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Evaporation Suppression from Water Surfaces

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Evaporation Suppression from Water Surfaces

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Abstract—Techniques used for measuring the effect of monomolecular films to suppress evaporation from water surfaces are reviewed. A brief history of chemical studies and field testing of organic compounds is presented. Research in Illinois by the State Water Survey indicates that normal evaporation may be reduced by as much as one-third by efficient use of monolayers.

Introduction—Hydrologic phenomena are extremely variable in their intensity, quantity, and time of occurrence. The more apparent factors such as rainfall and runoff have received much study, while equally important phenomena such as evaporation have been accorded comparatively little attention. Evaporation is an important factor from the water supply standpoint and in recent years many scientists all over the world have been experimenting on means to reduce this direct water loss. Since 19S2 the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) has been testing an insoluble chemical film to suppress evaporation from small water surfaces. W. \V. Mansfield, Physical Chemist, for whom the Australian process has been named, is the first man credited with developing the idea of using hexadecanol, which comes from whale oil, for reducing evaporation losses from small ponds. One-eighth inch diameter beads of this material were fed to the water from specially constructed rafts and a monomolecular skin covering formed which reportedly reduced evaporation up to 45 pct. Recently *Commonwealth Scientific and Industrial Research Organization* [1956] published a paper which reports that 25 pct of the water lost normally by evaporation could be saved.

An article by *Laycock* [1956] describes the work done by the East African Meteorological Department with cetyl alcohol (hexadecanol). An earlier article *[Anonymous,* 1955] stated that D. A. Davies, Director at the Nairobi Meteorological station, had been able to reduce evaporation 50 to 70 pct from four-foot diameter pans of water by using hexadecanol. Laycock indicated that fine copper-mesh anchored basket rafts are located one to each acre on the Nairobi reservoir of over 88 acres, with a capacity of 400,000,000 gal. In East Africa annual water losses through evaporation generally amount to six feet and in some cases are reported to be as great as ten feet. Australian figures also indicate evaporation losses up to ten feet. The published data indicate monthly savings of water from 15 to 24 pct on the African lake. The Australians report that their method of saving water is presently effective only in reservoirs up to two acres in area.

Properties required in a suppressant—An effective evaporation suppression agent must possess several characteristics. From the standpoint of the water for domestic use, it must be non-toxic and easily handled. It should be in a form that is readily applied to the reservoir surface and the cost should be reasonable. It must be sufficiently pure so as not to cause any taste problems in the finished water nor should it prevent proper treatment of the water.

The water conservationist is primarily interested in the ability of the agent to suppress evaporation in a lake. The substance must be lighter than water so that it will float but not be overly soluble. The film must spread easily and re-form readily after being broken by wave action or passage of boats. It must remain operative during the months of greatest potential evaporation. Fishermen have a question: what will such a covering do to aquatic life? Any film must be able to let oxygen into the water and be non-toxic to fish and other aquatic life. Lastly the covering must be invisible and odorless so that lake users will be neither aware of nor annoyed by its presence.

Chemical studies—Physical chemists have been carrying on studies with monomolecular layers for reducing losses from water surfaces for over forty years. *Langmuir* [1917] screened many samples of chemical compounds for their abilities to retard evaporation under laboratory conditions. *Hedestrand* [1924] tried using dilute benzene spreading solutions on water surfaces over which currents of air were moving. His experimental system led him to the conclusion that such films had little effect on the rate of water evaporation. *Rideal* [1925], on the other hand, showed that stearic acid monolayers greatly reduced evaporation but his analysis did not permit quantitative results. *Sebba* and *Briscoe* [1940] determined that the decrease in evaporation rate caused by monolayers was a function of surface pressure. *Langmuir* and *Schaefer* [1943] devised a technique for measuring evaporation resistance. They suspended a solid desiccant above the water surface and measured the amount of water evaporated by a stream of dry air blown over the surface film. The resistance to evaporation is represented as an energy barrier related to the film pressure. *Rosano* and *La Mer* [1956] carried on studies of evaporation rates through monolayers of esters, acids, and alcohols.

