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International Journal of Current Research
Vol. 12, Issue, 07, pp.12627-12637, July, 2020

DOI: https://doi.org/10.24941/ijcr.38706.07.2020

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

NUMERICAL STUDY OF HEAT AND MASS EVAPORATION-BASED TRANSFERS IN A LARGE DIMENSION RESERVOIR: THE INFLUENCE OF METEOROLOGICAL PARAMETERS AND RAYLEIGH NUMBER

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ARTICLE INFO

Article History:
Received 07th April, 2020
Received in revised form
25th May, 2020
Accepted 27th June, 2020
Published online 30th July, 2020

Key Words:
Numerical Study, Evaporation, Meteorological Parameters, Natural Convection, Water Retention.

ABSTRACT

A numerical study of heat and mass transfers in a large water reservoir is presented. This water reservoir is being considered as a parallelepiped tank which vertical and lower walls are adiabatic and impermeable. The equations that govern the natural convection in water are solved using the finite volume method and Thomas algorithm. The adequacy between the speed and pressure fields is ensured by the SIMPLE algorithm. We analyze the influence of water depth, the density of the solar flux captured by the free water surface, the ambient conditions (temperature and relative humidity of the ambient air, wind speed) on the spatio-temporal distributions of temperature and the speed in the water reservoir as well as the evaporated water mass flow. This modeling is completed by a simulation, using meteorological data from Burkina Faso and the concept of a standard day for the evaporation of this reservoir. The results obtained show that the evaporated water flow rate increases under a high solar flux rate and decreases in case of high relative humidity rate. The months of September and August have a lower evaporation rate according to the typical day used compared to the other months represented and the fluxes of the various heats have significant impacts on the evaporation rate.

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Citation: ***BAYALA Alfred, TUBREOUMYA G. Christian, BORO Drissa, IMBIDA B. Kossi1, BADO Nebon, ZEGHMATI Belkasem, KIENO P. Florent, BATHIEBO Joseph.* 2020.** "Numerical study of heat and mass evaporation-based transfers in a large dimension reservoir: the influence of meteorological parameters and Rayleigh number.", *International Journal of Current Research*, 12, (07), 12627-12637.

INTRODUCTION

In countries with hot and dry climates like the Sahelian ones, water is rare and in the water basin, losses due to evaporation are very high. Indeed, evaporation is a major component in terms of energy balance of surface waters of lakes and large reservoirs. This is difficult to be assessed because it involves several factors, notably climate and geographic ones. Controlling the evaporation of a reservoir is essential in water resources management, for large reservoirs water balance and for forecasting hydrological cycles in response to climate change (Finch 2001, Liu *et al* 2011, Xu and Singh, 2001) (1)(2)(3). Several methods are currently used to predict evaporation using weather data from open water reservoirs. They are generally classified according to: temperature and radiation (Xu and Singh 2000) (4), mass transfer (aerodynamics) (Singh and Xu 1997) (5), pan coefficient, energy budget and combination methods (Gianniou and Antonopoulos 2007, Rosenberry *et al*. 2007) (6) (7), for example, by Makkink (1957) (8), Blaney and Criddle (1950) (9), and Stephens and Stewart (1963) (10), Hamon (1961) (11), Priestley and Taylor (1972) (12), Stewart and Rouse (1976) (13), de Bruin and Keijman (1979) (14), Brutsaert and Stricker (1979) (15). Based on their application precision and simplicity, each of these methods has advantages and drawbacks. Several evaporation methods are

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exhaustively reviewed by DeBruin and Stricker (2000) (16), Lenters *et al*. (2005) (17), Rosenberry *et al*. (2007) (18), Stephen *et al*. (2007) (19), Shakir *et al*. (2008) (20), Gallego-Elvira *et al*. (2013) (21) and McJannet *et al*. (2012) (22). Winter and al. (1995) (23) compared 11 widely used methods with energy budget method over Lake Williams, and proposed a classification based on performance from best to worst. They classified these methods as follows: Penman, DeBruin-Keijman, Makkink, Priestley-Taylor, Hamon, Jensen-Haise, mass transfer, DeBruin, Papadakis, Stephens-Stewart and Brutsaert-Stricker. Rosenberry *et al*. (2007) (18) evaluated 15 methods based on the energy budget method. Rasmussen and al. (1995) (24) compared seven methods used in modeling the temperature of lakes. The evaluation of seven methods by Abtew (2001) (25) suggested that simple models like the modified Turkish model, which uses only solar radiation and the maximum air temperature could be more efficient than the Penman-combination models or Priestley-Taylor that require more entry parameters. Four methods from Priestley-Taylor, DeBruin-Keijman, Papadakis and Penman were compared to the energy budget method proposed by Mosner and Aulenbach (2003) (26) and the Priestley-Taylor method appeared to be the best among the four methods. Singh and Xu (1997a) (27) assessed and compared 13 evaporation equations which were part of the category of mass transfer method, and a generalized form of model for this category was developed. Singh and Xu (1997b) (28) studied more closely the sensitivity of evaporation equations based on mass transfer to errors in the daily and monthly data on inputs. More recently, Xu and Singh (1998) (29) have analyzed the dependence on evaporation on various meteorological variables at different time scales. In the 2000s, Xu and Singh (2000) (30) tested eight radiation-based evaporation models to estimate future lake levels. Delclaux *et al*. (2007) (31) compared five monthly evaporation methods and showed that the Abtew model and the Makkink model have enabled to make the best estimates on lake evaporation. Comparisons of estimation methods have also been made by Keskin and Terzi (2006) (32); Majidi and al. (2015) (33) and Sadek and al. (1997) (34). All of these comparisons have led to somehow different conclusions depending on the sites and data used. On the other hand, most of these studies were conducted when the required data measures were available.

