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EVAPORATION FROM WATER BODIES AND ITS CONTROL

BY

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PREFACE

Evaporation of water has an important role in the hydrologic cycle of nature. It is a natural process and occurs when solar radiation falls on a water body and the energy so transmitted is acquired by water molecules which in turn get separated and move upward causing the evaporation phenomenon. The loss of water from water storage structures like reservoirs, irrigation tanks through the process of evaporation causes considerable reduction in storage. The huge costs involved in the construction of these storage structures make it imperative to utilise every single drop of water stored. Estimation of evaporation loss in the country indicate that the annual evaporation from a water surface in the semi-arid tropics is as high as 2000 mm. Annual average value of evaporation ranges from 1400 mm to 1800 mm over a large portion of the country. More information about spatial variation of evaporation reveals that values exceeding 2000 mm occur over west Rajasthan and parts of Saurashtra and Tamilnadu, while less than 1400 mm is reported at coastal Mysore, Bihar plateau and east M.P.

Statistics reveal that about 70 M.ha.m of water evaporates from water bodies and land surfaces out of the total annual precipitation of 392 M.ha.m received in the country. The total evaporation losses from water surfaces only are about 5 M.ha.m from the total storage of 15 M.ha.m in the reservoirs, tanks and lakes spread all over the country. Studies disclose that evaporation loss from shallow lakes, small tanks and reservoirs can be of the order of about 50% of the capacity of the tank. As regards evaporation from cropped area, the total water loss due to evaporation is about 1/4 to 1/2 of the total water received or applied.

In view of the scarcity of this vital resources in most parts of arid and semi-arid regions, it is essential to conserve water by reducing evaporation losses as much as possible. Through this Water Science Educational Series, being brought out by National Institute of Hydrology, Shri M M Makwana, an expert in the area has shared his views and experience with a larger spectrum of readers. The Institute shall full rewarded if the contents help create awareness among the masses and educate the people about evaporation process, its importance and how to minimize it by adopting suitable techniques of evaporation control.

The valuable document has been prepared by Shri M M Makwana of Central Design Organisation, Gujarat. The Institute is grateful to Shri V B Patel, former Chairman, Central Water Commission, New Delhi & Chairman, Water Management Forum, Gandhinagar, Gujarat for taking keen interest in the preparation of the manuscript.

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EVAPORATION FROM WATER BODIES AND ITS CONTROL

1.0 INTRODUCTION

1.1 Water, most essential for survival of living organism, is one of the free gifts of Nature. With the rapid increase in population, intense agricultural practices, fast industrialisation and urbanisation, the strain on the available water resources is becoming more and more acute particularly in the arid and semi arid regions. Availability of water, now, can no longer be taken for granted. It has to be treated as a valuable resource.

1.2 The total water resources available on the earth are estimated to be about 1360 million cubic Km. Out of this only 2.5% viz. 33.5 million cubic Km is fresh water. Even this fresh water is not all exploitable physically or economically and it is estimated that less than 6.8 million cubic Km could be available for development. India possesses only about 4.2% of the total average runoff of the rivers of the world, although it sustains about 20% of world's population. The per capita availability of water in the country is only 2,500 cum/year compared to 6,500 cum/year in Japan and 6,200 cum/year in USA. The total water resources of india are estimated to be around 1,800 cubic Km out of which only about 700 cubic Km are considered as utilisable, due to topographical, hydrological and other constraints.

The current estimate in respect of surface water resources for India indicates that a fairly large quantum is available by way of runoff from precipitations and this quantity is 1780 Cub. Km. However, because of topographic and other constraints, only 670 Cub. Km can be utilised. Also out of about 600 Cub. Km of replenishable ground water estimated to be available, only 420 Cub Km can be tapped and utilised. An estimate of the total amount of water that may be utilised in India for various functions annually by 2000 A.D. is depicted in the table below :

TABLE - I

Water utilisation by 2000 A.D. (India) (in thousand million cum)

	ITEM	%use	Water used	Water consumed	Reused
a)	Irrigation	77	860	774	86
b)	Live stock	1	9	9	--
c)	Power	13	150	5	145
d)	Industries	3	35	10	25
e)	Municipal & Rural Water	6	62	34	31
Total		100	1116	832	287

1.3 The availability of water over the year depends upon the spatial and temporal variation of precipitation. Becuase of the nature of monsoons over India, water may be abundant during the monsoon season viz. June to October and scarce during the non monsoon season (November to May), when it is most needed. The ingenuity of man, therefore, lies in his ability to modify the pattern of availability of water to suit needs. One of the commonest forms of such modification is storage of water during monsoon season for its eventual use in lean season. However, storage over ground for irrigation, domestic and industrial consumption necessarily involves large losses, of which the most important are evaporation and seepage. The seepage losses which do not generally exceed 5% depend on geology and other local features from place to place and are to a large extent controllable with the present day seepage control technology. Evaporation losses, on the other hand, are very high in a tropical country like India because of higher temperature, larger overall aridity and a large number of sunshine days. The common man often fails to apreciate the magnitude of evaporation losses as they take place gradually. The annual Evaporation losses from the reservoirs in arid and semi arid areas vary from 1.5 m to 3.0 m, out of which about 50% of the evaporation may be in summer months. Thus it is evident that evaporation is the prime cause of water loss from all water storages. In view of the scarcity of this vital resource in most parts of arid and semi arid regions and present scenario of utmost strain in the water resources of the country, it is most essential to conserve water by reducing evaporation losses. This article primarily discusses general techniques of evaporation control and then provides a review of the present state of art in respect of use of various standards to reduce evaporation. Broad guidelines for field use of the evaporation retardant are also presented.

