Bouam et al., J Hydrogeol Hydrol Eng 2018, 7:2
DOI: 10.4172/2325-9647.1000170

Journal of Hydrogeology & Hydrologic Engineering

Research Article

A SCITECHNOL JOURNAL

Contribution to the Site Evaluation for the Power Plant Implantation: Hydrological Part

Bouam A[1]*, Dadda A[2], Graîne H[2], Kadi R[1], Messen N[2] and Koudiah N[1]

Abstract

The satisfaction of water needs is a very important exclusion criterion in the selection of sites for the installation of power plants (nuclear or fossil plants). It can only be considered acceptable if the cooling capacity is satisfactory. The identification of the best sites in the final choice depends on the total cost of the cold source. In this work, a computer code for calculating the cooling water requirements of a power plant using a universal wet tower has been established. The installation, taken as an example, is a power station up to 1200 MW_{El} in a site such as the highlands, have been studied. The computer code for the analysis of the closed cooling circuit, it allows to determine the losses by water evaporation and water deconcentration (dilution). The program is based on the analytical relationships of a hydrological balance applied in cooling tower using the NF E 38-423 French standard. The calculations were made in ambient temperature ranges, relative humidity and variable power levels, using average meteorological data for a region in the highlands of Algeria. The results obtained are in good agreement with those of an IAEA simulator "wamp" and with the operating data of a thermal installation given in the literature as the power plant of the French (EDF plant).

Keywords

Power plant; Ambient conditions; NFE 38-423 standard; IAEA simulator "wamp"; Cooling system; Cooling tower

Introduction

The choice of sites for the establishment of power plants (nuclear or fossil plant) is often an important issue of public utility, must take into account more and more varied considerations especially in the case of nuclear power. This choice assumes, in many cases, a compromise between the opposite requirements.

Thus, considerations of safety and security are favourable to the installation of a nuclear reactor to the variation of highly populated areas. On the other hand, it may be that, for economic reasons, it is necessary for the nuclear installation to be sufficiently close to the consumers so that the costs of transporting energy are at least reduced. Similarly, it may be desirable, for organizational or administrative reasons, for the Centre for Nuclear Studies to be established in close proximity to other elementary institutions of social infrastructure [1-3].

In addition, many other quantifiable criteria that generally refer to the technical standard of the present facility to which the site must necessarily obey so that the facility can function in relation to geology, civil engineering and the existence factor of a satisfactory cold source or the rejection of heat will be performed.

A power plant needs water to operate. This water, which can be supplied by a river, an estuary or by the sea, also makes it possible to ensure the dilution of discharges of thermal, chemical and radioactive liquid, within the limits prescribed by the regulations.

For a nuclear power plant consists of one or more nuclear reactors whose electrical output varies little megawatts with more than 1 500 megawatts. This installation requires mainly water in order to evacuate the heat generated in the heart of the engine. This water, once heated, is usually discharged a short distance from the sampling point [4-6]. For this, two types of cooling circuits are used: open circuits or closed circuits using "wet" cooling towers [7].

In this work, a program for calculating the cooling water requirements of a power station using a universal wet tower has been established. The installation, taken as an example, is a power station up to 1200 MW_{El} in a site such as the highlands, has been studied.

The program destined for the analysis of the closed cooling circuit and allows determining the losses by evaporation of water and deconcentration (dilution). The program is based on the analytical relationships of a water balance applied in a cooling tower using the NF E 38-423 standard.

The calculations were performed in ambient temperature ranges, relative humidity and variable power levels, using average meteorological data from the highlands region [8]. The results obtained offer many parameters that are in good agreement with those of an IAEA simulator [9,10], the literature and with those of the safety report of thermal installations [11,12].

Materials and Methods

Principle of Evaporative Cooling

Evaporative cooling is a physical phenomenon in which the evaporation of a liquid, typically in the ambient air, cools. The latent heat, the amount of heat needed to evaporate the liquid is sucked in by the air. Evaporative cooling works by using the enthalpy of water vaporization.

The dry air temperature can be significantly reduced by the phase transition from liquid water to steam water (evaporation), which can cool the air using much less energy than refrigeration. This latent heat of vaporization constitutes the major part of the heat exchange, completed by convective exchanges between water and air [13].