Several studies were carried out in order to compare and assess the evapotranspiration methods for land surfaces or the estimation of the parameters required under limited data conditions worldwide (Kisi and Cengiz 2013) (35). On the contrary, some studies were conducted to find the most suitable methods for estimating the evaporation of large lakes and reservoirs under the conditions where the required long-term data are not available. Therefore, there is no clear consent on methods if important long-term measured data such as temperature profile, radiation and heat fluxes are not available, as well as in the case of most lakes and reservoirs in countries with hot and dry climates including Sahelian countries (Burkina Faso). This paper is focused on a numerical study of heat and mass transfers in a large water reservoir, assimilated to a parallelepiped tank which vertical and lower walls are adiabatic and impermeable. The physical model and the transfer equations are first presented, then we show the numerical methodology used to solve them. After validating the numerical code that we have developed and analyzing the sensitivity of the results to the covering of the study area, we analyze the influence of water depth, the density of the solar flux captured by the free water surface, ambient conditions (temperature and relative humidity of the ambient air, wind speed) on the space-time distributions of temperature and the speed in the water reservoir and the mass flow rate of evaporated water. This modeling is completed by a simulation, using meteorological data from Burkina Faso and the concept of a standard day for the evaporation of this reservoir.

Position of the problem: The large water reservoir is assimilated to a rectangular cavity with the following dimensions: length L = 2m, height H = 0.5m which vertical and lower walls are adiabatic and impermeable (Fig. 1) The solar flux absorbed by this water leads, in the water, to natural convection and evaporation on the free surface of the water reservoir. To this physical model, we associate a Cartesian frame of reference in such a way that the origin is located at the lower right end of the cavity; the axis (Ox) is oriented positively from left to right and the axis (Oz), perpendicular to the axis (Ox) is oriented positively in the direction opposite to the gravity acceleration vector.

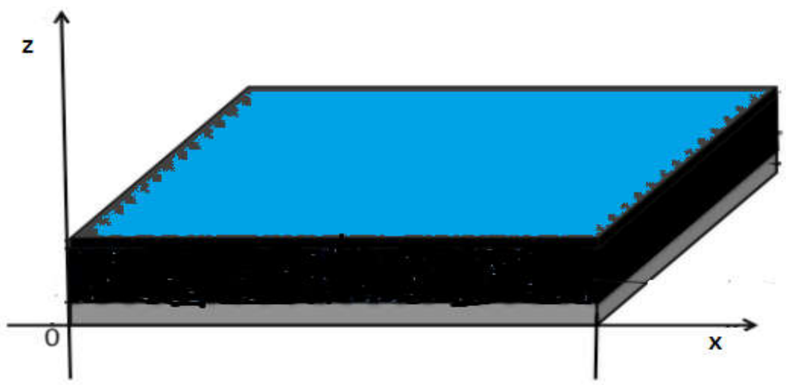

Figure 1. Physical Model

For the following simplifying hypotheses:

- Transfers are bi-dimensional, the width of the domain is supposed to be very large compared to the other dimensions,
- Water is incompressible and Newtonian fluid
- The viscous dissipation according to the energy equation is neglected.
- There is no chemical reaction
- Chemical properties of water remain constant except the volume mass that complies with BOUSSINESQ approximation.