2.0 ASSESSMENT OF EVAPORATION LOSSES IN INDIA :

2.1 As per available records, assessment of evaporation losses in the country was first made by D.A. Pamdas and presented in Symposium on Evaporation control in 1968. This assessment was based on the following assumptions :

Area of arid, Semi arid and long dry spell regions of India	2,000,000 sq. km
Estimated water area in this region (1%)	20,000 sq. km.
Estimated area where film application may be feasible	2,000 sq. km.
The evaporation loss from the above area	6,000 M. cum.

2.2 The National Commission on Agriculture (1976) had estimated that the annual evaporation losses from reservoir surfaces will be of the order of 50,000 M. cum.

2.3 The Water Management Forum (W.M.F.), a national body of the Institution of Engineers of (India) in their publication "Water Conservation by Evaporation Control, 1988" has indicated that on the Indian sub-continent the estimated total loss of water from large, medium and small storages will be to the tune of 60,000 M. cum, which according to WMF would be adequate to meet the entire municipal and rural water needs of India by 2000 A.D.

2.4 The CWC has estimated (as per the review of 1990) the annual evaporation loss from the water bodies as 56,000 M. cum. This figure is for the ultimate stage of development when the total surface area of large and small storages, lakes and tanks in the country is likely to be around 25000 sq. km.

2.5 It may not, however, be possible to take remedial measures of evapo-retardation on all storages/water bodies. It is seen that about 30% of evaporation retardation may be achieved by known evapo-retardation methods. Thus it may perhaps be possible to effect a saving to the extent of 3375 M. cum at the ultimate stage.

3.0 FACTORS AFFECTING EVAPORATION

3.1 Evaporation is a process by which a liquid changes into vapour form. Water molecules are in constant motion and some have the energy to break through water surface and escape into air as vapour. Evaporation in general is a beneficial phenomenon in regulating global water balance through the hydrological cycle and it is also the same phenomenon contributing to massive losses from water bodies. Control of evaporation from land based water bodies has thus remained one of the main planks of water conservation strategies. This assumes greater significance in arid regions, where water scarcities are already a common problem.

3.2 The major factors influencing evaporation are :

a) Vapour pressure difference.

b) Temperature.

c) Wind,

d) Atmospheric pressure and

e) Quality of water

As a factor at (a), the rate of evaporation depends on the difference between saturation vapour pressure at the water temperature and at the dew point of the air. Similarly, evaporation increases with increased temperature of the water surface. In respect of wind factor, it is found that 'higher wind speeds accelerate evaporation but experimental data do not disclose the exact nature of this relationship. The effect and the dimensions probably depends on surface roughness and the dimensions of the water body. Atmospheric pressure is so closely related to other factors affecting evaporation that it practically impossible to study the effect of variation under natural conditions. Evaporation loss would be higher if the atmospheric pressure reduces (e.g. at higher elevations). However, this higher loss may be compensated to a large extent by lower temperatures. Regarding water quality, the rate of evaporation is less for salt or saline water than for fresh water and this thus decreases as the specific gravity of the water body increases.

4.0 METHODS OF EVALUATING EVAPORATION

Evaporation can be determined by serval methods.

The following methods and their modifications are generally used :

a) Water budget or storage equation.

b) Mass transfer method or humidity and wind velocity gradients method.

c) Energy budget method or insolation method.

d) Measurement in an auxiliary pan and reduction of the pan evaporation to natural water surface evaporation

e) Empirical formulae.

4.1 Water Budget or Storage Equation Approach

This method involves the equation.

$$E = P + I - 0 \pm U \pm \Delta S$$

P is the precipitation on water surface, I the surface inflow, 0 the surface outflow, U the underground inflow or outflow with ΔS is the change in storage and E the evaporation, Δ S is positive for any increase and negative for a decrease in storage. The quantities are usually expressed in terms of depth in mm over the water area for some convenient time interval. The main disadvantage of the approach is that the quantities can be determined with only varying degrees of accuracy. All errors in measurements get accumulated and thrown into the resulting value of E. It is specially difficult to make accurate measurement or estimates of the under ground flow. In some cases, this quantity is negligible whereas in others it is an important factor. Springs may occur in the lake bed or if the bed and surrounding area are highly permeable the direct undergound inflow may be large. On the other hand, large underground seepage losses may also occur from artificial reservoirs. Unless loss of waters due to seepage is correctly assessed, this equation does not give the correct figures of evaporation. Two research stations of India viz.

a) **Irrigation Research Institute, Poondi, Madras and**

b) **Irrigation Research Institute, Roorkee**

have made attempts to develop methods for measuring seepage. Using the constant head seepage meter developed by I.R.I., Roorkee seepage loss from the water bodies can be measured with fair degree of accuracy.

