

Evaporation Control Research, 1955-58

By ROBERT R. CRUSE and G. EARL HARBECK, JR.

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1480

*Prepared in collaboration with the
Southwest Water Evaporation Research
Council, the Southwest Research Insti-
tute, and the Texas Board of Water
Engineers*



UNITED STATES DEPARTMENT OF THE INTERIOR

FRED A. SEATON, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

CONTENTS

	Page
Abstract.....	1
Introduction.....	1
Discussion of theory.....	4
Laboratory investigations.....	7
Laboratory screening of organic chemicals.....	7
Field screening, using 10-foot tanks.....	13
Miscellaneous laboratory studies.....	15
Bactericidal and bacteriostatic additives.....	15
Wind studies.....	17
Liquid-phase application methods.....	18
Cloud-point determinations.....	19
Wick-dispenser tests.....	21
Pelleting of solid evaporation retardants.....	27
Raft design.....	28
Considerations of toxicity.....	28
Large-scale field tests.....	30
Other methods of application.....	37
Application in a solvent.....	37
Application as a liquid.....	39
Application as a solid.....	39
Application as an emulsion.....	39
Suggestions for future work.....	39
The effect of impurities.....	39
Bactericides and bacteriostats.....	40
Bacteria-resistant materials.....	40
The effects of wind.....	40
Field studies.....	41
Screening apparatus.....	41
Technical details and specifications.....	41
Desiccant regeneration.....	41
Toxicity statement.....	42
References cited.....	44
Index.....	45

ILLUSTRATIONS

	Page
PLATE 1. Screening apparatus at Southwest Research Institute.....	4
FIGURE 1. Effects of molecular structure on compressibility of films of alkanols.....	5
2. Details of screening apparatus.....	8
3. Apparatus used for determining effects of wind on a monofilm..	17
4. Cloud-point temperatures for various ethanol-dodecanol (Lorol 7) mixtures.....	20
5. Cloud-point temperatures for various hexadecanol (Siponol CX)-dodecanol (Lorol 7) mixtures.....	21
6. Cloud-point temperatures for various hexadecanol (Siponol CX)-dodecanol (Lorol 11) mixtures.....	22
7. How to make an evaporation retarder.....	23
8. Sectional view showing method of installing dripper.....	23
9. Sketch showing arrangement of instruments.....	24
10. Variation of flow rate of dodecanol with time, using orlon wick (test no. 8).....	24
11. Variation of flow rate of dodecanol with time, using orlon wick in copper tubing (test no. 25).....	26
12. Variation of flow rate of dodecanol with time, using nylon wick in copper tubing (test no. 27).....	26
13. Miscellaneous raft designs.....	29
14. Dispensers used in Australia for large reservoirs.....	38

TABLES

TABLE 1. Compounds screened as evaporation retardants.....	9
2. Compounds rejected as evaporation retardants.....	12
3. Results of tests in 10-foot tanks.....	14

EVAPORATION CONTROL RESEARCH, 1955-58

By ROBERT R. CRUSE¹ and G. EARL HARBECK, JR.²

ABSTRACT

One hundred fifty-two compounds and compositions of matter were screened as potential evaporation retardants. The homologous straight-chain fatty alkanols are considered the best materials for retardants.

Several methods of application of the alkanols to the reservoir surface were investigated. Although wick-type drippers for the application of liquids and cage rafts for the application of solids appear to be the most promising methods from an economic standpoint, both methods have serious disadvantages.

Considerable study was given to reducing biochemical oxidation of the evaporation retardants. Copper in several forms was found adequate as a bacteriostatic agent but posed a potential hazard because of its toxicity. Many other bactericides that were tested were also toxic.

Two sets of large-scale field tests have been completed and several others are still in progress. On the larger reservoirs, the reduction of evaporation was not more than 20 percent under the prevailing conditions and the application procedure used.

Three major practical problems remain; namely, the effects and action of wind on the monofilm, the effects of biochemical oxidation, and the most effective method of application. Fundamental problems remaining include the effects of various impurities, and the composition of the best evaporation retardant; the long-range effects of monofilms on the limnology of a reservoir, including the transfer of oxygen and carbon dioxide; toxicological aspects of all components of any evaporation-retardant composition, plus toxicology of any composition chosen for large-scale use; and further studies of the calorimetry and thermodynamics involved in the mechanism of evaporation and its reduction by a monofilm.

INTRODUCTION

The purpose of the present investigation was to develop a practical, safe, and effective method of treating the surface of a water reservoir with a monomolecular chemical film to reduce losses of water by evaporation.

This report describes investigations made in Texas during the period 1955-58 on the use of a monomolecular film for the suppression of evaporation. The laboratory investigations were made by Southwest Research Institute of San Antonio, Tex., under a con-

¹ Southwest Research Institute.

² U. S. Geological Survey.

tract between the Institute and the Texas Board of Water Engineers, who acted as the contracting agency and fiscal agent for the Southwest Water Evaporation Research Council, Inc.

Funds for that part of the investigation made by Southwest Research Institute were contributed to the Southwest Water Evaporation Council by 86 different sponsors, among whom were municipalities, private industries—especially the private electric utilities—consulting engineers, technical societies, individuals, and other organizations.

The evaluation of the reduction in evaporation was made by the U. S. Geological Survey.

Technical articles from Australia in 1953 and 1955 (Mansfield, 1953, 1955) indicated the feasibility of control of evaporation from reservoir surfaces by thin chemical films—1 molecule, or one ten-millionth of an inch, thick. Reductions in the rate of evaporation of 45 percent were expected. The method was an application of the principles that were originally developed by Langmuir (1917). A duplex film was used initially, but later, a single-component film was applied with better results.

The work in Australia indicated that there were few, if any, problems under field conditions there. Differing climatic conditions, as well as vested public and private interests in many of the various reservoirs, dictated that the work in Australia, promising as it was, should be checked under conditions prevailing in Texas and southwestern United States before the procedures could be generally recommended in this country. These circumstances resulted in negotiations leading to a project at Southwest Research Institute to develop and modify the Australian process for use on both public and private reservoirs in the United States. Results obtained from tests made in stock tanks indicated that biochemical degradation of the materials recommended by the Australians was quite severe under conditions in the United States. These results were confirmed by independent investigations conducted by the Robert A. Taft Sanitary Engineering Center, U. S. Public Health Service, Cincinnati, Ohio, (Ludzack and Ettinger, 1957). Further, the wind provided a severe problem, contrary to Australian indications. This problem was not so pronounced on stock tanks as it was on larger reservoirs, where on windy days the films were found only on the downwind side of the reservoirs where they were compressed, and extended for distances varying from 3 to 30 feet from the shore. This phenomenon was noted when both liquid and solid retardants were used.

Restrictions on the use of any film-forming evaporation retardant are severe. The material used must not only reduce the rate of evaporation effectively, but it must be nontoxic to every beneficial kind of animal or plant using the reservoir water; it should, for economic reasons, be resistant to oxidation or degradation by microorganisms; it should not be detrimental to the biological balance of the reservoir, including effects on transfer of oxygen and carbon dioxide; and, as indicated by work done during this investigation, it should be effective in both hot and cold weather. Further, the cost of the process, including the initial cost of the material used, must be economical.

The economics of the process were promising at first. Mansfield (1956) estimated the cost at 2.5 cents per thousand gallons of water saved, based on a film life of 6 weeks and an application dosage of about 2.2 pounds per acre. This amount was found somewhat inadequate under prevailing conditions, but, using a solid retardant in cage rafts similar to those described by Mansfield, a dosage of 5 pounds per acre was found more satisfactory. Based on a cost of materials at 40 cents per pound in 1957, a film life of 60 days and a saving of 2 feet of evaporation in arid regions, the calculated cost of water saved by the monofilm technique under conditions in south-central Texas is about 5 cents per thousand gallons. Field tests indicated that these cost figures would apply primarily in areas of high evaporation, but not in areas of high humidity and low rate of evaporation.

Two items should be mentioned in connection with these costs. First, in a reservoir where evaporation makes the water slightly brackish, even a 20 percent saving of the water that would otherwise evaporate may be sufficient to render the entire reservoir usable. The water that evaporates is pure water; hence, any that is kept from evaporating reduces the concentration of dissolved solids in the reservoir. Any additional evaporation reduction over that needed to reduce the salinity level is an extra dividend in yield of usable water.

Second, in many areas a reduction in evaporation may mean that a reservoir will contain water for longer periods. The mere availability of even a small amount of water may be of sufficient economic importance that the cost of retarding evaporation is only a secondary consideration.

DISCUSSION OF THEORY

This work is an outgrowth of field investigations on evaporation control begun by Mansfield (1953, 1955) in Melbourne, Australia, in 1952. Mansfield's work, in turn, was an application of theoretical considerations developed by Langmuir (1917), and later applied by Hedestrand (1924), Adam (1941, chap. 2), Langmuir and Langmuir (1927), Rideal (1925), Langmuir and Schaefer (1943), and others to the reduction of evaporation of water.

Certain classes of organic compounds, having a hydrophylic (water-attracting) portion and a hydrophobic (water-repelling) portion in their molecular structures, possess the property of being able to spread out on a water surface. The hydrophobic portion of the molecule consists of a hydrocarbon structure—for this purpose, preferably, a long straight-chain structure of 10 or more carbon atoms. The hydrophylic portion is a functional group such as a hydroxyl, carbonyl, carboxyl, amine, amide, or nitrile group. Various hydrophylic groups, in combination with hydrophobic groups, known to form monomolecular films are given in the following list.

Hydrophylic groups forming monomolecular films

[Adam, 1941, p. 50]

<i>Group</i>	<i>Formula</i>	<i>Group</i>	<i>Formula</i>
Carboxylic acid.....	-COOH	Urea (substituted)	-NHCONH ₂
Hydroxyl.....	-OH	(below transition	
Amine (on alkaline	-NH ₂	temp.)	
water).		Nitrile.....	-CN
Amide.....	-CONH ₂	Ester.....	-COOR
Methyl ketone.....	-COCH ₃	Aldoxime.....	-CHNOH

Through a decrease in the free energy of the associated molecules in the solid or liquid state, caused by the greater attraction of the hydrophylic portion of the molecules for the underlying water than the interattraction of the molecules for each other, individual molecules of a compound will detach from a central source or reservoir of the material where placed on a clean water surface. The molecules will spread out radially until a barrier or shore line is reached. If enough material is exposed at the water surface, the molecules will continue to detach and spread out until they form a closely packed, or compressed film, one molecule thick, covering the entire reservoir surface. Such a film has been shown (Langmuir and Langmuir, 1927, Langmuir and Schaefer, 1943) to have the ability to retard the rate of evaporation of water.

The hydrophylic group used for the purpose of this application must be nontoxic. This criterion will essentially rule out most of the nitrogenous compounds given in the preceding list. The pres-



SCREENING APPARATUS AT SOUTHWEST RESEARCH INSTITUTE
Insulated trough contains battery jars used for testing various chemicals.

ence of calcium or magnesium ions in the water of the reservoir will essentially eliminate consideration of acids and esters; the acids will form the calcium or magnesium salts, which will no longer spread out to form or reform monomolecular films, and the esters will hydrolyze to give the same effects. This leaves the hydroxyl compounds, particularly the long straight-chain primary alkanols as the best materials to use. These straight-chain compounds, by nature of their chemical structure, will form the most effective evaporation-retardant film. (See fig. 1.) It will be noted that the

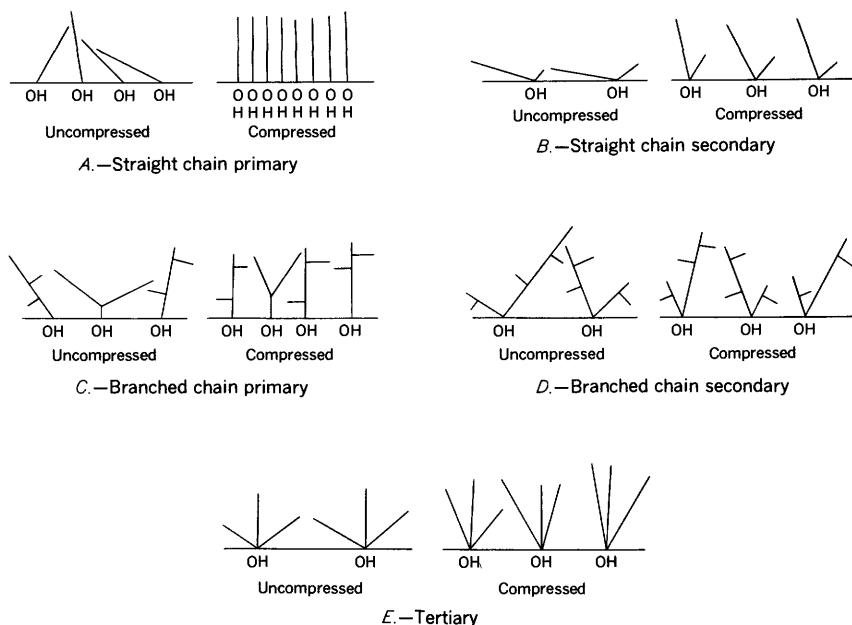


FIGURE 1.—Effects of molecular structure on compressibility of films of alkanols.

straight-chain primary structure is capable of forming a more highly compressed film than the secondary, tertiary, or branched-chain compounds. The effect of branching has been intensively studied with the 17 isomeric methylstearic acids and other materials (Weitzel, Fretzdorff, and Heller, 1951a, b).

Calculation of the effect of a monomolecular film has been done in several ways. Basically, the effect of evaporation retardation is described as a resistance to evaporation (Langmuir and Schaefer, 1943). If the evaporation of a clean, free water surface into a vacuum is taken as one resistance unit (Mansfield, 1956), the resistance of the laminar layer of water vapor and air immediately above the surface is about 600 units. If a perfect monomolecular film is taken as having a resistance to evaporation of 1,600 units,

the total resistance is 2,200 units, and the reduction of evaporation would be $1,600/2,200$ or 72.7 percent. Both wind velocity and relative humidity are critical factors, which vary widely, so that the rate of reduction of evaporation may vary from zero on a morning with 100 percent relative humidity to more than 90 percent on a hot, dry day with a steady wind blowing.

Anderson, Harbeck, and others (U. S. Geological Survey, 1954) were among those who developed the energy budget method of determining the rate of evaporation from a free water surface. This method consists of making an accounting of all incoming and outgoing energy; the difference is the energy utilized for evaporation. The application of an evaporation suppressant film does not affect the energy received as solar or atmospheric radiation. If evaporation is suppressed, the temperature of the water surface must rise until the energy, no longer being used for evaporation, is disposed of by other processes, such as back radiation and conduction, which will be described subsequently in detail. Thus after a calibration period needed to determine certain physical constants of a particular reservoir, the effectiveness of a film in suppressing evaporation can be evaluated and the resultant rise of water temperature computed. Temperature differentials of as much as 8°F have been observed between two adjacent steel stock tanks, each 10 feet in diameter, only one of which had a monomolecular film.

Important theoretical considerations are brought up by the method of application. Mansfield (1955) developed the l/A criterion, which is the ratio of length of exposed perimeter of solid particles of film-forming material to the area of exposed water surface to be covered. His calculations indicate a critical minimum l/A ratio of 2×10^{-3} centimeter⁻¹ (0.002 centimeter of perimeter per square centimeter of surface area) for film formation. This indicates that finely divided solid material is preferred to large lumps of material, if a solid is used as the film generator. The l/A ratio does not appear to hold for liquid materials. Likewise, the emulsion application procedure of Dressler (written communication, January 1958) either produces large exposed perimeter of material through formation of microparticles or is not governed strictly by the l/A ratio of Mansfield. Mansfield's l/A ratio indicates that 1 pound of flaked solid alkanol should be used for a maximum water surface area of 35,000 square feet.