Mathematical formulation

Given the simplifying hypotheses made above, the equations which govern transfers by natural convection in the water reservoir given in (O, X, Z) are written in the Cartesian reference framework

- Continuity Equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial z}=0 \quad (1)$$

- Equation of motion amount

Component according to (OX)

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial z^2}\right) \quad (2)$$

Component according to (OZ)

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial z}+\upsilon\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial z^2}\right)+\bar{g}\beta_T\left(T-T_{am}\right) \quad (3)$$

- Energy Equation

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial z}=\frac{\lambda}{\rho c_p}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial z^2}\right)+\frac{1}{\rho c_p}\frac{dE(z)}{dZ} \quad (4)$$

Where $E(z)$ is the solar flux density defined by:

$$E(z)=E_s e^{-\mu Z} \quad (5)$$

With μ: the mitigation coefficient

Initial conditions and conditions to limits

Initial Conditions

t_0 being the time when the solar flux impacts on the date

$\forall\ t < t_0$

$$p(x,z,t_0)=P_{atm} \quad (6)$$

$$v(x,z,t_0)=u(x,z,t_0)=0 \quad (7)$$

Conditions to limits

$\forall > t_0$

$x=0$, $0\le z\le H$ $\quad$ $x=L$; $0\le z\le H$

$$\left.\frac{\partial T}{\partial x}\right|_{x=0}=0 \qquad \left.\frac{\partial T}{\partial x}\right|_{x=0}=0 \qquad \left.\frac{\partial T}{\partial x}\right|_{x=L}=0 \quad (8)$$

$$\left.\frac{\partial u}{\partial x}\right|_{x=0}=\left.\frac{\partial v}{\partial x}\right|_{x=0}=0 \qquad \left.\frac{\partial u}{\partial x}\right|_{x=L}=\left.\frac{\partial v}{\partial x}\right|_{x=L}=0 \quad (9)$$

$z=0$;$0\le x\le L$

$$u(x,0,t) = v(x,0,t) = 0 \quad (10)$$

$$\left.\frac{\partial T}{\partial z}\right|_{x=0} = 0 \quad (11)$$

$z = H \;;\quad 0 \le x \le L$

$$k\left.\frac{\partial T}{\partial z}\right|_{z=H} + \varphi_s \alpha_{abs} = h_c(T(x,H,t) - T_a) + \sigma\varepsilon h_r(T(x,H,t) - T_c) + \rho L_{evap} k_m (C_{vs}(H) - C_v) \quad (12)$$

$$u(x,H,t) = 0 \quad (13)$$

$$v(x,H,t) = v_e \quad (14)$$

where v_e : evaporation speed

$$v_e = \frac{-D}{1 - C_i}(C_{vs}(T(x,H,t) - C_v)$$

With $D = 2.26 \times 10^{-5} \times \frac{1}{P_{atm}} \times \frac{(T(x,H,t))^{1.81}}{273}$

$C_i \approx 0$ dry air ration is zero

The mass transfer coefficient K_m is determined using expression given by (Leinhart, J.H. and Leinhard, V.J.H. ; 2005)(37) :

$$K_m = \frac{Debit}{C_{vs} - C_v} \quad (15)$$

$$\mathrm{Sh} = \frac{\mathrm{K_m} \,.\, \mathrm{H}}{\mathrm{D}} \quad (16)$$

Thus, the surface density of water evaporation from the reservoir is obtained from the following expression:

$$\text{Debit} = \mathrm{K_m}\ \rho\ (\text{cvs (T(H)-cv}) \quad (17)$$

With C_{vs} and C_v respectively, the concentration of saturated water vapor at water surface and water vapor in the air around water defined by:

$$C_{vs} = \frac{0{,}622\, P_{vs}}{P_{atm} - 0{,}378\, P_{vs}} \quad (18)$$

And

$$C_v = \frac{0{,}622\, P_v}{P_{atm} - 0{,}378\, P_v} \quad (19)$$

The saturated water vapor pressure (P_{vs}) is obtained from the following expression (38) (G. Bruhat; 1968):

$$P_{vs}(T_s) = 102325\left[10^{17{,}443 - \frac{2745}{T_s} - Log(T_s)}\right] \quad (20)$$

$0<T<200°C$

The water vapor pressure is deduced from the relative humidity of the air which is assimilated to a perfect gas.

$$P_v = H_r P_{vs}(T_{amb}) \quad (21)$$

We have calculated the surface density of evaporation based on the convection mass transfer coefficient (K_m) between water surface and the air around it.

$S_h = 0{,}14\ (G_r S_c)^{1/3}$ with $2{,}1\ 10^8 \le G_r \le 6{,}7\ 10^9$

The coefficient of heat transfer by natural convection (hc) between the surface of the reservoir water and the air around it is deduced from the Nusselt number.

$$N_u = \frac{3}{4}\frac{P_r^{\frac{1}{2}}}{2{,}5\left(0{,}5+P_r+P_r^{\frac{1}{2}}\right)}(P_r G_r)^{\frac{1}{4}} \tag{22}$$

We calculate the total surface density of water evaporation from the reservoir (Ahsan and Fukuhara, 2008) (Ahsan et Fukuhara, 2008) by:

$$Debit_T = H\int_0^L (Debit)dz \tag{23}$$

We will use the Simpson method to calculate this integral (equation (23)).