4.2 Mass Transfer Approach

As the name suggests two important factors (i) humidity and (ii) wind velocity form the basis of calculating the evaporation. The basic assumptions involved in this method are :

i) If the moisture gradient exists in air, water vapours will move towards points of lower moisture contents.

ii) The rate of movement of water vapour is accentuated by the intensity of turbulence in the air.

The method is applicable to both land and water surfaces. However, relatively expensive and highly sensitive hygrometers and wind velocity meters are required to measure the corresponding factors simultaneously at two different elevations above the ground.

4.3 Energy Budget or Insolation Method

This method was suggested by Angstorm in 1920 and is based on the conservation of heat within the body. For any given body of water, a balance must exist between heat gains and losses. Heat is normally gained by long and short-wave radiation, conduction and condensation. Heat losses result from direct land reflected radiation, conduction, convection and evaporation. Radiation conduction, convection and changes in the energy storage in water may be measured and the evaporation or condensation may be computed. In this type of calculation some factors, such as heating due to chemical and biological processes, conduction of heat trhough the lake bottom and transformation of kinetic energy into thermal energy are considered insignificant. Different equations relating each of the parameters mentioned have been developed by various research workers in the field. This method suffers from the main draw back of measuring various parameters accurately with the help of sensitive and costly equipped.

4.4 Measurement in an Auxiliary Pan

Kohler and others had calculated evaporation from lakes by converting measured evaporation from pans by applying a coefficient. Bleney had studied the effects of high altitude on evaporation from pans and determined suitable coefficient. Studies by Bigelow has shown that the location of pans relative to the water of a reservoir has significant effect on the calculated evaporation. He concluded that evaporation from natural lakes or reservoirs is about five eighth of that measured from an isolated pan placed outside the vapour blanket. Further studies by Rohwer, Kohler, Mansfield showed that the evaporation coefficient ranges anywhere between 0.2 to 1.5 and this factor is dependent upon size, depth, and location of pan. With this kind of evaporation measurement, it is essential that the coefficient of evaporation be measured under all different conditions, which is not practically feasible in large water storage systems.

The present practice is to estimate evaporation loss from land pan evaporimeter. In the studies being done at IHH, Poondi a floating evaporimeter is used for the experiments. A floating evaporimeter made of GI sheet was initially used. Later on it was found that the stored energy inside the waterbody has a significant effect on the evaporation loss. To have this effect truly reflected, IHH found it necessary to have a suitable material for manufacturing floating evaporimeters. An ideal materials to achieve this objective should perhaps be the one which will have a thermal conductivity equivalent to that of water, but at the same time nonleaky. With this in mind, a study of the thermal conductivity of some materials was made. Thermal conductivity of water is 0.556 W/m C. It is 0.75 for iron, 0.60 for brick, 0.78 for window glass, 0.1 for concrete and 0.02 for plastics. It shows that plastics and concrete have low values and the metals have high values. Ideally brick or glass should be made use of for making floating evaporimeter. But the brick is heavy and highly permissible and the glass is brittle. Hence a new material, perspex sheet, which is akin to glass but at the same time non-brittle and workable was chosen as an alternative material for the fabrication of floating evaporimeter installed at Poondi reservoir.

From the experiences so far gained in the installation of a floating evaporimeter, an arrangement that might perhaps sub-serve the objective of rational determination of evaporation loss and the seepage loss as a by product, as devised by IHH, Poondi. The arrangement consists of an evaporimeter (made up of perspex sheet) which is enclosed by a sliding type of wave arrester (again made up of perspex sheet). This sliding unit slides on the suporting legs of the stand which carries the evaporimeter with a wire drop and a pulley. Equipment like wind anemometer, thermometers etc. can be mounted on the outer sliding frame work. The main advantage of this system is that the sliding arrangement follows the water surface and could be fixed at the desired location. Further, the unit remains at a fixed location. A graduated gauge of requisite least count when fixed to the frame work shall enable the observation of water level fluctuations at the site of evaporation through the transparent perspex sheets.

Since the meterological factors affecting hydrological processes including evaporation vary over the year, IHH plans to obtain data for a few years for deriving reliable results for possible use in reservoirs analysis problems.

4.5 Emperical Formulae

The rate of evaporation at a given location depends upon a number of parameters as explained earlier. Dalton was one of the first scientists to have empounded an emperical formulae for evaporation loss which states that :

$$E = C (Pw - Pa)$$

Where E	=	Rate of evaporation in inches per day of the exposed surface
Pw	=	vapour pressure in the film of air next to water surface
Pa	=	vapour pressure in the air above the film
C	=	coefficeint dependent upon barometric pressure, wind velocity and other variables.

