INTRODUCTION

Future increases in human and livestock populations will create increasing demands for fresh water. In many areas, including semi-arid and arid regions of Western Canada, the available water supply is limited. In order to utilize the water resources to their maximum efficiency, water conservation becomes a necessity.

Water is lost through the process of evaporation from free water surfaces, evaporation from moist soil, and through deep percolation into ground water. The elimination of unnecessary waste is the first step in the water conservation program. The losses from soil and water surfaces through evaporation perform little useful function except replenishing the air vapour storage with moisture necessary to complete the hydrologic cycle. In semi-arid and arid regions the potential evaporation losses exceed the total precipitation.

There are several methods of reducing evaporation from water surfaces. The concentration of water into large deep reservoirs with a minimum surface area helps to reduce evaporation. Windbreaks designed to reduce the wind velocity and consequently the evaporation rate have been recommended. Even roofs and floating covers have been proposed in certain areas. The use of monomolecular films is one of the methods employed to reduce evaporation from free water surfaces. This paper presents data of evaporation control with monomolecular films formed by hexadecanol.

REVIEW OF LITERATURE

The first successful use of monomolecular films to retard evaporation was reported in 1927 by Langmuir (4) who found that hexadecanol films reduced evaporation by fifty per cent. Since that time many experiments, mainly laboratory studies, have been concerned with the ability of various chemicals to form monolayers. Mansfield (5) reported that hexadecanol significantly reduced evaporation from pans and larger bodies of water. Hexadecanol along with other alcohols, esters, and acids was recognized by Rosano and La Mer (7, 8) to control evaporation from free water surfaces. Of over approximately 100 evaporation retardants tested by the U.S. Bureau of Reclamation, hexadecanol and octadecanol showed the greatest promise (3). In Canada there is a need to evaluate the available data and to test successful methods under our domestic conditions.

Evaporation is defined by Dalton's Law: E = C (pw - pa)
where
E = evaporation rate;
pw = maximum vapour pressure corresponding to the temperature of water;
ap = vapour pressure in air;
C = coefficient depending upon wind velocity, barometric pressure, etc.;

(pw - pa) = pressure gradient.

Several types of organic molecules (fatty acids, fatty amides, fatty alcohols) when applied to water surfaces will form a film one molecule thick over the surface of the water. These molecules possess a polar group such as OH, C=O, and NH2. The –OH polar groups are strongly attracted to water molecules which possess a permanent dipole (2). When packed together, the molecules stand on end and form a film that helps resist evaporation of the water thus covered (1). An excess of film forming material is necessary at all times to keep the film tightly packed and to repair it if it should be broken. The rate of spreading of the monomolecular film depends on the surface temperature of water and the characteristics of the chemical compound. The average rate of spreading for alcohols recommended for water conservation is approximately twenty to thirty centimeters per second at 20°C (6).

The hexadecanol film is about two millionths of a millimeter thick and is not visible to the naked eye; however, since it reduces ripples on the water surface the extent of spreading can be observed. As the spreading proceeds within the reservoir the surface pressure increases and the rate of spreading decreases until an equilibrium pressure is reached. A surface film must meet the following requirements: (1) to form an unbroken surface film over the entire water surface; (2) to be impervious to water vapour; (3) to be able to regenerate the film when broken; (4) to be odorless and non-toxic; (5) to be easily generated by using chemicals of reasonable cost; and (6) it must not seriously retard the diffusion of oxygen and carbon dioxide in water. A reduction in the rate of movement of such gases would seriously upset the biological balance of bodies of water so treated.

MATERIALS AND METHODS

Four separated 4-foot diameter tanks as shown in Fig. 1 were installed in the ground within the enclosure of the Summerland Research Station Weather Station. The tanks were of cylindrical design, 24 inches deep with an inside diameter of 471/4 inches. The tanks extended 2 inches above the ground surface.
RESULTS

The addition of hexadecanol in flake form was found to be unsatisfactory. For this reason, in all subsequent studies, it was dissolved in gasoline and applied to the surface by means of an eyedropper. Non-leaded gasoline was preferred since it is more volatile than ordinary motor fuel which contains lead compounds.