Nondimensionalization: Equations (1, 2, 3, 4), the initial and boundary conditions have been dimensioned using the following dimensionless variables:

$$x^+ = \frac{x}{H}, z^+ = \frac{z}{H}\ ; u^+ = \frac{uH}{\alpha}\ ; v^+ = \frac{vH}{\alpha}\ ;\ T^+ = \frac{(\mathrm{T}-\mathrm{T_a})}{\Delta T}, t^+ = \frac{\alpha t}{H^2} p^+ = \frac{H^2 p}{\alpha^2 \rho} \tag{24}$$

The introduction of dimensionless variables (24) into equations (1, 2, 3, 4) gives the following dimensionless equations:

Continuity Equation

$$\frac{\partial u^+}{\partial x^+} + \frac{\partial v^+}{\partial z^+} = 0 \tag{25}$$

Equation of the motion amount

- Component according to (OX)

$$\frac{\partial u^+}{\partial t^+} + u^+\frac{\partial u^+}{\partial x^+} + v^+\frac{\partial u^+}{\partial z^+} = -\frac{\partial p^+}{\partial x^+} + P_r\left(\frac{\partial^2 u^+}{\partial x^{+2}} + \frac{\partial^2 u^+}{\partial z^{+2}}\right) \tag{26}$$

- Component according to (OZ)

$$\frac{\partial v^+}{\partial t^+} + u^+\frac{\partial v^+}{\partial x^+} + v^+\frac{\partial v^+}{\partial z^+} = -\frac{\partial p^+}{\partial z^+} + P_r\left(\frac{\partial^2 v^+}{\partial x^{+2}} + \frac{\partial^2 v^+}{\partial z^{+2}}\right) + R_a P_r T^+ \tag{27}$$

Energy Equation

$$\frac{\partial T^+}{\partial t^+} + u\frac{\partial T^+}{\partial x^+} + v\frac{\partial T^+}{\partial z^+} = \left(\frac{\partial^2 T^+}{\partial x^{+2}} + \frac{\partial^2 T^+}{\partial z^{+2}}\right) + \frac{\mathrm{H}^2}{\alpha\rho c_p \Delta T}\frac{dE(z)}{dZ} \tag{28}$$

With $\mathrm{Pr} = \frac{\mu C_p}{k}$: number of Prandtl

$\mathrm{Ra} = \frac{g\,\beta \Delta T\, H^3}{\nu\alpha}$: Number of Rayleigh

$$A_l = \frac{\mathrm{H}^2}{\alpha\rho c_p \Delta T}\frac{dE(z)}{dz}$$

With $\Delta T = T - Tam$

The initial and non-dimensional boundary conditions confirm the following expressions:

Initial Conditions

$\forall\, t^+ < \frac{\alpha}{H^2} t_0$

$$T^+(x^+, z^+, {t_0}^+) = 0 \tag{29}$$

$$P^+(x^+ z^+, {t_0}^+) = \frac{H^2 P_{atm}}{\alpha^2 \rho} \tag{30}$$

$$u^+(x^+ z^+, {t_0}^+) = v^+(x^+ z^+, {t_0}^+) = 0 \tag{31}$$

Conditions to limits

$x^+ = 0$ and $0 \le z^+ \le 1$

$$\left.\frac{\partial T^+}{\partial x^+}\right|_{x^+=0} = 0 \tag{32}$$

$$\left.\frac{\partial u^+}{\partial x^+}\right|_{x^+=0} = \left.\frac{\partial v^+}{\partial x^+}\right|_{x^+=0} = 0 \tag{33}$$

$x^+ = \frac{L}{H}$ with $0 \le z^+ \le 1$

$$\left.\frac{\partial T^+}{\partial z^+}\right|_{z^+=0} = 0 \tag{34}$$

$$u^+(x^+, 0, t^+) = v^+(x^+, 0, t^+) = 0 \tag{35}$$

$z^+ = 1$ Et $0 \le x^+ \le \frac{L}{H}$

$$u^+(x^+, H, t^+) = 0 \tag{36}$$

$$v^+(x^+, H, t^+) = -\frac{H}{\alpha} \times \frac{D}{1 - C_i}(C_{vs}(H) - C_v) \tag{37}$$

$$\left.\frac{\partial T^+}{\partial z^+}\right|_{z^+=1} = A_1 + A_2 + A_3 + A_4 \tag{38}$$

With

$$A_1 = \frac{h_c H}{k} \qquad A_2 = \frac{h_r H \varepsilon \sigma}{k}\left(T^+ + \frac{T_a - T_c}{\Delta T}\right)$$

$$A_3 = \frac{\rho L_{evap} k_m (C_{vs}(H) - C_v)}{\text{k}\Delta\text{T}} \qquad A_4 = -\frac{\varphi_s \alpha_{absgH}}{k\Delta T}$$

Numerical Methodology and validation: The dimensionless equations (25-28) associated with initial conditions (29-31) and limits (32-38) are solved using the finite volume method described by Patankar (39) on a uniform coverage and Thomas algorithm. The coupling between the speed and pressure fields is ensured using the SIMPLE algorithm. In order to validate our calculation code, we applied it with the problem of V.P.SINGH and C.Y.XU (40) who conducted a comparative study on the evaluation and generalization of the methods to calculate the radiation-based evaporation. Eight radiation-based equations for calculating evaporation were evaluated using meteorological data from the Changins station in Switzerland from 1990 to 1994. This station is located in latitude 46°24′and longitude06°14′.