Many other scientists have proposed different modifications of this evaporation equation by taking into account various related factors. Fitzgerald modified the Dalton's equation by taking into account the effect of wind velocity on evaporation. Carpenter subsequently further modified the Fitzgerald equation by taking modified coefficient factor for wind velocity and his equation was found applicable to the conditions in western United States. Research scientists, Boelter, Hickox, Thomas and Fergusal have later significantly contributed in the development of evaporation equations and removal of doubts and confusion of terms adopted by different authors.

However, as can be seen from the equation, some parameters like temperature conditions, wind velocity etc. have not been separately considered but their effect is lumped in the form of coefficient C.

In India, S.P.Ghosh and S.R.Sarkar of River Research Institute, West Bengal had made attempts to develop equations, correlating evaporation with meterological factors like temperature, degree of saturation of water vapour, wind velocity and atmospheric pressure. They have suggested the following equation for calculation of Pan evaporation from meteorological factors :

$$E = [1.3684 - 0.0189B\ (0.41 + 0.136W)\ (es-ed)]$$

Where

E	=	daily evaporation in inches
B	=	mean barometric pressure in inches of mercury
W	=	mean velocity of ground wind in miles per hour
es	=	Mean, vapour pressure of saturated air at the temperature of water surface in inches of mercury
ed	=	mean vapour pressure actually present in the air in inches of mercury

The pan evaporation as calculated can be converted into reservoir evaporation by multiplying with standard pan coefficient. The accepted standard coefficient for 1.22m dia US Class A land pan is 0.70.

The above equation has been developed based on the limited years of meteorological data of four stations having, evaporation ranges from 0.041 inch to 0.389 inch, (1.04 mm to 9.88 mm), barometric pressure ranges from 25.54 inches to 30.07 inches (648.72 mm to 763.78 mm) of mercury, ground wind velocity ranges from 0.30 to 5.78 miles per hour (0.48 to 9.30 km/hr) and temperature ranges from 51.75°F to 97.22°F (10.97°C to 36.23°C). In view of this, the equation suggested can be considered as a generalised equation for regions having meteorological values within the range indicated. G.B.Pant University of Agriculture and Technology, Pantnagar, UP had conducted experiments to determine the effect of application of chemical films namely hexadecanol and octadecanol in reduction of evaporation from free water surface at different wind velocities by use of wind tunnel. Based on these studies the following equations were suggested for predicting evaporation rate from free water surface with and without use of chemical films;

i) free water surface:

$$F = (0.1184 + 0.0025W)\ (es - ea)$$

ii) with the application of hexadecanol:

$$E = (0.0014 + 0.0044W)\ (es - ea)$$

iii) with the application of octadecanol:

$$E = (0.0039 + 0.0057W)\ (es - ea)$$

Where E is evaporation rate in mm per hour, W is wind velocity in km per hour, es and ea are the saturation and actual vapour pressure respectively in millibars. The values of vapour pressure deficit (es-ea) have been calculated by the following relationship:

(es -ea) = 0.644 (Td - Tw), where Td and Tw are the dry bulb and wet bulb temperature (°C) respectively.

5.0 VARIATION IN EVAPORATION IN INDIA

The number of agro-meteorological observatories have now been considerably increased. Based on the network of IMD Evaporimeter stations existing in India and the available evaporation data thereform, L.S.Rathore and H.C.Biswas of the Division of Agricultural Meteorology, Pune has prepared climatological maps. Apart from data input from a large number of observatories, these maps are based on fairly long period of evaporation data of periods varying from 12-16 years. The basic data used are daily evaporation of 24 hours observed at 08.30 hrs.

6.0 EVAPORATION CONTROL METHOD

A number of approaches have either been applied or considered by Engineers and Scientists in their attempt to reduce evaporation losses from surface of water bodies. Since the basic meteorological factors affecting evaporation cannot be controlled under normal conditions, efforts have so far been restricted to managing the suppression of inhibition of evaporation from water surfaces by physical or chemical means. The methods generally used for being tried are broadly listed below:

i) wind breakers

ii) covering the water surface

iii) reduction of exposed water surface

iv) underground storage of water

v) integrated operation of reservoir

vi) treatment with chemical water Evapo Retardants (WER)

6.1 Wind Breakers

Wind is one of the most important factor which affects evaporation from water surface. The greater the movement of air above the water, greater is the loss of water vapour. Therefore, planting of trees normal to windward direction is found to be an effective measure for checking evaporation loss. As a matter of fact, this practice, of growing plants (trees, shrubs or grass) around the rim of tanks in a row or rows to act as wind breakers has been an age old practice. These wind breakers influence greatly the temperature, atmospheric humidity, soil moisture, evaporation and transpiration of the area protected.

