EVAPORATION SUPPRESSION FROM WATER SURFACES USING CHEMICAL FILMS

Dr. Umesh J. Kahalekar¹, Hastimal S. Kumawat²

¹(Professor and Head- Dept. of Civil Engineering, Government College of Engineering Aurangabad-431005 (M.S.), India)
²(Post Graduate Student- Government College of Engineering Aurangabad-431005 (M.S.), India)

ABSTRACT

The extremely high rate of Evaporation from water surfaces day by day is reducing the optimal utilization of water reservoirs. The work presented in this study aims to investing the use of Chemical films as Evapo Supprentants for reduction of evaporation from the open water surface so as to increase the storage efficiency. Particular emphasis will be on practical procedures and techniques that professionals can use to estimate and/or to suppress evaporation from shallow water bodies. The natural evaporation loss taking place from pan evaporimeters of two alcohols were observed and compared. The important meteorological factors affecting the natural evaporation such as Temperature, Relative Humidity, Wind Velocity, Sunshine Hours, etc. were also observed.

Cetyl and Stearyl Alcohols were selected to reduce the evaporation during the study period in Aurangabad region with two US Class-A evaporation pans. Different concentrations of Cetyl and Stearyl alcohols were used in different pans. First pan EP₁ was filled with water without adding chemical while in pan EP₂ alcohols was added. The preliminary results of the study indicated that evaporation rate from surface water was reduced overall upto 28% in pan EP₂ as compared to pan EP₁ while the Cetyl alcohol individually gives the average reduction is 27% and the Stearyl alcohol gives 27% and Both Cetyl and Stearyl Alcohol combine gives the average reduction is 30%. The Penman’s Equation is used to compare the evaporation values in evaporation pan 1.

Keywords: Cetyl & Stearyl Alcohols, Class-A Pan, Evaporation Reduction, Evaporation Suppression, Penman’s equation
1. INTRODUCTION

Water is one of the nature’s precious gifts, which sustains life on earth. Civilizations over the world have prospered or perished depending upon the availability of this vital resource. Water has been worshiped for life nourishing properties in all the scriptures. Vedas have unequivocally eulogized water in all its virtuous properties.

The total water resources on earth are estimated to be around 1360 Million cubic km. Out of which only about (33.5 Million cubic km) is fresh water. India possesses only 4% of total average runoff of the rivers of the world although it sustains 16% of the world's population. The per capita availability of water in the country is only 1820 m$^3$/year, compared to 40855 m$^3$/year in Brazil, 8902 m$^3$/year in USA, 2215 m$^3$/year in China, 2808 m$^3$/year in Spain, 18162 m$^3$/year in Australia, 3351 m$^3$/year in France, 3614 m$^3$/year in Mexico and 3393 m$^3$/year in Japan. The total water resources of India are estimated to be around 1,869 Billion cubic meters. Due to topographic, hydrological and other constraints, only about 690 BCM of total surface water is considered as utilisable [1].

Due to high temperatures and arid conditions in about one third of the country, the evaporation losses have been found to be substantial. Therefore, it is imperative to minimise evaporation losses in the storages/water bodies.

Evaporation losses from on-farm storage can potentially be large, particularly in irrigation areas in where up to 40% of storage volume can be lost each year to evaporation. Reducing evaporation from water storage would allow additional crop production, water trading or water for the environment. The need for prevention of enormous evaporation losses assumes greater significance, in view of the predictable scarcity of water; the country will be facing in future. It has been assessed that against the utilisable water resources of the order of 1123 BCM, the requirement by 2025 AD to be met from surface water resources will be around 1093 BCM, thereby surplus by just 30 BCM[1, 2].

Due to intense agricultural practices, rapid increase in population, industrialization and urbanization etc., scarcity of water is being increasingly felt. In the present scenario of utmost strain on the water resources, of the country, it becomes necessary to conserve water by reducing evaporation losses. National Water Policy-2002 under Para 19.1 emphasises that evaporation losses should be minimised in drought-prone areas [1].

The internet was also browsed to search the information on any new researches or identification of any new technology / chemicals to retard the evaporation rate. The search on internet, resulted in finding some case studies done in this field in other countries, however, the chemicals / technology used is the same. Some websites are from the manufacturers of WER chemicals such as Hexadecanol or Octadecanol or Acilol claiming to have conducted experiments in other countries towards evaporation control [3, 4, 5].

