WATER CONSERVATION THROUGH
CONTROL OF EVAPORATION

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Necessity for Water Conservation

The old saying: "You never miss the water 'til the well runs dry", has never been more to the point than it is now. The demand for water for municipal, industrial, and agricultural purposes in the United States has increased tremendously in recent years. Critical shortages of water in several major areas have resulted, especially in the Southwestern United States. In Texas, the state is experiencing a severe drouth, which has been termed a "major disaster" by John White, Texas Commissioner of Agriculture. Many counties in South Central, North Central, and West Texas have been declared disaster areas, eligible for federal relief measures. Other states, also, have recently experienced the same general situation with regard to water shortages.

Adding to the burden imposed by drouth conditions on our water supplies, we have a constantly increasing expansion of our population, industries and the use of irrigation on our farms and ranches. Consequently, the increased demands for water are more and more pronounced. The report by the Presidential Advisory Committee of Water Reserve Policy (issued in 1955) estimated that by 1975 the water requirements of the United States would reach 350 bgd. This is an increase of 90% over the requirements of 1950.

Our municipalities, as well as farm and ranch areas, have suffered shortages and, at times, have allocated and curtailed their water usage. An example of critical municipal water shortages is that experienced in New York City in 1950. In other instances, industries have refrained from moving into, or expanding in, locations where water shortages had developed, or appeared imminent.

Means of Conserving Water

There are a number of methods of conservation of water, including recycling, repurification and reuse; and, in rural areas, soil conservation techniques such as small reservoirs and catch basins, cover crops, contour plowing and other anti-erosion methods. A major conservation of water would be possible if evaporation from large reservoirs and lakes could be retarded by any of several control methods or combinations of these. For example, the State of Texas has natural and artificial reservoirs with a surface area of 3800 square miles. The total estimated gross loss by evaporation,

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based on records of the evaporation stations of the Texas Agricultural Experiment Station, is about 18 million acre-feet per year, of which about 10,500,000 acre-feet are replaced in a year of average rainfall. The net loss by evaporation, in excess of the rainfall, from the reservoirs of Texas, therefore, is about 7,500,000 acre-feet. Since the present annual consumption of water in Texas for all purposes -- municipal, industrial, and agricultural, is 8,000,000 acre-feet per year, the size of the evaporation losses, both gross and net, becomes apparent. Since these figures are based on a year of average rainfall, the situation existing under drouth conditions takes on an added significance. Even under normal conditions net losses by evaporation are nearly as great as the total consumption, while gross evaporation losses are over twice as much as consumption.

The States of Louisiana, Missouri, Arkansas, Texas, Kansas, Colorado, Oklahoma and New Mexico have a combined reservoir area of 9600 square miles. This area represents a total yearly evaporation loss of over 39 million acre feet of water (See Appendix A attached.)

Evaporation from reservoirs, especially in hot, arid climates, represents a very significant loss -- in some cases, as much as ten vertical feet of water depth per year. Thus, the full significance of the value of evaporation loss control is apparent. Methods and techniques, once developed, could be utilized throughout the United States and, indeed, world-wide.

The problem of evaporation in the United States has been studied since just before the turn of the century. Studies in Nebraska running from 1895 to 1910 [1] showed that the daily evaporation during the period from April to October was in excess of the rainfall.

Control of Water Evaporation Losses

Losses of water by evaporation can be retarded in several ways. These include [2]:

1. Monomulecular film applied to the water surface.
2. Construction of reservoirs with maximum average depth (minimum exposed surface area).
3. Concentration of water into single reservoirs.
4. Elimination of marine growths.
5. Elimination of shallow water areas.
6. Storing of water in ground water reservoirs (recharge of underground aquifers).
7. Reservoir roofs, floating covers, and sealants.
8. Wind breaks.

It is believed that the methods listed are, in general, self-explanatory. Basically, they serve either to reduce the amount of exposed surface of the reservoir, or to moderate conditions which favor or effect evaporation. The monomolecular film method, we believe, has considerable possibilities as a practical means of reducing evaporation. Consequently, this discussion will concentrate on this method of control, and on the research project now under way on this method, at Southwest Research Institute.