An air-cooling tower uses the evaporative cooling principle to cool a given water flow to obtain the desired temperature difference between the temperature of the hot water entering the tower and the temperature of the water cooled by the tower. The efficiency of the exchange of the cooling tower is conditioned by the difference

***Corresponding author:** Bouam Abdallah, Thermal hydraulic Department Nuclear Research Centre of Birine, Ain-Oussera, Djelfa, Algeria, E-mail: bouam05_ab@yahoo.fr

Received: August 16, 2018 **Accepted:** November 26, 2018 **Published:** December 03, 2018 *doi: 10.4172/2325-9647.1000170*

between the temperature of cold water and that of the humid bulb of the air [14,15].

Prediction of Losses by Evaporation

The thermal power of a cooling tower, shown in Figure 1, is given by the following formula:

$$P = \dot{Q}_e.c_p.\Delta T \quad (1)$$

The control volume of a counter-flow cooling tower presented in Figure 2. The major assumptions, which are uses showing the important states is used to derive the basic modelling equations, are summarized by [14-16].

- heat and mass transfer is in a direction normal to the flows only;
- negligible heat and mass transfer through the tower walls to the environment;
- negligible heat transfer from the tower fans to the air or water streams;
- constant water and dry air specific heats;
- constant heat and mass transfer coefficients throughout the tower;
- constant value of Lewis number throughout the tower;
- water lost by drift is negligible;
- uniform temperature throughout the water stream at each cross section; and;
- uniform cross sectional area of the tower.

From steady-state energy and mass balances on an incremental control volume (see Figure 3), one gets [15]:

$$\dot{m}_a dh_{f,w} = -\left[\dot{m}_w - \dot{m}_a (W_0 - W)\right] dh_{f,w} + \dot{m}_a .dW h_{f,w} \quad (2)$$

The water energy balance can also be written in terms of the heat- and mass-transfer coefficients, h_c and h_D, respectively, as:

$$-\dot{m}_w dh_{f,w} = h_c A_V dV (t_w - t_{db}) + h_D A_V dV (W_{s,w} - W) h_{fg,w} \quad (3)$$

This evacuation of heat is determined by a heat balance applied to a control volume of a cooling tower, shown schematically in Figure 4.

The power dissipated by convection and evaporation is expressed by:

$$\dot{Q}_e c_{pe} (T_s - T_e) = \underbrace{\dot{Q}_e c_{a,h1} (T_{a2} - T_{a1})}_{Q_{cond}} + \underbrace{\dot{Q}_{Evap} (\mathrm{h_{lv}} + c_{pv} T_{a2} - c_{pe} T_e)}_{Q_{Evap}} \quad (2)$$

The thermal balance for a wet coolant, assuming that the air is saturated with steam water at the exit of the exchange zone, gives us an approximation of the power P which it evacuates towards the atmosphere. This power depends on the water temperature at the outlet of the dry cooler Te, the air outlet temperature T (which is equal to the average of the inlet and outlet water temperatures) and the air temperature ambient T_0 by:

$$P = \dot{Q}_a \left[c_{p,a} (T - T_0) + \frac{M_L}{M_a} \left(\frac{(p_{sat}(T) + \phi P_{sat}(T_0))}{P} \right) L \right] \quad (3)$$

The determination of the rate of steam disappeared in the atmosphere, as well as the air flow rate necessary for cooling by evaporation will be determined by the combination of equations (2 and 3).

Description of the Calculation Program

We have established a program for calculating the water consumption of the cooling circuit of a thermal power station, using the Fortran compiler. This program destined for the analysis of the cooling circuit of a thermal power generation plant.

Calculation procedure

Organigram: The calculation procedure is presented in the following flowchart (Figure 5):

Data exploitation: The operating data file of our model, given in Table 1, is divided into two parts: the first consists of operating data of a power plant and the second means the metrological data

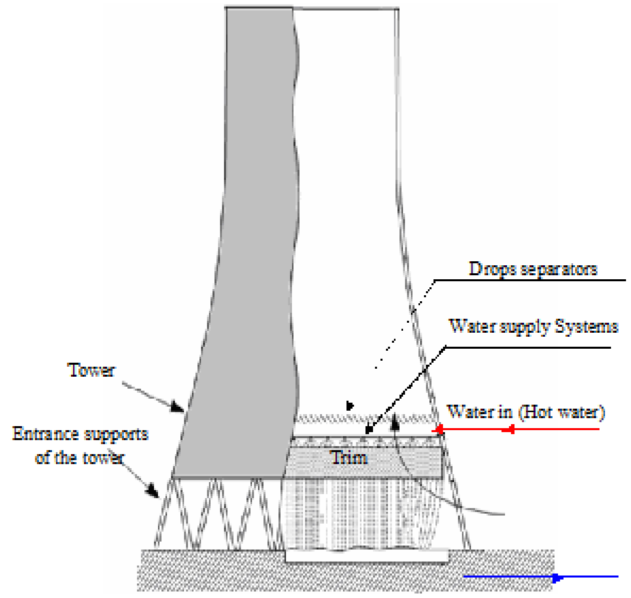

Figure 1: Study area and location of the bridges.