It was found in a short trial period that the spreading pressure of the hexadecanol film should be main-
crease in effectiveness of the film was observed. Film pressures in this investigation were thus maintained between these two pressures.

In general, increased rates of hexadecanol caused progressive reductions in evaporation rates (Fig. 2). Applications of less than $\frac{2}{3}$ pounds per acre produced erratic results where the reduction in evaporation ranged from 10 to 20 percent. When $\frac{2}{3}$ pounds were applied the reduction in evaporation was between 20 and

The effects shown in Fig. 2 were studied for 5 days with the two lowest rates, 6 days for the 0.655 pounds per acre, 2 days with 1.09 pounds per acre, 34 days at the 2.34 addition, and 4 days for the highest rate. The effect of impurities in the hexadecanol solutions was studied from July 12 to 16. During this interval the water surfaces were not cleaned of foreign matter as was usually done.

Two indicator oils, oleic acid and castor oil, with spreading pressures of 30 and 17 dynes per square centimeter, respectively, were used to obtain an estimate of the spreading pressure of the hexadecanol monolayer.

THE EFFECT OF HEXADECANOL ON EVAPORATION

FIG. 2

Application rates versus reduction in evaporation.

DIURNAL VARIATION IN THE EVAPORATION RATES

FIG. 3

Figure 3. Diurnal differences in evaporation rates.
The results illustrated in Fig. 3 indicate that greater diurnal differences occurred in the evaporation rates from surfaces covered with a monomolecular film than from a free water surface. During the day evaporation was markedly lower through a monomolecular film than from an untreated surface. At night the rate of evaporation from both was approximately the same with the loss from free water surfaces being slightly higher.

The effectiveness of the hexadecanol film diminished quickly unless it was renewed daily. Figure 3 presents the reduced effect of the film between July 29 and August 3 when the film pressure remained above 17 dynes per square centimeter without daily renewal of the film. On August 3rd the pressure dropped below 17 dynes and daily applications were resumed.

The rate of evaporation which depends upon the vapour pressure gradient reached its maximum after sunset when water temperature was highest and when the air temperature decreased. The efficiency of the hexadecanol monolayer probably decreased with an increase in temperature of the water since the interaction between permanent dipoles is known to decrease with a rise in temperature (2). The cooling process itself which involves the movement of warm water molecules to the surface may interrupt the continuity of the film as well as contribute to the effect of temperature on the interaction. This tendency for the warmest molecules to appear at the surface will maintain the vapour pressure gradient at a maximum. It is suggested that for these reasons evaporation reached a maximum after sunset.

The vapour pressure gradient during the sunlight hours was usually less than at night. Following sunrise the air was normally warmed up quickly and approached or exceeded the temperature of the water in the tanks. As a result the vapour pressure gradient was low or even assumed a negative value (see Dalton's Law). Since evaporation is a function of vapour pressure gradient, a low gradient is associated with low evaporation rates. During the warming process evaporation was not enhanced as in the cooling process. Apparently the surface water molecules that were warmed because of their decreased density, remained at the surface. The dipole interaction, which increases with decreasing temperature, became stronger because of the cooling effect of evaporation. A stronger interaction would tend to increase the effectiveness of the film and, therefore, reduce evaporation.

Fig. 4 shows that the effectiveness of the monomolecular film on the retardation of evaporation was greatly reduced by the accumulation of floating foreign material on the surface. Where the surfaces of the water covered with the hexadecanol monolayer were not cleaned daily a rapid increase in the evaporation rate occurred. At the end of three days diurnal differences occurred in the rates of evaporation from hexadecanol-treated water as compared to the untreated water surfaces.

CONCLUSIONS

Evaporation was reduced between 20 and 30 percent through hexadecanol monolayer when 2½ pounds of hexadecanol per acre were used. On occasion reductions of 46 percent were observed with application of 4½ pounds. Foreign matter accumulating on the water surface markedly reduced the effectiveness of the monomolecular film. Daily additions of hexadecanol were necessary to suppress evaporation effectively. Greater

REFERENCES


ACKNOWLEDGEMENT

The authors are grateful to Dr. J. C. Wilcox, Head of the Department of Irrigation and Plant Nutrition at the Summerland Research Station for his assistance and criticism during the course of this study.