

EVAPORATION SUPPRESSION IN LABORATORY AND FIELD

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INTRODUCTION

The storage of water in reservoirs has long been relied upon to bridge the gap between the time of precipitation and the time of need for water. In many areas, and particularly in the arid West, reservoirs are essential for storing the spring flood waters derived from melting of the winter snows for irrigation during the summer. The loss of water by evaporation from those reservoirs is the toll exacted by Nature.

Annual gross evaporation losses from lakes and streams in the Colorado River basin total more than $2\frac{1}{4}$ million acre-feet, according to preliminary results of a study being made by J. Stuart Meyers of the Geological Survey. Although this loss is but a drop in the bucket compared with approximately 150 million acre-feet a year supplied by precipitation on the basin, the interest shown in the possibility of reducing evaporation indicates that even small savings are important. Also, it should be remembered that the water evaporated is pure water, and the water saved would dilute the undesirably high amount of dissolved solids of some supplies.

The use of a monomolecular film to suppress evaporation has been known for many years, but until recent years the phenomenon was apparently regarded as a laboratory oddity. In the last few years many investigators in Australia, Africa, and the United States have been delving into the problem. There is yet much to be learned, but preliminary results are encouraging.

COOPERATIVE STUDIES IN TEXAS

The history of the cooperative studies on evaporation control in Texas has been described by Stephens [1]. Drought conditions in Texas stirred interest in evaporation suppression as a means of conserving water. In 1955, representatives of a number of interested organizations met at Southwest Research Institute (SwRI) at San Antonio to discuss the advisability of research in this field. An organization later known as the Southwest Water Evaporation Research Council, Inc., was formed. The financial support of both public and private groups was obtained, and the funds contributed were deposited with the Texas State Board of Water Engineers, who entered into a contract with SwRI for a study of the problem.

The Geological Survey, because of its interest in the water resources of the nation, was keenly interested in the project and collaborated informally with the Texas groups. The evaluation of the success of the field tests on ponds was the responsibility of the Geological Survey. The laboratory screening tests and the application of the film-forming material were made by SwRI.

LABORATORY SCREENING TESTS

As a result of publicity on the subject of suppressing evaporation, manufacturers submitted many samples of various compounds that might be suitable. It was considered essential to test these compounds under controlled conditions in the laboratory, after which the most promising were to be tested in the field, first using metal tanks and then reservoirs.

The laboratory screening apparatus, as described by Dressler [2], consisted of 18, nine by twelve-inch round battery jars. They were placed in an insulated constant-temperature bath 16 feet long, 12 inches wide, and 10 inches deep. The circulating water in the bath was maintained at 86°F.

Each jar had a specially designed lid, an air inlet, and an auxiliary reservoir containing distilled water for evaporation replenishment. The lid was designed so that the air velocity was constant across the top of the water in the jar. The evaporated water was replaced automatically to keep the water level constant at all times. The air was dried with silica gel driers.

Several jars were used as controls, and contained only distilled water. The amount of suppressant tested was equivalent to 1 pound of the material per acre of water-surface area. Many of the tests were run for 5-day periods, but some experiments to determine film life were conducted for longer periods.

Altogether some 150 compounds were tested. Some had no effect whatever on evaporation. Others were highly efficient in suppressing evaporation, at least under controlled conditions in the laboratory. For example, one sample of hexadecanol reduced evaporation by 45 per cent. One brand of octadecanol gave a saving of 60 per cent, while a mixture of hexadecanol and octadecanol gave a saving of 54 per cent. A sample containing mostly dodecanol reduced evaporation by 56 per cent. In some instances, samples furnished by other manufacturers gave greatly different results. Four different samples of hexadecanol of the same commercial grade produced savings ranging from 27 to 45 per cent. Two hexadecanol-octadecanol mixtures made by the same manufacturer and with almost identical proportions showed savings of 19 and 38 per cent. Such erratic results cannot be accounted for by experimental error. There is apparently a great difference to be expected between samples of hexadecanol of the same

technical grade as prepared by different manufacturers. Also, minor changes in proportions of mixtures of hexadecanol, octadecanol, and dodecanol seem to have great effect on the efficiency of the mixture in suppressing evaporation.