The plants to act as wind breakers are usually arranged in such a way that the tallest plants are in the middle rows and the smallest (shrubs) along the end rows, so that more or less a conical cross section is formed. Trees grown as wind breakers are constanly subjected to usual stress of wind, temperature, moisture, evaporation, insects and diseases. Hence only those species which are resistant to these stresses are to be selected. ICAR had recommended the types of trees, shrubs and grass for planting as wind breakers in various regions of india in their Technical Bullentin (AGRIC) no.22, ICAR, New Delhi. The spacing between trees varies from place to place depending upon the climate and type of soil. The most commonly followed spacings in the country are given below:

Shrubs	0.60 m to 1.00 m
Medium height broad leaved trees	1.50 m to 2.00 m
Medium to tall evergreen trees	2.10 m to 2.40 m
Tall broad leaved trees with conical crown	2.40 m to 3.00 m

Spacing of 3m and above is reportedly found to have little effect on overall wind velocity of the protected area.

Sometimes the trees themselves involve transpiration losses. To avoid such losses, some scientists also advocate use of synthetic polytrees and poly shrubs in place of vegetative trees, keeping in view the vast availability and economy of this product in the country. According to them these synthetic plants can be raised as barriers against the hazardous wind in minimum possible time, particularly in arid areas, where it is otherwise difficult to grow vegetation. However, no experimental data to substantiate the effectiveness of these synthetic plants and its economy in conservation of water is available. Wind breakers are found to be useful under limited conditions for small ponds. In larger reservoirs wind breakers are not effective, as their effect is limited to a short distance from the rim of the reservoir, thereby exposing the inner water spread area to the hazards of wind. Considering these effects, the wind breakers are commonly employed for specific high wind locations. In such locations, chemical method of evapo-retardation may not be feasible as the monolayers of Water Evapo-Retardants (WER) are found to break at wind velocities from 10-16 km per hour.

6.2 Covering the Water Surface:

By covering the surface of water bodies with fixed or floating covers considerable saving in water could be achieved as these covers provide protection against rise in temperature of water surface and effects of air currents. The air would be literally trapped under the cover and deprived of its capacity to transfer water vapour to outer atmosphere

It is obvious that fixed covers are suitable only for relatively small storages. Thus the idea of using floating covers or mats are thought of by some researchers. The idea mainly emanated from chemical industry, where it is a comon practice to reduce evaporation losses by floating particles of various plastic materials. The plastic floating materials can be very useful and effective. However, cost of such floats would be prohibitive when used to cover large water surfaces. Further in the reservoirs with flood spillway, there is the danger of floats being lost over the spillway. In view of these problems, use of floating mats has limited utility for larger water bodies. Genet and Rohner had reported that floating spheres of a polystyrol reduced evaporation to 80% in small experimental tanks. The white spheres have the added advantages of reflecting solar energy and thus influencing evaporation.

Department of Soil and Water Conservation Engineering College of Technology and Agriculture Engineering, Rajasthan Agriculture University has done experiments with other floating bodies as vegetable oils, wax, wheat husk, paddy husk, wooden blocks, saw dust and thermocol boards. According to these studies conducted for a limited period of 15 days, the most effective evaporetardant is mustard oil, which resulted in 46% of saving in water. The next in the order of effectiveness was found to be thermocol, followed by wax. Paddy straw, wheat straw, saw dust and wooden blocks were found to have less effect on reducing the evaporation. However, mass scale and economic use of these materials were not recommended, till conclusive results providing their economics and utility are available based on some more experiments under varying conditions and on varying sizes of water bodies.

6.3 Reduction of exposed Water Surface

In this method shallow portion of the reservoirs are isolated by constructing dykes and water diverted or pumped to appropriate deeper pockets so that the surface exposed to evaporation is effectively reduced. This method is one of the recognised methods of conservation in drought areas and has been successfully tried for lake worth in Texas, USA. In India this method has been tried for Nayka Reservoir supplying water to Surendranagar in Gujarat which yielded good results. The compartmentalisation work proposed in the lakes supplying water to Madras city has indicated that this method is more economical and effective than chemical WER method.

6.4 Storing Water in Underground Storage

This is a radically different approach for control of evaporation losses, which comprises storage of water in underground cavities or aquifers. This can certainly be done with great advantage in specific cases where aquifers for such storages are available and do not entail higher lateral dispersion losses. Sub-surface dams can also be constructed in such schemes to prepare limited aquifers and thereby raise the level of storage, reducing subsequent pumping. Sub-surface dams or underground check dams have been constructed in Maharashtra, Andhra Pradesh, Gujarat and some other states across streams or rivulets in water deficient areas to hold ground water and recharge the adjoining limited aquifers. They can be of masonry or rolled impervious fill depending on the rocky or alluvial strata. Problems of water supply by raising of groundwater, thus have been mitigated for many settlements. One outstanding application of this method was recharge of the aquifer adjoining Talaji rivulet near the town of Talaja in Bhavnagar District of Gujarat where significant water level rise was registered, after the limited monsoons. The main advantage of this method is that loss of valuble lands and forest areas due to surface submergence can be altogether avoided. The method has a great future all over India in view of the environmental advantage.

