EVAPORATION EFFECTS IN PONDS

EVAPORATION EFFECTS INPONDS

In some situations where holding capacity is marginal, or where flows are too low to maintain adequate pond depths, evaporation can be an important factor in wastewater treatment in a pond environment. There are several environmental factors that affect the rate of evaporation. This paper discusses the principles behind evaporation rates and the influence that the Sunflo^2 unit (solar powered) technology may have on those principles.

Evaporation is the process by which a liquid (or solid) is converted to a gas. In this case, the liquid under discussion is water contained in a pond. The rate of evaporation is controlled by the availability of energy at the evaporating surface, and the ease with which water vapor can diffuse into the atmosphere. Primary influences on the rate of evaporation are: water temperature, air temperature, and the level of moisture saturation in the air. The main sources of energy for evaporation on a pond are primarily sunshine, and heat from the earth and the air. Evaporation rates are, therefore, strongly related to climatic factors such as latitude, season, humidity, time of day, cloud cover, etc.

Knowledge of evaporative processes is important in understanding how water losses through evaporation from a lake or pond are determined. With respect to wastewater treatment ponds, evaporation decreases the hydraulic detention time, but effectively increases the storage capacity of a given size pond. It also has a cooling effect on the body of water. The following discussion is intended to provide a basic understanding of the principals involved when water evaporates from a natural, unassisted pond. Differences that may change the evaporation rate in wastewater treatment ponds compared to natural occurring bodies of water are noted.

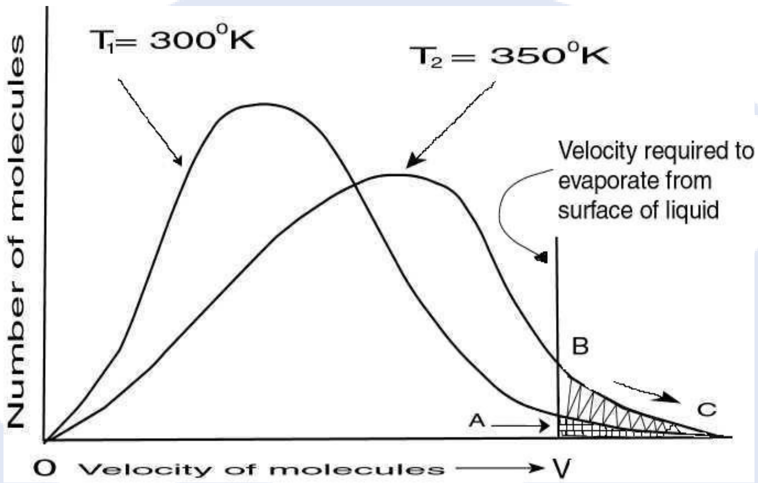
The ideas of kinetic theory and of bonds between molecules of a liquid help to explain the phenomenon of evaporation. Water placed in a pan on a shelf will gradually disappear; if the pan is heated, the water will disappear much more rapidly. When two bodies attract each other, energy is required to separate them, whether the bodies are barbells and the earth, or a pair of water molecules. The process of molecular separation and subsequent evaporation is random but depends upon the following conditions: the molecule must be in the surface layer, must have enough speed (energy) to break away from the attractive forces surrounding molecules, and must be moving in a direction away from the attractive forces.

When these conditions exist in water the molecules at the surface will escape from the liquid state (at a rate proportional to the temperature) and become a water-vapor molecule.

To measure the temperature of water is effectively a measure of how much the medium of the thermometer; for example, a column of mercury, expands in response to the energy of the molecules that strike the bulb. The temperature of a wastewater treatment pond is an indirect measure of the velocity of the molecules that contact the thermometer, even if it is a high-tech temperature probe. The thermometer does not measure the total heat (kinetic energy) contained in the pond.

When taken together, kinetics and bonding principles explain why water evaporates more rapidly when heated, with ambient temperature being an indirect measure of the average kinetic energy of the molecules. Water temperature is the most significant single factor in determining evaporation losses. Figure 1 illustrates this concept.

FIGURE 1. THE DISTRIBUTION OF VELOCITIES IN THE MOLECULES OF WATER.



The velocity, *V*, is required for a water molecule to be able to escape the attractive forces of its fellows. At temperature, *T1*, only those molecules under the line, *AC*, on the tail of the distribution curve will have a speed of *V* or greater. This is a very small fraction of the total area under the *T1*, curve, and the evaporation rate will be slow.