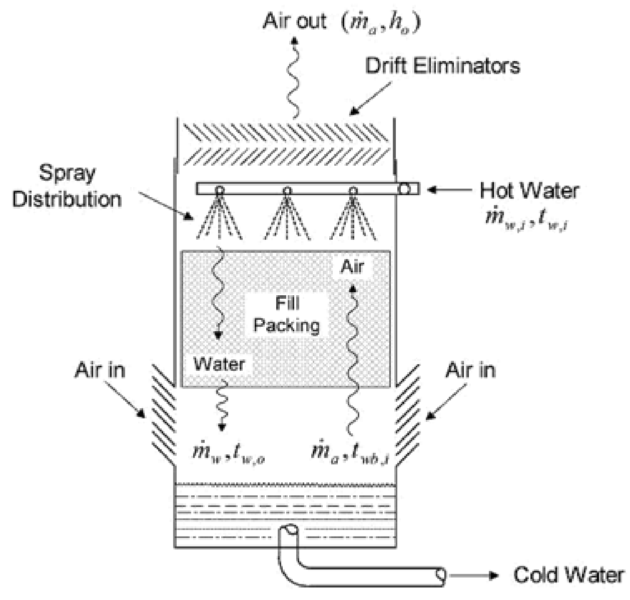

Figure 2: Schematic of a counter-flow wet cooling tower.

doi: 10.4172/2325-9647.1000170

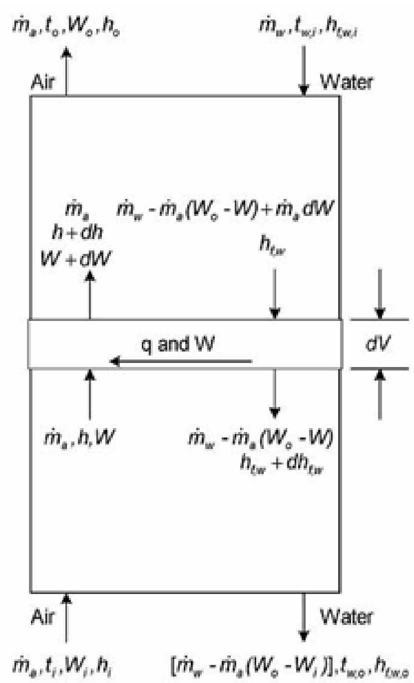

Figure 3: Mass and energy balance of a counter-flow wet cooling tower.

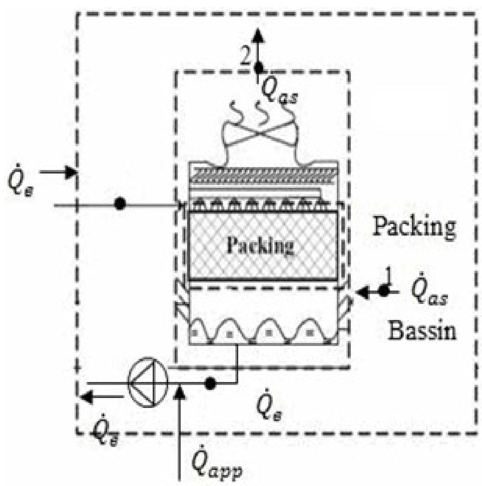

Figure 4: Control volume of TAR (Thermal balance Application).

for the year 2009 (the year of our water needs analysis for a power station). The different parameters are defined for a one hour step such as temperature, relative humidity and pressure [8].

Results and Interpretation

Ambient conditions influence of on evaporative losses

The distributions of the different hourly flows (dilution, evaporation and booster) during the year, for a power of 30 MWTh, assuming a continuous operation throughout the year, are shown in Figure 6.

It is noted that water consumption is important during the summer months, especially by evaporation.

Evacuated power influences on evaporation losses

In order to study the influence of the evacuated power on the extra flow required for the preceding operation, the different flow rates are presented in Figure 7, for powers ranging from 300 MWE1 to 1200 MWEl.

The same findings are possible on this analysis. We also note that when the power increases, we need a significant amount of water to evacuate the heat generated inside the plant.

We also note that the consumption of evaporative cooling water begins to increase slightly from the beginning of February to April. And a significant increase of this point to a maximum value until the month of July. Consumption decreases from this point until December. The average of these results is in agreement with the operating data of this installation and with those of the literature.