They also used several meteorological variables such as water temperature, relative humidity, ambient temperature, wind speed, solar flux released and vapor pressures. Through well-defined constant values, these authors have stated that the equations of Makkink, Priestley and Taylor are good choices to calculate the evaporation in the studied region (Switzerland) with regard to radiation-based methods. As Figure 2a shows it, our results perfectly align with their results qualitatively and quantitatively. In fact, the maximum relative gap between our results and those of (40) does not exceed 5.12%. We also applied our calculation code to a reservoir that was subject of a numerical study reported by DJAMEL (41). The surface flow rate of evaporated water calculated using our calculation code perfectly aligns with that of (41) qualitatively and quantitatively. Indeed, the maximum relative deviation noticed does not exceed 3% (Fig.2b).

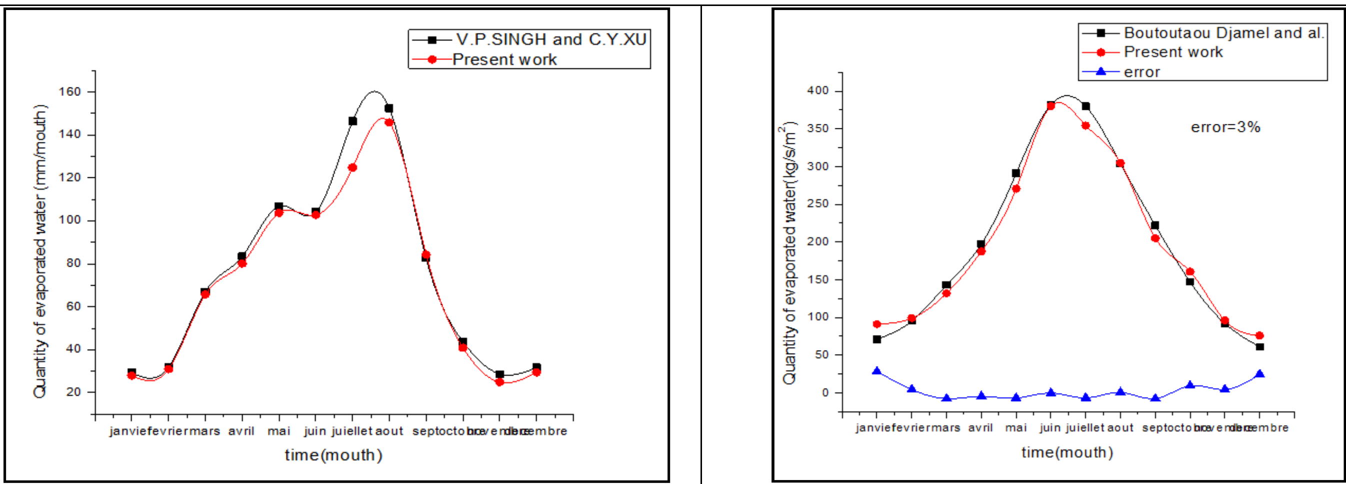

Figure 2a | Figure 2b

Figure 2. Validation of the Model

Sensitivity to coverage

With a non-dimensional time pace $\Delta t^{+} = 1,45 \times 10^{-5}$ that corresponds to $\Delta t = 25s$, we have considered three coverages (101 120), (126 105) and (105 126) corresponding respectively to dimensional space paces ((Δ□ ,Δ□): (5 10^{-3} m, 4.2 10^{-3} m), (4 10^{-3} m, 4.8 10^{-3} m) and (4.8 10^{-3} m, 4 10^{-3} m). We notice (Table 1) that the relative gap between the values of the surface flow rate of evaporated water from the water reservoir calculated with the coverages (101 120) and (126 105) does not exceed 10^{-2}. Then, we have chosen the coverage (126 105) to model and simulate heat transfers in the large water reservoir.