At *T2*, however, the entire curve is shifted to the right, and at this higher temperature all the molecules under the line *BC* will have enough speed to escape. This is a much greater fraction of the total number of molecules and, as a consequence, the rate of evaporation will be increased a great deal more than would be expected from a mere comparison of temperatures. In this example, a temperature increase of only about 17% increases the evaporation rate by more than 100%.

Although temperature is an indicator of the activity of molecules, it is heat that gives them energy. Heat, being energy, can be measured in foot-pounds, however, it is more convenient to define another unit to measure heat-energy. This special unit is the *calorie*, which is defined as the amount of heat necessary to raise the temperature of one gram of water by one centigrade degree. With this definition, one can calculate the amount of heat required to raise the temperature of a pond of known volume with the following equation:

$$Q = m\,S\Delta T, \qquad (1)$$

where,
Q = quantity of heat (calories),
M = mass of water (gm),
S = specific heat of water (cal/gm/°C = 1), and
ΔT = temperature change (°C).

As water molecules leave the surface, they each carry with them a small amount of energy. For each gram of water changing from the liquid state to the gaseous state at the same temperature, 539 calories of heat energy are required. This is known as the “latent (hidden) heat of vaporization.” High rates of evaporation cause a cooling affect in ponds due to the loss of this energy to the atmosphere.

The cooling affect can be roughly calculated by modifying equation (1) as follows:

$$\Delta T = \frac{Q}{\Delta m\,S,} \qquad (2)$$

where,

ΔT = the change in temperature due to evaporation (°C),

Q = latent heat of vaporization (539 cal/gm),

S = specific heat of water (cal/gm/□C = 1), and

Δm = mass of water evaporated (gm).

In order to solve this equation, it is necessary to know the amount of water that is evaporated. It is also necessary to assume that all of the heat for vaporization comes from the volume of water remaining in the pond. Of course, this is not the case, as heat will continue to be supplied (from the sun, earth, air and from any warmer influent water). In order to calculate an accurate cooling affect, one would need a far more complex formula that takes into account other heat transfer mechanisms.

Besides heat energy, the nature of the atmosphere above the surface has a significant effect on the rate of evaporation. When water molecules leave a liquid surface, they produce a vapor pressure in the air over the surface. Because the evaporation rate is directly proportional to the temperature of the water surface, so is the vapor pressure at the surface. Some molecules of water vapor already in the air will be going the other direction however, and condense on the liquid surface. The net gain or loss of water at the surface depends on the differences in vapor pressure between the atmosphere and the surface.

The rate of evaporation or condensation is directly proportional to the magnitude of those vapor pressure differences. In a semi-arid climate, evaporation usually proceeds at a higher rate than in humid air.

If the air above a water surface is still, and if evaporation from the surface continues long enough, the air above the surface becomes saturated. There are no longer vapor pressure differences, and evaporation stops. If evaporation is to continue, the layer of air on the surface must be constantly removed and replaced with unsaturated air. Over wastewater stabilization ponds, wind is required for the removal and replacement of air. The faster the wind is blowing, the faster evaporation will take place.

Because the evaporation rate is dependent upon temperature and density at the surface, heat dispersion from any source within the pond is also an important aspect in the amount of evaporation that takes place in a given environment. The amount and extent of turbulence at the thermal entry; whether from the air above the surface, from the earth through the pond bottom and sidewalls, or from the influent water, is very important in determining how the heated water disperses.

Experiments have shown that the total heat content is much less in stratified water than it is in water where complete or partial mixing has occurred, because heat losses occur more quickly in the first case than the second during cooling conditions. It is evident that even small differences in density and viscosity resist the dispersion of heat. Mixing therefore, disperses heat more uniformly and generally increases the rate of evaporation for any given environmental conditions.

The area of the surface is also a factor. Since evaporation is an “escape” mechanism by which water literally moves from one state of matter through the surface-air interface, the size of that area is directly related to the volume of evaporation.

The effective size of the surface area, and therefore the total volume of evaporated water, is increased by the height, number, and speed of waves on the surface. After temperature, humidity, and atmospheric exchanges have been considered for any given pond size, the roughness of the water surface becomes the chief factor governing the evaporation rate.