As recapitulations, the water requirement for such a power is mentioned in the table below:

Validation

The flow rate for an EDF plant gives values comparable to those of our calculations [13,14]. The three flows, experimental and literature are in agreement with each other, as shown in Figure 8. The water consumption remains lower than that elaborated in the safety report of such a nuclear power plant.

The monthly cooling water requirements for a power plant of 100 MWE1 up to 600 MWEl are shown in Figures 9A-9D. The same observations can be envisaged in these figures. When the power increases, we need a significant amount of water to evacuate the heat generated inside the plant. We also note that the consumption of evaporative cooling water begins to increase slightly from the beginning of February to April. And a significant increase of this point to a maximum value until the month of July. Consumption decreases from this point until December. This is due to the weather conditions in the area. It is noted that the consumption of cooling water by this power plant calculated by our model is in good agreement with the operating data by the central described by references [17-19].

Figure 10 shows the need for water in a plateau of varied power up to 1200 MWEl and for different regions of Algeria (east, west and centre). The operating data of reference [11] is important due to the meteorological conditions in this region where the plant is installed.

In general, the results obtained offer many parameters that are in good agreement with those of an IAEA simulator [9,10], the literature and with those of the safety report of thermal installations [11,12].

Conclusion

The Summary of Prediction of Mean Water Demand Values for a Power Plant in a High Palatine Site is described in Table 1. In this work, we have established a computer code for calculating the water consumption of power plant cooling circuit. The program is based on the analytical relationships of a hydrological balance applied in a cooling tower using the NF E 38-423 standard. The illustration of the results obtained clearly shows the qualitative and quantitative appearance of the parameters describing the annual water demand for this thermal production facility (proposed) and in good agreement with the data provided by the safety report. The satisfaction of water needs is a very strong criterion of exclusion, in the selection of sites for the installation of power plants (nuclear or fossil). It can only be

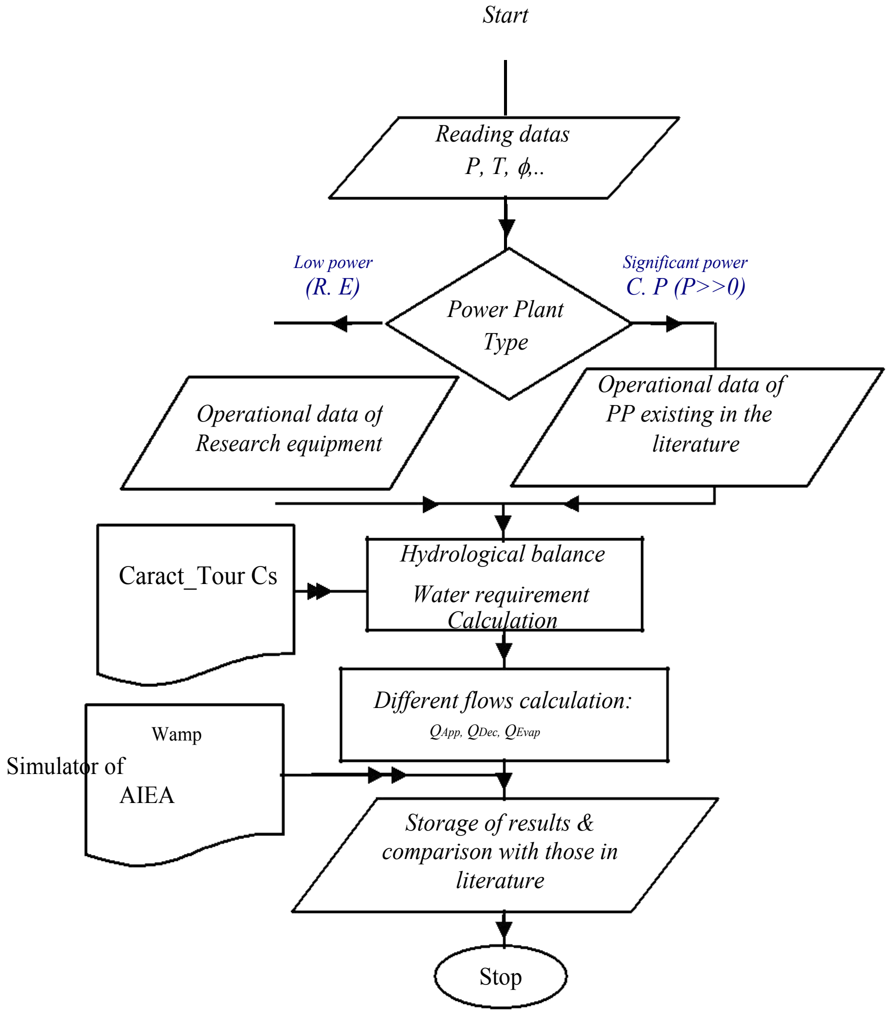

Figure 5: Steps for the need cooling water predict.