Theory of Action of Monomolecular Films

Certain types of organic compounds -- fatty acids, fatty amids, fatty alcohols, fatty amines, fatty nitriles, and certain special organic materials -- posses the property of forming a film one molecule in thickness when applied to a water surface. These molecules have in their molecular structure a hydrophilic portion, which is attracted by the water (e. g. the --COOH, $-CH_2OH$, $\_CONH_2$, $-CH_2NH_2$, CH_2CN groups, etc.) and a hydrophobic portion (the long carbon chain - 12 or more carbon atoms) attached to one of the above hydrophilic radicals, which is repelled by the water. Thus, when packed together, the molecules stand on end closely packed, and form a resistance to evaporation of the water thus covered. Chemical materials of this type applied to the surface of water will, by their own special nature, spread continuously unless confined by physical barriers such as shore lines, reservoir walls, etc. At any time that a material is present in excess over that amount necessary to form a compressed film one molecule deep, the film-forming material may function as an effective evaporation retardant[2].

History of the Monomolecular Film Technique

As has been previously mentioned, the study of evaporation of water from reservoirs in the United States goes back as far as 1895[1]. Records kept over a period of fifteen years showed that evaporation, even then, was in excess of local precipitation.

Certain effects of thin films of oil have been known for at least 2,000 years (oil has been used by mariners to calm the actions of stormy seas since ancient times). It was not until 1917, however, that Langmuir[3] reported his work on monomolecular films and their use in determining molecular size and shape. Langmuir's work introduced new concepts and experimental methods, and was the first to utilize fatty acids and alcohols. The first attempts to use the monofilm technique to reduce evaporation rates were reported in 1924[4]. These were not successful. The first successful results of the use of a monofilm to reduce evaporation were reported by Langmuir in 1927[5]. The use of a hexandecanol film gave a 50% reduction in the rate of evaporation. The use of an alkylphenol, or cresol, and mineral oil film was patented in 1939[6], but the process did not appear promising for such water bodies as lakes and reservoirs used for drinking water and recreational purposes.

More recently, large scale work utilizing hexadecanol was started in 1952 in Melbourne, Australia[7], with the express idea of reducing evaporation losses in large bodies of water. Although the information reported is incomplete, and somewhat preliminary, the technique and the material used are claimed to be both practical and effective. For normal summer condition in inland Southern Australia, a mean reduction of about 45% of the water loss is predicted.

The Australian research people have not reached definite conclusions, and plan to treat a number of large bodies of water and have an evaluation of the methods within two years.

In Kenya, East Africa, some work has been in progress in the form of field trials on reservoirs of one to ten acres in size.

In the United States, work is being conducted by the U. S. Bureau of Reclamation, the State Water Survey Division of Illinois, and by the Southwest Research Institute.

On a laboratory scale, La Mer and co-workers at Columbia University have recently published their studies [8, 9] on the action of fatty acids, esters and alcohols in reducing evaporation of water. Under the best available laboratory conditions, rate reductions of up to 99.99% were obtained.

Even if the best methods developed do not produce an evaporation reduction of over 45%, this saving is highly significant to the water economy of the United States.

It has been calculated that, on a basis of an application rate of 2.2 pounds of material per acre, a reduction of evaporation of 45%, and a film life of 30 days, the cost of saving (or producing) an acre-foot of water by this process is $1.60, or approximately one-half cent per 1,000 gallons.

The Southwest Research Institute Program

The results from practical tests in Australia may not be applicable to the United States due to differences in climatology, soil, and water conditions. It is therefore desirable to conduct laboratory and field trials here.

The Southwest Research Institute first became interested in the subject of water evaporation control in July 1954, when Dr. Ian W. Wark, of Australia addressed the San Antonio Section of the American Chemical Society on the Australian work on the utilization of the monofilm technique. The plan evolved that experimental work should be done here to develop water evaporation control measures as expecially adapted to our general and climatic conditions.

A full-day meeting was held among persons representing thirteen organizations in Texas interested in water control, and Southwest Research Institute representatives, at the Institute offices in San Antonio on December 1, 1955.

This meeting resulted in a plan for the organization, financing, and management of the water evaporation control program. The tentative project was called "The Southwest Cooperative Project on Control of Evaporation from Reservoirs." The program was set up for a research period of eighteen months, and at an estimated cost of $25,000. Colonel E. V. Spence, General Manager, Colorado River Municipal Water District, Big Spring, Texas, was named Chairman and Mr. Uel Stephens, Manager, Fort Worth Water District, Fort Worth, Texas, was named Secretary-Treasurer of the sponsoring group. The Texas State Board of Water Engineers agreed to act as the contracting agency for the sponsors. The current list of sponsors is shown in Appendix B attached.

The Southwest Research Institute has hoped that research and development of water evaporation control can be a cooperative venture on a wide - even international - basis. Workers in foreign countries and co-workers in the United States have been contacted in a spirit of cooperation, such as the U. S. Bureau of Reclamation, the U. S. Corps of Engineers, the Illinois State Water Survey Board and others. Industries, such as petroleum and chemical companies, who have a major interest in water have been invited to share in this program, and some have done so.