Field research in the United States—In the United States, research in evaporation suppression has been carried on by federal, state, and private organizations in addition to the studies by physical chemists. The United States Bureau of Reclamation and the United States Geological Survey have both made fundamental studies on energy balance and film spreading techniques and several laboratory studies of evaporation savings. A team of North Texas State College students in collaboration with six government agencies has conducted studies on physical and biological effects of hexadecanol in a five-acre lake near Oklahoma City. The Southwest Research Institute has a program of research on control of evaporation from reservoirs in Texas.

The Illinois program—The work of the Illinois State Water Survey in this field has been concentrated on the measurement of differences in evaporation rates from pairs of identical water containers where one surface is unprotected and the second surface has a coating of hexadecanol. These studies have also been applied to a 100,000-gallon capacity tank.

The Survey operates three evaporation stations, in northern, central, and southern Illinois. These are Class A pan installations and Stevens-Roberts evaporimeters *[Roberts,* 1954] which record water losses graphically from a three-square foot surface. In February 1956, two identical evaporimeters Figure 1, were installed at the Survey's Urbana evaporation station. One was seeded with one milligram of hexadecanol; the second had water without any protective coating. The water containers were approximately two feet in diameter and one inch deep with built-in overflows to waste excess precipitation. During the spring and early summer months the effect of the monolayer cover was negligible, but there were individual days during July and August when the pan with the hexadecanol cover had water loss of nearly 30 pct less than the pan without the chemical cover. Figure 2 shows the cumulative evaporation from both pans for the period July 1 to September 20, 1956. The average reduction in evaporation was ten per cent for the period.

FIG. 1 - Evaporimeters at Urbana, Illinois, evaporation station

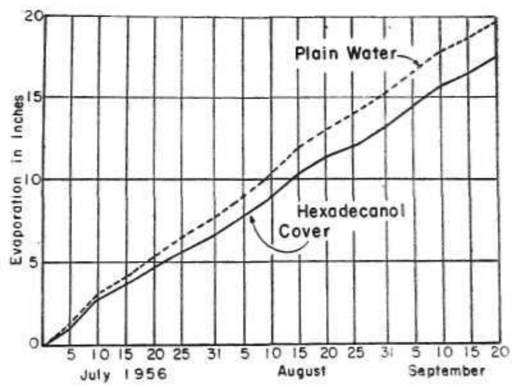

FIG. 2 - Cumulative evaporation from evaporimeter pans at Urbana, Illinois

In June 1956, two 55-gallon drums, with one end of each removed, were buried adjacent to each other at the evaporation station. The open ends of the drums extended two inches above the ground surface. Angle-iron supports for hook gages were constructed across the open ends and the pans were filled with water to the ground level. Thermocouples were inserted just below the water surfaces to give continuous measurements of water temperatures in each of the containers. One was filled with plain water and the second was given an application of one mg of hexadecanol. Once-daily readings with hook gages were made on both pans. Water losses from the two drums for the period July 1 to September 20, 1956 differed by 27 per cent loss as shown in Figure 3. After each two weeks of oper-

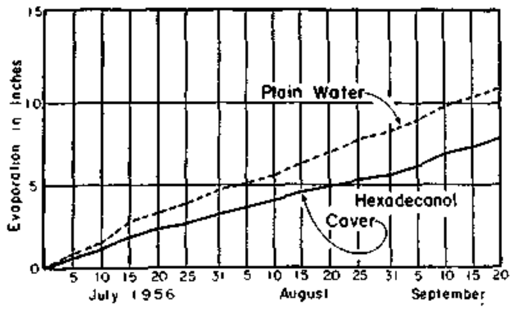

FIG. 3 - Cumulative evaporation from three-foot deep buried pans at Urbana, Illinois