In an unassisted pond, the wind is the only source of energy to create roughness. When wind blows over a water surface, it applies shear forces on that surface. This shear stress causes waves. In the case of ponds, without velocity distribution (as might be found in a flowing stream), when there is no wind there are no waves. Wind therefore has at least two positive effects on the increase in evaporation: increasing the surface area, and the removal rate of the saturated vapor above the surface.

Both the roughness and the resistance to mass transfer at the surface interface are affected by surface tension. Molecular attraction forces acting along the liquid surface tend to shrink that surface to the smallest possible size. The liquid behaves as though its surface was covered with a sort of elastic membrane that has a tendency to constantly shrink in size. The strength of this "membrane" is the measure of the surface tension. Surface tension on a pond is increased by fats, oils, greases, and other compounds that float on the surface and which tend to form a film due to their own molecular attraction forces. The stronger the surface tension, the more resistance to mass transfer through the surface. Surface tension also tends to restrict wave and rippling motion, thereby further reducing the rate of evaporation.

Besides their influence on the surface tension, water composition, turbidity, and salinity have other molecular effects on the rate of evaporation for any given climatic condition. Like the climate, these factors may not be controllable in an unassisted wastewater stabilization pond.

Evaporation, E, in wastewater stabilization ponds effectively increases the quantity of total pond effluent, Qe, as shown in equation (3). Therefore, the hydraulic detention time, Dh, in equation (4), is decreased when evaporation rates are increased.

$$Q_e = (Q_o+E+P_e)/\text{day}, \quad (3)$$

where,

Q_e = total pond effluent discharge rate (gallons/day),

Q_o = effluent out drain (gallons),

E = evaporation (gallons), and

P_e = percolation (gallons).

$$D_h = V/Q_e, \quad (4)$$

where,

D_h = hydraulic detention time (days), and

V = pond volume (gallons).

On the other hand, because evaporation reduces the volume of the water to be held, a pond of any given size will be capable of receiving more water when the evaporation rate is increased. As examples: summer operations will allow more influent and compensate somewhat for precipitation and infiltration; a pond in a windy location is capable of receiving more water than one of the same surface area located in a stagnant basin.

Because evaporated water does not carry with it BOD, bacteria, nutrients, minerals, or organic compounds, concentrations of these components in wastewater will increase slightly. Evaporating water will however, release to the atmosphere any dissolved gasses it may have contained.

Increased evaporation does not affect the mean cell residence time or the physical residence time. See equations (6) and (7) of the Technical Review.

As it is extremely difficult to actually measure evaporation from a lake or pond, indirect methods have been developed. One involves measuring all inflows, such as precipitation, and outflows, such as discharges from the pond, and calculating the difference. This approach is called the Mass Balance or Water Budget method. The major problem is quantifying the subsurface inflows and outflows. Additionally, in the case of lakes, irregular shorelines result in only rough calculations of the total volume.

The Evaporation Pan was developed as a surrogate for measuring evaporation from lakes or ponds where there are unknown volumes and flows. The U.S. Weather Bureau, Class A Pan has a standard design into which water from the pond or lake to be measured is put.

The Pan is at the same elevation and in the same climatic conditions as the lake, and the measure of evaporation in the Pan is assumed to be proportional to that from the lake or pond. The problem with this approach is, the Pan absorbs heat from its sides and bottom resulting in an increased evaporation rate over that of the body of water to be measured.