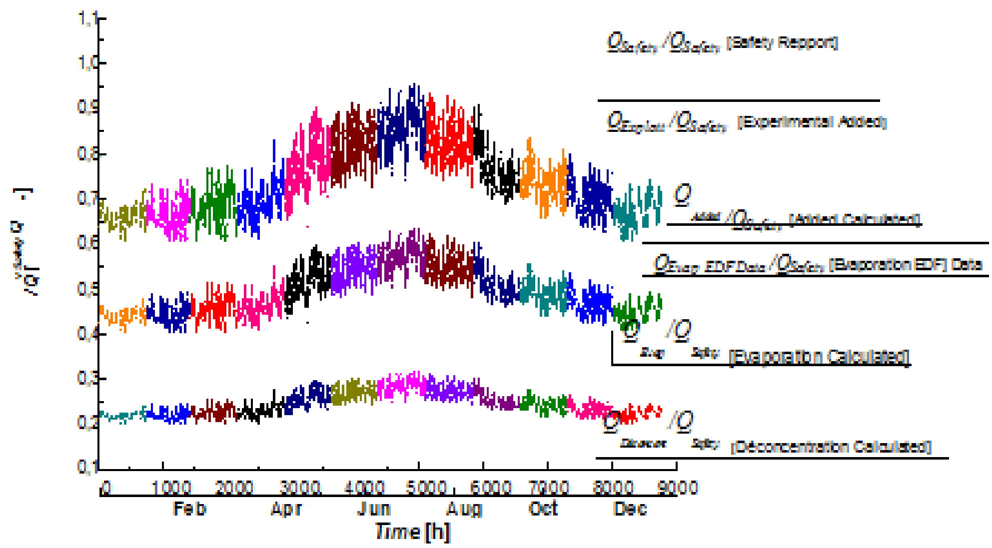

Figure 6: Need flow rates for water by the plant of 15 $MW_{Th.}$

Table 1: Operating data file.

Operating data of power plant						
Number of hours in the year				Coefficient of an universal wet tower Cf[-]		
8760				3		
Type of the Circuit (fermé ou ouvert)						
P_{Ther} [KWat]		QPrim [m3/h]	QSec [m3/h]		T [°C]	ηPP [%]
50		400	2850		5.7	33
Climatological data of the year : 2009						
Janaury Month						
Number of hours in January						
744						
N° Hours	Month	Day	Hours [h]	Relative humidity Φ [%]	Tair *10 [°C]	p [bar]
1	1	1	0			
2	1	2	1			
3	1	3	2			
..	..	..	..			
..	..	..	..			
744	1	31	23			
February Month						
Number of hours from January to February						
1416						
N° Hours	Month	Day	Hours [h]	Relative humidity Φ [%]	Tair *10 [°C]	p [bar]
745	2	1	0			
746	2	2	1			
748	2	3	2			
..	..	..	..			
..	..	..	..			
1416	2	28	23			
..	..	..	..	..	..	..
..	..	..	..	..	..	..
..	..	..	..	..	..	..
..	..	..	..	..	..	..
December Month						
Number of hours in year of 2009						
8760						
N° Hours	Month	Day	Hours [h]	Relative humidity Φ [%]	Tair *10 [°C]	p [bar]
1	12	1	0			
2	12	2	1			
3	12	3	2			
..	..	..	..			
..	..	..	..			
8760	12	31	23			

Table 2: Summary of Results.