The homologous straight chain fatty alkanols that are most readily available—those having even numbers of carbon atoms—suffer from a major disadvantage, despite their theoretical superiority, of being susceptible to biochemical oxidation. This oxidation not only takes place on the film after formation, but on the reserve supply if it is

stored on the water surface. Similar straight-chain primary alkanols containing odd numbers of carbon atoms were not available during the course of this investigation.

A secondary problem, apparently common to all monomolecular evaporation retardant films, results from the film being swept off the reservoir and piled up on shore by the action of the wind.

LABORATORY INVESTIGATIONS

The laboratory work in this program was done in two stages. The first stage consisted of the laboratory screening of organic chemicals deemed to have some value as evaporation-retardant materials. Emphasis was placed on commercially available materials. Two preliminary specifications were that the molecular structure must have the basic chemical characteristics, and it must comprise a minimum of 10 carbon atoms. It was felt that any lesser number of carbon atoms in the straight chain would not only be too volatile, but would also provide a film too thin to be effective (Archer and La Mer, 1954).

The second phase of the laboratory work consisted of further evaluation, in stock tanks 10 feet in diameter, of those compounds or mixtures showing promise in the screening program.

LABORATORY SCREENING OF ORGANIC CHEMICALS

The screening apparatus used in the laboratory, for which technical construction details are given on page 41, is shown in figure 2 and plate 1. As originally constructed, the apparatus held eighteen 9-inch battery jar test units. The apparatus was subsequently modified to accommodate only 14 units; the other space was occupied by a coil of copper tubing immersed in the insulated trough to bring the temperature of the air up to that of the water in the trough and test units as nearly as possible. Each test unit consisted of a battery jar 9 inches in diameter by 12 inches deep, fitted with a specially designed lid, an inlet for dry air, and an automatic feed reservoir containing distilled water to replace that evaporated by the air stream. The design of the lid was such that with a $\frac{1}{4}$ -inch clearance between the bottom of the lid cone and the water surface, the air velocity was constant across the entire surface area. A manometer was placed in the incoming air line and calibrated by means of a rotameter, in order to determine the rate of air flow.

Air, dried by passing over silica gel, was passed over the water surface at the rate of 12.5 liters of free air per minute. In the test units, the compounds to be tested were applied in solid or liquid

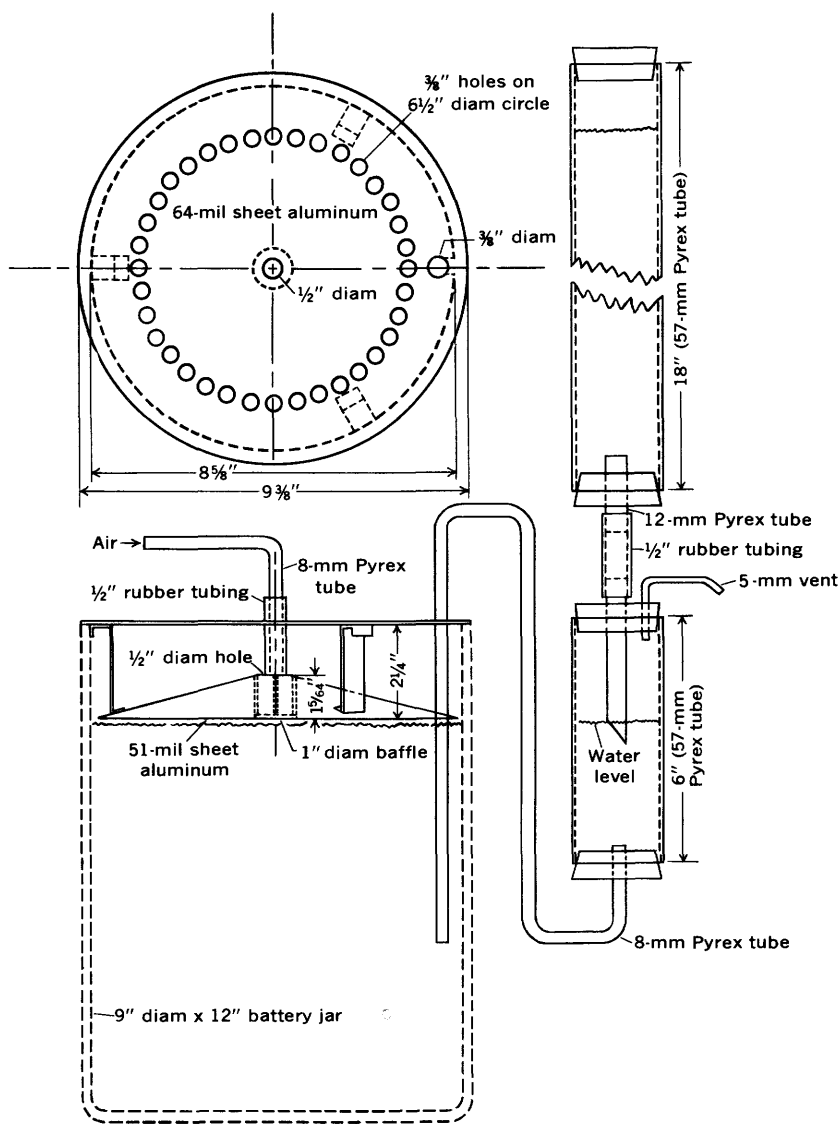


FIGURE 2.—Details of screening apparatus.

form at a dosage equivalent to 1 pound per acre of water surface. This was a 5-milligram dose on the surface, 9 inches in diameter. Two jars containing untreated water were used as control units in each test bank. As the water in the jar evaporated, the water level was maintained by automatic replenishment with water from the reservoir. By starting at a predetermined level and refilling the reservoirs to this level, the amount of water evaporated could be easily determined. It was found necessary to replace the water

in the feed reservoir every 24 hours. At a trough temperature of 30°C (86°F), the control units generally lost about 2.5 liters of water over a test period of approximately 110 hours of continuous operation. Such a test period gave results reproducible to within 5 percent.

Materials screened and the results obtained are summarized in table 1. Materials rejected as evaporation retardants due to high water solubility are summarized in table 2.

Several samples of hexadecanol and other alkanols, several silicones, and other miscellaneous materials were not screened.

TABLE 1.—Compounds screened as evaporation retardants

Sample No.	Test No.	Composition	Trade name	Saving in evaporation (percent)	Code No. of test
Primary alkanols (saturated)					
1	6	1-hexadecanol, N.F.	1-hexadecanol, N.F.	27.0	682-WE.
2	7	do.	Cachalot, C-50.	23.0	Do.
3	8	1-hexadecanol, technical	1-hexadecanol, technical.	34	712-WE, No. 15.
13	9	N.F.	Adol 52.	36.2	682-WE.
14	10	cosmetic grade.	Adol 54.	22.0	699-WE, No. 43.
16	11	{1-hexadecanol, 28 percent. 1-octadecanol, 70 percent.	Adol 63.	54	699-WE, No. 55.
17	12	{1-hexadecanol, 52.5 percent. 1-octadecanol, 39.8	Adol 65.	19.2	682-WE.
18	13	{1-hexadecanol, 52.7 percent. 1-octadecanol, 40.0 percent.	Adol 66.	37.8	Do.
84	15	1-hexadecanol, N.F.	Lorol 24.	37.8	682-WE, No. 52.
91	16	{1-hexadecanol, 34 percent. 1-octadecanol, 64.8 percent.	Dytol E-46.	30	699-WE, No. 45.
15	19	1-octadecanol, U.S.P.	Adol 62.	68	712-WE, No. 38.
19	20	90 percent.	Adol 68.	37	699-WE, No. 47.
110		1-hexadecanol, N.F.	Cachalot, C-52.	44.6	682-WE.
116	46	{C ₁₂ C ₁₄ Alkanols, 4 percent. C ₁₆ C ₁₈ Alkanols, 92 percent.	Siponol TX.	31	699-WE.
120	81	{1-hexadecanol, 6 percent C ₁₄ . 70 percent C ₁₆ .	Siponol CX.	42	Do.
81	3	{1-dodecanol, 61 percent. 1-tetradecanol, 23 percent.	Lorol 5.	21	712-WE.
82	4, 42	{1-dodecanol, 55 percent. 1-tetradecanol, 21 percent.	Lorol 7.	56	Do.
83	5	{1-dodecanol, 71 percent. 1-tetradecanol, 26 percent.	Lorol 9.	18	Do.
4	17	1-dodecanol, crude.	Adol 10.	54	Do.
5	18, 40	saturated coconut	Adol 11.	65	Do.
6	19	90 percent C ₁₂ .	Adol 12.	15	Do.
7	20	55 percent C ₁₂ .	Adol 13.	60	Do.
9	21	68 percent C ₁₂ .	Adol 15.	None	Do.
11	23	1-octadecanol.	Adol 42.	50	Dc.
87	29	{1-dodecanol, 60 percent. 1-tetradecanol, 25 percent.	Dytol B-35.	16	Do.
88	31	{1-dodecanol, 71 percent. 1-tetradecanol, 27 percent.	Dytol A-24.	19	Do.
89	32	{1-dodecanol, 80 percent. 1-tetradecanol, 19 percent.	Dytol J-68.	21	Do.
90	33	1-dodecanol, 90 percent.		25	Do.
8	43	62 percent.	Adol 14.	28	Do.
128	66	1-hexadecanol, 90 percent.	90 percent cetyl alcohol.	21.5	Do.
130	68	90 percent.	Cetyl alcohol.	43	Do.
134	8	{1-dodecanol, 70 percent C ₁₂ . 25 percent C ₁₄ .	Siponol L2X.	None	721-WE.
135	9	{1-dodecanol, 62 percent C ₁₂ . 23 percent C ₁₄ .	Siponol L6X.	60.5	Do.
136	11	{1-hexadecanol 1-octadecanol} 50:50.	Cetyl-stearyl mixture.	49	Do.

TABLE 1.—Compounds screened as evaporation retardants—Continued

Sample No.	Test No.	Composition	Trade name	Saving in evaporation (percent)	Code No. of test
Primary alkanols (saturated)—Continued					
142	12	1-tetradecanol.....	Myristyl alcohol.....	None	721-WE.
143	14	1-hexadecanol.....	Cetyl alcohol, N.F., extra pure.....	1.3	Do.
93	17	Hydroabietyl alkanol.....	Abitol.....	10.8	Do.
142	24	1-tetradecanol.....	Myristyl alkanol.....	14.4	Do.
143	25	1-hexadecanol.....	Cetyl alkanol, N.F.....	56.2	Do.
144	26	1-octadecanol.....	Stearyl alkanol.....	57.8	Do.
85	42	1-octadecanol, industrial grade.....	Lorol 28.....	55	699-WE.
79	48	1-docosanol.....	Adol 60.....	45	Do.
80	49	1-docosanol.....	Adol 67.....	53	Do.
84	1, 14	1-hexadecanol, N.F.....	Lorol 24.....	44	712-WE.
21	26	Dimethyl octanol.....	Primary decanol.....	None	Do.
129	67	Fatty alkanol mixture.....	Fatty alkanol mixture.....	None	Do.
145	28	Fatty alkanol mixture.....	Ceramol.....	52.2	721-WE.
155	-----	1-hexadecanol.....	Cetalol O.....	(²)	
157	-----	Octadecanol, from acid.....	3101-R-485-104R.....	2.3	
Primary alkanols (unsaturated)					
11	17	1-hexadecanol, 35.5 percent.....	Adol 42.....	25	682-WE.
		1-octadecanol, 16 percent.....			
		1-octadecanol, 46 percent.....			
115	6	9-octadecen-1-ol.....	Adol 80.....	None	712-WE.
10	22	13-docosen-1-ol.....	Adol 22.....	7.5	
20	24	9, 12, 15-octadecatrienol.....	Unadol 90.....	6	Do.
86	61	9-octadecenol.....	Unadol 40.....	8	Do.
		9, 12, 15-octadecatrienol.....			
Secondary alkanols (saturated)					
112	51	Methyl heptadecyl carbinol.....	Methyl heptadecyl carbinol.....	34	699-WE.
113	76	12-tricosanol.....	Diundecyl carbinol.....	None	Do.
114	79	18-pentatriaicosanol.....	Diheptadecyl carbinol.....	None	Do.
22	34	5-ethyl-2-nonanol.....	Undecanol.....	1	712-WE.
23	35	2, 6, 8-trimethyl-4-nonanol.....	Trimethylnonanol.....	None	Do.
24	36	7-ethyl-2-methyl-4-undecanol.....	Tetradecanol.....	15	Do.
25	37	3, 9-diethyl-6-tridecanol.....	Heptadecanol.....	1	Do.
Nitriles					
62	59	Octadecyl nitrile.....	Arneel 180.....	None	699-WE.
Dihydroxy and polyhydroxy compounds					
12	18	1, 12-octadecandiol.....	Adol 45.....	None	682-WE.
27	68	2, 5-dimethyl hexane-2, 5-diol.....	Dimethyl hexanediol.....	11	699-WE.
28	27	3, 6-dimethyl-3, 6-octanediol.....	Dimethyl octanediol.....	16	712-WE.
Ethylene oxide condensation products					
121	28, 41	Polyoxyethylated tallow alkanols.....	X-69.....	51	712-WE.
102	52	N, N-polyoxyethylene fatty acid amide, 5 mols ethylene oxide.....	Ethomid HT/15.....	18	Do.
104	53	Mono fatty acid ester of polyoxyethylene glycol.....	Ethofat 60/12.....	15	Do.
101	25	Polyoxyethylene-tertamine.....	Ethomeen 2 c/18.9.....	None	715-WE.
103	26	Mono fatty acid ester of polyoxyethylene glycol, 2-mols ethylene oxide.....	Ethofat 60/15.....	None	Do.

See footnotes at end of table.