Table 1. Study of the sensitivity to meshing

$\Delta t(s)$	$N \times M$	$\Delta x(m)$	$\Delta z(m)$	Evaporated flow (kg/m^2/s	Relative gap
25	101×120	5 ×10^{-3}	4,2 ×10^{-3}	3,59×10^{-5}	10^{-2}
25	126× 105	4,8 ×10^{-3}	4 ×10^{-3}	1,89×10^{-6}	10^{-2}
25	105×126	4,8 ×10^{-3}	4 ×10^{-3}	6,66×10^{-4}	10^{-1}

RESULTS AND DISCUSSION

The calculations were made for four relative humidity values of the ambient air between 5% and 100%, two densities of the solar flux 50 and 100 W m^{-2} and three values of the ambient temperature: 303K, 310K and 320 K. The values of the physical properties of the water were assessed at the reference temperature equal to the ambient temperature (Table 2)

Table 2 : The physical water properties

Physical properties	water
Volume mass $\rho(kg.m^{-3})$	1000
Thermal capacity $c_p(J.kg^{-1}.K^{-1})$	4200
Thermal conductivity $\lambda(W.m^{-1}.K^{-1})$	0,6
Dynamic diffusivity $D_{iff}(m^2.s^{-1})$	5.10^{-8}
Dynamic viscosity $\mu(Pa.s)$	10^{-3}

The density of evaporated water flow from the reservoir is higher than the density of the solar flux on the surface of this reservoir (Fig. 3). Indeed, water temperature, notably that on the surface of the reservoir increases as the density of the solar flux increases. This leads to the increase in the concentration of saturated water vapor and therefore in the gap between this concentration of saturated vapor and that of water vapor in the air around the free water surface, therefore leading to an increased density of evaporated water flow.

As shown in Figure 4, the density of evaporated water flow is proportional to the gap between the concentration of saturated vapor on the surface of the basin and the concentration of water vapor of the air around it decreases with the increase in the relative air humidity. Indeed, the concentration of water vapor in the air is higher when the relative humidity of the air is high. The spatial distribution of temperature in water is analyzed for various values of the solar flux at a given relative humidity, wind speed and air temperature (Fig. 5). This solar flux is higher when the temperature in the basin is high. This increase is much higher at the surface of the reservoir, which corresponds to the higher value of the solar flux. Wind speed has a negative role on water temperature (Fig. 6). High values of this speed cause convection in water and an increase in the temperature gradient. That is why water temperature increases with high values according to wind speed. Through the Figure (Fig. 7), it appears that the Rayleigh(Ra) number is an increasing function of the temperature. For a Ra value lower than a critical value 1700, conduction appears in water; but when Ra values are higher than the critical value 1700, water therefore becomes the heart of a natural convection. Therefore, Ra depends on temperature gap; the more this gap increases, the more this dimensionless number increases, which causes an increase in temperature gradient. This explains the increase in temperature in the basin with the Rayleigh Ra number. Figure 8 represents the evolution of the quantity of water evaporated per the time for a given temperature variation. The analysis of this Figure shows that, over time, the evaporation process has a positive correlation with air temperature. This means that the higher the air temperature, the greater the amount of water evaporated. We agree with Vanney (1991) when he says that the highest evaporation rate is encountered in regions, between longitudes 60^o and 80^o West and the altitudes 30^o and 40^o North. This means that Burkina Faso is located in these regions, which explains the high rate of evaporation. Figure 9 shows the monthly evolution of the density of water flow evaporated from the water reservoir under Burkina Faso climate conditions. The analysis of this Figure shows that the amount of water evaporated is important during arid and semi-arid months such as March, April, February, May and January following this order. This means that over these months, all the meteorological conditions are met including very high solar flux, high temperature, very low humidity and high wind speed.

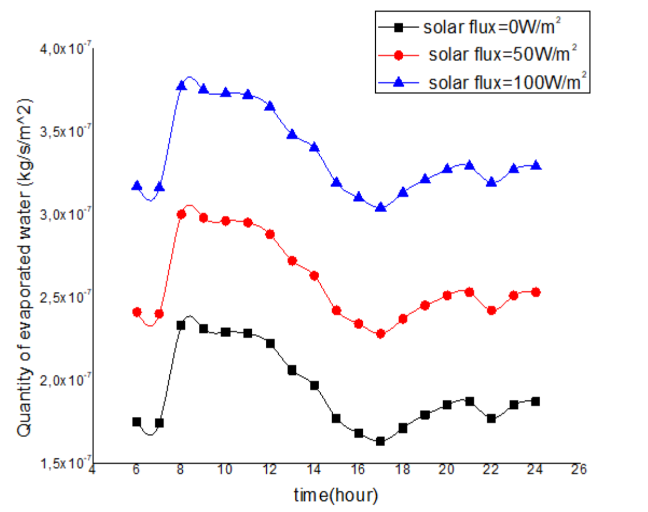

Figure 3: Influence of the solar flux on the quantity of evaporated water over time