6.5 Integrated Operation of Reservoirs

This method can be adopted when a system of reservoirs is available and can be operated in an integrated way. The method consists of operating the system of reservoir in such a way that the total exposed water surface area is kept minimum for the system as a whole, so that the evaporation loss is minimum. For keeping the exposed surface area minimum, water use should be planned in such a way that shallow reservoirs with large water spread area are depleted first. This method has been successfully practiced by Bombay Municipal Corporation in their water supply scheme. Such techniques were also tried in the Hiran dam 1 & 2 in Junagadh district of Saurashtra region of Gujarat. The Madras Metropolitan Water Supply and Sewerage Board (MMWSSB) has also been practicing intergrated operation of Red Hills, Cholavaran and Poondi reservoirs, which supplies water to Madras City, so that the exposed water surface is kept minimum.

6.6 Treatment with Chemical Water Evapo-Retardants (WER)

In this method, a chemical capable of forming a thin monomolecular film on the water surface is used. The film so formed reflects away energy inputs from atmosphere, as a result of which evaporation is reduced. The film allows enough passage of air through it, hence aquatic life is not affected. A film developed by using fatty alcohols of different grades has been found most useful for control of evaporation. In general these materials form a film of monomolecular layer of thickness less than a millionth of an inch, when applied on water surface and works as a sort of barrier between water body and the atmospheric conditions. All these materials can be used in powder solution or emulsion form.

The method of using chemical Water Evapo Retardants (WER) has the disadvantage of its high cost of application in normal conditions. The cost may not, however, be considered high during crisis/scarcity periods, drought etc., when this method may be much cheaper than bringing water from far off places by manual or mechanical transport. The chemical WER have another limitation that monolayer formed is found to break at high wind speeds. Although, the manufacturers of water evaporation retardants claim that the materials used do not have any toxic effects on aquatic and human life and there is no change in water quality, these claims are to be confirmed by Govt. laboratories for its general acceptance and to remove doubts and hesitation in use of WERs. Even though the chemical methods of control of evaporation have certain limitations, this method has evoked maximum attention all over the world as a practical solution for saving fresh water compared to other physical methods of inhibiting evaporation.

7.0 PROPERTIES OF CHEMICAL WATER EVAPO-RETARDANT MONOLAYERS

For the evaporation control by chemical retardants the chemical used may have the following basic properties:

i) It should be spread easily and form an even, compact cohesive monomolecular film on water surface. The pressure of film so formed is also found to have a definite relation to the efficiency of the monolayer.

ii) The thin film formed by spreading WER should be pervious to oxygen and carbon dioxide, but tight enough to prevent escape of water molecules.

iii) It should be sufficiently durable and should be able to reseal itself, in case broken due to external disturbances as wind, waves etc.

iv) The chemical WER should be tasteless, odourless, non toxic and non-inflamable. It should have no effect on quality of water.

v) It should not be affected by water borne bacteria proteins and other impurities in the water.

The compounds, having the above desired properties mainly used for evaporation retardation are Cetyle alcohol or hexadecanol (C16-H330H), Stearyl alcohol or Octadecanal (C18-H37-CH) and behenyl alcohol, docosanol (C22-H45-OH) or a mixture of these compounds. National Chemical Laboratory (NCL), Pune have developed one more compound by synthesizing alkoxy-ethonols. All these alcohols should be 99% pure for getting the desired properties of monolayer. Studies on cetyle alcohol (hexadacanol) have shown that it satisfies the following two conditions.

i) It gives a compact monolayer with strong cohesive forces between the residual chains and

ii) Spreading rate and resealing ability are fairly good.

While the first property results in greater reduction in evaporation loss, the later leads to better resilience to wind and wave action. The film undulates, contracts and expands with the wave action of surface water, instead of breaking beyond certain wind speed.

Another important property of the monlayer formed from the compound hexadecanol is that the molecules stand on ends like bristles of a brush with one end attracted to water and the other repelled by it. With sufficient hexadecanol available, the molecules join with each other tightly preventing the escape of water vapour. The film, however, is porous to the passage of oxygen and carbon dioxide, a quality which renders its use environmentally safe.

7.1 The Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia had recommended hexadecanol " SI-RO Seal" a pure form of that chemical containing the alcohols in the following proportions, for efficient evaporation control by forming monolayer:

Hexadecanol	:	Not less than 80%
Octadecanol	:	Not more than 10%
Tetradecanol & Dodecanol	:	Not more than 5.5%
Alcohols of chain length less than 10	:	Not more than 0.5%
Unsaturated Alcohols	:	Not more than 4%

Some of the other properties of hexadecanol are:

Iodine value	:	less than 3
Acid value	:	less than 0.3
Saponification value	:	less than 0.5
Hydroxyl value	:	225-230
Melting point	:	45-50°C

7.2 The compound octadecanol is known to be more powerful evaporation retardant than hexadecanol, but its spreading ability is comparatively less.

Water Management Form (A National Body of the Institution of Engineers (India), Gujarat had also suggested certain desired properties of chemical WER for its effective use as a evaporation retardant.