Chemical substances such as Cetyl and Stearyl alcohols can be sprayed periodically on water surface to reduce evaporation. After a detailed review of the available evaporation reduction methods, surface water cover technique was selected using Cetyl and Stearyl alcohol emulsion substances to form a thin monomolecular film over water surface to reduce evaporation [6]. This method has several advantages over other methods. It is economically feasible due to low cost of substances and easily available. It mixes with water easily and when added to large water surface; it forms a thin invisible film that reduces evaporation considerably. It decomposes easily and doesn't dissolve in water.

There are several methods to measure evaporation from free water surfaces through (US weather class-A pan), or more accurately by using energy balance equations. Due to
several factors including air movement and fluctuations of water surface, which affect the accuracy of measurement of evaporation depth therefore, standard and well recognized method of (US weather class-A pan) was selected for the present study [7].

The present study was conducted to measure the reduction of evaporation on relatively small and controlled water surface of two pans (US weather class-A pan) with continuous measurement of air temperature, relative humidity, wind velocity and evaporation rates and evaluated the results in terms of efficiency in reducing evaporation. The evaporation pan 2 was added with Cetyl and Stearyl alcohols as thin film on water surface to reduce evaporation. Based on material safety data sheet, the substance does not have any harmful effects on human beings, animals or plants however; further study is required to determine the potential environmental, health and ecological impacts of the substance on aquatic animals and plants [8,9,10].

2. MATERIALS AND METHODOLOGY

The study was conducted at Aurangabad (Marathwada region of M.S.) with the help of a fully operated meteorological station with sensors to measure sunshine hours, air temperature, wind velocity and relative humidity. Two US weather class-A pans were used with an accurate measuring tool to measure daily water depth in the pans. A protection cover was constructed to protect the pans from birds and other animals.

The amount of chemical films (Cetyl and Stearyl alcohols) added to the two evaporation pans was calculated and applied to one of the pan for fifteen days duration. No chemical was added to pan (EP1) to measure natural evaporation rate due to ambient conditions and for comparison. In pan (EP2), 50 mg per m² of water surface per day, to make the effective substance in pan (EP2) is 58.35mg/day and as that of 100mg and 150 mg is calculated.

A monolayer is formed on a water surface when long-chained alcohols such as Cetyl alcohol (Hexadecanol) are spread across the water. The chemical spreads spontaneously across the surface resulting in a layer only one molecule thick (about two millionths of a millimetre). The molecules of the monolayer ‘stand’ on the surface because they are amphiphilic i.e. they have a soluble end and an opposing insoluble end (Fig.1).

![Figure 1](image_url) Monolayer molecules ‘standing’ on the water surface (courtesy Geoff Barnes, University of Queensland)

Duration the entire study period (Jan-Sept 2012), Cetyl and Stearyl Alcohols was sprayed daily in evaporation pan EP2 and meteorological parameters including air temperature, relative humidity, wind speed and sunshine hours as well as water levels in two
pans were measured. The standard procedure was strictly followed and maintained during measurements of the readings for accuracy and consistency of the results throughout the duration of the study. All the pans were cleaned regularly to remove sediments from pans, if any.

3. RESULTS AND DISCUSSION

The results of the study indicated that air temperature ranges from 15.0-41.0°C with average of 34.5°C, while wind velocity ranges from 0.4-12 km/hr with average of 3.9 km/hr. The relative humidity ranges from 25-95% with average of 66.8%. Similarly, the daily pan evaporation rates ranges from 1-9.7 mm/day with average of 6.4 mm/day. The pan evaporation rate reached its peak in June and it reached 9.7 mm/day.