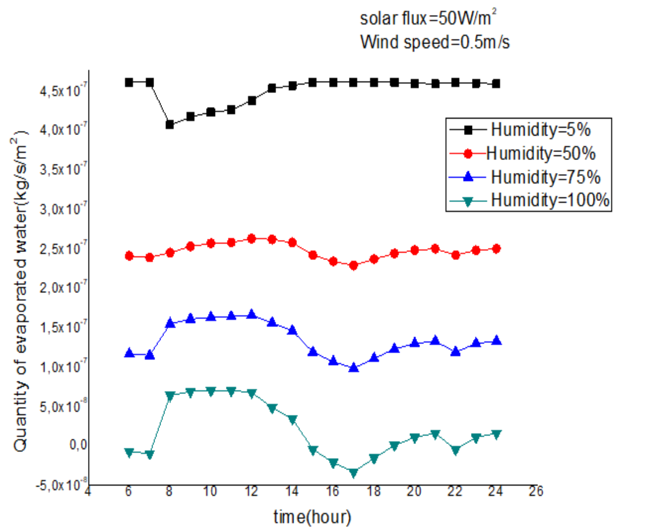

Figure 4. Influence of relative humidity on the quantity of evaporated water over time

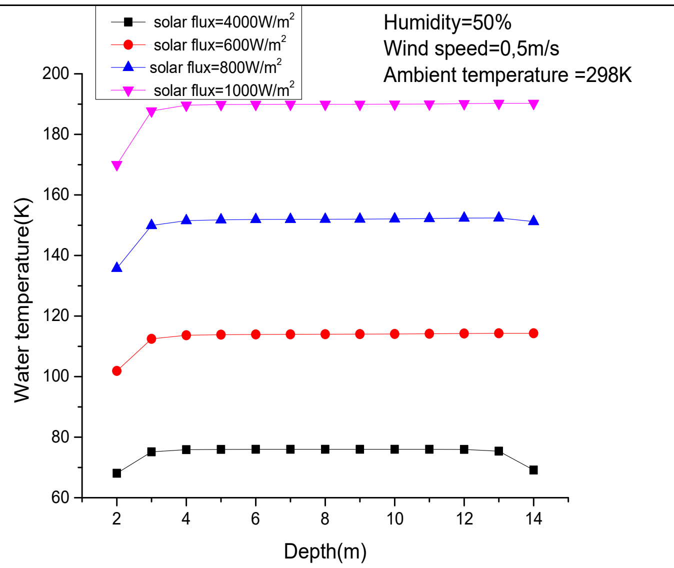

Figure 5. Influence of solar flux on water temperature

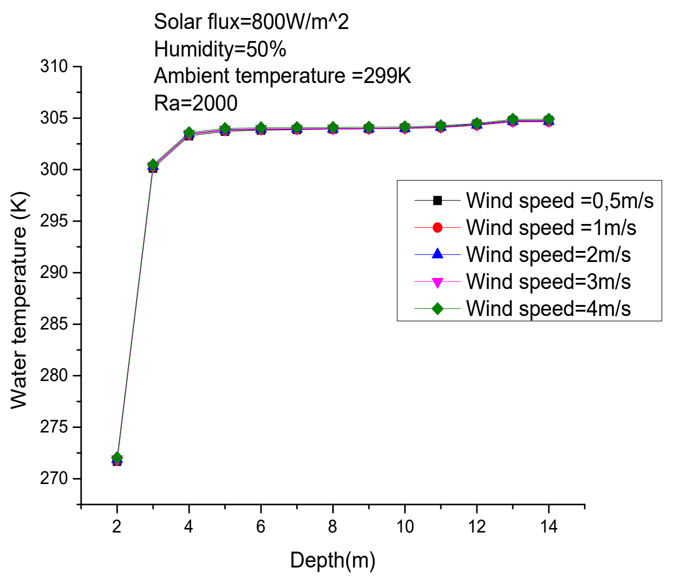

Figure 6. Influence of wind speed on water temperature

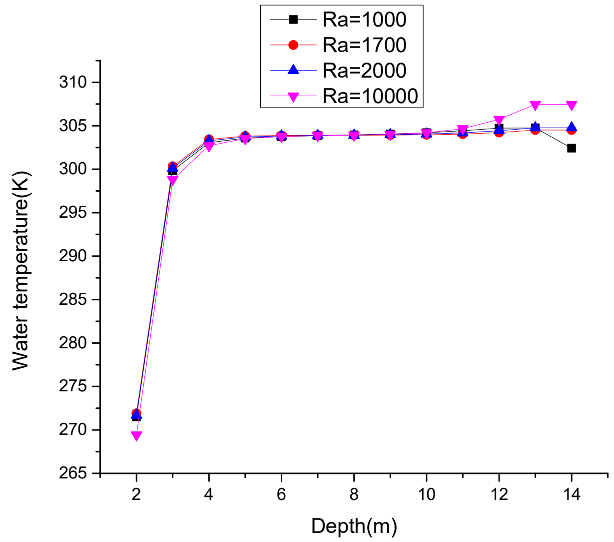

Figure 7 : Influence of Rayleigh number on water temperature

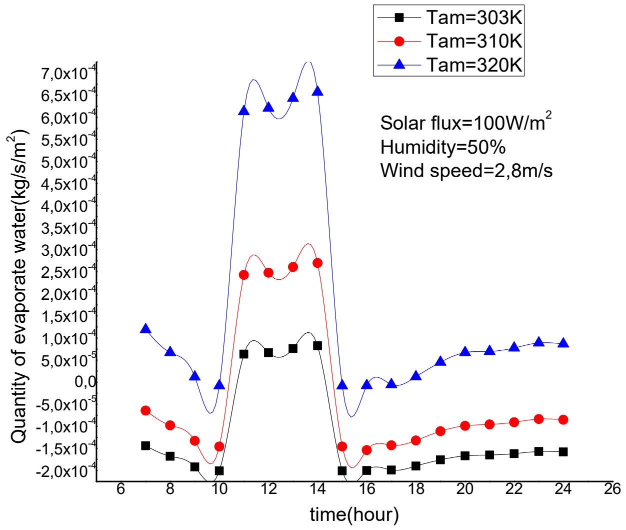

Figure 8: Influence of ambient temperature on the evaporated water over time

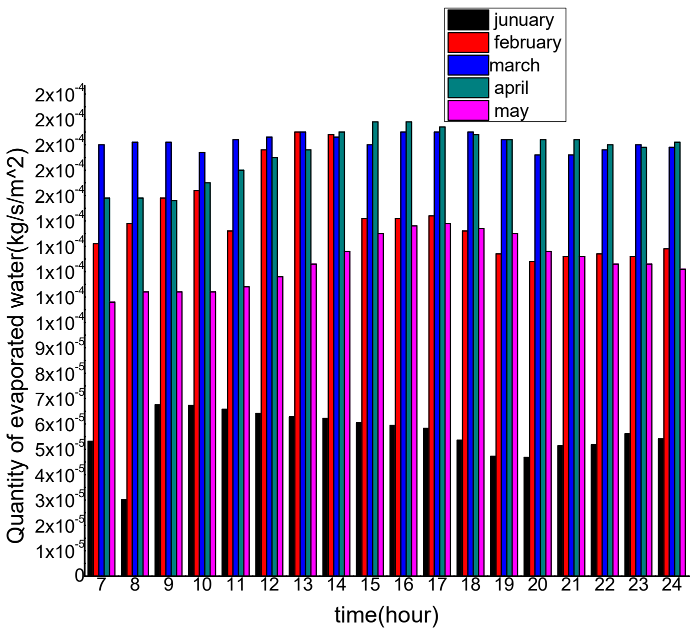

Figure 9. Evolution of the evaporation rate over time

Conclusion

We have numerically studied heat and mass transfers in a large water reservoir under Burkina Faso meteorological conditions. We have used the finite volume method, the THOMAS algorithm, the SIMPLE algorithm and an iterative procedure to solve the transfer equations for water reservoir. The surface flow rate of evaporated water is higher when, on the one hand, the ambient air temperature and speed and solar radiation are significant, and on the other hand, when air relative humidity is low. The monthly simulation of the behavior of this reservoir shows that hot periods record a significant amount of water lost due to evaporation compared to cold periods. That is why we have chosen these months (January, February, March, April, May) to