TABLE 1.—Compounds screened as evaporation retardants—Continued

Sample No.	Test No.	Composition	Trade name	Saving in evaporation (percent)	Code No. of test
Ketones					
56	57	Methyl pentadecyl ketone.....	Methyl pentadecyl ketone.	12	699-WE.
57	58	Methyl heptadecyl ketone.....	Methyl heptadecyl ketone.	22	Do.
58	66	Diocetadecyl ketone.....	Stearone	6	Do.
54	12	2-undecanone.....	Methyl nonyl ketone..	None	712-WE.
94	46	13-pentacosanone.....	Laurone	30	Do.
55	22	2-tridecanone.....	Methylundecyl ketone.	None	715-WE.
124	64	2-hydroxy-4-methoxy-benzophene.	UV absorber 9.....	None	712-WE.
131	70	Anthraquinone.....	Anthraquinone.....	None	Do.
Silicones					
108	1	Methyl silicone.....	D-C 200 fluid, 100 cks. ²	17.8	721-WE.
109	2	do.....	D-C 200 fluid, 1000 cks.	17.0	Do.
132	3	do.....	D-C 510 fluid.....	20.4	Do.
133	5	Methyl phenyl silicone.....	D-C 550 fluid.....	26.2	Do.
137	6	Methyl silicone.....	Silicone SF-96, 40 cks.	10.0	Do.
146	7	Methyl phenyl silicone.....	D-C 702 fluid.....	None	Do.
156		Silicone.....	Z-411.....		
Phenols					
111	13	2-naphthol.....	Beta-naphthol.....	14	712-WE.
105	55	3-N-pentadecyl phenol.....	3-N-pentadecyl phenol.	20	Do.
106	56	5-N-pentadecyl resorcinol.....	5-N-pentadecyl resorcinol.	None	Do.
107	19	Pentadecane-1, 8-bis phenol.....	Cardolite 6463.....	20.1	Do.
Amines					
59	67	Aminopropyl tallow amine.....	Duomeen T.....	None	699-WE.
60	60	Octadecyl amine.....	Armeen 18.....	None	Do.
65	9	Tertiary C ₁₈ —C ₂₄ amines (mixture).	Primeen JM-T.....	None	712-WE.
66	11	Tertiary C ₁₂ —C ₁₈ amines (mixture).	Primene 81-R.....	3	Do.
61	6	Stearyl dimethyl amine.....	Armeen DM-18.....	34	715-WE.
63	7	N-coco morpholine.....	N-coco morpholine.....	None	Do.
64	8	N-tallow morpholine.....	N-tallow morpholine.....	None	Do.
127	14	Oleyl-N-alkylimidazoline.....	Amine O.....	None	Do.
125	28	Lauryl-N-alkylimidazoline.....	Amine C.....	None	Do.
122	62	Stearoguanamine.....	Stearoguanamine.....	6	712-WE.
126	65	Stearyl-N-alkyl imidazoline.....	Amine S.....	None	Do.
Acids					
44	53	Stearic acid single pressed.....	Stearic acid single pressed.	None	699-WE.
39	70	Hydrogenated marine fatty acid, No. 52.	Hydrogenated marine fatty acid, No. 52.	12	Do.
40	71	Hydrogenated tallow fatty acid, No. 57.	Hydrogenated tallow fatty acid, No. 57.	12	Do.
41	72	Hydrogenated tallow fatty acid, No. 58.	Hydrogenated tallow fatty acid, No. 58.	22	Do.
45	73	Triple pressed stearic acid.....	Neofat 18-55.....	8	Do.
48	74	Terephthalic acid.....	T.P.A., technical.....	None	Do.
32	77	Hydrogenated oleic acid.....	Fatty acid RG.....	8	Do.
119	80	Mixed C ₁₈ dicarboxylic acids.....	Isosebatic acid.....	11	Do.
96	48	N, N-diocetadecyl carboxyamino acid.	Di HT zwitterion.....	14	712-WE.
98	50	9 (10) monohydroxystearic acid...	Monohydroxystearic acid.	6.5	Do.
29	1	Oleic acid.....	Emersol 210 elaine.....	None	715-WE.
30	2	Oleic acid (low linolenic).....	Emersol 233 elaine.....	None	Do.
36	3	Fatty acid No. 35.....	Fatty acid No. 35.....	5	Do.
38	4	Tallow fatty acid.....	Fatty acid No. 42.....	3	Do.
92	12	C ₂₀ dibasic acid.....	Empol 1022.....	None	Do.
31	151	Oleic acid.....	Sap. Gr. red oil.....	None	Do.

See footnotes at end of table.

TABLE 1.—Compounds screened as evaporation retardants—Continued

Sample No.	Test No.	Composition	Trade name	Saving in evaporation (percent)	Code No. of test
Acids—Continued					
33	16	Coconut fatty acid.....	Fatty acid 8D.....	None	715-WE.
34	17	Corn oil fatty acid.....	Fatty acid No. 20.....	6	Do.
35	19	Soya oil fatty acid.....	Fatty acid No. 25.....	None	Do.
37	20	Cottonseed fatty acid.....	Fatty acid No. 36.....	14	Do.
42	21	Fatty acid No. 36.....	Fatty acid No. 86.....	None	Do.
46	57	Pulverized limestone, coated with stearic acid.....	Pulverized limestone, RP-1.....	6	712-WE.
47	58	Pulverized limestone, coated with stearic acid.....	Pulverized limestone, R-2.....	None	Do.
Amides					
50	61	Coco acid amide.....	Armid C.....	None	699-WE.
51	63	{Palmitamide, 22 percent. Stearamide, 75 percent.....}	{Armid HT.....	None	Do.
52	62	Palmitamide.....	Armid 16.....	None	Do.
53	65	Stearamide.....	Armid 18.....	None	Do.
97	49	Methylene bis stearamide.....	Armowax.....	None	712-WE.
123	63	N-tertoctyl acrylamide.....	N-tertoctyl acrylamide	None	Do.
Esters					
69	56	Dimethyl terephthalate.....	DMT.....	9	699-WE.
49	75	Hydrogenated castor oil.....	Castorwax.....	None	Do.
117	7	Methyl ester of tallow acids.....	Methyl tallowate.....	None	712-WE.
118	8	Methyl linoleate.....	Methyl linoleate.....	None	Do.
75	10	Isooctyl thiolglycolate.....	Isooctyl thiolglycolate.....	None	715-WE.
77	23	Cetyl palmitate (technical).....	Moby Dick Sperm 90.....	39	Do.
76	59	Sperm oil.....	Moby Dick N.W. 45°.....	16	712-WE.
Miscellaneous					
78	44	Hydrogenated sperm wax.....	Hywax 120.....	10	712-WE.
95	47	N-octadecyl maleic anhydride, product condensation.....	HT-maleamic acid.....	23	Do.
99	51	Dialkyltertamine stearate.....	2 HT methyl stearate.....	18	Do.
70	9	Microballoons (phenolic resin).....	Lucite (powder).....	None	715-WE.
71	11	Methyl methacrylate polymer.....	Ethoduomeen T/13 distearate.....	None	Do.
100	24	Trimethyl-N-alkyltrimethylene diamine distearate.....	N-hexadecane.....	11	Do.
72	10	N-hexadecane.....	A-C, grade 6.....	None	721-WE.
73	15	Powdered polyethylene.....	Resoflex 296.....	14.1	Do.
74	16	Alkyd resin polymer.....	Tagol 10.....	4.8	Do.
138	20	Still bottoms from Adol 10.....	Tagol 34.....	24.1	Do.
139	21	Still bottoms from Adol 34.....	Tagol 40.....	None	Do.
140	22	Still bottoms from Adol 40.....	Tagol 65.....	32.5	Do.
141	23	Still bottoms from Adol 65.....		5.6	Do.

¹ This value is pro rata. The film broke up and lost its effectiveness at different times in a duplicate set of reruns. At the time this value was determined, both tests were nearly identical. Elapsed time about 70 hours. Average value at end of test (114 hours) 27 percent.

² Test conducted on 10-foot tanks only.

³ Cks, centistoke.

TABLE 2.—Compounds rejected as evaporation retardants

Sample No.	Composition	Trade name	Lot or serial No.	Appearance	Reasons for rejection
26	Polyvinyl alcohol resin.	Vinol FH 600..	2834.....	White powder.....	Did not form a film; sank to bottom of beaker and dissolved slowly.
67	Dodecyl diethylene triamine.	Amine ODT..	55-11-178..	Viscous tan liquid amine odor.	Dispersed, formed turbid, translucent mixture.
68	Polyethoxylated vegetable oil.	Emulphor E1-719.	None.....	Oily, yellow liquid.	Dissolved—completely miscible with water.

FIELD SCREENING, USING 10-FOOT TANKS

Two corrugated stock-watering tanks, 10 feet in diameter and 2 feet deep, were buried in the ground to within 2-3 inches of the top. Each tank was fitted with a brass stilling well set on a notched glass plate. The test area was fenced off with 1-inch mesh chicken wire. In operation, the tanks were thoroughly cleaned, using acetone when necessary, and flushed and filled with clean water. The material to be tested was applied by one of several methods to the surface of one tank; the other tank was used as a control. Evaporation was allowed to proceed under natural conditions until the film-forming material gave no further positive evaporation reduction effect as determined by inspection of the data obtained daily.

Generally, solid material was applied by means of a small cage raft floating on the surface and held in place by a string or wire stretched taut across the top of the tank. Buoyancy was maintained by large corks or cork rings. Liquid materials were either applied all at once, in somewhat lesser quantities than the solid compounds, or were applied slowly by gravity feed through a capillary tube.

Recorded data included the level of the water, as determined by an average of three readings of the hook gauge in the stilling well in each tank, the surface temperature of the water in each tank, the air temperature, the wind velocity and direction, and the wet-bulb temperature. These data were obtained in the morning and evening during the week, and once a day on Saturday and Sunday. From them, the rate of evaporation under the prevailing conditions was easily determined as was the percent reduction of evaporation.

Test results using the 10-foot tanks are summarized in table 3. It will be noted that until some bacteriostatic agent was utilized, the film life was very short. This indicated that the problem of biochemical oxidation was one to be reckoned with, contrary to preliminary experience in Australia. Other conclusions drawn from this phase of the work were:

1. Even in cool weather, a dry "norther" will cause considerable evaporation. This indicates that the use of the monofilm technique is, under certain circumstances, advisable the year round.
2. A compressed film will assist in keeping a reservoir from freezing over. Examination of the energy budget theory confirms this experimentally determined phenomenon; the extra energy not consumed in evaporation must be withdrawn from the reservoir before freezing can occur.

TABLE 3.—*Results of tests in 10-foot tanks*

Test No.	Evaporation retardant	Amount used (g)	Length of test (days)	Type of application	Reduction of evaporation (percent)	Remarks
1	Hexadecanol (Fisher).	1.8	7	0.8 g, broadcast; 1.0 g, in raft (aluminum screen).	25.9	Amount equivalent to 1 lb per acre broadcast, and 1.2 lb per acre in reserve supply.
2	Octadecanol (Adol 62).	1.8	11	do.....	24.9	
3	Dodecanol (Adol 11).	1.8	7	Broadcast.....	4.3	
4	X-69 (tallow alkyl-ethylene oxide condensation product; American Alcolac)	1.8	13+	0.8 g, broadcast; 1.0 g, in raft (aluminum screen).	None	Material broadcast; added as a melt.
5	Octadecanol (Adol 62).	1.8	19	do.....	15.4	
6	do.....	108.6	9	Raft (aluminum screen).	11.8	Larger raft used; film generation from raft only.
7	Hexadecanol (Adol 54).	113.4	47	Raft (copper-bronze screen).	33.0	11.2 g cupric sulfate pentahydrate, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ (=0.6 ppm Cu) added to water.
8	Hexadecanol (mixed brands).	50	64	do.....	16.7	Hexadecanol compounded with 1 percent cupric stearate.
9	Hexadecanol (Cetalol O).	50	35	do.....	35.0	Hexadecanol compounded with 1 percent "G-4 Dichlorophene" (Sindar).
10	Hexadecanol (Lorol 24).	50	61	do.....	25.7	Hexadecanol compounded with 5 percent "Chlorhydrol" $\text{Al}_2(\text{OH})_2 \text{Cl}_2$, Reheis Co., a 50 percent by weight aqueous solution.
11	Hexadecanol (Siponol CX) in dodecanol (Lorol 7), 15 percent by weight.	54	19	Liquid phase, dripper.	30.8	Applied from canister dripper, with 0.0135-in. drip hole in bottom.
12	do.....	122	27	do.....	25.6	Canister dripper, 0.019-in. I.D. stainless steel drip tube in bottom. See under No. 11 also.
13	do.....	7	8	do.....	28.0	Canister dripper, 0.020-in. brass plate, with 0.0135-in. hole, in bottom. See under No. 11 also.
14	Methyl heptadecyl carbinol.	50	7	Raft, copper screen..	17.7	

¹ 74 hours.

- Rain will break up the film; it will re-form promptly, however, if adequate material reserves are present.
- During periods of high humidity, the saving in evaporation was small. Thus in humid areas, the use of a film would probably not be economical, but in such areas the loss by evaporation is generally of little consequence.

5. Any compound not giving excellent results in the laboratory screening phase was of little value in this phase of the program.

MISCELLANEOUS LABORATORY STUDIES

BACTERICIDAL AND BACTERIOSTATIC ADDITIVES

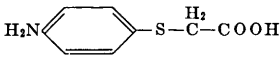
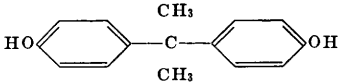
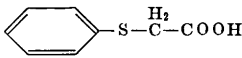
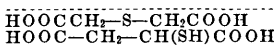
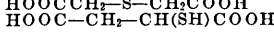
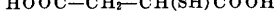
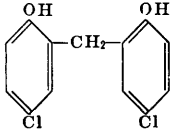
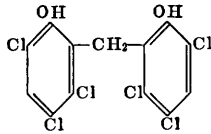
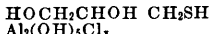

The results on the first few tests in the 10-foot tanks indicated that some destruction of the film was taking place, or some other phenomenon was occurring that caused the effective life of the film to be shortened. When 0.6 ppm (parts per million) copper as cupric sulfate pentahydrate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) was added to the water in the tanks, the effective life of the film increased markedly (test 7). This emphasized the necessity for inclusion of some bacteriostatic or bactericidal material either in the water or in the film itself. The former alternative was promptly ruled out, on both cost and safety considerations. To bring Lake Mead, for example, to a concentration of 1 ppm of copper would require approximately 160,000 tons of copper sulfate pentahydrate, and there is no assurance that distribution would be sufficiently uniform to eliminate the possibility that the water might be poisonous in some areas. Inclusion of the bacteriostat in the film appeared to be much more promising. Copper salts of several organic acids were prepared, several other acids were collected for preparation of copper salts, and samples of a few cosmetic bacteriocides not containing copper was also obtained for testing.

The copper salts were compounded with hexadecanol or octadecanol by melting and cooling with stirring. Generally, 1 percent by weight of the copper salt was incorporated into the alkanol. The solubility of the copper salts in the hexadecanol depended upon the acid structure. The various copper salts and their relative solubility in hexadecanol and other bacteriostatic materials used in this phase of the investigation are shown in the following lists.

Solubility of various copper salt bactericides in hexadecanol

<i>Copper salt</i>	<i>Solubility in molten hexadecanol</i>
Isosebaccate.....	Fairly good.
12-hydroxystearate.....	Very good.
Gluconate.....	Very poor.
Benzoate.....	Poor.
Salicylate.....	Fairly good.
Succinate.....	Do.
Tartrate.....	Extremely poor.
Stearate.....	Very good.
Laurate.....	Do.

Compounds used as bacteriocides or bactericide intermediates

Name	Formula
Aminophenylmercaptoacetic acid.....	
Hydrogenated bisphenol A.....	
Phenylmercaptoacetic acid.....	
Sesame oil USP.....	
Thiodiglycolic acid.....	
Thiomalic acid.....	
G-4 Dichlorophene.....	
G-11 Hexachlorophene.....	
Monothioglycerol (Thiovanol).....	
Chlorhydrol (aluminum chlorohydroxide complex).....	

The copper salts of the various acids were prepared by dissolving a slight excess of copper sulfate pentahydrate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) in hot distilled water, and adding the acid in the desired amount. The mixture was stirred vigorously, while concentrated ammonium hydroxide (28 percent NH_3) was cautiously added. If the acid was a solid, it was generally melted, if possible, in the hot copper sulfate solution before adding the ammonia. This promoted a faster and more complete reaction. The addition of ammonia was continued until a slight excess was present as indicated by the formation of the deep blue cuprammonium complex. The mixture was then allowed to cool. The precipitated copper salt was filtered off, washed free of the cuprammonium complex, and air dried.