P	[M WE1]	300	600	900	1200
Treated Supplemental					
Water	[M m3/An]	12	23	34	46

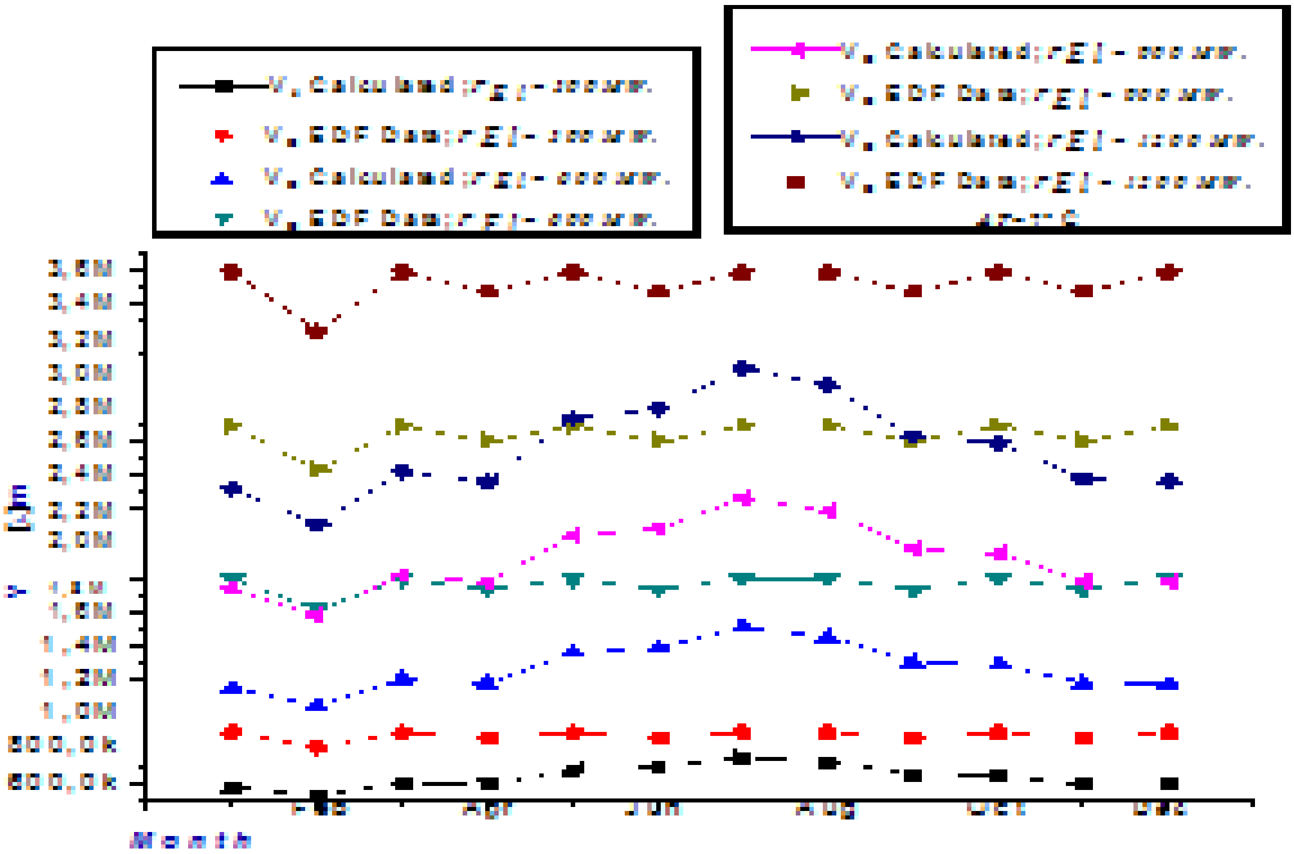

Figure 7: Need flow rates for water by the plant of (P = 300 ® 1200 MW_{EI}).

