

Measurement and Estimation of Evaporation from Water Surfaces: Application to Dams in Arid and Semi Arid Areas in Algeria

Malika Fekih, Mohamed Saighi

Abstract—Many methods exist for either measuring or estimating evaporation from free water surfaces. Evaporation pans provide one of the simplest, inexpensive, and most widely used methods of estimating evaporative losses. In this study, the rate of evaporation starting from a water surface was calculated by modeling with application to dams in wet, arid and semi arid areas in Algeria. We calculate the evaporation rate from the pan using the energy budget equation, which offers the advantage of an ease of use, but our results do not agree completely with the measurements taken by the National Agency of areas carried out using dams located in areas of different climates. For that, we develop a mathematical model to simulate evaporation. This simulation uses an energy budget on the level of a vat of measurement and a Computational Fluid Dynamics (Fluent). Our calculation of evaporation rate is compared then by the two methods and with the measures of areas in situ.

Keywords—Evaporation, Energy budget, Surface water temperature, CFD, Dams

I. INTRODUCTION

ONE of the simplest and oldest techniques to measure evaporation from a natural surface and from a dam is made, in different countries and in particular in Algeria, is based on the measurement of the water evaporation from a pan. The basic idea in the use of evaporation pans was that these measurements can be assumed to be proportional to evaporation from an open water surfaces, such as lakes or dams.

II. MEASUREMENT METHODS

Evaporation pans have been used to measure evaporation for over a century. Two kinds of pans are widely used in the world.

The class “A” pan and the sunken pan. The later is the one used in Algeria. It consists of a pan of a square cavity of dimension 0.92m×0.92m×0.50m, almost totally buried in the ground.

It contains water surface up to the original ground surface. The Class-A pan is considered to be the standard international pan [1]-[2].

M.Fekih is with the Laboratory of Thermodynamics and Energetically Systems LTSE ,Physics Faculty, University of Science and Technology Houari Boumediene,U.S.T.H.B, Bab Ezzouar 16111, Algiers Algeria (e-mail: fekih.mali2005@ yahoo.fr).

M.Saighi is with the Laboratory of Thermodynamics and Energetically Systems LTSE, Physics Faculty, University of Science and Technology Houari Boumediene,U.S.T.H.B, Bab Ezzouar 16111, Algiers Algeria Faculty of physics, U.S.T.H.B. BP 32 Bab Ezzouar, Algiers, Algeria (e-mail: saighimohamed@yahoo.fr).

The rate of evaporation depends on the [3]:

- Type of pan
- Type of pan environment
- Method of operating the pan
- Exchange of heat between pan and ground
- Solar radiation
- Air temperature
- Wind; and
- Temperature of the water surface.

Almost universally, a simple ‘pan factor’ K_{pan} is then introduced and where E_{pan} is the measured evaporation from the pan [4]-[5], the water storage evaporation E is then given by:

$$E = E_{pan} - K_{pan} \quad (1)$$



a



b

Fig. 1 a) Measure evaporation on sunken pan b) Class « A » pan

III. CALCULATION METHODS

We choose to calculate the evaporation rate from the pan using the energy budget equation and the computational fluid dynamics. They will be detailed as follows:

A. The energy budget method

The energy budget method is recognized as the basic method to determine evaporation from an open water surface.

The equation of the energy budget is written as:

$$R_n = L_v E + H + G \quad (2)$$

where R_n is the net radiation on the surface.

A part of it is used to vaporize water and gives rise to a latent heat flux $L_v E$, where E is the evaporation speed per unit area and L_v the latent heat of water vaporization (2.4 106 J/Kg). The remainder is dissipated as sensible heat flux H which heats the air and as a heat flux G stored in water. Since we can neglect the term of storage compared to the other terms, we let $G \cong 0$ [6]-[7] and [8].

Then the rate of evaporation becomes:

$$E = \frac{R_n - H}{L_v} \quad (3)$$

with

$$H = h_c (T_s - T_a) \quad (4)$$

and

$$R_n = (1 - \alpha)R_g + \varepsilon\sigma(T_a - 6)^4 - \varepsilon\sigma T_s^4 \quad (5)$$

where h_c is the coefficient of convective heat transfer in turbulent boundary layer on flat plate [9]:

$$(h_c = 5.907 V^{0.8} L_c^{-0.2}) \quad (6)$$

R_g : is the global radiation which corresponds to the sum of the direct and diffuse solar radiations of short wavelength. it is written as:

$$R_g = 0.271 I_0 \lambda A_1 \sinh + 0.706 I_0 A_1 \sinh \exp\left(\frac{-A_1}{\sinh}\right) \quad (7)$$

The temperature at the surface T_s is an important input parameter. It's calculated from the resolution of the energy budget equation at the surface (equation (1)). The latent heat flux is calculated from a Stefan equation (equation (5)) based on the Fick law [10]-[11] and [12].