perform the simulation. We analyzed the influence of the Rayleigh number on the water temperature and this revealed that a high Rayleigh number generates a high temperature gradient while the low value decreases the temperature gradient.

Acknowledgment
The ISP, Uppsala University, Sweeden os gratefully acknowledged force their support to project BUFO1

Nomenclature:

C_i concentration of air on the surface (-)
C_p specific heat (J/kg/K)
C_v Water vaporconcentration (-)
C_{vs} concentration of saturated water vapor(-)
D broadcast coefficient (m²/s)

E_s Solar constant (W/m²)1000
$\mathrm{E(Z)}$ incident solar radiation (W/m²)
g acceleration of gravity (m/s²)
Gr Grashof number(-)
H height of the basin (m)
$\mathrm{H_r}$ Air relative humidity (%)
h_c convective exchange coefficient (W/m²)
h_r radiative exchange coefficient (W/m²)
Km Mass Transfer coefficient (m/s)
L length of the basin (m)
l basin width (m)
$\mathrm{L_{evap}}$ latent evaporation heat (J/kg)
Nu Nusselt number(-)
P_a Water vaporpressure (Pa)
P_{atm} atmospheric pressure (Pa)
Pr Prandtl number(-)
P_{vs} Saturated water vapor pressure(Pa)
Sc Schmidt number(-)
Sh Sherwood number(-)
T_{am} ambient temperature (K)
T_c temperature of the sky (K)
u velocity component along (Oy) axis (m/s)
v velocity component along (Oz) axis (m/s)
v_e Evaporation velocity (m/s)

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