During the large-scale field tests, it was found that copper stearate tended to undergo ion exchange to calcium stearate. This latter salt formed a hard crust on the surface of the particles of hexadecanol and interfered with the formation of the film. Copper laurate appeared to be much better from this standpoint than copper stearate; however, the rate of formation of a film from hexadecanol compounded with copper salts of fatty acids was not entirely satisfactory. Other bactericides tested in the 10-foot tanks were G-4 Dichlorophene, and Chlorhydrol, an aluminum chlorohydroxide complex, $\text{Al}_2(\text{OH})_5\text{Cl}_x$.

WIND STUDIES

The effects of wind on the film constituted a recurring problem. Although the effect of wind on the test films in the 10-foot tanks was minor, preliminary calculations indicated that on a large reservoir (several square miles or more), wind effects could cause a prohibitively large consumption of evaporation retardant.

In order to make a preliminary study of the effects of wind, a plywood superstructure was constructed for the thermostat trough of the screening apparatus. Sliding plastic windows were placed at about 2-foot intervals along the side of the cover. Both ends were left open. The trough was filled as nearly as possible to the brim; the plywood cover and the water surface thus formed a wind tunnel. A sketch of the cover is given in figure 3. By inserting

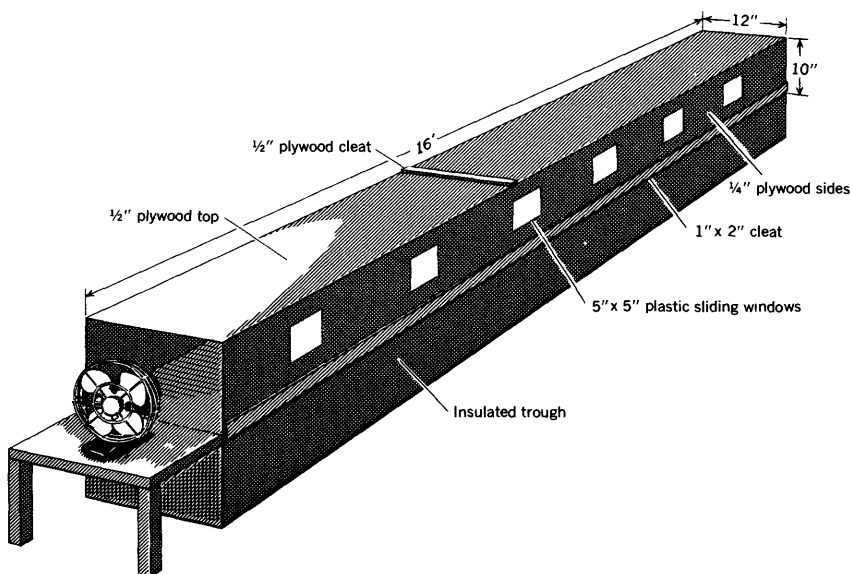


FIGURE 3.—Apparatus used for determining effects of wind on a monofilm.

an anemometer through the windows, the air velocity at the particular area in the tunnel could be measured. The windows also permitted observation of the spreading behavior of the film. A 12-inch electric fan, connected to a variable transformer and placed at one end of the apparatus, furnished a 10 mph wind easily. Wind velocities above this caused wave motion which resulted in some of the water in the trough splashing out at the downwind end.

Tests were made by placing a supply of hexadecanol at either the downwind or upwind end of the tunnel, and timing the rate of

spreading as observed through the windows. Usually, the front of the newly-formed film was discernible from the presence of small particles of hexadecanol, or by a difference in the reflection of light from the surface. Although this procedure is highly subjective, it was possible to draw two general conclusions from the tests run:

1. Although some upwind spreading was noticed against a 10-mph wind, it was so slow as to be impractical. It is doubtful that complete coverage would be obtained from the downwind shore alone on any reservoir with a surface area of more than 1 acre.
2. The film is piled up downwind when the hexadecanol is applied at the upwind end. Recovery, on a small scale, is rapid, however. On a large scale, some recovery can be expected; shore losses will, however, use up some of the material.

No attempt was made to vary the wind velocities, for winds of 10 mph or more are common in Texas, and it was assumed that a wind of less velocity would offer less resistance to the spreading of the film.

LIQUID-PHASE APPLICATION METHODS

Work on evaporation control by the East Africa High Commission on an 88-acre reservoir near Nairobi, Kenya, British East Africa, utilized the application of hexadecanol in "illuminating paraffin," or kerosene (Grundy, 1957). The use of kerosene—or any other flammable solvent, for that matter—on practically any reservoir in the United States would be undesirable, if not actually forbidden. Since liquid phase application of the evaporation retardants is attended by several advantages over solid phase application, methods of applying liquid materials were studied.

The liquid materials investigated included 15 percent hexadecanol in commercial dodecanol, commercial dodecanols, and commercial dodecanol in ethanol. The dodecanols used generally contained 15-30 percent of the C_{16} and C_{18} homologs in their composition. Lorol 7, Siponol L5X, and Adols 10, 11, and 13 were the principal materials used. All of these, in themselves, showed at least 50 percent reduction of evaporation in the screening program. Ethanol was used to lower the cloud point of the commercial dodecanols so that they could still be applied in the liquid phase in cool weather.

Canisters 3 inches in diameter and 10 inches high were used in the initial tests. Holes were drilled in the bottoms of several such cans, and the rate of flow measured. Holes three sixty-fourths

and one thirty-second inch in diameter were found to be so large as to permit the liquid material to flow in a steady stream. A hole 0.0135-inch in diameter produced a satisfactory flow rate.

Tests were made on these canisters, and on several other dripper applicators described below, on the 10-foot tanks. The dripper was filled with the liquid and fastened to a rod or stake with a ring clamp. The liquid was allowed to drip onto the water surface. The same kind of data described on page 13 for 10-foot tank tests was obtained. In addition, the dripper was weighed daily to determine the weight loss (amount of liquid applied to the water surface).

Other drippers with the following modifications were made:

A stainless steel tube, 6 inches long and with an inside diameter of 0.019 inch, was soldered into the bottom of a canister. The tube was extended $\frac{1}{2}$ inch into the can above the bottom in order to prevent clogging by particles of foreign matter. This dripper proved to be quite fragile, and the tube was knocked loose several times, despite considerable care in handling.

The bottom of a canister was cut out and replaced by a 0.020-inch brass plate having a 0.013-inch hole drilled in the center. The hole plugged quickly, because particles of foreign matter were inadvertently introduced in handling and refilling.

Performance data on the above applicators are included in table 3.

CLOUD-POINT DETERMINATIONS

In making the liquid-phase application tests, it was noted that the liquid dodecanol often solidified in the canister and drip tube or hole. Solidification occurred generally at about 20° C, or 68° F. As it was felt desirable to continue application at temperatures below 68° F, means of lowering the cloud point or freezing point of the material were studied. Several solvents were utilized for this purpose. The cloud points of the pure commercial dodecanols and mixtures of these with petroleum ether, Freon 11, and ethanol were determined by Official Method Cc 6-25, of the American Oil Chemists' Society. Results are summarized in the table on page 20. The variations of the cloud points of ethanol-dodecanol and hexadecanol-dodecanol mixtures are plotted in figures 4-6.

The government regulations pertaining to the use of ethanol would present problems although it is possible that a dodecanol-ethanol mixture may be considered to be a specially denatured formula for use as an evaporation retardant.

Cloud points of dodecanol, hexadecanol, and solvent mixtures

Composition	Percent	Cloud point, °F	Composition	Percent	Cloud point, °F	Composition	Percent	Cloud point, °F
Lorol 5.....	100	69.8	Ethanol.....	5	62.5	Adol 10.....	100	59.0
Lorol 7.....	100	68.0	Lorol 7.....	95		Siponol L5X.....	100	66.3
Lorol 11.....	100	68.0	Ethanol.....	10	53.6	Ethanol.....	15	39.5
Siponol CX.....	30	75.0	Lorol 7.....	90		Siponol L5X.....	85	
Lorol 11.....	70		Ethanol.....	15	50.0	Freon-11.....	20	50.0
Siponol CX.....	50	89.6	Lorol 7.....	85		Lorol 7.....	80	
Lorol 11.....	50		Ethanol.....	20	46.4	Freon-11.....	15	42.0
Siponol CX.....	70	105.8	Lorol 7.....	80		Adol 10.....	85	
Lorol 11.....	30		Ethanol.....	25	43.0	Freon-11.....	5	118.4
Siponol CX.....	10	73.4	Lorol 7.....	75		Siponol CX.....	95	
Lorol 7.....	90		Ethanol.....	30	42.8	Freon-11.....	20	102.2
Siponol CX.....	20	78.8	Lorol 7.....	70		Siponol CX.....	80	
Lorol 7.....	80		Ethanol.....	35	37.4	Freon-11.....	15	53.6
Siponol CX.....	30	87.0	Lorol 7.....	65		Adol 11.....	85	
Lorol 7.....	70		Ethanol.....	40	35.6	Evaportrol.....	100	107.6
Siponol CX.....	40	93.2	Lorol 7.....	60		Petroleum.....		
Lorol 7.....	60		Ethanol.....	45	33.8	Ether.....	5	61.0
Siponol CX.....	50	96.5	Lorol 7.....	55		Lorol 11.....	95	
Lorol 7.....	50		Ethanol.....	50	32.0	Petroleum.....		55.0
Siponol CX.....	60	102.2	Lorol 7.....	50		Ether.....	10	
Lorol 7.....	40		Adol 11.....	100	66.0	Lorol 11.....	90	
Siponol CX.....	70	109.0	Ethanol.....	15		Petroleum.....		62.6
Lorol 7.....	30		Adol 11.....	85	44.6	Ether.....	5	
Siponol CX.....	80	113.	Ethanol.....	15		Lorol 7.....	95	
Lorol 7.....	20		Lorol 11.....	85	41.1	Petroleum.....		59.0
Siponol CX.....	90	116.6	Ethanol.....	15		Ether.....	10	
Lorol 7.....	10		Adol 10.....	85	39.2	Lorol 7.....	90	

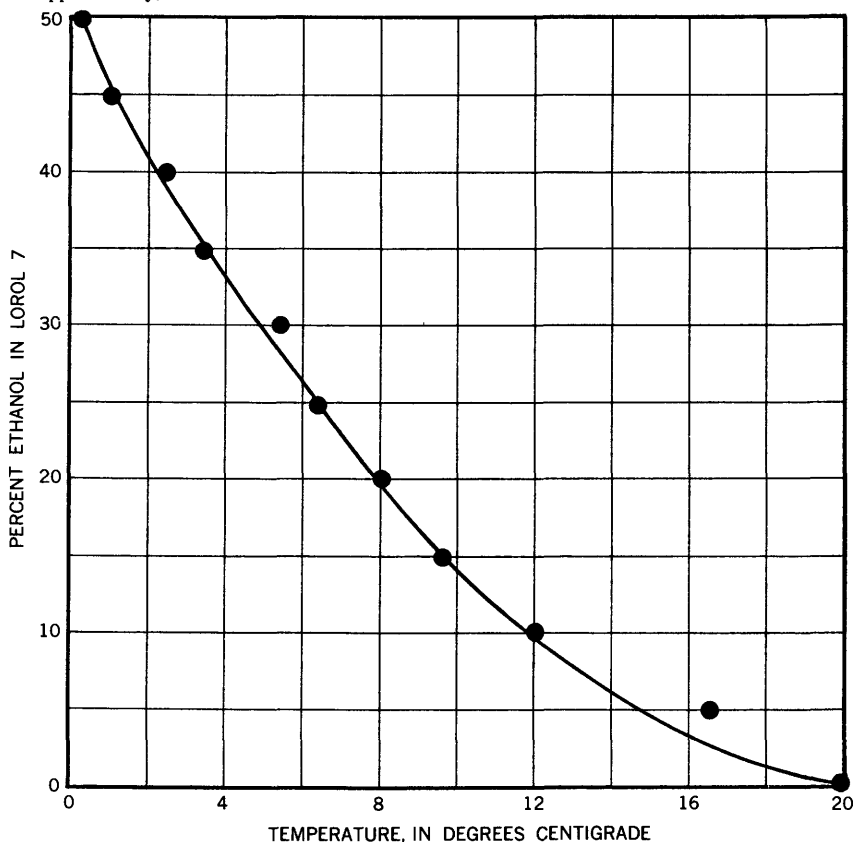
¹ Approximately.

FIGURE 4.—Cloud-point temperatures for various ethanol-dodecanol (Lorol 7) mixtures.

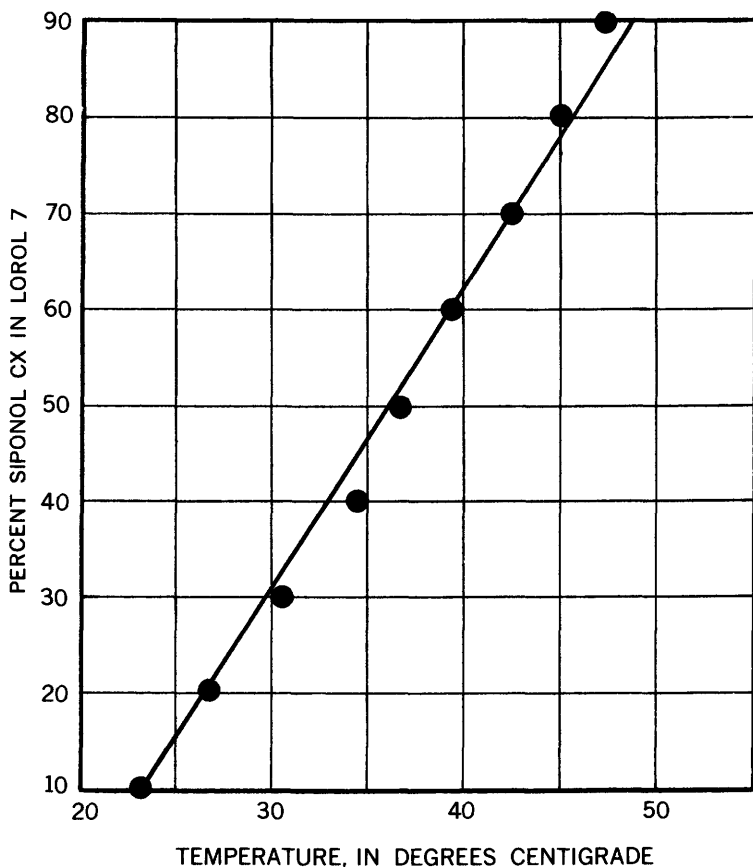


FIGURE 5.—Cloud-point temperatures for various hexadecanol (Siponol CX)-dodecanol (Lorol 7) mixtures.

WICK-DISPENSER TESTS

Wicks were considered as an inexpensive and simple method of controlling the rate of application of a liquid evaporation retardant. Tests were made on various natural and synthetic fibers as potential wick materials. For preliminary tests, a hole was punched in the bottom of a 6-ounce can with a 4d nail, and the necessary twine drawn through the hole with another strand of twine. (See fig. 7) The doubled ends were cut to make single strands extending below the bottom of the can. The rates of flow for various intervals were then determined.