Thus, we have:

$$L_v E = \frac{L_v K_E M_w}{RT_a} [P_{vs}(T_s) - P_v(T_a)] \quad (8)$$

Where K_E : is the convective mass transfer coefficient calculated from the Lewis hypothesis.

$$K_E = \frac{h_c}{\rho c_p} \quad (9)$$

P_{vs} : is the saturated vapour pressure calculated from Clapeyron-Clausius formula:

$$P_{vs}(T) = \exp\left(25.5058 - \frac{5204.9}{T}\right) \quad (10)$$

$$\text{and } p_v(T_a) = H_r P_{vs}(T_a) \quad (11)$$

Replacing equations (4), (5) and (7) in equation (2), the energy budget is finally written as:

$$(1 - \alpha)R_g + \varepsilon\sigma(T_a - 6)^4 - \varepsilon\sigma T_s^4 - h_0(T_s - T_a) = \frac{L_v K_E M_w}{RT_a} [P_{vs}(T_s) - P_v(T_a)] \quad (12)$$

The resolution of equation (12) allows us to calculate the surface temperature T_s at every moment of the day according to the hourly data of the following parameters: the net radiation R_n per unit area, the air temperature T_a , the relative humidity H_r and the wind speed V . The resolution of this equation is carried out with Dichotomy method. The value of the surface temperature T_s calculated at every moment gives us access to the water flux evaporated at the surface.

B. Numerical model and calculation method

The domain of study is a two-dimensional model and has been constructed using the finite control volume approach on a vertical section of a 0,92m x 0,92m x 0,5m ring tank Fig. 2 (b).

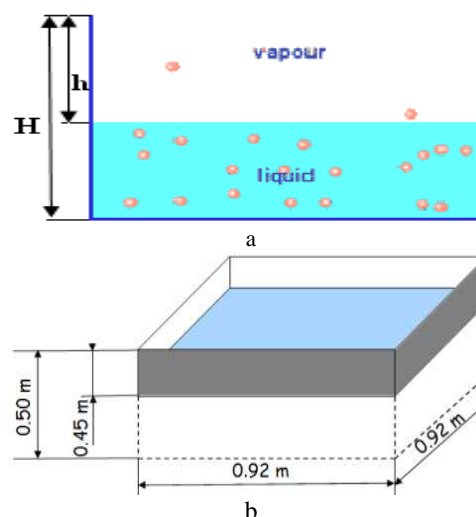


Fig. 2 a) Dimensions of the Problem $H=0.5\text{m}$; $h=0.20\text{m}$
 (b)Geometry of the Pan modeled

A computational grid was established using GAMBIT software and computational fluid dynamics (CFD) was then performed using FLUENT version 6.3 software. The flow is governed by the incompressible unstable equations of Navier-

Stokes and energy to determine the heat flux within the pan. We adopt the Boussinesq approximation. Computational Fluid Dynamics (CFD), based on the solution of continuity, energy, Navier-Stokes equations, k-ε standard model of turbulence and under the Boussinesq hypothesis, can provide the air speed, temperatures and heat flux.

The continuity equation is:

$$\frac{\partial u_i}{\partial x_i} = 0 \quad (13)$$

The momentum equation is:

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = f_c \varepsilon_{ij3} \Omega_j u_j - \frac{1}{\rho} \frac{\partial P^*}{\partial x_i} + \nu \frac{\partial^2 u_i}{\partial x_j^2} \quad (14)$$

The energy equation:

$$\frac{dT_v}{dt} = \frac{\lambda}{\rho c_p} \Delta T_v \quad (15)$$

Simplified Assumptions:

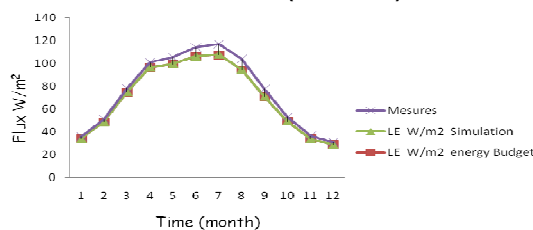
- Near the surface, the airflow is quasi- steady.
- We can neglect the effects of pressure and Coriolis forces.
- The flow is modelled by a turbulent flow, homogeneous horizontally, with constant flux, we neglect the interaction of radiative flux and the effect of moisture on the various turbulent mechanisms.
- The corrections made by the introduction of the virtual temperature of the air (to take into account the presence of water vapor) and of the potential temperature (to take into account the variation of the temperature with altitude) can be neglected (for the first meters from the surface).

IV. RESULTS AND DISCUSSION

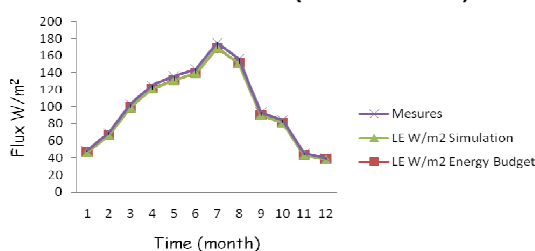
We calculated the evaporation rate for June month of year 2004 for three regions of Algeria:

- Humid region (Kaddara Dam)
- Semi arid region (Foum El Gheiss Dam)
- Arid region (Djorf Ettorba Dam)

Keddara Dam (Wet area)



Foum El Gheiss Dam (Semi arid area)



