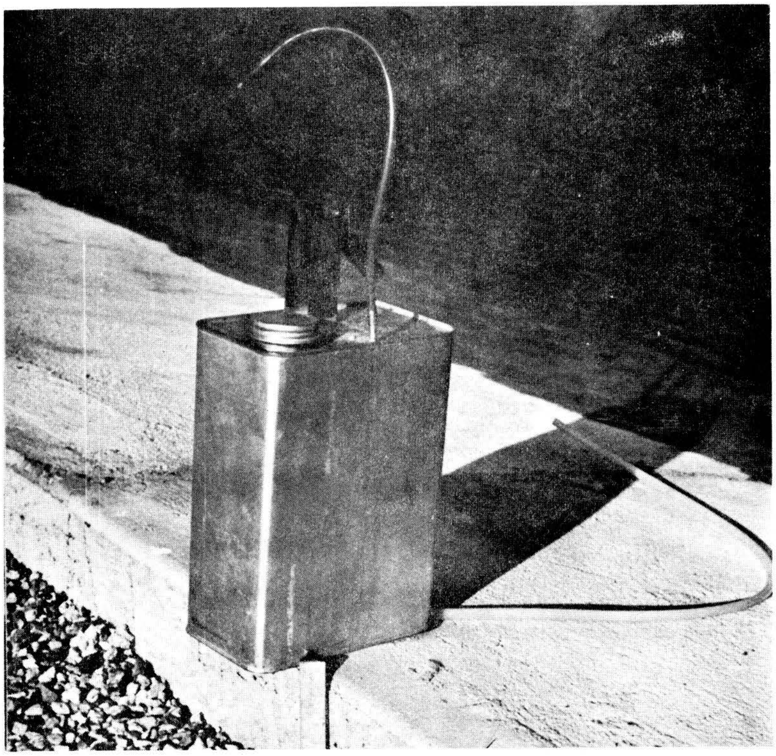

FIGURE 9. APPARATUS FOR THE CONTINUOUS DISPENSING OF LONG-CHAIN ALCOHOLS IN EMULSIONS. NOTE PRESSURE REGULATOR.

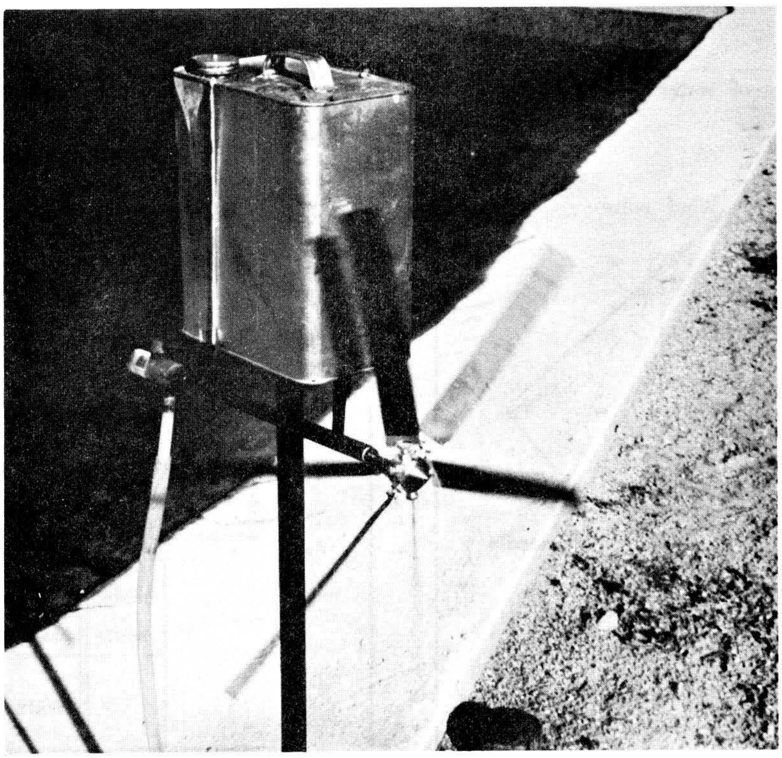

FIGURE 10. WIND ACTIVATED DISPENSER OF LONG-CHAIN ALCOHOLS IN EMULSIONS.

TABLE 1

Specifications of Emulsifiers Used in Evaporation-Suppression Investigations

Emulsifier Number	Chemical Components
1	Glycercol Monostearate
2	Polyoxyethylated Fatty Alcohol
3	Lauryl Sulfate, Arokyl Sulfonate, Amine Condensate, EDTA
4	Not Available at Present. (Recommended by Agricultural Research Service)

TABLE 2

SPECIFICATIONS OF CHEMICALS USED IN EVAPORATION-SUPPRESSION INVESTIGATIONS

Chemical Number	Percentage Composition of Alcohol*					Color	Density	M. P.	Ester Value	Hydroxyl Value	Iodine No.	Acid Value
	C_{14}	C_{16}	C_{18}	C_{20}	C_{22}							
1		95+				White	.82	46-48°C	0.6	220-230	1.0	0.1
2			95+			White	.81	53-55°C	0.7	200-205	1.5	0.2
3		50	50			White	.81	45-50°C	0.5	220-235	2.0	0.1
4	4	90	6			White	.82	47-51°C	2.0	227-231	1.5	1.0
5	2	95	3			White	.82	47-49°C	2.0	224-238	2.0	0.1
6	4	33	63			White	.80	52°C	N.R.	210	2.0	0.3
7	2	8	80	8	2	White	.82	51-54°C	2.0	206-216	3.0	1.0
8			8	77	12	White	.82	54-58°C	N.R.	N.R.	N.R.	N.R.
9		100				White	.82	48°C	N.R.	N.R.	N.R.	N.R.

* C_{14} - n-tetradecanol - myristic alcohol
C_{16} - Hexadecanol - cetyl alcohol
C_{18} - Octadecanol - stearyl alcohol
C_{20} - 1-Eicosanol - eicosyl alcohol
C_{22} - Docosanol

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