TESTS WITH STEEL STOCK TANKS

Two 10-foot diameter stock tanks were installed at SwRI in May 1956. Tests made before any compounds were applied showed that natural evaporation losses were the same from both tanks, within experimental error limits. Hexadecanol was used for the first test in June 1956. The film was apparently destroyed or its effectiveness dissipated by heavy rain after the film had been in place for 8 days. By this time the effectiveness had dropped to almost zero, although the average reduction in evaporation was approximately 25 per cent for the entire period. An octadecanol film was then applied, and the results were not greatly different from those obtained with hexadecanol. Tests during the summer of 1956 indicated that somewhat better results were obtained with octadecanol than with hexadecanol, at least under the conditions of high water temperatures experienced in the San Antonio area.

The short film life was not totally unexpected. A report [3] on the Kids Lake tests at Oklahoma City in 1956, mentioned that Ludzack and Ettinger, of the Robert A. Taft Sanitary Engineering Center, had found a strong indication that hexadecanol was consumed by organisms contained in river water. It remains to be seen whether the rate of consumption under natural conditions is sufficiently great to make the use of a hexadecanol film impractical. Use of a bactericide does not seem practical; killing the bacteria after they have already ingested the hexadecanol does not seem logical. Bacteriostasis has also been suggested as a possibility, if a suitable method can be found. But if a suitable bactericidal or bacteriostatic agent is available, the cost must be considered. If the chemical is effective in concentrations as low as 1 ppm, the cost might still be excessive. For example, the capacity of Lake Mead is about 30 million acre-feet. At a concentration of 1 ppm, 30 acre-feet of the chemical would be needed. Copper sulphate is widely used for controlling algae in water-supply reservoirs. A volume of 30 acre-feet of copper sulphate would weigh 187 million pounds and at current prices would cost about \$20 million. As the capacity of Lake Mead is approximately twice the normal annual inflow, it would cost \$10 million each year to maintain the 1 ppm concentration of copper sulphate, if complete mixing took place. If the consumption of hexadecanol by organisms in the water should turn out to be the controlling factor in determining whether its use is economically justified, research will be needed to find an additive that will make the hexadecanol unpalatable to

the organisms. Control by bactericidal or bacteriostatic agents does not appear to be practical.

Many other tank tests were made during the fall and winter of 1956-57 using hexadecanol and similar compounds with various bacteriostatic and bactericidal agents. During a 35-day test using a mixture of hexadecanol and 1 per cent dichlorophene, a reduction in evaporation of 35 per cent was obtained. The material consumed was 0.14 pound per acre per day. During one 60-day test a mixture of hexadecanol with 5 per cent chlorhydrol was used. A reduction of about 25 per cent in evaporation was obtained with the consumption of 0.65 pound of film material per acre per day.

EVALUATION OF SUCCESS OF FIELD TESTS

Some investigators have used auxiliary evaporation pans to measure the reduction in evaporation caused by a monolayer film, but the accuracy of the results may be questionable. The statement has been made [4] that "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." Although it is generally conceded that in most instances annual reservoir evaporation can be computed with reasonable accuracy by applying a coefficient to measured evaporation from a pan, the seasonal variation in pan coefficients make this technique questionable, if used to measure reductions in evaporation for short periods, such as a week or month.

Other techniques for computing evaporation include the energy-budget and mass-transfer techniques. These were tested at Lake Hefner [5] and applied at Lake Mead [6]. A combination of these two techniques provides a method [7] to evaluate the success of a monolayer film for the suppression of evaporation. A complete description of the method, including the theoretical analysis, is beyond the scope of the present paper. The application of a monomolecular film to suppress evaporation will cause a rise in water-surface temperature. The presence of a film does not change the amount of energy received as solar and atmospheric radiation.