Regarding alkoxy ethanols, National Chemical Laboratory, (NCL) Pune had developed a series of these compounds on laboratory scale, having the formulae Cn-OC2H4OH, where n = 16,18,20,22. These chemicals are characterised for their purity and several monolayer properties as rate of spreading, film pressure represented by Area Isotherm (π-A), collapse pressure etc. A comparison of these monolayer properties of alcohols and alkoxy ethanols are given below:

a) Rate of spreading and equilibrium spreading pressure

These properties are important to understand whether the compounds spread reasonably fast or not. Also the equilibrium pressure obtained should be high. The alkoxy ethanols exhibit high rate of spreading (DN/dt) as well as equilibrium spreading pressure (We) as compared to alcohols.

b) Film pressure (Area Isotherms, Wa)

All the alcohols and alkoxy ethanols which have been obtained in pure form (99 percent) have been tested for W-a isoltherms by NCL, Pune. This property gives an idea whether particular film forms condensed film or not and also gives various two dimensional phase changes especially liquid condensed to solid state.

c) Collapse pressure

It is observed that higher the collapse pressure better will be the stability of the film. From the study conducted by NCL, it has been observed that collapse pressure of alkoxy ethanols are higher than alcohols. All the above characteristic properties can be measured with the help of Langmuir film pressure balance which is necessary for testing the quality and to standardise the compounds for water evaporation control both in the Laboratory and field experiments.

7.3 Indictor oils used for testing pressure of WER Monolayer

For effective retardation of evaporation, the molecular film formed should develop adequate pressure. In most cases, the initial film pressure is in the range of 20-30 dynes/cm and equilibrium pressure of 40 dynes/cm can be achieved with appropriate dosage. For testing the pressure of WER film, oils of known spreading pressure are used.

8.0 CHEMICAL WATER EVAPO-RETARDANTS IN USE IN INDIA

Chemical like cetyl alcohol or stearyl alcohol were used for evaporation control in the initial periods of study (1957) by different agencies. Later studies indicated that a mixture of cetyle alcohol and stearyl alcohol, known as cetyl stearyl alcohol is more effective in evaporation retardation. Another compound manufactured by mixing of alcohols and alkoxy ethanols, the process technology for which was developed by NCL, Pune also used effectively.

NCL, Pune is also developing a process for preparation of pure alkoxy ethanol of C18 and C22 chain length. It is claimed that this compound gives better results compared to other products. However, data of commercial use of this compound are not available.

9.0 MERITS & DEMERITS OF SOLID FORM AND EMULSION FORM OF WER

The Acilol TA - 1618 WER" is available in solid lump form as well as in emulsion form. In Saurashtra region of Gujarat state, evaporation control works have been carried out extensively with Acilol TA - 1618 in powder and emulsion form during 1985-86 to 1987-88. The WER "Linoxyd CS 40" is available in emulsion form only. This WER was used for evaporation control in Maharashtra during the periods 1977-78 to 1979-80 and 1983-85. The merits and demerits of using powder and emulsion form for evaporation control on the basis of their use in Gujarat and Maharashtra have been reported by the Directorate of Irrigation Research and Development, Pune and are given below:

i) **Dosage:** The dosage of WER generally adopted in case of powder form is 75 gm/ha of area to be treated. In case of emulsion form the genera dosage is 500 gm/ha, which can be reduced to 250 gm/ha/day after first 15 days. Thus the consumption of the material in emulsion form is about 3 times.

ii) Procedure of Spreading: In the powder form the procedure of chemical spreading is found to be simple, while in the emulsion form the procedure for diluting, mixing and spreading is reported to be cumbersome.

iii) Effect of wind: The uniformly dusted WER in powder form develops thin film over water surface, which is reported to be disturbed during high wind velocities. In case of emulsion form, the experiments conducted with "Linoxyde CS 40" by Directorate of Irrigation Research and Development, Pune have indicated that monomolecular film gets broken and accumulates to one side when wind velocity is greater than 10 km/hour.

10.0 EFFECTIVENESS OF CHEMICAL WER

10.1 The effectiveness of chemical WER Acilol TA-1618 "as well as "Linoxyde CS-40" for retardation of evaporation has been proved through the experiments carried out by various states/agencies. However, the quantity of water saved in evaporation primarily depends on the site conditions. The higher the temperature of water body, less will be the quantity of water saved from evaporation. Similarly higher the wind speed less will be the saving in evaporation. The study done shows that for velocities above 16 km/hour, the monolayer breaks rendering the treatment ineffective.

11.0 GUIDELINES FOR USE OF CHEMICAL WER

11.1 Based on the work done in India and in other countries and the present technological status on the subject, the following guidelines are suggested for using WER in arid, drought-prone or water deficit areas. These guidelines are generally based on the guidelines suggested by "Water Management Forum", Gandhinagar, Gujarat.

11.2 Application of WER in Emulsion Form

11.2.1 The doses of emulsion per day is suggested to be 500 gm/day/ ha of open water surface initially for 15 days. It can then be reduced to 250 gm/ha/day. The calculated amount of emulsion is diluted with water 20 to 25 times by volume for obtaining ease in application. Mixing can be done either manually or mechanically. The latter gives a more homogeneous mix. The diluted mix is filtered to separate out lumps or impurities, which could block the dripping line.

