A Note on Minimising Temperature Rise by Restricting Evaporation From Small Open Water Surfaces

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Abstract

In countries situated at certain (low) latitudes high daily insolation results in high rates of evaporation from open water surfaces. A cheap and efficient method to minimise evaporation from small water bodies is to cover the surface of the water completely with small, floating polystyrene spheres. Furthermore by consideration of the surface energy budget, it is shown that, in general, the temperature rise of the water is restricted. The lower temperature of the stored water (in comparison with that of a free water surface) permits higher concentrations of dissolved oxygen at saturation, discourages unwanted growths and makes for a more palatable water.

Introduction

One of the biggest problems in many low latitude semi-arid areas is the high rate of evaporation from open water surfaces. In countries (industrialised or developing) where water is scarce it is of paramount importance to the inhabitants to preserve water once collected. Containers open to the atmosphere specifically to collect precipitation are particularly prone to evaporation losses. Covered containers may not be economically feasible (especially in Third World countries) and the restricted availability of oxygen in the closed air space above the water surface may well lead to a poor quality of the stored water and provide a breeding ground for insects. One compromise is to use a floating lid, which will still permit direct infiltration of rainwater. To accomplish this it would be technically feasible and economically acceptable to "carpet" the open water surface with small, floating polystyrene spheres. (Experiments using one metre polystyrene hexagons have been undertaken on storage reservoirs with great success; Pereira, 1973). However, on this scale a carpet of spheres may suffer from accumulation downwind under windy conditions. The application of such a technique to small containers (e.g. water butts) will not suffer this effect.

As well as permitting infiltration, there will be some restriction on the particulates (deposited from the air) entering the water (especially if the spheres are weighted slightly to retain their orientation and stability). This lid will physically prevent evaporation. In addition, it will be shown, by consideration of the surface energy budget, that the temperature rise (over the year) of the water in the container is constrained, if there is a negligible heat flux through the sides of the container. This permits a greater concentration of dissolved oxygen to remain in the water (Henderson-Sellers, 1979a, b) and does not encourage algal growths and insect and bacterial breeding that may well occur at a higher temperature (e.g. Moss, 1980).

In this paper a theoretical analysis of the surface energy budget is undertaken to calculate the effect on water temperature and evaporation.

Surface Energy Budget

(a) Without Polystyrene Spheres

The surface energy budget of an open water surface must take into account incident solar radiation Φ_s, incident long-wave (atmospheric) radiation Φ_{r2}, long-wave radiation losses Φ_{r1}, latent heat flux Φ_e and sensible heat transfer Φ_c (where all energy values are in W m^{-2}). The reflectivity of the surface for both short and longwave radiation (A_s and A_L respectively) are also required. Here the energy budget is considered on an annual time scale so that all energy fluxes are expressed as mean daily values i.e. variability on a diurnal scale is ignored.

The net energy flux, Φ_{Nb}, available to the water body is then given by

$$\Phi_{Nb} = \Phi_s(1-A_s) + \Phi_{r2}(1-A_L) - \Phi_c - \Phi_e - \Phi_{r1} \qquad (1)$$

where the subscript b indicates calculation before the introduction of the spheres.

All the energy fluxes on the right hand side of this equation can be computed using empirical or semi-empirical formulae. These are discussed in detail by Ryan and Harleman (1971) and Henderson-Sellers (1976). The recommended formulations (Henderson-Sellers, 1980) are given in Table 1.

If it is assumed that this energy is mixed evenly throughout the volume V of the water, where the surface area is A. then the rate of increase of temperature T is given by

$$\frac{\partial T_{wb}}{\partial t} \rho \; c_p V = A \Phi_{Nb} \qquad (2)$$

Over an annual period the maximum temperature occurs (in late summer) when $\frac{\partial T}{\partial t} = 0$. This is given by a zero net flux i.e. (from equations 1 and 2).

$$\Phi_s(1-A_s) + \Phi_{r2}(1-A_L) - \Phi_c - \Phi_e - \Phi_{r1} = 0 \qquad (3)$$

The two long-wave radiative fluxes Φ_{r1}, Φ_{r2} are given in Table 1.

Hence, substituting these expressions into equation 3, gives an expression for T_{wb};

$$T_{wb}^4 = \frac{\Phi_s(1-A_s) + \epsilon_a \sigma_a T_a^4 (1-A_L) - \Phi_e - \Phi_c}{\epsilon_w \sigma} \qquad (4)$$

(Note in some situations Φ_c is sufficiently small to be neglected in this equation.)

(b) With Polystyrene Spheres

Figure 1 depicts the energy fluxes needing consideration when

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