It was found that the drip rate decreased abruptly after 24–72 hours. At first, this slow-down was attributed to swelling of the wick fibers by the dodecanol. This is no doubt still part of the trouble. It was noted, however, that the cans tended to rust around the wick hole. Thus, the rust was also a factor in the

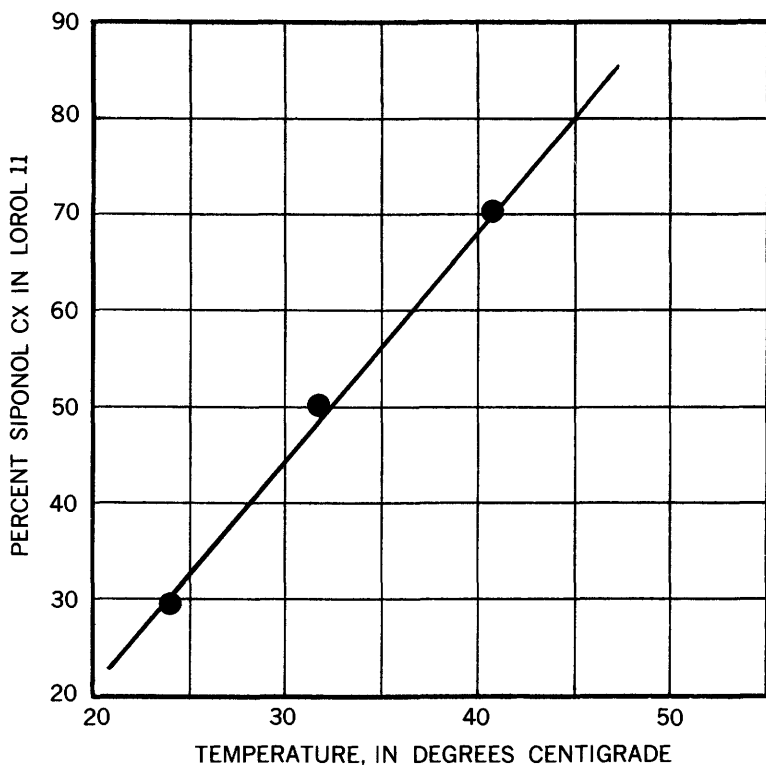


FIGURE 6.—Cloud-point temperatures for various hexadecanal (Siponol CX)-dodecanol (Lorol 11) mixtures.

decrease of the drip rate. In an effort to combat this corrosion, a small piece of $\frac{1}{4}$ -inch (outside diameter) copper tubing was soldered to the bottom of the can, and the wick pulled through the tubing.

In searching for a cause of the rust, it was found that the dodecanols used (Lorol 7 and Siponol L5X) were hygroscopic. Moisture analysis on two samples of these materials that had been exposed to the atmosphere for a period of 4-6 weeks indicated a moisture content of about 0.2 percent. A sample of Lorol 7 withdrawn from a fresh, factory-sealed drum was found to be anhydrous. Subsequent analysis of this material after approximately 2 weeks in the open indicated a moisture content of 0.1 percent. Such moisture would undoubtedly cause a "tin can" to rust, even though slowly.

The combination of the hygroscopic nature of the dodecanol and the swelling characteristics of the wick fibers essentially ruled out the extended use of the simple "tin-can" wick dripper for this program. The use of this dripper may possibly be practical in

extreme cases. Figure 7-9 are illustrated directions for the use of this type applicator.

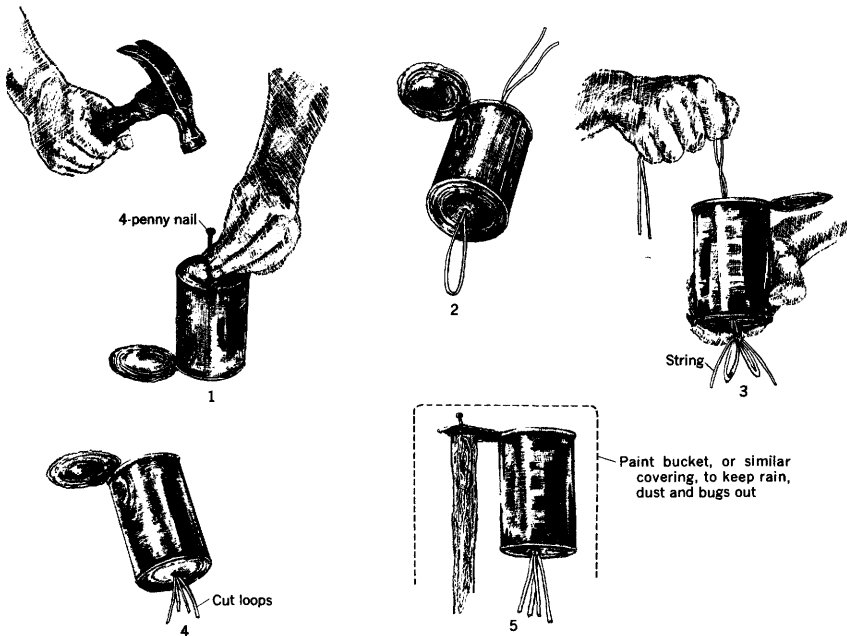


FIGURE 7.—How to make an evaporation retarder.

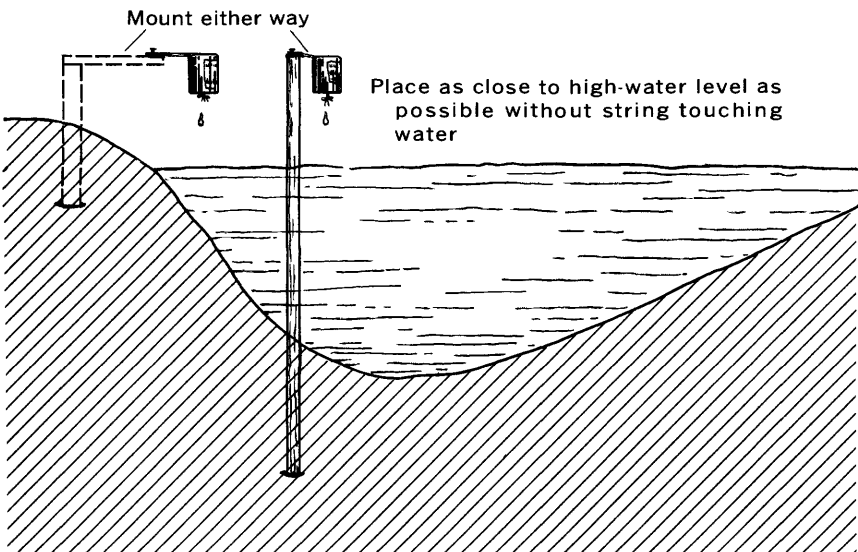


FIGURE 8.—Sectional view showing method of installing dripper.

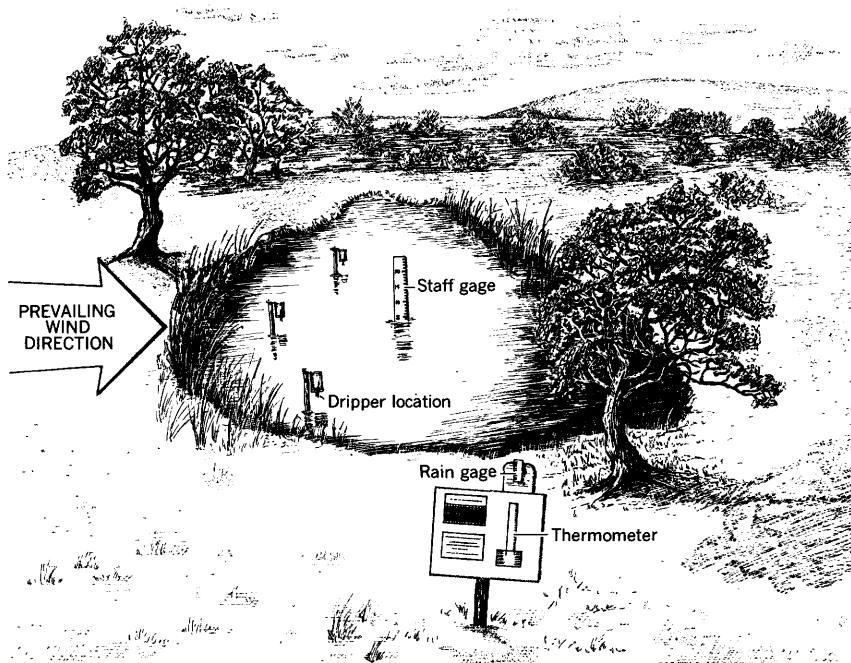


FIGURE 9.—Sketch showing arrangement of instruments.

A summary of the data is presented in the table on page 25. Most of the tests were made at temperatures of 70° to 75° F. Flow rates versus time for various wick materials are plotted in figures 10-12.

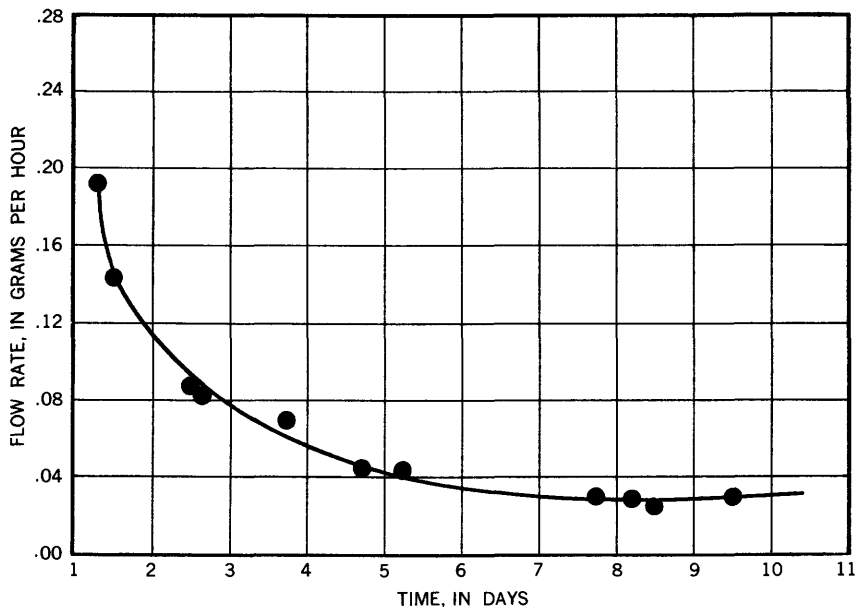


FIGURE 10.—Variation of flow rate of dodecanol with time, using orlon wick (test No. 8).

Flow rates of dodecanol (Siponol L5X) through various wick materials

[In grams per hour at 70° to 75° F]

Test No.	Wick material	Number of strands	Rate of flow											
			November					December						
			20	21	25	25 1	29	2	4	6	12	16	18	19
8	Orlon	14	0.1932	0.1433	0.0873	0.0825	0.0714		0.0451	0.0449		0.0359	0.0309	0.0262
9	Cotton (mercerized)	2 96	.5549	.1810	.2143	.1966	.1423		.0683	.0827		.0332	.0243	.0189
10	Rayon	12	.4161	.3120	.1335	.1256	.0977		.0594	.0607		.0464	.0322	.0263
11	Nylon	16	.2377	.1667	.0940	.0335	.0215		.0173	.01255		.0143	.0118	.0066
12	Silk	160	.1735	.1382	.0279	.0881	.0655		.0489	.0517		.0439	.0359	.0385
13	Wool	24	1.2547	1.6253	.2232	1.1185	.0627		.02795			.0242	.0139	.0139
14	Nylon	3 4						0.6723	.0862	.1437		.0947	.0443	.0345
15	Asbestos	8											.0834	.0685
16	Fiberglass	(1)									0.3896		.0834	.0550
17	Fiberglass	(2)									.0690		.0845	.0504
18	Fiberglass	(3)											.03712	.0298

Test No.	Wick material	Number of strands	Rate of flow													
			January													
			3	7	8	9	10	13	14	16	17					
19	Fiberglass string	2	1.5575	0.4387	0.2531		0.1286	0.0404	0.0386	0.0284						
20	Fiberglass (loose)	(4)	.393	.1615	.1008		.077	.0602	.0614	.0524						
21	Nylon (string)	10	3.057	.3494	.1618		.1235	.0677	.0707	.0607						
22	Asbestos	6	3.1101	.2052	.1409		.1385	.1408	.1472	.1571						
23	Cotton (in glass tube)	12			1.2777	1.4166	.907	.5698	.4882	.6252						
24	Cotton (in plastic bottle)	12			.1784	.1761	.139	.0851	.0753	.0775						
25	Orlon (in 1/4-inch copper tubing)	12			5.2118	4.9469	4.6255	4.6525	4.5944	4.5394						
26	Nylon (in 1/4-inch copper tubing)	34			1.7490	1.6527	1.433	1.1437	1.1011	1.0775						
27	Cotton (in copper tubing)	30			12.1642	10.9491	7.40	4.0269	3.7632	3.5925						
28	Nylon (in capillary tubing)	7					13.369	2.1303	.7243	.4305						

1 Observations repeated owing to a lowering of temperature of the laboratory.

2 Two ply.

3 Three ply.

4 Loose fiberglass, unbraided. Test No. 16 was packed more tightly than test No. 20.

5 Braided fiberglass from heating tape ties.

6 Twisted glass fibers from glass wool.

7 Terminated.

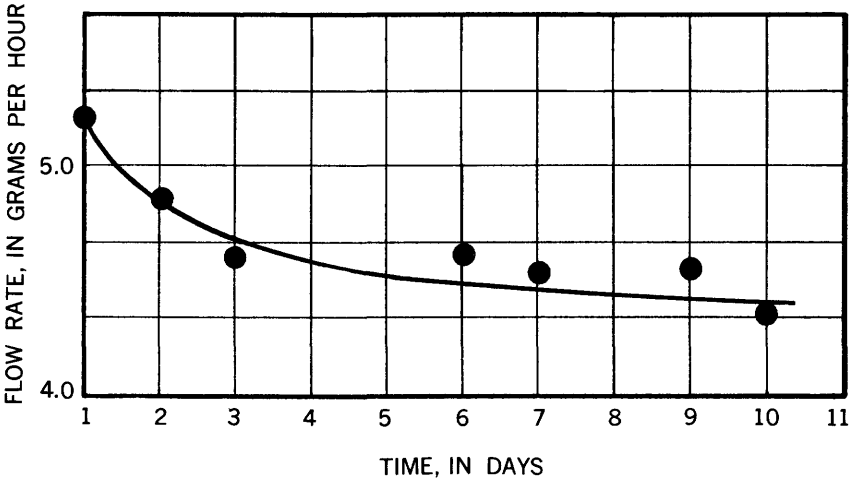


FIGURE 11.—Variation of flow rate of dodecanol with time, using orlon wick in copper tubing (test No. 25).