If the amount of energy being utilized for evaporation is decreased, the energy being disposed of in other ways must increase correspondingly. The most important of these are back radiation and conduction, which are proportional to the water-surface temperature. Accordingly, when a film is applied, evaporation is decreased, and the water-surface temperature rises until equilibrium is reached and most of the energy no longer being utilized for evaporation is being returned to the atmosphere by back radiation and conduction.

When the film has been applied, evaporation can be measured using the energy-budget method. The water surface temperature and evaporation

that would have been observed if no film had been applied are both unknown. Simultaneous equations based upon both energy-budget and mass-transfer theory can be solved for the two unknowns.

FIELD TESTS IN TEXAS

Essar Ranch Lake, a small ranch stock pond several miles from SwRI at San Antonio was selected for the first field tests. A hydrographic survey furnished by SwRI shows that the maximum area of the pond at spillway level is approximately 28 acres; during the test period, however, the water surface area was about 4 acres.

During the period June 22 to July 15, 1956, evaporation was measured using the energy-budget method. Data were obtained to permit evaluation of certain empirical constants needed in the previously described evaluation technique.

For each field test the compounds used were applied in solid form. Powdered material was broadcast by hand from a boat for the original application. Replenishment material was supplied from small rafts having a supply of pellet-sized material in a wire-mesh container.

During the period August 1 to 10, 1956, octadecanol was applied at the rate of 2.2 pounds per acre. The computed reduction in evaporation was 4 per cent, and the water-surface temperature was 0.7°C higher than it would have been if no film had been applied.

During the period September 10 to 20, 1956, octadecanol was again used, at the rate of 20 pounds per acre. Evaporation was reduced 9 per cent, and the resultant temperature rise was 1.2°C .

In the third test, October 10 to 31, 1956, hexadecanol was used, at a rate of 20 pounds per acre. The results were much more encouraging, for the indicated saving in evaporation was 18 per cent. The rise in water-surface temperature was 1.9°C .

Results of a subsequent test were inconclusive because of greatly increased volumes of inflow. The owner of the reservoir decided to use it to store the portion of the water being pumped from nearby wells that was not needed at the moment for irrigation.

The next tests were conducted at McFaddin Reservoir, at the Moss Bluff plant of the Texas Gulf Sulphur Company, near Liberty, Texas. 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 pretreatment calibration period March 12 to April 19, 1957, hexadecanol was applied for the first test, which continued until June 17. One per cent 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 pound 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 per cent, 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 pound per acre per month. It should be noted, however, that natural evaporation rates in this area are low owing to prevailing high humidity, and the accuracy of the results is not believed to be high.

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 Company were available to make observations and service the recording equipment. Unfortunately, the high humidity and the sulfide corrosion 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. Built by Tarrant County Water Control and Improvement District No. 1, Cement Creek Reservoir 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 have caused the application of a film to be postponed because of the frequent spilling of the reservoir.

EFFECT OF HEXADECANOL ON WATER QUALITY

In the summer of 1956 tests were made to determine the effect of hexadecanol on the quality of water in Kids Lake at Oklahoma City. Kids Lake is a 6-acre pond adjacent to Lake Hefner, one of the City's water supply reservoirs. A committee composed of representatives of U.S. Bureau of Reclamation, city of Oklahoma City, North Texas State College, Oklahoma State Department of Health, U.S. Public Health Service, and U.S. Geological Survey collaborated in the tests which were coordinated and reported on by the U.S. Bureau of Reclamation [3].

The initial treatment at Kids Lake was hexadecanol, at a rate of 8 pounds per acre. Replenishment material was provided by a supply of hexadecanol in a screened mesh container supported by a small raft.