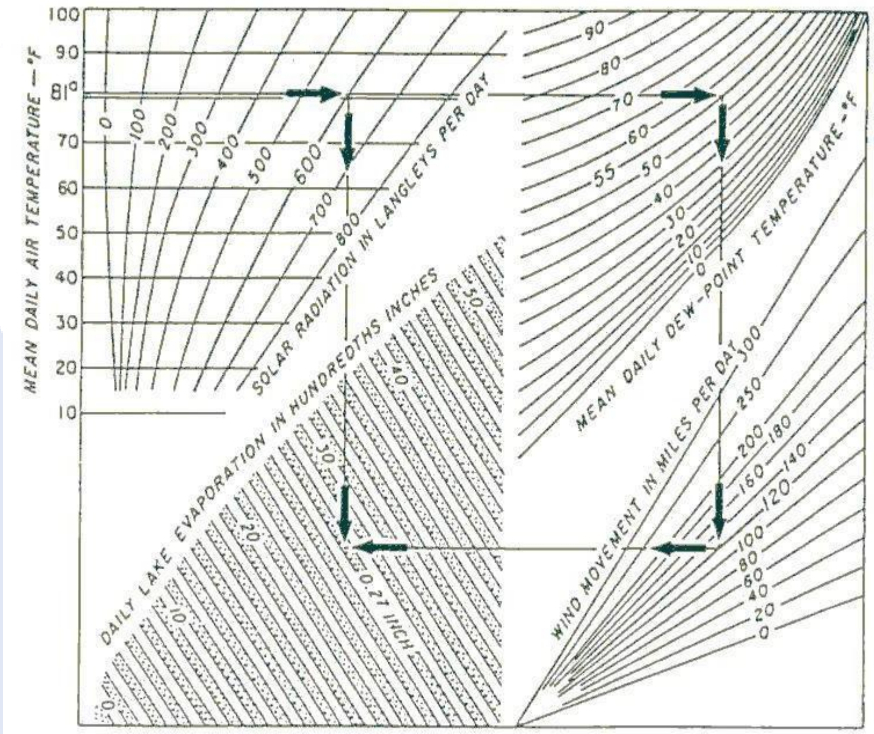
The Energy Budget approach quantifies the energy flows to and from a body of water and determines the energy lost in evaporation as a residual. All modes of energy transfer; convection, conduction and radiation, must be accurately determined. The primary drawbacks of the Energy Budget approach are equipment expense and the spatial and temporal variability of the energy fluxes.

A pioneering and comprehensive research project centered on techniques for measuring evaporation was conducted at Lake Hefner, Oklahoma, in 1950-51. The Energy Budget data from a Weather Bureau, Class A Evaporation Pan, was used to evaluate the study.

From that study, the US Weather Bureau developed the four-quadrant, nomograph diagram shown in Figure 2, for general use in determining evaporation from a lake. Subsequently, the formula for a mathematical solution of the nomograph was adapted from computer use (Lamdreaux, 1962). These procedures allow lake and pan evaporation to be computed from four items of climatic data, i.e., air temperature, dew point temperature, wind movement, and solar radiation.

The nomograph displays solar radiation in "Langleys" named for Samuel P. Langley (1834-1906), a pioneering solar energy researcher of the Smithsonian Institute. This unit of radiant flux is one calorie per square centimeter (cal / cm2). To convert Langleys to watt-hours per square meter, divide langleys by 0.0860.

FIGURE 2. LAKE EVAPORATION NOMOGRAPH (KOHLER ET AL., 1959).



Solar radiation data (in watt hours per square meter) for various locations in the United States can be obtained from:

User Services
National Climatic
Data Center
Federal Building
Asheville, NC 28801-2696
Telephone: 704-259-0682
Fax: 704-259-0876

Products can be accessed at: http://rredc.nrel.gov/solar.

The ***Mass Transfer*** method requires very accurate measurement of the vertical profiles of wind and humidity. More often, however, both the ***Mass Transfer*** and ***Energy Budget*** approaches are dealt with semi-empirically; that is, some of the more complex formulations have been parameterized, and simple coefficients replace those components that are either relatively invariable or, more often, the most difficult to determine. The more empirical a formulation is, the less reliable the results.

When considering the physics involved, one can conclude that the functions of the Sunflo² unit will tend to increase the rate of evaporation in a given body of water over that which would otherwise be expected from natural forces alone. This is principally due to three factors:

(1) Increased surface area, due to the wave action produced in the radial distribution of water,

(2) Reduced surface tension, due to enhanced biodegradation of fats, oils, greases, and other floating compounds that may contribute to surface tension and,

(3) Redistribution and destratification of heat sources, due to vertical and lateral mixing functions.

The ***Water Budget*** method was used to measure the evaporation rate attributable to the Sunflo² Model SS. An experiment was conducted in a 26-acre wastewater-polishing pond, having an average operating depth range of 10 to 16 feet, with concrete bottom and sides. Carefully measured inflow and outflow data, as well as evaporation rates from several years before the Sunflo² unit (one) was installed were compared to the measured flows during the two-year period after installation. The evaporation rate, after the Sunflo² unit installation, was found to range from two to three times that of the unassisted pond.