Table 1. Summary of the experiment results of the daily reduction of pan evaporation rates for different months

<table>
<thead>
<tr>
<th>Duration</th>
<th>Evaporation mm/day (EP₁)</th>
<th>Evaporation mm/day (EP₂)</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 Jan - 31 Jan</td>
<td>5.41</td>
<td>4.16</td>
<td>23.13</td>
</tr>
<tr>
<td>01 Feb - 29 Feb</td>
<td>5.72</td>
<td>4.36</td>
<td>23.97</td>
</tr>
<tr>
<td>01 Mar - 31 Mar</td>
<td>6.15</td>
<td>4.40</td>
<td>28.37</td>
</tr>
<tr>
<td>01 Apr - 30 Apr</td>
<td>7.55</td>
<td>5.26</td>
<td>30.29</td>
</tr>
<tr>
<td>01 May - 31 May</td>
<td>8.15</td>
<td>5.14</td>
<td>36.93</td>
</tr>
<tr>
<td>01 June - 21 June</td>
<td>7.11</td>
<td>5.40</td>
<td>23.76</td>
</tr>
<tr>
<td>22 Aug - 31 Aug</td>
<td>3.68</td>
<td>2.68</td>
<td>25.69</td>
</tr>
<tr>
<td>01 Sept - 12 Sept</td>
<td>3.89</td>
<td>2.76</td>
<td>28.01</td>
</tr>
<tr>
<td>Average</td>
<td>5.96</td>
<td>4.27</td>
<td>27.52</td>
</tr>
</tbody>
</table>

Table 2. Summary of the experiment results - chemical wise reduction in percentage

<table>
<thead>
<tr>
<th>Reduction using only cetyl alcohol</th>
<th>Reduction using only stearyl alcohol</th>
<th>Reduction using cetyl + stearyl alcohol</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.13</td>
<td>22.66</td>
<td>25.28</td>
</tr>
<tr>
<td>27.07</td>
<td>26.73</td>
<td>29.67</td>
</tr>
<tr>
<td>33.85</td>
<td>31.98</td>
<td>41.88</td>
</tr>
<tr>
<td>21.06</td>
<td>24.48</td>
<td>25.73</td>
</tr>
<tr>
<td>26.17</td>
<td>28.01</td>
<td>25.21</td>
</tr>
<tr>
<td>Average Reduction</td>
<td>26.26%</td>
<td>26.77%</td>
</tr>
<tr>
<td>Average Reduction</td>
<td>25.28%</td>
<td>29.55%</td>
</tr>
</tbody>
</table>

Table 1 shows the daily average evaporation rate for 8 months from January to September. In table 2 the chemical wise reduction is shown. The average reduction recorded using only Cetyl alcohol is about 26.26%. The average reduction recorded using only Stearyl alcohol is about 26.77%. The average reduction recorded using Cetyl and Stearyl alcohol is about 29.55%.
Chemical and concentration wise reduction in percentage is shown in table 3. It is cleared from this table as the concentration is increased the reduction is also increased while the cetyl and stearyl alcohols combine perform better than other two concentrations and chemicals. In table 4 the reduction in percent concentration wise is shown.

Table 3. Summary of the experiment results - chemical and concentration wise reduction in percentage

<table>
<thead>
<tr>
<th>Reduction using only cetyl alcohol</th>
<th>23.13 for 50mg/m²/day</th>
<th>27.07 for 100mg/m²/day</th>
<th>-- for 150mg/m²/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>26.62</td>
<td>33.85</td>
<td>Average</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reduction using only stearyl alcohol</th>
<th>22.66 for 50mg/m²/day</th>
<th>26.73 for 100mg/m²/day</th>
<th>-- for 150mg/m²/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>27.37</td>
<td>31.98</td>
<td>Average</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reduction using cetyl + stearyl alcohol</th>
<th>25.28 for 50mg/m²/day</th>
<th>29.67 for 100mg/m²/day</th>
<th>-- for 150mg/m²/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>27.44</td>
<td>41.88</td>
<td>Average</td>
</tr>
</tbody>
</table>

Table 4. Summary of the experiment results - concentration wise reduction in percentage

<table>
<thead>
<tr>
<th>for 50mg/m²/day</th>
<th>for 100mg/m²/day</th>
<th>for 150mg/m²/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.13</td>
<td>27.07</td>
<td>33.85</td>
</tr>
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<tr>
<td>21.06</td>
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<td>--</td>
</tr>
<tr>
<td>24.48</td>
<td>25.21</td>
<td>--</td>
</tr>
<tr>
<td>25.73</td>
<td>28.01</td>
<td>--</td>
</tr>
<tr>
<td><strong>Avg. 23.72</strong></td>
<td><strong>Avg. 27.14</strong></td>
<td><strong>Avg. 35.90</strong></td>
</tr>
</tbody>
</table>

Difference Between 50mg/m²/day and 100mg/m²/day: **3.42**
Difference Between 100mg/m²/day and 150mg/m²/day: **8.76**

The daily average pan evaporation rate for 4 summer months (March, April, May and June) was measured as 6.15, 7.55, 8.15 and 7.11 mm/day, respectively. Thus, middle four months (March to June) witnessed the highest evaporation rates due to high temperature and low humidity.