No attempt was made to evaluate the success of the film in suppressing evaporation. The basic conclusion of the committee was that "insofar as

criteria of water quality, including taste, odor, color, toxicity, and other chemical qualities are concerned, nothing has been determined from this study to preclude further investigations with hexadecanol." The effects of the film on biological and limnological factors were also investigated. It was concluded that temperature rises resulting from the film were not great enough to have any limnological importance, and that hexadecanol does not greatly reduce the dissolved oxygen even near the surface. The committee also concluded that hexadecanol caused no deleterious effect on the plankton population, nor did it affect the bottom fauna. No harmful effects on fish were observed. Although the number of certain bacteria increased, it was considered that the increase was not adverse insofar as water quality of Kids Lake was concerned.

FUTURE STUDIES

Although much has been accomplished in the last few years in the use of a monomolecular film for the suppression of evaporation, much remains to be done. Techniques have been developed to identify the presence of a film and to measure its pressure. The results are applicable only to a specific point; an optical means of identifying the areal extent of film coverage is needed.

Better methods of applying the film are needed. Perhaps a suitable volatile solvent can be found. The solution must, of course, be nontoxic. If consumption of the film material by microorganisms requires excessive amounts of replenishment material, an additive may be necessary to make the material unpalatable, if one can be found.

Thus it appears that evaporation suppression research is a fertile field of endeavor for physical chemists and biochemists, engineers, limnologists, and optical physicists. And if their efforts are successful, the water economy of the arid West will be benefited.

ACKNOWLEDGMENTS

A number of public and private groups cooperated in the Texas evaporation suppression studies. The project sponsors contributed financially, and other groups participated actively in the laboratory and field studies.

Southwest Research Institute personnel designed and constructed the laboratory equipment used for the screening tests of many compounds. They made the tests in the 10-foot diameter steel tanks, and made the observations at Essar Ranch Lake. Application of the film-forming material used in the field tests was the responsibility of SwRI.

Personnel of Texas Gulf Sulphur Company, Inc., assisted with installation of equipment at McFaddin Reservoir, and made the field observations. Texas Electric Service Company of Fort Worth loaned a multi-channel

recording potentiometer and an underwater thermometer for the evaluation studies, and assisted with equipment servicing at Cement Creek Reservoir. Personnel of Tarrant County Water Control and Improvement District No. 1 made thermal surveys of Cement Creek Reservoir and serviced equipment installed at the reservoir.

REFERENCES

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DISCUSSION

Arthur Toch requested clarification of the speaker's figures on evaporation and water supply in the Colorado Basin. The speaker stated that the total annual supply, obtained by planimetry of a map showing annual precipitation is about 150 million acre feet. The average annual runoff at the Lower Colorado is about 16 million acre feet and the preliminary estimate of the evaporation loss from reservoirs, lakes and flowing streams of the Colorado river basin is 2.25 million acre feet per year. This estimate does not include transpiration from vegetation or irrigated areas; it is only the evaporation from free water surfaces.

Maurice Albertson asked about the influence of wind shear and wind waves, whether the film damps the waves, and at what wind speed the film breaks up. The speaker answered that he had observed the wake behind the rowboat from which the material was being broadcast and there was some damping effect. However, the film does not show on aerial photographs and no correlation has been possible between wind speed and the breakup of the film. A little experimenting has been done with infrared photography, but the only information obtained is that the film is broken up by large waves. A coat of film remains and the material on the lake re-forms the film when the wind goes down; material blown up on shore will be recovered

by a rise in water level. Up to now small ponds have been treated successfully and probably part of the reason for the success is the absence of large waves. An effective demonstration of the film is to put some carbon black or talc on the surface of a beaker and drop in a very tiny bit of hexadecanol. The film formed will immediately chase the carbon black or talc to the sides and up the sides of the beaker.

Charles Lee inquired about the method of application. The speaker said that the material had been broadcast by hand on small ponds only. However, the Bureau of Reclamation plans to make tests this summer of mixing the hexadecanol with water and spraying the mixture over a lake. The Geological Survey is to evaluate the results of the experiment. There is still much to be learned about the method of application.