The Program

The proposed research program was designed to give information on the following pertinent subjects:

1. The present status of development by others.
2. The best compound to be used.
3. The best methods of application.
4. Explanations of how the films work.
5. The coverage and life of a film.

6. The biological effects.
7. The effect on physical objects in the water.
8. The effect of pysical factors such as water, temperature, rain, dust, freezing and wave action.
9. The general effectiveness of the treatment.
10. The cost of treatment in terms of acre feet of water saved.

Program - Phase I

A complete bibliography is to be compiled on all subjects relative to water evaporation and its control. This will include theory, methods suitable, means of application, techniques for water evaporation measurement, and all obtainable results of work to date.

Program - Phase II

Phase II concerns the preliminary laboratory work in the screening of organic chemical samples that may be applicable in water evaporation control. As a result of publicity, over one hundred forty-six different samples have been submitted by individual companies for testing, some of them at our request and others offered voluntarily. These are of a great variety of materials, such as alkanols, organic acides, amines, amides, ketones, silicones, diols, etc. Some of the samples are not pure compounds but are mixtures, such as preparations from the treatments of oils and fats (tallow). Inert materials such as ground plastics, plastic bubbles, ground cork, plastic air pillows and membranes, are also on hand for testing.

A fundamental study will be made of the physical chemistry of monomolecular films and chemical substances that are suitable, with the objective of correlating molecular structor or physical properties with their effectiveness as water evaporation retardants.

The major part of the biological work will be done by the U.S. Public Health Service. This will include tests for toxicity of the chemical compounds to be used, their effect on marine animal and plant life, their effect on oxygen and CO_2 transfer rates between air and water, and similar studies. Under the direction of Mr. Bernard B. Berger, work is under way at the Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio.

Program Phase III

Concurrently with the laboratory screening tests, evaluation of hexadecanol and other materials showing promise in the screening work is being investigated in ten-foot stock tanks. This phase will evaluate in a preliminary way the performance of the film under field conditions. In addition to providing a further screening of evaporation retardants showing promise in the laboratory, this phase is also expected to provide a technique which can be used on similar tanks on ranches and farms, after the toxicological effects of the material or materials used have been investigated. Climatic effects, methods of application, life expectancy, etc., can be explored further during this phase.

Program - Phase IV

This phase of the work is similar to Phase III, except that the work will be performed on a larger scale, such as swimming pools, and ponds and reservoirs up to five acres in size. Those compounds showing the most promise in Phase II and III will be further evaluated. At this stage the cost and economics of the process can be calculated with some reality. A large part of the work of this phase will be conducted in cooperation with the U. S. Geological Survey, Denver, Colorado under the direction of Mr. G. Earl Harbeck.

Program - Phase V

As the final step in the program, as now outlined, it is planned to present a schedule of tests and a program for treating large reservoirs (several hundred acres to several square miles). This will be done only after full clearance has been obtained from local, state, and U. S. Government Agencies, such as the local health departments, Fish and Game Commission, State Health Department, U. S. Public Health Service, Food and Drug Administrations, etc., including assistance from the U. S. Bureau of Reclamation and the U. S. Geological Survey. Thus, large bodies of water, particularly those used by animals or humans as drinking water sources, will not be used in the testing program until all possible deleterious effects have been eliminated.

Tests Currently in Progress at Southwest Research Institute

In the Chemistry and Chemical Engineering laboratories at Southwest Research Institute, the screening tests are near completion. One hundred thirty-six samples have been evaluated as of September 1, 1956.

The screening apparatus consist of an insulated constant temperature bath, containing water maintained at about 30°C. Battery jars placed in the trough contain the water under test. Sweep air is dried by being passed over silica gel. It then flows over the water surface at 0.3 mph. Water levels are maintained automatically by means of inverted, closed top cylinders (similar to a chicken-watering device).

Test dosage has been one pound of material per acre. Twelve samples and two control tests make up each test bank.

The fatty alkanols have shown up best to date. Although the fatty acids and fatty amides are known to form monofilms, and the former, under most precise laboratory conditions gave over 99% reduction of evaporation, neither type of compound has shown up well under conditions here. It is felt that the test conditions at Southwest Research Institute give a fair indication of preformance to be expected, at least for a short time, in the larger field tests. Tests which have been conducted in the ten-foot stock tanks tend to confirm this.