The readings are validated with help of Penman’s equation for evaporation [11], the following equation were used.

\[
E = \frac{\left( \frac{Q_e \Delta}{L_e} + 0.00061 P \cdot E_a \right)}{\left( \Delta + 0.00061 P \right)}
\]

(1)

where,

\(Q_e\) is the net solar radiation used in evaporation in cal/sq.cm
\[ Q_i = Q_i (1 - r) - Q_b \]  

(2)

\[ Q_i \] is the incoming solar radiation

\[ Q_i = Q_0 \left( a + 0.55 \frac{n}{N} \right) \]  

(3)

\[ Q_0 \] is the radiation in cal/cm\(^2\)/day received at the top of the atmosphere

\[ a = 0.29 \cos \theta \]  

(4)

\[ \theta \] is the latitude of the place

\[ n \] is the actual number of sunshine hours in the day,

\[ N \] is the maximum possible hours of bright sunshine

\[ r \] is called the reflection coefficient or the albedo whose value may be taken as 0.05 for water surface

\[ Q_b \] is the net outgoing longwave radiation

\[ Q_s = \sigma T^4 \left( 0.56 - 0.09 \sqrt{e_a} \right) \left( 0.1 + 0.9 \frac{n}{N} \right) \]  

(5)

\[ \sigma \] is the Stefan-Boltzman constant

\[ \sigma = 118.944 \times 10^{-9} \text{ cal/cm}^2/\text{day}/\text{°K} \]  

(6)

\[ T \] is the mean daily temperature in °K

\[ e_a \] is the actual vapour pressure of air in mm of mercury

\[ e_a = \frac{100e_s}{R.H.} \]  

(7)

R. H. is the Relative Humidity in %

\[ \Delta \] is the slope of saturation vapour pressure curve at air temperature \( t \) in mb/°C

\[ \Delta = \frac{4098e_s}{(237.3 + t)^2} \]  

(8)

\[ e_s \] is the saturated vapour pressure corresponding to the mean daily air temperature

\[ e_s = 6.11 \exp \left( \frac{17.27T}{237.3 + T} \right) \]  

(9)

\[ t \] is the air temperature in °C

\[ L_e \] is the latent heat of vaporization of water in cal/g which varies with the temperature and can be obtained from

\[ L_e = 597.3 - 0.564 t \]  

(10)

\[ P \] is the atmospheric pressure in kPa
\[ P = 101.3 \left( \frac{293 - 0.0065z}{293} \right)^{5.26} \]  

(11)

\( z \) is the elevation above sea level in m  
\( E_a \) is the evaporation from the water surface when water and air temperatures are equal

\[ E_a = 0.35(0.5 + 0.54V)(e_s - e_a) \]  

(12)

\( V \) is in m/s measured at a height of 2 m above the free surface

The regression model is shown in Fig. 2 is drawn for the study period 16 January to 21 June. The data is best fitting by the regression analysis. The best fit for \( EP_1 \) got from model is 45.94%. The best fit for using Penman’s equation got from model is about 46.1% and that of \( EP_2 \) the best fit get from model is about 32.52%. These regression models are showing the linearity of recorded data and Penman’s equation data.

The regression model shown in Fig. 3 indicates the study period between 16 Jan to 12 Sept. firstly it decided to check the efficiency of cetyl and Stearyl alcohols in summer therefore the reading were taken for the period 16 Jan to 21 June. Whatever readings were not available in the graph that is due to evaporation reading and other data are not recorded for period 22 June to 21 Aug. the reading and other data were continues after this gap and respective regression model is drawn for remaining period upto 12 Sept.