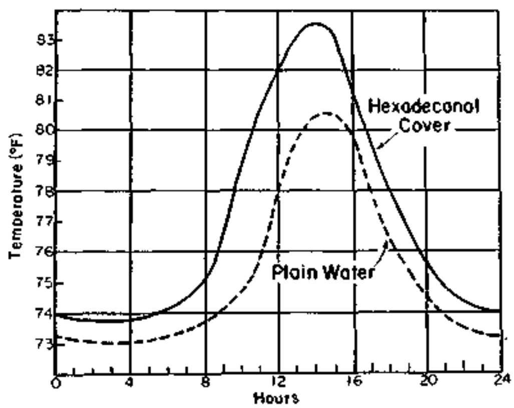

FIG. 4 - Surface water temperature curves for three-foot deep buried pans one day after application of hexadecanol

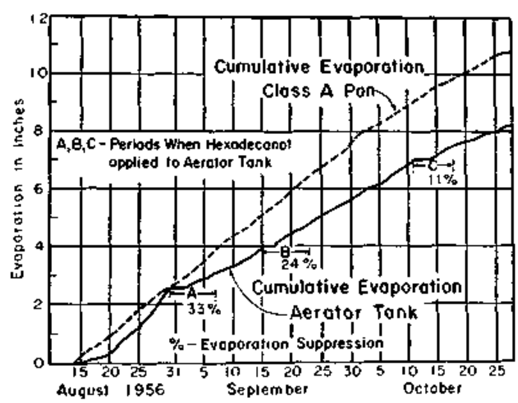

FIG. 5 - Evaporation from Class A pan and 100,000-gallon aerator tank at Urbana, Illinois

ation the drums were drained, cleaned, and refilled with water, and the experiment repeated with the treatment reversed to counterbalance any local effect of exposure. Similar data were obtained. One minor aspect of the study is the increase in surface temperature of the treated water as compared with the untreated surface. A study of the thermograph traces for the days after the pans were treated with hexadecanol indicated that at the warmest time of the day, when evaporation would be greatest, the water directly under the monolayer surface was two to five degrees F warmer than the plain water (Fig. 4).

Although hexadecanol films are reported *[Anonymous,* 1956] to allow the free transfer of oxygen and carbon dioxide from the air through the film to the water, there was some evidence that the film had a retarding effect. Rust collected along the inside of the drum filled with plain water to a depth of six inches from the surface while less than one inch of rusting was noted in the drum that had the monolayer covering.

In August 1956 the University of Illinois made available for this project a 100,000-gallon capacity aerator tank 30 ft in diameter and 14 ft deep located on the campus of the University at Urbana. During August-October, tests were made for water losses from this, using alternately plain water surfaces and surfaces with monolayers. The water was changed before each treatment began. Figure 5 shows the cumulative evaporation from the aerator tank and from a nearby Class A pan.

During the periods marked A, B, and C the aerator water surface was treated with hexadecanol. For the week of August 30 to September 7, evaporation from the aerator tank was 33 pct less than normal and was credited to the evaporation suppression effect of hexadecanol. Similar credits of 24 pct and 11 pct are shown for the periods September 14 to 23 and October 11 to 18. It can be seen that the evaporation suppression effect of the chemical becomes less as summer ends and fall weather begins. Sampling of the interim periods indicates close agreement between pan and aerator tank evaporation rates.

Examination of the lower curve shows that efficiency of the chemical was highest during the first two or three days of application and dropped considerably during the latter part of each period. This trend may indicate that the methods of applying the chemical and of maintaining its effectiveness should be improved.

Figure 6 shows one section of the aerator tank including the hook gage, temperature recorder, and the water-level recorder.

Cost of retarding water evaporation—The small quantity of chemical used so far in the Illinois research program has cost $2.10 per 500 grams, roughly $2.00 per pound. The Australians report their cost for hexadecanol as 7s per pound or about

75 cents. The evaporation retardant material used in the Texas studies was reported to cost 40 cents per pound.

Dressier [1956] points out that the film-forming material accounts for two-thirds the cost of evaporation-control treatment; the remaining one-third to getting the chemical on the water. The results of several research projects throughout the world indicate that the water saved is worth 20 or more times the cost of treatment, with indications that greatest savings could be effected if the treatment can be applied on larger water bodies.