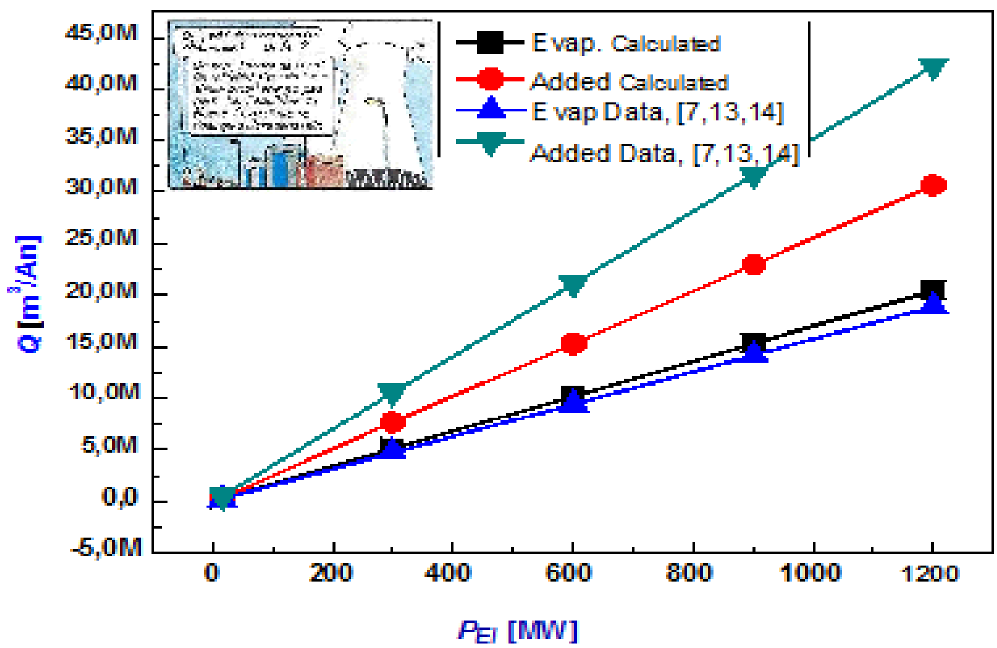

Figure 8: Power influences on annual consumption.

doi: 10.4172/2325-9647.1000170

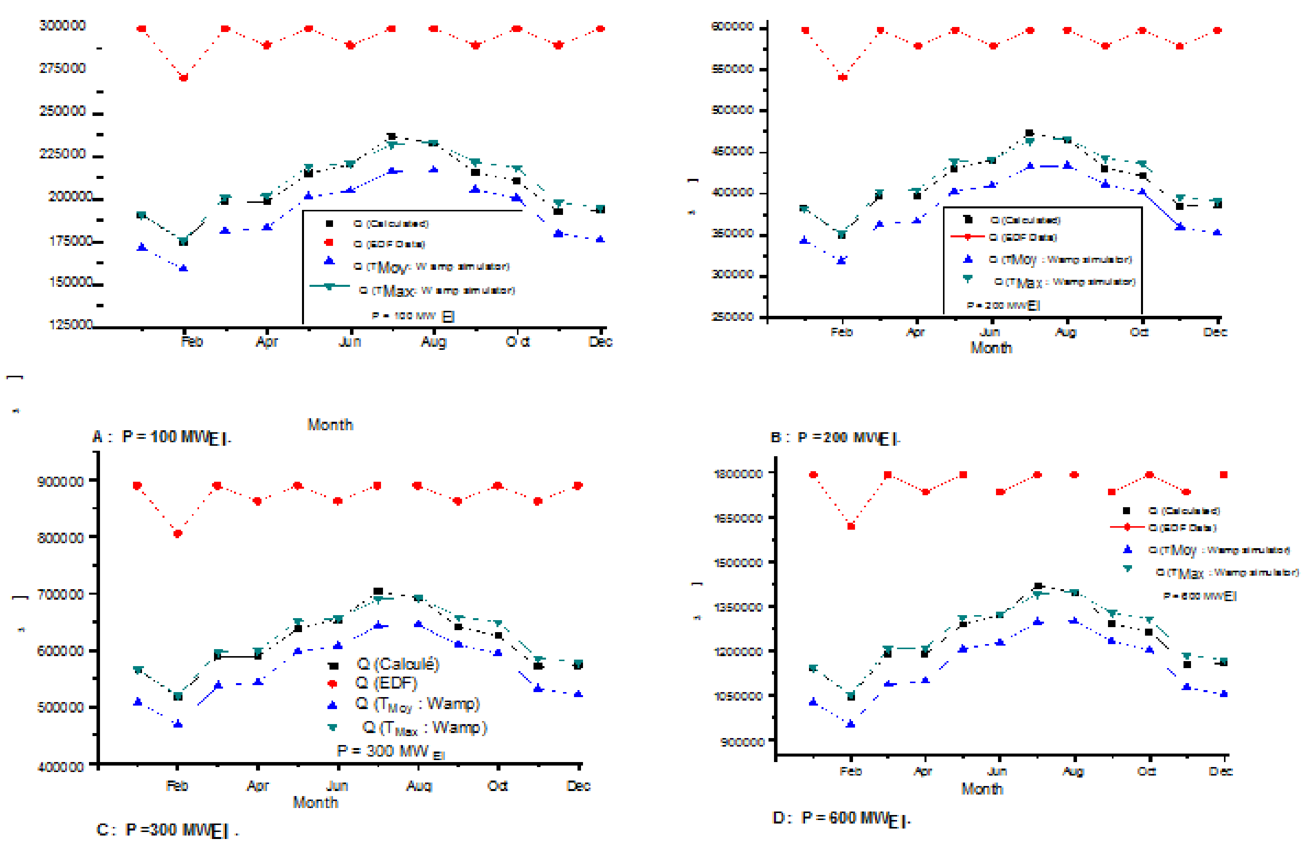

Figure 9: (A-D) Monthly water consumption in the Beni Haroun region (center of Algeria) V.S the power.