**Figure 2.** Linear regression model showing \( EP_1 \), \( EP_2 \) and evaporation using Penman’s eqn (depth in mm) {16 Jan -21 June}
Figure 3. Linear regression model showing $E_{P1}$, $E_{P2}$ and evaporation using Penman’s eqn (depth in mm) {16 Jan -12 Sept}

After these observed data the respective regression models is plotted. From this model it is observed that the model is not fitting to that extent. So, from all these studies it is concluded that the films are not that much efficient in rainy season as that of in summer season.

It is observed that splashing or overflowing of the pan may cause the flowing of chemical film with it. The high wind velocity breaks or may breaks therefore no layer is form and therefore water gets evaporated. Again the rain droplets may reduce the efficiency of the chemical films.

The relationship of air temperature, wind velocities and relative humidity with the evaporation was determined with the help of linear regression analysis of daily observed data. A linear regression model for best fit of observed data for daily air temperature and daily evaporation depth in mm for both pans ($E_{P1}$and $E_{P2}$) was developed as in Fig. 4.
Figure 4. Linear regression model for daily air temperature and daily evaporation

{16 Jan- 12 Sept}

The model indicated that there is a direct correlation between air temperatures with the daily pan evaporation rates. Similarly, a linear regression model for best fit of observed data for wind velocity and daily evaporation depth (mm) was developed as in Fig. 5.

Figure 5. Linear regression model for daily wind velocity and daily evaporation

{16 Jan- 12 Sept}

The model indicated that there is a direct correlation between wind velocities with the daily pan evaporation rates. In addition, a simple regression model for best fit of observed data for daily relative humidity and daily evaporation depth (mm) was developed as in Fig. 6.
The model indicated that pan evaporation rates decreases as humidity increases and that there is an inverse correlation between average daily relative humidity with the daily pan evaporation rates. The results of the pan evaporation control experiment after adding chemical film solution with different concentrations and without application in two different evaporation pans from January to September is presented in Fig. 7.

Similarly daily average gross evaporation rates for different months for two pans were compared and the evaporation reductions in percentage were calculated. Table 1 show that the average daily average gross evaporation rates and percentage of reduction of evaporation rate for different months for two pans.
The pan evaporation rates are smaller in winter as compared to the summer months. In general, evaporation rate from pan EP<sub>1</sub> is reduced by 27.52% as compared to pan EP<sub>2</sub> when the recommended concentration was applied. Similarly, in table 4 the reduction in percent concentration wise. The concentration where used as per recommendations it is observed that 23.72% reduction is achieved. If this quantity is doubled i.e. 100mg then 27.14% average reduction is possible. If this quantity is tripled then the results are tremendously increased i.e. about 35.90% reduction is possible.

These findings confirmed that there is a significant reduction in evaporation from free water surfaces when we applied the chemical films i.e. Cetyl and Stearyl alcohols and it is highly feasible and cost effective to use the substance to reduce evaporation.

![Figure 5](evaporation_depth.png)

**Figure 5.** Monthly evaporation depth in mm {16 Jan - 12 Sept}

4. **CONCLUSION**

As the duration of rainy season and quantity of rainfall is reduced, the demand of water is day by day increasing due to increase in population and Industrialization therefore, the economic value also increases. Therefore the government should adopt the strategic plans for storage and maximum utilization of rainwater. Protecting the stored water in water bodies (Dams, Reservoirs, Lakes, etc.) from evaporation remains an integral part of sustainable planning, especially during the summer hot months, when temperature is high and humidity is low, which leads to extremely high rate evaporation from water surfaces. Chemical films such as Cetyl and Stearyl alcohols are one of most feasible and cost effective evaporation retardants which reduces evaporation significantly. The present study has confirmed that a chemical film produces an invisible thin monomolecular film over water surface that significantly reduces evaporation. The experimental study was conducted to demonstrate the effectiveness of evaporation reduction on US weather class-A pans adding chemical films of different concentrations of 50, 100 and 150 mg/m<sup>2</sup>/day. The study concluded that evaporation was reduced up to 28% as compared to without addition of chemical films. Therefore, these chemicals are highly feasible and cost effective to apply the present evaporation reduction technique on a large scale to a large number of reservoirs of the Marathwada region to reduce the water loss through evaporation from water surfaces.
REFERENCES