Applying the film—A total of four hexadecanol distributors, shown in Figure 7, was used on the Illinois Water Survey's aerator tank. The distributors had wooden bases ten inches long and wooden ends 4 x 4 inches. The sides and tops were made of 12-mesh copper screen wire. The wire mesh floating container, one anchored in each acre of water area, has been the popular means in Australia, Africa, and the United States for getting the film on the water. This method of propagation is probably unsuitable for large-scale control of evaporation from lakes where there is considerable boat traffic.

It is suggested that boats could be one means of applying the monolayer to Illinois lakes and water-supply reservoirs. On most large lakes a police boat regularly patrols the waters. A simple attachment on the water pump of the boat engine would channel a stream of water through a vessel containing the chemical and into the lake. The chemical would be spread by the wake of the boat and the area and schedule of seeding could be adjusted to the needs of the individual lakes. The program cost would be little more than the cost of chemicals. The labor expense would be absorbed in the cost of operating the patrol boat. A few floating distributors may be necessary on the windward sections of the lakes to insure maximum effect of the monolayer. (Since preparing this manuscript continued research has developed additional methods of applying the film. During the summer and fall of 1957, tanks containing mixtures of powered hexadecanol and protective chemicals in water solution were used to produce strong films on a five-acre lake in central Illinois. Data from this part of the research are not complete.) As the value of monolayer coverings becomes better known in the field of water resources management, the problems of developing practical and economical methods of producing the coverings will probably be quickly developed.

Toxicity and attrition of films—According to

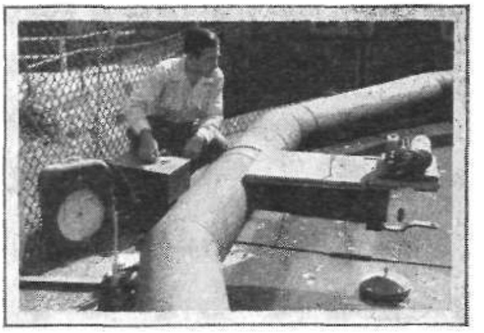

FIG. 6 - View of test equipment at the 100,000-gallon aerator tank

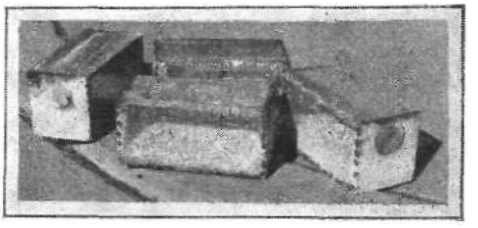

FIG. 7 - Hexadecanol distributors

Bernard Berger (personal communication), film destruction by organisms in a well-seeded natural water may be an important factor. *Ludzack* and *Etiinger* [1956] have found that emulsions of hexadecanol and pellets of the material suspended in baskets have been observed to undergo biological destruction in laboratory test studies. They report that on two different runs at 20°C suspensions of hexadecanol in very gently aerated carboys showed a weight loss averaging $3\frac{1}{2}$ and $4\frac{1}{3}$ pounds per acre per week.

The non-toxicity of commercial preparations containing hexadecanol, as determined by the Robert A. Taft Sanitary Engineering Center, was accepted as a basis for Illinois tests, in the absence of direct evidence against hexadecanol as a hazard to health.

Conclusions—Although the Illinois State Water Survey evaporation suppression study has been in operation only a year, a literature search indicates that our experiences in this study confirm much that has been found experimentally elsewhere although our findings appear to be generally more conservative. Most of the studies have been carried on in areas of the world where normal evaporation amounts are two or three times greater than those observed in Illinois. Under Illinois conditions our studies indicate that the rate of natural water loss by evaporation may be reduced by a maximum of *33* pct during the warmest part of the summer and by about 11 pct during the cooler frost-free periods by application of hexadecanol. Many Illinois water-supply reservoirs store nearly 50 pct of their capacity in the top three feet. Normal evaporation exceeds three feet per year in reservoirs in the southern half of the state where surface waters provide most municipal supplies. Assuming full reservoirs, if evaporation could be reduced by one-third it would be equivalent to a 17-pct increase in Illinois reservoir storage capacity.

During the summer of 1957, the program was expanded to include studies on suppressing evaporation from larger water bodies and of problems encountered so far in our work in Illinois.

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