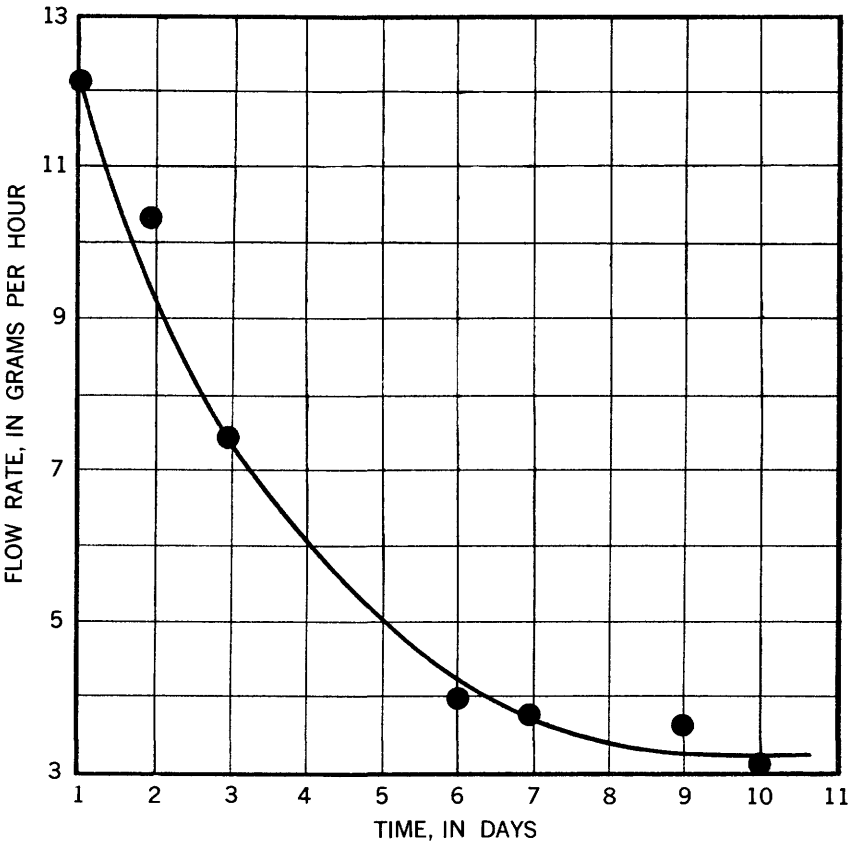


FIGURE 12.—Variation of flow rate of dodecanol with time, using nylon wick in copper tubing (test No. 27).

PELLETING OF SOLID EVAPORATION RETARDANTS

In the large-scale field test, described on page 30, it was noted that there was considerable loss of solid material by attrition and abrasion of the flakes in the generating rafts. A short study of methods of getting small, hard pellets of material was therefore undertaken. Mansfield (1956) described a procedure used in Australia in which molten hexadecanol was passed upward through a perforated plate into hot water. The water in a tall tank was cooled at the top, and the beads of organic material thus solidified as they passed upward through the water. The water was overflowed slowly and the pellets were caught in a sieve.

Attempts to pelletize the flake material in a tablet machine of the type used in the pharmaceutical industry were unsuccessful. Extrusion of material heated to about 35°–40° C was somewhat more promising, although the strength of the particles produced was lower than desired.

Material which had been melted, cast into blocks, ground, and screened to pass a 1/4-inch mesh and be retained on a No. 10 mesh was found to be fairly satisfactory, although a particle size passing a No. 6 mesh and retained on a No. 14 mesh would have been better from the 1/A ratio criterion. This method was used for the hexadecanols and octadecanols that were utilized in most of

Effect of concentration of polyethylene on the evaporation-retarding efficiency of 1-hexadecanol

[After Michaels, 1957]

Surface treatment	Particle of size treating agent	Initial water (grams)	Final water (grams)	Time of test (hours)	Average evaporation rate (g per hr per sq ft)	Reduction evaporation (percent)	Remarks
None.....		985	247	69			
None.....		985	247	69	44.0	0.0	
1-Hexadecanol:							
pure.....	Fine powder.....	880	609	69	16.1	63.2	0.0515±0.0006 g of additive on surface; surface area 35 in ² (21 lb per acre).
plus 0.1 percent polyethylene.....	do.....	837	610	69	13.5	69.4	
plus 1.0 percent polyethylene.....	do.....	883	610	69	16.3	63.0	
plus 10.0 percent polyethylene.....	do.....	867	312	69	33.1	24.8	
None.....		822	192	41.5	62.5	0.0	
1-Hexadecanol:							
pure.....	40–60 mesh granules.....	873	691	41.5	18.1	71.0	0.0500±0.0009 g of additive on surface 35 sq in. surface area (20 lb per acre).
plus 0.1 percent polyethylene.....	do.....	782	608	41.5	17.3	72.5	
plus 1.0 percent polyethylene.....	do.....	822	602	41.5	21.8	65.0	
plus 10.0 percent polyethylene.....	do.....	839	625	41.5	21.2	66.0	

the large-scale field trials. A pellet about the size of prilled ammonium nitrate—a sphere or spheroid about 2 millimeters in diameter—is the most desirable form of the solid evaporation retardants.

Michaels (written communication, June 7, 1957) described the incorporation of polyethylene into hexadecanol (Lorol 24). He tested his materials in photographic trays, set in the draft of a hood. Four tests and one untreated pan for a control test were run. His results are summarized in the table on page 27.

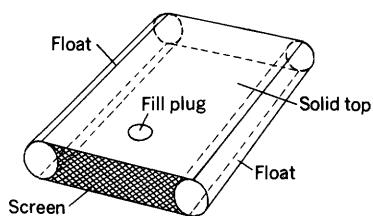
RAFT DESIGN

The first several large-scale field tests made in this investigation were carried out using hexadecanol or octadecanol in rafts 2 feet square, made of 2 x 4 lumber, heavily varnished, put together in the form of an H, and covered with window screen. Aluminum and galvanized screening were found to be completely unsuitable, the former due to fouling by algae, the latter by both fouling and corrosion. Copper bronze and Saran screens were found generally satisfactory. It was necessary to hold the screen in place with wooden molding strips fastened with brass screws, as staples and nails corroded quickly. The rafts were constructed with the 4-inch side of the lumber parallel to the water surface, so that the raft rode very low in the water. As a result, there was a loss of hexadecanol by attrition against the top of the raft during periods of rough water caused by winds. Sketches of various types of rafts are presented in figure 13.

CONSIDERATIONS OF TOXICITY

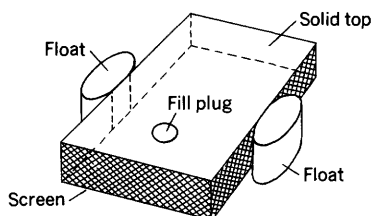
The toxicological aspects of several of the materials under consideration have been mentioned on page 4. As it is desired to utilize these materials on any type of reservoir, including those which may serve as public water supplies, it is imperative that any material or combination of materials be nontoxic to man, farm animals, fish, and wildlife. Further, the aquatic balance of the reservoir should be affected as little as possible, if at all.

The Robert A. Taft Sanitary Engineering Center, of the U. S. Public Health Service, Cincinnati, Ohio, has issued a comprehensive statement of clearance, from a consideration of the toxicity of 1-hexadecanol conforming to USP or NF specifications. The Public Health Service, also, has specifically withheld clearance for dodecanol, and by inference, any other composition of matter other than USP or NF hexadecanol. Copies of these statements are given at the end of this report.

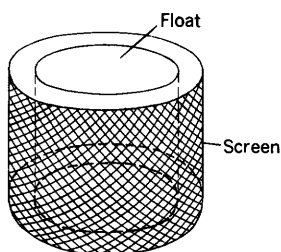


1

Australia No. 1 Fiberglass

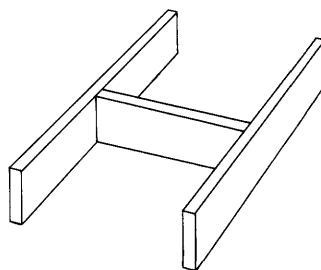


2

Australia No. 2 Wood;
adjustable plastic floats

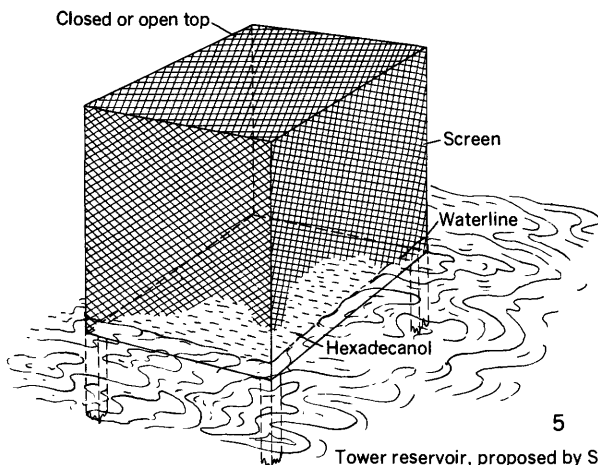
3

Circular metal design



4

H-frame, SwRI experimental



5

Tower reservoir, proposed by SwRI for a 35-acre lake,
near Seadrift, Tex. Legs are anchored in the
bottom of the lake. Screen extends below waterline

FIGURE 13.—Miscellaneous raft designs.

LARGE-SCALE FIELD TESTS

The evaluation of different chemicals as evaporation suppressants is relatively simple in the laboratory. Under carefully controlled conditions reliable results can be obtained with one or more containers of untreated water for control purposes. Although laboratory tests are invaluable for comparing the relative effectiveness of different chemicals, the results obtained are perhaps the most favorable possible; and it is unlikely that water savings under natural conditions will be as large.

An out-of-doors test using containers as large as possible would be desirable; but, as the cost of metal tanks rises sharply with increased diameter, it is not economically feasible to use tanks large enough to simulate conditions found in natural ponds or reservoirs. The metal tanks used in the tests previously described had a diameter of 10 feet. One was left untreated and used as the control. It was thereby assumed that the natural evaporation from the two pans, if both were untreated, would be the same. A pre-treatment test indicated this to be true. Although the 10-foot diameter tanks were large enough to permit making determination of the spreading velocity of a monomolecular film, they were not large enough for the wind to generate waves of any significant height. Field tests on natural ponds were thus considered necessary.

The use of ponds and reservoirs to test the effectiveness of a monomolecular film in suppressing evaporation introduces certain problems. Although it would be possible to construct two identically shaped ponds, there is no assurance that other physical characteristics would be identical. Seepage losses or gains would not necessarily be the same; even if the seepage rates were the same at one time, there is no assurance that they would remain the same over an extended period of time. Lining the ponds is not necessarily a panacea. Concrete-lined tanks are expensive and are not necessarily leak-proof. Plastic linings would be cheaper but are susceptible to mechanical damage. If a tank began to leak during a test, the results would be erroneous; but what is more serious is the possibility that the leak might not be detected.

One way to take into account the inherent differences between two natural ponds is simply to duplicate the experiment using first one ponds and then the other as the control. Two disadvantages of this scheme are the length of time required for the experiment is doubled, and the difficulty of being certain that all the film-forming material has been removed from the treated reservoir at

the conclusion of the first half of the experiment. Although it might be impossible to find any evidence of hexadecanol on the surface of the previously treated reservoir, some material may have been cast on shore and could possibly return to the water surface if the stage rose.

Some investigators have relied on data obtained from evaporation pan or evaporimeters to evaluate the reduction in evaporation. The usual technique is to plot pan evaporation against change in reservoir stage during a pretreatment calibration period. The slope of the line is the pan coefficient, and the intercept is the reservoir seepage loss or gain. The basic assumption is that the pan coefficient and seepage rate determined during the calibration period are applicable after the reservoir is treated. The validity of the pan coefficient theory is not unquestioned. Kohler, Nordenson, and Fox (1955) stated "It is not clear by what reasoning process it was conceived that lake evaporation should be proportional to that observed in a nearby pan, and there is little to be gained by speculation at this time."

The assumption that the pan coefficient during the treatment period is the same as during the calibration period is questionable. The Lake Hefner studies (Kohler, 1954; 1952) indicated that the monthly pan coefficient ranged from 0.13 to 1.32 for the class-A pan, and from 0.22 to 1.56 for the BPI (sunken) pan. For a small, shallow pond, the monthly variation in pan coefficient presumably would be less than for Lake Hefner, but the assumption that there is no month-to-month variation is not acceptable.

The second assumption, that the seepage rate during the calibration period is the same as during the treatment period, is acceptable provided the reservoir stage is the same during the two periods. Culler (oral communication) found that seepage losses from stock-water reservoirs in the upper Cheyenne River basin in Wyoming increased with stage, as it might be expected.

Because of the unsuitability of the above techniques for evaluating the effect of a monomolecular film in suppressing evaporation, a method was developed (Harbeck and Koberg, 1959) that is based upon both the energy-budget and mass-transfer theories of evaporation. A detailed description of the method is beyond the scope of this report, but the basic theory will be described.

The water budget, which is probably the simplest way of measuring evaporation, is based on the fundamental equation inflow minus outflow equals change in storage. Evaporation, one of the outflow items, can be computed if all other terms in the equation can be

measured. Unfortunately this method can be used at only a few reservoirs in the United States, for evaporation in this equation is a residual, and small percentage errors in measuring inflow and outflow items usually result in an evaporation figure of doubtful accuracy.

The energy-budget method is also an inflow-outflow change in storage equation, but instead of measuring volumes of water, an accounting is kept of all incoming and outgoing energy and the change in energy stored in the reservoir. The energy utilized for evaporation, one of the outflow items, is again the residual. However, the evaporation item is much larger compared to other items in the equation in the energy-budget equation than in the water-budget equation. Although a residual, it can be determined with adequate accuracy.

A film applied to a reservoir to suppress evaporation does not affect the amount of incoming energy, both solar and atmospheric. The film suppresses evaporation; this decreases the amount of energy utilized for evaporation. The energy that is no longer utilized for evaporation must be disposed of by other physical processes. The most important of these are back radiation and conduction, both of which depend on water-surface temperature. When a film is applied, the water surface temperature must rise until the energy no longer being utilized for evaporation is disposed by back radiation and conduction. With certain approximations, the mathematical equation is

$$0.970\sigma[(T'_0+273)^4-(T_0+273)^4]+[\rho E' L'-Nu(e_0-e_a)]+Ku(T'_0-T_0)=0 \quad (1)$$

in which σ =Stefan-Boltzman constant for black-body radiation
($=1.171 \times 10^{-7}$ cal cm^{-2} deg^{-4} day^{-1})

T'_0 =observed water-surface temperature in $^{\circ}\text{C}$

T_0 =water-surface temperature in $^{\circ}\text{C}$ that would have been observed if film had not been applied

ρ =density of evaporated water ($=1$ cal g^{-1} deg^{-1})

E' =observed evaporation in g cm^{-2} day^{-1} ($=\text{cm day}^{-1}$)

L' =latent heat of vaporization at T'_0 in cal g^{-1}

N =an empirical constant

u =wind speed in knots

e_0 =saturation vapor pressure at T_0 in mb

e_a =vapor pressure of the air in mb

K =an empirical constant

The values of empirical constants N and K are determined during a pretreatment calibration period using equations derived from basic theory of heat and mass transfer. The only unknown in equation 1

is T_0 , as e_0 is explicitly determined by T_0 . Because the relation between T_0 and e_0 is not linear, a direct solution of equation 1 is impracticable, and it is simpler to assume successive values of T_0 with equation 1 balances. Then E , the evaporation that would have occurred if no film had been present, can be computed from

$$E = \frac{Nu (e_0 - e_a)}{L} \quad (2)$$

Equations 1 and 2 are in effect two simultaneous equations which provide a means of solving for the two unknowns, E and T_0 .

The instrumentation used in the field evaluation studies included the following: A total hemispherical radiometer, an Eppley pyr-heliometer, a copper-constantan thermocouple psychrometer, a Robinson-type 3-cup anemometer, a Whitney underwater thermometer, a reservoir staff gage, a Six's maximum-minimum thermometer, and a standard 8-inch rain gage. The output of the radiometer, pyr-heliometer, and psychrometer were all recorded on a multi-channel recording potentiometer.

The first tests were made at Essar Ranch Lake, about 2 miles from Southwest Research Institute. The reservoir was constructed in 1946-47, and was first filled in 1950. At full pool the surface area is about 28 acres, but at the start of the field tests in the summer of 1956, the prolonged drought and seepage losses had reduced the surface area to less than 4 acres.