Four of the best materials produced by the screening program have been evaluated in the ten-foot tanks. Excellent reduction of evaporation has been achieved but only for a short time - five to eight days. Ways and means to increase the film life are being studied.

The basic evaporation and seepage characteristics of a four-acre lake located on the Essar Ranch, about six miles from Southwest Research Institute, have been determined in cooperation with the U. S. Geological Survey in Denver, Colorado. Two sets of tests have been conducted, one with hexadecanol and one with octadecanol. The technique of application was apparently faulty, as little, if any, evaporation reduction was effected. Our work will be continued as rapidly as possible.

The U. S. Public Health Service indicates some bacterial attack on hexadecanol. Results are preliminary, however, and investigations are continuing.

Summary

It has generally been found that long straight-chain primary compounds appear to show the most promise as evaporation retardants, which is in agreement with published theories. These have one disadvantage in that they may be subject to biochemical oxidation. This is especially true of the alkanols, although these materials form a film having a more sustained reduction of evaporation than acids, amides, or amines of various types.

Small, hard lumps of materials not over 2 mm diameter are believed to be the most desirable physical form of the solid film-forming material. The film does not generate rapidly from particles one-fourth inch and larger. Liquid materials offer the problem of how best to store the necessary reserve material to replace that consumed by shore losses and adherence to piers, boats and other objects in the water, and other losses.

The best evaporation retardants have shown savings of evaporation of as high as 93% for short periods of time, and 45-50% for as long as fifteen days in the laboratory and 5-8 days in the field. This short life in the field indicates the need for refinements in techniques of' application. Some of these are presently under consideration.

In addition to the increased water supplies to be made available by reducing the amount of water lost by evaporation, the same technique may make usable some water reservoirs now brackish or saline. Inasmuch as it is water only that evaporates, reduction of evaporation may save enough water to render usable some borderline water sources.

The ultimate objective will be to develop a practical and economic method for reservoir evaporation control - one that will be of maximum benefit to water users in the Southwest and other portions of the United States, and, indeed, the world.

APPENDIX A

WATER EVAPORATION LOSSES BY STATES*

State	Inland Water Surface	Annual Evap. Depth	Annual Evap. Loss, Acre Ft.	Loss Cubic Miles
Louisiana	3361 square miles	52 inches	9,321,000	2.76
Missouri	448 " "	85 "	2,031,000	.60
Arkansas	429 " "	69 "	1,579,000	.47
Texas	3826 " "	89 "	18,160,000	5.37
Kansas	168 " "	85 "	762,000	.23
Colorado	325 " "	100 "	1,733,000	.51
Oklahoma	888 " "	102 "	4,830,000	1.43
New Mexico	155 " "	114 "	942,000	.28
			39,358,000	11.65

*Taken from the 1956 World Almanac. (Bureau of Census Information)

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APPENDIX B

RESERVOIR EVAPORATION CONTROL SPONSORS AS OF AUGUST 11, 1956

Freese and Nichols
City of Weatherford
Pioneer Natural Gas Co.
Central Power & Light Co.
City of Abilene
Empire Southern Gas Co.
Houston Lighting & Power Co.
City of Waco
General Telephone Co.
City of Dallas
City of Fort Worth
Cosden Petroleum Corp.
Colorado River Municipal Water Dist.
Tarrant County Water Control & I.D. #1
Southwestern Bell Telephone Co.
W. S. Dickey Clay Manufacturing Co.
Texas Vitrified Pipe Co.
Powell and Powell, Engineers
Forrest and Cotton, Consulting Engrs
Lone Star Steel Company
Texas Electric Service Co.
Gulf States Asphalt Company
Dallas Power & Light Co.
Gifford - Hill - American, Inc.
James B. Clow & Sons, Inc.
Texas Water Conservation Assoc.
U. S. Pipe & Foundry
West Texas Chamber of Commerce
Wyatt B. Hendrick, Lawton, Okla.
El Paso Natural Gas Co.
United Gas Pipeline Co.
Sabine River Authority
West Texas Utilities Co.
Brown County Water Impvt. Dist.
American Cast Iron Pipe Co.
Allis-Chalmbers Mfg. Co.
City of San Angelo
Ambursen Engr. Co.
Texas Gulf Sulphur Co.
Humble Oil & Refining Co.
Fairbanks, Morse, & Co.
American Water Works Assoc.
Rockwell Manufacturing Co.
Continental Oil Co.
City of Houston
City of Wichita Falls
Rohm & Haas Co.
Lower Colorado River Authority
Gulf States Utilities Co.
Archer-Daniels-Midland Co.