Evaporation

Evaporation is the process in which a liquid changes to the gaseous state at the free surface, below the boiling point through the transfer of heat energy.

The rate of evaporation is depended on the following:

(i) Vapour Pressure

\[ E_L = C(e_w - e_a) \]

Where \( E_L \) = rate of evaporation (mm/day)
- \( C \) = a constant
- \( e_w \) = the saturation vapour pressure at the water temperature in mm of mercury
- \( e_a \) = the actual vapour pressure in the air in mm of mercury

This equation is known as Dalton’s law of evaporation after John Dalton (1802) Who first recognized this law. Evaporation continuous till \( e_w = e_a \). If \( e_w > e_a \) Condensation takes place
(ii) Temperature

The rate of evaporation increases with an increase in the water temperature.

(iii) Wind

The rate of evaporation increases with the wind speed up to a critical speed beyond which any further increase in the wind speed has no influence on the evaporation rate.

(iv) Atmospheric Pressure

A decrease in the barometric pressure, as in high altitudes, increases evaporation.

(v) Soluble Salts

When a solute is dissolved in water, the vapour pressure of the solution is less than that of pure water and hence causes reduction in the rate of evaporation. For example, under identical condition evaporation from sea water is about 2 – 3% less than the fresh water.
(vi) Heat Storage in Water Bodies

Deep water bodies have more heat storage than shallow ones.

Evaporimeters

The amount of water evaporated from a water surface is estimated by the following methods:
(i) using evaporimeter
(ii) empirical evaporation equations and
(iii) analytical methods
Types of Evaporimeters

Class A Evaporation Pan

- Water level in pan
- GL: 1210 Dia.
- Wooden support (SQ)
- Dimensions:
  - 50
  - 255
  - 150
Colorado Sunken Pan

Water level same as GL

460

50

920 Sq
US Geological Survey Floating Pan

Square pan 900 mm side and 450 mm depth supported by drum floats in the middle of a raft (4.25 m x 4.87 m) is set a float in a lake. The water level in the pan is kept at the same level as the lake leaving a rim of 75 mm.

Pan Coefficient Cp

Evaporation pan are not exact models of large reservoirs and have the following principle drawbacks:

1. They differ in the heat storing capacity and heat transfer from the sides and bottom. The sunken pan and floating pan aim to reduce this deficiency. As a result of this factor the evaporation from a pan depends to a certain extent on its size.

2. The height of the rim in an evaporation pan affects the wind action over the surface.

3. The heat transfer characteristics of the pan material is different from that of the reservoir.
Thus a coefficient is introduced as
Lake evaporation = $C_p \times$ pan evaporation
In which $C_p =$ pan coefficient. The values of $C_p$ in use for different pans are given in the following Table

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Types of pan</th>
<th>Average value</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Class A Land Pan</td>
<td>0.70</td>
<td>0.60-0.80</td>
</tr>
<tr>
<td>2</td>
<td>Colorado Sunken Pan</td>
<td>0.78</td>
<td>0.75-0.86</td>
</tr>
<tr>
<td>3</td>
<td>USGS Floating Pan</td>
<td>0.80</td>
<td>0.70-0.82</td>
</tr>
</tbody>
</table>
Evaporation Stations
The WMO recommends the minimum network of evaporimeter stations as Below.
1. Arid zones – one station for every 30,000 Km²
2. Humid temperate climates – one station for every 50,000 Km², and
3. Cold regions – one station for every 100,000 Km².

Empirical evaporation Equations
Meyer’s Formula (1915)

\[ E_L = K_M (e_w - e_a) (1 + u_9/16) \]

In which, \( u_9 \) = monthly mean wind velocity in km/h at about 9 m above ground and

\( K_M \) = coefficient accounting for various other factors with a value of 0.36 for large deep and 0.50 for small shallow waters.
Rohwer’s Formula (1931)

\[ EL = 0.771(1.465 - 0.000732 \, Pa) \, (0.44 + 0.0733 \, U_0)(e_w - e_a) \]

\( Pa = \) mean barometric reading in mm of mercury
\( U_0 = \) mean wind velocity in km/h at ground level, which can be taken to be the velocity at 0.6 m height above ground.

The wind velocity can be assumed to follow the 1/7 power law

\[ U_h = C \, h^{1/7} \]

Where, \( U_h = \) wind velocity at a height \( h \) above the ground and \( C = \) constant.

This equation can be used to determine the velocity at any desired level.
Example: A reservoir with a surface area of 250 hectares had the following average values of parameters during a week: water temperature = 20°C, relative humidity = 40% wind velocity at 1.0 m above ground = 16 km/h. Estimate the average daily evaporation from the lake and volume of water evaporated from the lake during that one week.

Solution:

\[ \varepsilon_w = 17.54 \text{ mm of Hg} \]
\[ \varepsilon_a = 0.40 \times 17.54 = 7.02 \text{ mm of Hg} \]
\[ U_9 = \text{wind velocity at a height of 9.0 m above ground} \]
\[ U_1 = 16 \text{ km/h} \quad U_9 = ? \]
\[ U_h = C (h)^{1/7} \]
\[ U_h = C (1)^{1/7} = 16 \text{ km/h} \]
\[ U_9/U_1 = C ((9)^{1/7}) / C ((1)^{1/7}) \]
\[ u_9 = u_1 (9)^{1/7} \]
\[ = 16 (9)^{1/7} \]
\[ = 21.9 \text{ km/h} \]

By Meyer’s formula
\[ E = 0.36 (17.54 - 7.02) (1 + 21.9/16) \]
\[ = 8.97 \text{ mm/day} \]

Evaporated volume in 7 days
\[ = 7 \times 8.97/1000 \times 250 \times 10000 \]
\[ = 157,000 \text{ m}^3 \]
Analytical Methods of Evaporation Estimation

The analytical methods for the determination of Lake evaporation can be broadly classified into three categories as:
2. Energy – balance method, and
3. Mass – transfer method

**Water – Budget Method**

\[ P + V_{is} + V_{ig} + V_{os} = V_{og} + E_L + \Delta S + T_L \]

Where,
- \( P \) = daily evaporation
- \( V_{is} \) = daily surface inflow into the lake
- \( V_{ig} \) = daily groundwater inflow
- \( V_{os} \) = daily surface outflow from the lake
- \( V_{og} \) = daily surface outflow
EL = daily lake evaporation
ΔS = increase in lake storage in a day
TL = daily transpiration loss
Energy – Budget Method

\[ H_n = H_a + H_e + H_g + H_s + H_i \]

Where, \( H_n \) = net heat energy received by the water surface

\[ = H_c (1 - r) - H_b \]

\( H_c (1 - r) \) = incoming solar radiation into a surface of reflection coefficient (albedo) \( r \)

\( H_b \) = back radiation (long wave) from water body

\( H_a \) = sensible heat transfer from water surface to air

\( H_e \) = heat energy used up in evaporation

\[ = \rho L E_L \] where \( \rho \) = density of water,

\[ L = \text{latent heat of evaporation and} \]

\[ E_L = \text{evaporation in mm} \]

\( H_g \) = heat flux into the ground

\( H_s \) = heat stored in water body

\( H_i \) = net heat conducted out of the system by water flow (advected energy)
Fig. Energy balance in a water body