During a pretreatment calibration period, June 22 to July 15, 1956, values of the empirical constants N and K (see equation 1) were determined. The seepage loss was computed using the method developed by Langbein (Langbein and others, 1951).

For the tests, the desired amount of film-forming material (hexadecanol or octadecanol) was weighed out and apportioned equally among eight 2-foot square rafts, constructed of Douglas fir 2 by 4's and covered with standard window screen (14 x 18 mesh). Aluminum screen was used initially; copper bronze screen was substituted when it was found that the aluminum screen was soon fouled by algae.

The eight rafts were concentrated in the upwind part of the lake. Daily readings of the anemometer and staff gage and observations of maximum and minimum water-surface temperatures were made by SwRI personnel. Thermal surveys were made at 5-day intervals, using the Whitney underwater thermometer. At 18 points on the lake, temperatures were measured at the surface and at depths of 0.5 foot, 1 foot, and at intervals of 1 foot thereafter. A summary of the results is given in the following table.

Results of evaporation studies at Essar Ranch Lake, 1956

Period	Treatment	Amount used (pounds per acre)	Actual evaporation energy budget method (feet per day)	Computed natural evaporation (feet per day)	Observed water surface temperature (°F)	Computed natural water surface temperature (°F)	Saving in evaporation (percent)
June 22 to July 15	None.....	-----	0.0295	0.0295	83.4	83.4	-----
August 1-10..	Octadecanol (Adol 62).....	2.2	.0251	.0261	85.6	84.4	4
September 10-20.	do.....	20.0	.0149	.0163	85.3	83.1	9
October 10-31.	Hexadecanol (Adol 54) with 1 percent cupric stearate.	20.0	.0097	.0119	75.6	72.3	18

During the course of the experiment the lake was used for both fishing and duck hunting. Apparently neither the fish nor ducks were affected by the film. As many as 200 ducks were seen at the reservoir at one time.

During the winter of 1957, runoff into Essar Ranch Lake began to increase, as pumped ground water that was no longer needed for irrigation was stored in the lake. The volume of inflow became so large as to cast doubt upon the accuracy of the advected energy term in the energy budget equation, and it was therefore decided to make further tests at another site.

The next tests were made at McFaddin Reservoir, at the Moss Bluff plant of the Texas Gulf Sulphur Co., near Liberty, Tex. This lake is somewhat larger than the pond used for the previous tests, and during most of the spring and summer of 1957 its surface area was 12 to 15 acres. Following a calibration period March 12 to April 19, 1957, hexadecanol was applied for the first test, which continued until June 17. One percent of cupric laurate was added to the hexadecanol in an attempt to reduce the consumption of the film-forming material by bacteria. The amount of hexadecanol actually used (0.64 lb per acre per month) was determined by weighing the material placed in each raft at the beginning of the test and again at the end of the test. However, the reservoir overflowed into a drainage ditch on one occasion, and some hexadecanol may have been lost. The reduction in evaporation was computed to be 5 percent, and the temperature rise was 0.5° C.

The next test was made during the period June 17 to August 5, 1957. Octadecanol was the film-forming material used, but there was no apparent reduction in evaporation. The amount of octadecanol used was 0.78 lb per acre per month. However, because natural evaporation rates in this area are low, owing to prevailing high humidity, results may not be very accurate.

Because natural evaporation rates are low and relative errors in evaluating savings might conceivably be large, it was decided that satisfactory tests could not be made at McFaddin Lake. However, in many respects the lake was excellent for this purpose, it was regular in shape, inflow and outflow were very small, and well qualified technical personnel of the Texas Gulf Sulphur Co. were available to make observations and service the recording equipment. Unfortunately, the high humidity and the hydrogen sulfide from the sulfur plant caused frequent malfunctioning of the temperature and radiation equipment, which introduced additional complications.

The equipment was moved to Cement Creek Reservoir at Fort Worth in August 1957. Cement Creek Reservoir, which was built by Tarrant County Water Control and Improvement District No. 1, is used for flood control and has a small permanent pool below the level of the uncontrolled morning-glory spillway. During the fall of 1957, pretreatment calibration data were obtained. Heavy rains during the spring of 1958 caused the application of a film to be postponed because of the frequent spilling of the reservoir.

Studies were also made using Leonard Lake near Monte Alto, Tex. This lake was originally a highway borrow pit but has been filled with water as a result of natural runoff and by drainage from the surrounding irrigated area in the Hidalgo and Willacy County Water Control and Improvement District No. 1. The lake is approximately rectangular in shape and, in 1957, had a surface area of about 6 acres.

Instruments were not available to permit the measurement of evaporation using the energy budget technique. Radiation data are not required for the solution of equation 1, but evaporation (measured by either the energy budget or water budget method), air and water-surface temperature, humidity of the air, and wind speed are needed. At Leonard Lake an anemometer and a water-surface temperature recorder were mounted on a raft on the lake. A hygrothermograph was used to obtain records of air temperature and humidity. A water stage recorder was used to obtain a continuous record of lake stage. Surface inflow to the reservoir was infrequent and usually small, and it was hoped that with the Langbein technique, recorded changes in stage could be separated into the two components of evaporation and seepage.

After a 5-week calibration period to determine the values of K and N in equation 1, eight drippers, filled with dodecanol (see fig. 7) and containing 26 strands of cotton twine as wicks, were installed in December 1957.

After 2 weeks, it was noted that although the dodecanol in the drippers was still liquid, the drip rate had dropped almost to zero. The drippers were readjusted to a faster dripping rate by removing one strand of each wick. The rapid spread of the film was evident by the quieting of the waves under it. The effect could be easily seen.

Prior to readjusting the drip rate, tests for presence of the film indicated its absence except for a strip about 4 feet wide on the lee side of the lake. After readjustment, and overnight operation, during which time the dodecanol solidified in the cans, and also formed "icicles" about 4-inches long from the wicks, there was still no film on the body of the lake. The film along the lee side of the reservoir was about 20 feet wide, however, at this point.

The presence or absence of the film was tested by covering an area of the water surface with carbon black and adding one drop of dodecanol to the center of the covered area. If the carbon black is spread very rapidly, there is no film present originally. If the carbon black does not spread, a compressed film exists. If there is a slow movement of the carbon black, some film is present. The degree of compression varies with the rate of movement of the carbon black. It should be emphasized that if no film is present, the movement of the carbon black is almost instantaneous over a distance of at least 4-6 feet.

As a result of heavy rains in January 1958 the dam was overflowed and breached. The first test was not long enough to yield significant results. After the dam was repaired, another calibration check was made, and the second test was begun in April 1958. The number of drippers was increased to 18, and gallon cans were used instead of the small cans shown in figure 7. The gallon can had a 1/4-inch copper tube soldered into the bottom, through which a wick composed of 23 strands of twisted Orlon yarn was placed. The second test was completed in early May, but the results were inconclusive. A third test was begun in mid-May and was completed in August. Dodecanol was used as in the earlier tests, except that a different brand was tried.

The fact that the results of all the tests at Leonard Lake were inconclusive was believed due to the complicated ground-water conditions in the area. Although it was possible to determine the net seepage into the lake by means of the Langbein technique, the seepage rate apparently changed markedly as ground-water levels in the area changed. The seepage inflow was at times large compared with evaporation, and it was impossible to separate the total change in stage into its two components of seepage and evaporation with any reasonable degree of accuracy.

Although the Leonard Lake tests gave no reliable results insofar as reduction in evaporation was concerned, the tests yielded valuable information on dripping and spreading rates. Although increasing the number of dispensers from 8 to 18 did increase the film coverage, a complete compressed film was not obtained.

Tests on miscellaneous small reservoirs have utilized two ponds sufficiently close to each other so that seepage and evaporation characteristics of both can be assumed to be similar; this eliminates the necessity for comprehensive instrumentation. Each pond was equipped with staff gages; the pond to be treated was equipped additionally with wick-drip applicators. A board holding a thermometer, a rain gage, and a pad of data sheets was set up in the immediate vicinity of the ponds; one such board was installed near each pond if the ponds were more than a few hundred yards apart. The equipment used is shown in figure 10.

OTHER METHODS OF APPLICATION

Effective application of evaporation retardants to a large reservoir is a major technological problem in itself. Rafts and drippers have constituted the only two methods investigated to any degree in this program; however, in addition to the rafts previously described, other methods of application have been considered for future reference.

APPLICATION IN A SOLVENT

The application of a retardant in a solvent has been used on an 88-acre lake near Nairobi, Kenya. Although the use of kerosene in the United States is not desirable, its use in a state of dire emergency is possible, and withdrawal of the water below the surface followed by the usual chlorination and other purification procedures should avoid inclusion of the kerosene in the water. Recent communications from Australia indicate that a mixture of kerosene, or other hydrocarbon solvent, and ethanol has been used to distribute the hexadecanol on a 930-acre reservoir at Broken Hill, New South Wales. Dispensers of the type shown in figure 14 were used; the valve was replaced later by a capillary tube at the end of the outlet. These dispensers, used one to every 80 acres of water-surface, applied 1.6 imperial gallons of solution per unit per day (I. W. Wark, written communication January 1958). Wark also stated that the reservoir refills only every 3-4 years; hence, the need for conservation of the water by any means possible is urgent and takes precedence over any possible or potential recreational use

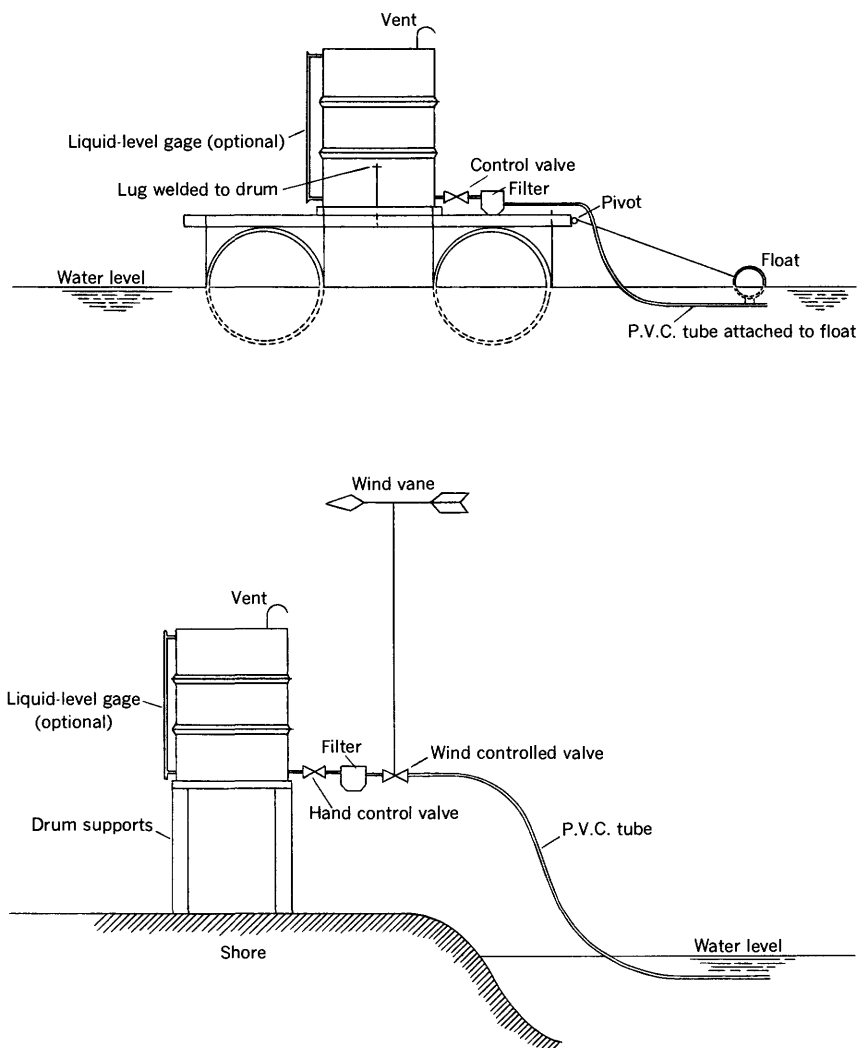


FIGURE 14.—Dispensers used in Australia for large reservoirs.

of the reservoir. This criterion is generally not true in the United States.

Ethanol has been considered as a solvent and cloud-point depressant for dodecanol, as previously mentioned. It is also a possible solvent for hexadecanol. U. S. Treasury regulations concerning tax-free or specially denatured ethanol must be carefully studied in this regard, however.

Other solvent methods of application which have been considered are the use of an aerosol-type spray applicator utilizing Freon 12, or a mixture of Freon 11 and 12, or other fluorinated hydro-

carbons; and a low-pressure application system utilizing liquefied petroleum gases (butane, propane, or mixtures of these). These methods appear somewhat expensive, and in the case of the liquefied petroleum gases a fire hazard is also involved.

APPLICATION AS A LIQUID

The use of liquid alkanols has been discussed to some extent in the preceding sections. In the following section on "Suggestions for Future Work," there are described several new and novel chemical materials that are liquids and believed to be bacteria resistant. The use of liquid alkanols as solvents for additional quantities of solid materials has also been proposed.

APPLICATION AS A SOLID

In addition to the rafts and the cast cake formulations of alkanols, other cast cake formulations utilizing a polyoxyethylene-polyoxypropylene spreader (Pluronic F-68) have been considered. Some formulations of this material with hexadecanol have been used by Shulman (written communication, J. A. Langford, February 1956) in evaporation control experiments in South America. A preliminary test in the Southwest Research Institute laboratory utilizing hexadecanol with 10 percent Pluronic F-68 showed little superiority to pure hexadecanol in cool weather.

APPLICATION AS AN EMULSION

Dressler (written communication, January 1958) has proposed the use of a stable dispersion of hexadecanol. This could be applied in liquid form; the emulsifying agents could possibly assist in spreading the material in cold weather. The toxicological properties of any emulsion or dispersion formulation would have to be cleared by the U. S. Public Health Service prior to any large-scale use.

SUGGESTIONS FOR FUTURE WORK

Several suggestions were advanced in the course of this work on monomolecular films for future study as time and circumstances permit, as follows.

THE EFFECT OF IMPURITIES

A good many different hexadecanol-octadecanol and dodecanol mixtures were tested in the screening phase of the program. As can be seen from table 1, the effectiveness as evaporation retardants for some of them was excellent, others fair, and still others

poor. A fundamental study on this aspect is an indicated possible program. Artificial mixtures of pure materials are suggested.

BACTERICIDES AND BACTERIOSTATS

It was not possible to evaluate all the bacteriostatic or bactericidal materials or intermediates on hand during the screening or field-screening work. Evaluation of these and other bactericidal materials compounded with the alkanols is in order. Irradiation of the evaporation retardants prior to use has been suggested.

BACTERIA-RESISTANT MATERIALS

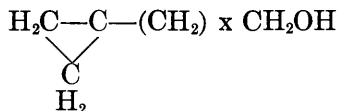
The following general types of compounds have been proposed as being evaporation retardants that are, by their structure, potentially immune to, or less susceptible to biochemical oxidation.

1. Monosilanols— RSiH_2OH , where R is a straight-chain aliphatic hydrocarbon chain of at least 10, and preferably 16 or more carbon atoms.

2. Primary alkanols containing carbon chains with odd numbers of carbon atoms. It is understood that at least two petroleum companies are obtaining 1-tridecanol from oxo-process oxidation. Longer chain alkanols are possible.