11.2.2. Application of the solution is done by dripping from a storage drum fitted on a floating raft. A drum of 30 litres capacity covers a water surface area of about one ha. whereas a drum of 200 litres capacity covers a water surface area of about 7 ha. Four drips are provided in the latter case so that more area is covered. In the former case two drips are provided on opposite sides of the drum.

11.2.3 The floating rafts are positioned in a grid, depending upon the size of the drum to cover the entire area of the water surface. The rafts are anchored to avoid drift. If anchoring is difficult due to large depth in a reservoir, the rafts can be positioned along the periphery in shallow depths where anchoring is possible. Prevailing wind direction helps in spreading and build of a film and hence rafts are suitably located. Heavy wind velocity and changes in wind direction may break the film continuity and, hence, special efforts are required for the maintenance of the film after such events.

11.2.4 Presence and continuity of the film can be ascertained by putting a drop of a indicator oil like castor oil on the treated water surface. If the drop of indicator oil maintains its shape, it shows the presence of the film.

11.3 Application of WER in Powder Form

11.3.1 The suggested dose per day is about 75 gm/hectare of water surface/day. As the power is supplied in lump form, it is to be pulverised into a fine powder form in a manual or mechanical pulveriser. The powder is dispersed on the water surface from a boat, by means of two manually operated dusters placed on both sides. Speed of the boat is so regulated as to cause minimum disturbance on the water surface while completing the dusting as quickly as possible. Depending on the area of water spread, passes of the boat are arranged to take advantage of the wind direction.

11.3.2 Presence of the film on water surface is ascertained as in the case of solution form. About 10-15% of the daily does may be kept reserved for use whenever the film is broken.

11.3.3 More often, a method of combining the two is found optimal. In this combination, the WER solution can be sprayed on the water surface during the day time, taking into account the wind direction and to keep the film intact by means of selective spraying. At night use is made of drip located in the reservoir on floating rafts. The comination ensures maintenance of continuous film on the reservoir surface and saves significant quantitites of water from getting evaporated.

11.4 Procedure for testing film pressure on monolayer

11.4.1 The pressure that a monolayer builds on the treated surface of water can be indicated by use of oils of known spreading pressures. One such oil is applied in the form of small drop to the surface, whose pressure is to be measured. If the drop spreads, it indicates that the water surface carries a film at a pressure lower than spreading pressure of indicator oil. If the drop does not spread it indicates that the film pressure is greater than the spreading pressure of oil. A grade of oils of different spreading pressures in the working range may be kept ready before field application of WER.

12.0 ECONOMICS OF EVAPORATION CONTROL MEASURES BY COMPARTMENTALISATION OF RESERVOIRS

12.1 The compartmentalisation work done in Bhogovo-I reservoir during the year 1988 involved a cost of Rs. 12.0 lakhs for construction of bunds. Another amount of Rs. 15.0 lakhs was spent for pumping water from one compartment to another. This measure had resulted in saving of one month supply of water. This quantity of water, if provided through water tankers would have cost Rs. 32.00 lakhs. The main advangage of compartmentalisation is that expenditure incurred on construction of bunds is a one time measure only. Another benefit from compatmentalisation is that the emptied bed of the reservoirs could be used for raising various dry crops using the available soil moisture. In Bhogavo-I reservoir two crops of green fodder of value Rs. 40.0 lakhs were reportedly raised on the emptied bed of reservoir.

12.2 The compartmentalisation work being carried out in Red Hill lakes supplying water to Madras city is also found to be more economical than application of WER. It was assessed that possible annual saving in water due to application of WER through the year would be around 8 M cum involving a recurring expenditure of Rs. 6.5 million. Compared to this, a quantity of 6.68 m cum of water could be saved by construction of two bunds at an estimated cost of around Rs. 2.0 million as a one time measure.

12.3 This is not to suggest that the chemical evaporetardants are not to be used. However, other means of controlling evaporation could also be explored in areas with recurring droughts and scarcities and if found more economical and practical, the same could be beneficially resorted to.

13.0 CONCLUSION

The annualised cost of creation of storage can be around Rs. 0.30 per cum of storage created and the economic return from one cum of water saved could be around Rs. 0.70. Whereas a great deal of variation is found in cost of using chemicals. The variations observed are:

	State	Cost/cum of water Saved			
a)	In Rajasthan	Rs.	1.00	to	13.90 (1987 figures)
b)	In Gujarat	Rs.	0.25	to	0.87 (1986 figures)
c)	In Maharashtra	Rs.	10.00	to	13.43 (1985 figures)

A great deal of variation is observed from State to State and within the same state also. It depends mainly on the site conditions. However cost of supplying drinking water by mechanical transport during the drought years, as done in Gujarat State was around Rs. 60 per cum of water.

From the experience gained so far it can safely be concluded that the use of WER may be employed in the drought and scarcity conditions. More reserach work need to be caried out to make the use of chemical more viable.

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