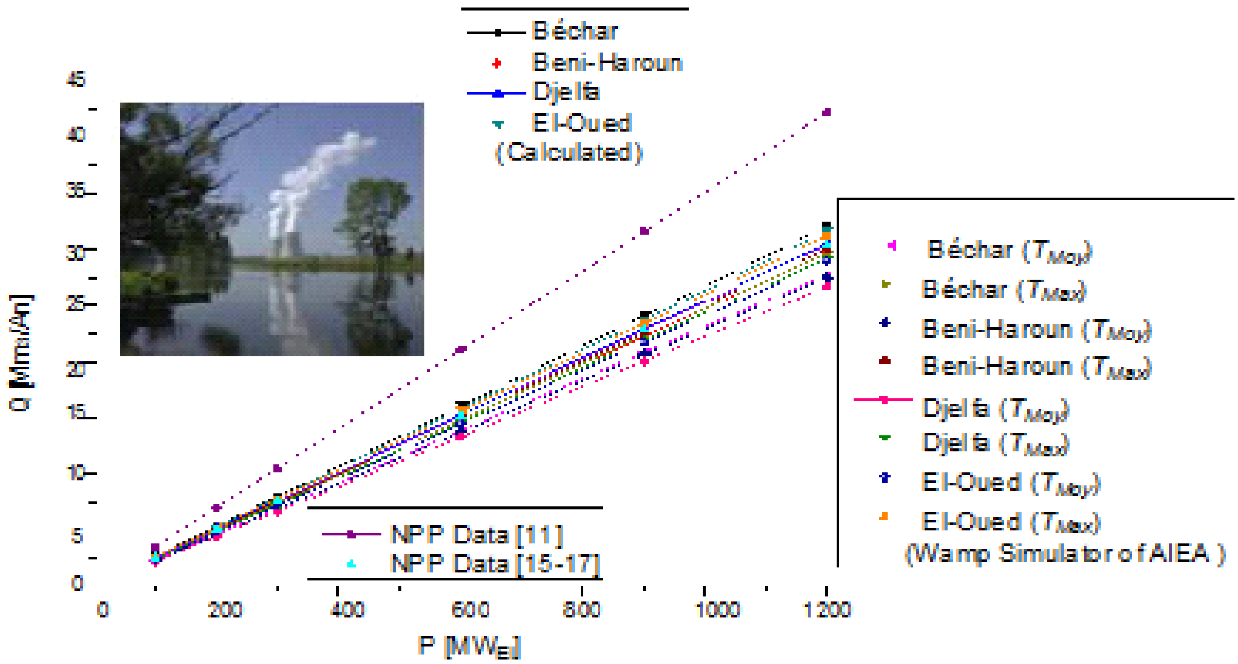

Figure 10: Annual consumption in different regions of high palatals in Algeria (WAMP Simulator of AIEA), our model & literature data.

List of symbols

Variable	*Description*	*Unit*
c_p	Specific heat at constant pressure	[kJ/kg K]
L	Latent heat	[kJ/kg]
M_a	Molar mass of air	[g/mol]
M_L	Molar mass of liquid	[g/mol]
P	Power	[MW]
Q^i	Volume flow rate	[m^3/h]
T	Temperature	[°C]
ΔT	Difference in temperature	[K]
V	Cool volume	[m^3]
Variable grec		
tc	Nombre of concentration cycle	[-]
f	Relative Humidity	[%]
η	Power plant efficiency	[%]

Indices et Exposant			
a	Air	*C. Ther*	Thermal power plant
e	Water	*EDF*	French Electricity Plant
El	Electricity	*C.R*	Thermal Power Plant
Sat	Saturation	*C.P*	Power station
Th	Thermal	*Max*	Maximum
Evap	Evaporation	*NF E*	French Standard
Moy	Average		

considered acceptable if the cooling capacity is satisfactory. When making the final choice, it is essentially the total cost of the cold source that marks out and identifies the best sites.

Acknowledgment

This work was mainly carried out at the Birine Nuclear Research Center of the Atomic Energy Commissariat, within the Thermo hydraulic Department of the Nuclear Technology Division. The authors thank Mr. Abdelmouman KERRIS, General Director of the CRNB, Mr. Abdelhafithe BENAZZA, General Secretary of the CRNB and Mr. Salah BELAID, Director of the Division of Nuclear Technologies, for their encouragement and the material means that were granted to us and put at our disposal.

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Author Affiliations

Top

Civil Engineering Department, Indian Institute of Technology, New Delhi, India