3. Omega-unsaturated primary alkanols. One such, 10-undecen-1-ol is obtained by dry distillation of castor oil and subsequent reduction of esters of the resulting acids. These have the general formula: $\text{H}_2\text{C}=\text{CH}(\text{CH}_2)_x\text{CH}_2\text{OH}$, and have been covered by invention disclosure.

4. Omega-cyclopropanoalkanols. The cyclopropane nucleus is an integral part of the chemical structure of pyrethrins; also, allethrin, and lactobacillic acid. Such a structure should be bacteria resistant, but not toxic to warm-blooded mammals, including man. Toxicity to fish should be checked, however. The general formula is:



THE EFFECTS OF WIND

A recent communication from Australia (I. W. Wark, written communications, January 1958) advises that: "... the solvent process does not seem to behave badly when the wind velocity is below 2 mph or if it is above 10 mph. This has been traced to poor spreading of the hexadecanol-solvent mixture."

This investigation has shown that effects of wind on the film are a major problem, especially on larger reservoirs at any wind velocity. Windbreaks, both natural and artificial, around the reservoir and networks of ropes, optionally saturated with hexadecanol or having cakes of hexadecanol cast on the rope, placed on the water surface are two proposed mechanical aids.

FIELD STUDIES

More data from small reservoirs and ponds, especially in arid areas such as the Sonoran Desert are needed, as it is in arid areas where the monofilm technique will be of most value. The use of a film in areas of high humidity does not appear to be economically practical, unless a prolonged drought (such as 1947-1956) occurs in the area.

SCREENING APPARATUS

TECHNICAL DETAILS AND SPECIFICATIONS

Trough (thermostat).—Sixteen feet long, 12 inches wide, 10 inches deep; constructed of 16-gauge galvanized sheet iron; 1/2-inch drain soldered into the bottom at one end.

Insulation.—One-inch fiberglass wrapped in 5-mil sheet polyvinyl copolymer, and held in place by 2-inch spring binder clamps and oak strips 3/4-inch wide by 3/8-inch thick.

Circulating pump.—Motor-pump, rated at 10 gpm, and driven by a 1/4-HP electrical motor; 1/2-inch black pipe circulation system.

Thermoswitch.—10 amp., 115 volt rating.

Heater.—Low drift flexible immersion heater, 750 watt.

Air system.—Driers were constructed of 3-inch black pipe, 4-feet long; connected to the system through 1/2-inch unions to facilitate removal for regeneration of the silica gel desiccant.

Manifolds were standard chrome-plated brass hose connectors, 3/8-inch male pipe threads.

Connecting pipelines were 1/2-inch black pipe. Copper or galvanized pipe is recommended for future installations.

The pressure regulator had an overall diameter of 9 inches.

DESICCANT REGENERATION

The exhausted silica gel (10-12 pounds per drier) was removed from the drier and regenerated in an electric oven at 350° F. The material was spread out in shallow trays to facilitate the operation.

During the operation of a test bank in the screening apparatus, it was customary to alternate the driers; the silica gel from one was regenerated while the other drier was in use.

TOXICITY STATEMENT

The following statement concerning toxicity of hexadecanol and dodecanol was received from the Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.³

A. Opinion on toxicity of hexadecanol proposed for use in evaporation control

It is our opinion that no hazard to public health should result from the use of hexadecanol in the amount and manner proposed to produce a monomolecular film on water surfaces in evaporation reduction.

Although there is no report of information known to us on the long-term ingestion studies of hexadecanol, this material in one form or another has been used in a domestic manner for many years without evidence of detrimental effects on the health of individuals. Indirect, but important, evidence indicating safety in the use of the long-chain alcohols is presented in the work of Treon⁴ of the Kettering Laboratory. Treon found that the oral toxicity of aliphatic straight-chain alcohols decreased sharply at the C-10 chain-length. This implies that alcohols of longer chain-length, because of lessened solubility and other characteristics, would have still further reduced toxicity. Supporting evidence is contained in the work of Stetten and Schoenheimer⁵ who noted that hexadecanol is oxidized to the corresponding fatty acid, palmitic acid. This is a component of normal fat which, of course, is a common foodstuff. Additional supporting evidence is the information provided by A. J. Lehman,⁶ who cited evidence that amounts of hexadecanol up to 0.1 percent in the diet were completely metabolized (like a fat) and that the Food and Drug Administration saw no objection to application of hexadecanol to produce monomolecular layers, provided the alcohol is pure and the materials applied with it are harmless.

Octadecanol, tetradecanol, and the unsaturated C-18 alcohols, often associated with commercial hexadecanol, are normal metabolites of commonly ingested foodstuffs and, consequently, would not be expected to present a health hazard upon ingestion in any reasonable amount.

Accordingly, in view of (a) the lack of direct evidence of the hazard to health upon ingestion, (b) certain evidence favoring the view of its probable innocuousness, and (c) the improbability of ingestion of any but extremely trivial amounts as a result of the method of use, it does not seem reasonable to anticipate that any hazard to health would result from its use for the purpose of producing monomolecular films on water surfaces, and under the conditions proposed for this use, even though exposure was to be for the lifetime of the individual.

³ Written communication, U. S. Public Health Service, Department of Health, Education, and Welfare.

⁴ Written communication from J. F. Treon, The Kettering Laboratory, Cincinnati, Ohio.

⁵ Stetten, DeWitt, Jr., and Schoenheimer, Rudolf, 1940, The biological relations of the higher aliphatic alcohols to fatty acids: Jour. Biol. Chemistry, v. 133, p. 346-57.

⁶ Oral communication from Arnold J. Lehman, chief, Division of Pharmacology, Food and Drug Administration.

It is necessary to add that chemicals used with hexadecanol could conceivably produce a mixture with enhanced toxic properties. Therefore, preparations proposed for use should be independently reviewed for possible toxicity potential.

B. Opinion on toxicity of dodecanol proposed for use in evaporation control

Available information is inadequate to justify a favorable opinion on the use of dodecanol for the purpose of producing a monomolecular film on water surfaces in evaporation reduction.

The evaluation of acceptability of dodecanol (lauryl alcohol) as an aid in control of evaporation of water from reservoirs is based on the following information which constitutes all of that available to the above-signed at the present time. Data may be obtained from other sources, such as the Food and Drug Administration or in certain company files, but it is believed that sufficient information is already available for the development of an opinion.

The unpublished work of Treon⁷ on the minimal lethal oral toxicity for animals using single doses of the aliphatic alcohols, including dodecanol, indicated a sharp decrease in toxicity at the C-10 chain-lengths (decanol). One infers from this that the alcohols of longer chain-lengths, because of lessened solubility and consequent absorbability, would have still further reduced toxicities. The irritant properties of the alcohols, including dodecanol, are not reduced, however.⁸

Lauryl alcohol is a closely related reduction product of a constituent of coconut oil. I have received information⁸ that a product of lauryl alcohol, lauryl gallate, has been approved by the Federal Drug Administration for use as an antioxidant in foods. This approval was based on information of the type described by Allan and DeEds⁹ in which long-term feeding experiments of albino rats, involving concentrations of lauryl gallate as high as 0.5 percent in the diet produced no observable adverse effects; higher levels definitely produced toxic effects. A Japanese report¹⁰ involving a toxicity study in rats of a series of fatty alcohols, from C6-C18 including dodecanol, indicate a toxic effect was obtained with dodecanol, but not with hexadecanol, under similar conditions of test. These results are at variance with the above-quoted American Experience, and could possibly be attributed to dietary inadequacies in the Japanese study.

On the other hand, the irritant properties of lauryl alcohol are well known. Those of coconut oil are ascribed to its lauryl acid ester component. The irritant property of dodecanol is a plaguing one in the light of current knowledge that irritants may enhance the carcinogenicity of cancerigenic agents.

It is therefore believed that before the use of dodecanol can be approved for the purpose of producing monomolecular films on water surfaces, further toxicological studies data justifying a favorable opinion should be obtained.

⁷ Written communication from Joseph F. Treon, past chief toxicologist, Kettering Laboratories, Cincinnati, Ohio.

⁸ Written communication from John A. Zapp, Jr., Haskell Laboratory, E. I. DuPont de Nemours and Company, Wilmington 98, Del.

⁹ Allen, S. C., and DeEds, F., 1951, The chronic toxicity of lauryl gallate: Jour. Am. Oil Chemists' Soc., v. 28, p. 304.

¹⁰ Miyazaki, M., 1955, Nutritive value and toxicity of saturated alcohols with 6-18 carbon atoms: Jour. Agr. Chem. Soc., Japan, v. 29, p. 501.

REFERENCES CITED

- Adam, N. K., 1941, *The physics and chemistry of surfaces*: 3d ed., Oxford Univ. Press.
- Archer, R. J., and LaMer, V. K., 1954, The effect of monolayers on the rate of evaporation of water: *New York Acad. Sci. Ann.*, v. 58, p. 807-829.
- Grundy, F., 1957, The use of cetyl alcohol to reduce reservoir evaporation: *Inst. Water Engineers Jour.*, v. 11, p. 429-437; *East African Meteorol. Dept. Mem.*, v. 2, no. 11, p. 1-11.
- Harbeck, G. E., Jr., and Koberg, G. E., 1959, A method of evaluating the effect of a monomolecular film in suppressing reservoir evaporation: *Jour. Geophysics Research*, v. 64, no. 1, p. 89-93.
- Hedestrands, G., 1924, The influence of thin surface films on the evaporation of water: *Jour. Phys. Chemistry*, v. 28, p. 1245-1252.
- Kohler, M. A., 1954, Lake and pan evaporation, in *Water-loss investigations: Lake Hefner studies*, technical report: U. S. Geol. Survey Prof. Paper 269, p. 127-148; reprint of U. S. Geol. Survey Circ. 229, 1952.
- Kohler, M. A., Nordenson, T. J., and Fox, W. E., 1955, Evaporation from pans and lakes: U. S. Weather Bur. Research Paper 38.
- Langbein, W. B., Hains, C. H., and Culler, R. C., 1951, Hydrology of stock-water reservoirs in Arizona: U. S. Geol. Survey Circ. 110.
- Langmuir, Irving, 1917, The shapes of group molecules forming the surfaces of molecules: [U. S.] *Natl. Acad. Sci. Proc.*, v. 3, p. 251-257.
- Langmuir, Irving, and Langmuir, D. B., 1927, The effect of monomolecular films on the evaporation of ether solutions: *Jour. Phys. Chemistry*, v. 31, p. 1719-1731.
- Langmuir, Irving, and Schaefer, V. J., 1943, Rates of evaporation of water through compressed monolayers on water: *Franklin Inst. Jour.*, v. 235, p. 119-162.
- Ludzack, F. J., and Ettinger, M. B., 1957, Biological oxidation of hexadecanol under laboratory conditions: *Am. Water Works Assoc. Jour.*, v. 49, p. 849-858.
- Mansfield, W. W., 1953, Effect of surface films on the evaporation of water: *Nature*, v. 172, p. 1101.
- 1955, Summary of field trials on the use of cetyl alcohol to restrict evaporation from open storages during the season 1954-55: Commonwealth Scientific and Industrial Research Organization, Div. of Indus. Chemistry, serial 74, 8 p., Melbourne, Australia.
- 1956, The use of hexadecanol for reservoir evaporation control, in *Proceedings of First International Conference on Reservoir Evaporation Control*, San Antonio, Tex., April 14: Southwest Research Institute.
- Rideal, E. K., 1925, The influence of thin surface films on the evaporation of water: *Jour. Phys. Chemistry*, v. 29, p. 1585-1588.
- U. S. Geological Survey, 1954, *Water-loss investigations: Lake Hefner studies*, technical report: U. S. Geol. Survey Prof. Paper 269; reprint of U. S. Geol. Survey Circ. 229, 1952.
- Weitzel, Gunther, Fretzdorff, A. M., and Heller, Siegfried, 1951a, Monomolecular films of several methylated palmitic acids, pt. A: *Hoppe-Seyler's Zeitschr. physiologische Chemie*, v. 288, p. 189-200.
- Weitzel, Gunther, Fretzdorff, A. M., and Heller, Siegfried, 1951b, Monomolecular films of several methylated stearic acids, pt. B: *Hoppe-Seyler's Zeitschr. physiologische Chemie*, v. 288, p. 200-215.

INDEX

	Page		Page
Abstract.....	1	Hexadecanol, cloud point for.....	20
Acids, laboratory tests of.....	11-12	effect of adding polyethylene to.....	28
Alkanols, laboratory tests of.....	9-10	results of tests.....	34
Amides, laboratory tests of.....	12	Hydrophobic portion of the molecule, defini-	
Amines, laboratory tests of.....	11	tion.....	4
Bacteriocides, compounds used for.....	16	Hydrophylic groups, formulas.....	4
copper salts.....	15	Hydrophylic portion of the molecule, defini-	
Bacteriocidal additives, use of.....	15-16, 40	tion.....	4
Bacteriostatic additives, use of.....	15, 40	Impurities, effect of.....	39-40
Cement Creek Reservoir, tests at.....	35	Instrumentation for field tests.....	33
Cloud point, determinations.....	19-20	Introduction.....	1-3
Copper salts, preparation of.....	16	Ketones, laboratory tests of.....	11
solubility in hexadecanol.....	15	Laboratory tests of organic chemicals.....	7-9
Desiccant regeneration.....	41	Laboratory work, stages.....	7
Dihydroxy compounds, laboratory tests of....	10	Leonard Lake, tests at.....	35-37
Dodecanol, cloud point for.....	20	McFaddin Reservoir, tests at.....	34
field tests for.....	35-37	Mononuclear film, calculation of effect of....	5-6
flow rates.....	25, 26	effect of wind on.....	7
Energy budget method of determining rate of		formed by hydrophylic groups.....	4-5
evaporation.....	6, 31-32	method of application.....	6-7, 18-19, 27, 37-40
Essar Ranch Lake, tests at.....	33-34	test for presence of.....	36
Esters, laboratory tests of.....	12	Nitriles, laboratory tests of.....	10
Ethylene oxide condensation products, labora-		Pellets, preparation of.....	27
tory tests of.....	10	Phenols, laboratory tests of.....	11
Evaporation control, theory.....	4-7	Polyhydroxy compounds, laboratory tests of..	10
Evaporation pans, use of, in testing.....	31	Rafts, construction.....	27-28, 29
Evaporation rate, method of determining.....	6	use of, in field tests.....	33-34
Evaporation retardants, application as a		Rate of evaporation, method of determining..	6, 31-33
emulsion.....	39	References cited.....	44
application in a solvent.....	37-39	Screening apparatus, details and specifications.	41
application of liquids.....	18-19, 39, 40	Silicones, laboratory tests of.....	11
application of solids.....	27, 39	Test for evaporation retardants. <i>See</i> Labora-	
composition.....	9-12	tory tests <i>and</i> Field tests.	
determination of cloud point.....	19-20	Toxicity, considerations of.....	28
rejected compounds.....	12	Toxicity statement.....	42-43
results of field tests.....	14	Trade names of evaporation retardants.....	9-12
results of laboratory tests.....	9-12	Water budget, rate of evaporation determined	
trade names.....	9-12	by.....	31-32
Field studies, need for.....	41	Wick dispensers, tests.....	21-26
Field tests, instrumentation for.....	33	Wick materials.....	25
large scale.....	30-37	Wind, effects of.....	17-18, 40-41
problems.....	30		
reactions of bacteriocides.....	16		
use of ponds and reservoirs.....	30-31		
use of 10-foot tanks.....	13-15, 30		
Future work, suggestions for.....	39-41		