Djorf Ettorba Dam (Arid area)

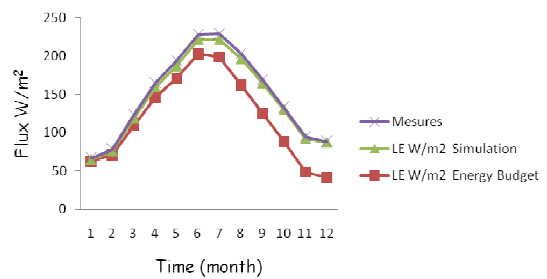


Fig. 3 Comparison between measured and simulated and energy budget method evaporation from the pan for the three areas of Algeria

The form of the curves, obtained by the various formulas used for the evaporation calculation, is similar for the three studied areas. We observe a significant difference between the simulated and the measured evaporation in the hot period for the wet area. We observe concerning the arid area, a shift between measurement and simulation from June on. Theoretically, the maximum solar radiation is reached in June 21st, but really the temperature of the air reaches its maximum in July and up to fifteen of August.

V. CONCLUSION

Pans are a very practical tool to measure evaporation, especially in the areas where the input climatic variables are not available. But, the comprehension of the phenomenon related to it remains a difficult task. We note that the evaporation calculation, made by the two methods used (Energy budget and using CFD), gives identical results. In addition, this investigation shows:

- A notable difference between simulated evaporation and that measured in summer period for the wet area. We can not give a coherent explanation to this phenomenon, especially when this variation does not hold for the two other regions. We intend to continue our research in order to give a physical acceptable explanation for this variation.
- The influence of the lateral conduction between the adjacent soil; in the case of the sunken pans; and the walls of the pan (or between the lateral walls of a class « A » pan and the near air) is minor on the evaporation simulation.
- The flow mode, which prevails above the pan, is undoubtedly a laminar mode, which is different from the fully turbulent mode at the surface of a dam. To circumvent this problem, it is necessary to use a larger size pan so that the analogy with a barrage would be closer to reality.
- Many problems associated with small pans can be eliminated if the size of the pan is increased. Trials with very large pans or tanks are taking place now. With these pans, the height of the lip is small compared to the overall width of the pan, so lip errors are significantly reduced.

ACKNOWLEDGMENT

Our calculations required a minimum of climatic data including: the air humidity, the wind speed and the air temperature. They were gracefully given to us by the National office of Meteorology (Office Nationale de Météorologie: ONM). Concerning the specific characteristics of the dams, we thank the National Agency of Dams and Transfers (ANBT: Agence Nationale des Barrages et Transferts) for their assistance.

REFERENCES

- [1] Craig, I.P, Mossad, R., and Hancock, N. Development of a CFD based Dam Evaporation Model. International Symposium on Environmental Health Climate Change and Sustainability. (2006).
- [2] Craig, I.P, Literature Review of Methods for Assessing Dam Evaporation. Draft report for the Rural Water Use Efficiency Initiative Evaporation Control Project, NCEA Draft Report, University of Southern Queensland (2004).
- [3] Jones Frank. E. Evaporation of water with Emphasis on Applications and Measurements, Lewis Publishers, Michigan, USA, 1992.
- [4] Oroud I.M, The influence of heat conduction on evaporation from sunken pans in hot, dry environment. Journal of Hydrology, Vol. 210, pp. 1–10 (1998).
- [5] Martinez. M.J.M, Alvarez Martinez V, Gonzalez-Real M.M., Baille. A. A simulation model for predicting hourly pan evaporation from meteorological data. Journal of Hydrology, Vol. 318, pp250–261, 2006.
- [6] Fennessey. N. M, Vogel. R.M. Regional models of potential evaporation and reference evapotranspiration for the northeast USA, J Hydrology, Vol.184, pp. 337-354.
- [7] Saïghi. M, Nouveau modèle de transfert hydrique dans le système sol- plante- atmosphère, Thèse de Doctorat USTHB, Alger (2002).
- [8] Eichinger.W.E., Nichols. J, Prueger .J.H, Hipps. L.E., Neale .C.M.U, Cooper. D.I, and Bawazir.A. S. Lake evaporation estimation in arid environments: Final Report, IIHR - Hydroscience & Engineering, IIHR Report No. 430, University of Iowa, pp1-29, July 2003.
- [9] Sartori. E, Convection coefficient equations for forced air flow over flat surfaces. J Solar Energy, Vol. 80, pp. 1063–1071(2006).
- [10] Mosner. M.S. and Aulenbach .B.T, (2003). Comparison of methods used to estimate lake evaporation for a water budget of Lake Seminole, southern Georgia and northwestern Florida. Proceedings of the 2003 Georgia Water Resources (2003). Conference, held April 23–24, 2003, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, the University of Georgia, Athens, Georgia, pp.1-4.
- [11] Lewis. J.M. The history behind the Bowen ratio, Bulletin of the American Society, Vol.76, No.12, December 1995.
- [12] Bowen, I.S. 1926 .The ratio of heat losses by conduction and by evaporation from any water surface. Phys. Rev. 27 779-787.