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ARTICLE

Modeling of Flow Field and Heat Transfer in a Swimming Pool

Abdelkader Doudou[1,2]

1 ESE, OLMAN-RL, Mohammed First University
2 Polydisciplinary Faculty of Nador, BP 300, 62700 Selouane, Morocco.
Corresponding: a.doudou@ump.ac.ma

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ABSTRACT

Heating swimming pools in an efficient and ecological way has become mandatory for the protection of the environment, but also for technological development and energy saving. The heating must maintain the quality of bathing water, avoiding temperature variations between the different depths and locations of the pool. There are currently several types of heating systems for swimming pool water among which we can mention; heat pumps, gas heating and electrical resistance, etc. All of these systems are very expensive and voracious in energy consumption. However, solar thermal heaters can be a good solution because they are inexpensive and environmentally friendly. The purpose of this work is to use the COMSOL MultiPhysics software to model the distribution of the flow field velocity and the temperature distribution according to the design of the pool and the inflow and outflow of water and climatic conditions in the province of Nador, in northeastern Morocco.

1. Introduction

Scientists and engineers around the world are working together to find (1) new strategies to reduce energy demand, (2) smart methods of securing supply, (3) techniques to increase energy efficiency, (4) new renewable energies to replace the fossil energies that are harmful for the environment and human health. But right now, applying thermal solar energy and reducing energy consumption are the two efficiency ways to reduce energy costs and to preserve the environment from pollution [1]. Thus, the energy demand for heating is important, as for the swimming pools.

The flow field in the pools depends on the number, the form and positions of the water inlets and outlets, the geometric shape of the pool and the feed flow rate. Currently, there is no universal regulation on the design of pools. The International Swimming Federation (FINA) has imposed only geometries of 25 m x 15 m x 1.6 m for regional competitions and 50 m x 21 m x 1.8 m for national and international competitions [2], without specifying anything about entries and exits of water. When a competition is going to take place, the organizers demand that the water does not move and that the temperature is uniform throughout the pool. In fact, swimming pools can be used for different purposes: refreshing, recreational and learning swimming, training and competition, or for therapeutic purposes, all with different water temperature requirements. The average temperature for a comfortable swim is 27°C, although it can vary by 5°C according to

**Corresponding Author:*
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the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) [3].

In recent years, the great development of computer tools has allowed the application of numerical simulation and modeling methods for complex physical processes by obtaining a good accuracy of the results. Some studies have been conducted to obtain a reliable method of predicting energy losses depending on the geometry of the pool and the ambient conditions in which it is located. The relation between evaporation of water and air movement to determine the mass flow rate of evaporation to obtain the appropriate dimensioning of swimming pool ventilation systems has been studied [4]. Water evaporation models on the pool surface have been developed using 2/3D CFD (Computational Fluid Dynamics).

A development of a model for swimming pools with TRNSYS software to determine the energy demand in the pool enclosure and the evaporation losses of the fluid depending on the water temperature in the pool and the ambient air showed that the pool water heating accounted for about 22% of the heat demand. While heating and ventilation consumed about 60% of the energy in the pool enclosure, evaporation losses ranged from 46% to 54% of total losses from the pool [5].

On the other hand, a numerical and experimental study revealed the effect of the pool design on hydraulic behavior considering the pool as a chemical reactor with its hydraulic and macro-mixing characteristics [6]. The mathematical model developed on the base of the stirred reactor principle could be used as a first approach to describe the hydraulic behavior of ordinary swimming pools. The approach was an appropriate example for the study of physical and chemical phenomena with long characteristic periods, notably: the prediction of the concentrations of chemical species, as well as the optimization of the chlorination and the daily renewal of the water. Dougha et al. [7] determined the hydrodynamic characteristics for three swimming pools by numerical simulation in terms of water quality. The work done has shown how pool design affects hydrodynamic behavior, controlling the influence of design and hydraulic conditions in terms of improving water quality based on CFD and experimental study data.

The CFD can highlight the short circuit or dead zones without swimmers in the flow configuration. In addition, turbulence is important in itself to evaluate the effectiveness of disinfection, as several studies have reported [8,9]. For this reason, it is important to use a suitable turbulence model to correctly predict both the velocity and turbulence fields. These turbulence models derived from Master-strokes equations. Turbulence models with numerical methods are used to simulate flow fields in environmental engineering problems, such as water pools [6,9,10,11].

For swimming pool heating, the thermal process involves the use of high thermal loads [12,13] and reflects high investment and operating costs, which can be reduced in different ways. The heating of the pool is realized by designing and realizing heating systems capable of responding to the appropriate heat load to obtain and maintain the necessary comfort by homogenizing the appropriate temperature in the pool. This last point is the main objective of this work which aims to study this aspect under different entry positions.

The present work deals with the application of the COMSOL Multiphysics software to simulate the heat transfer and the evolution of the flow velocity in the pool. The COMSOL Multiphysics software has of course been validated numerically and experimentally previously in our laboratory and with our collaborators [14-23]. The simulations are carried out in order to follow the evolution of the temperature until its homogenization within the pool according to the geometrical characteristics, the location of the injection and suction points in the ambient conditions of the province of Nador at northeastern Morocco. The results will allow us to obtain optimal positioning of injectors and ejectors of water in the pool.

2. Problem Formulation and Modeling

2.1 Geometry and Application Conditions

The pool studied in this work is located in the province Adorn in northeastern Morocco. The pool characteristics and ambient conditions used for the simulation are shown in Table 1. The heating of swimming pools is accomplished by designing and realizing a heating system to meet the thermal load necessary to reach and maintain the necessary comfort.

Table 1. Pool Characteristics and Ambient Conditions

Dimension and conditions of the swimming pool	
Width	12 m
Length	25 m
Ship depth	1,65 m
Water depth	1,48 m
Sought temperature	27°C
Thermal cover	Yes
Hours of use	9:00 AM - 7:30 PM

Maintenance	8:00 PM - 7:00 AM
Hours of Cover	8:00 PM - 7:00 AM
Ambient conditions in the province of Nador	
Temperature	22,25°C
Wind speed	4,84 m/s
Solar radiation	5,15kWh/m2/day

2.2 Simplifying Assumptions

Before solving a physical problem, it is necessary to make a number of assumptions:

- The pool is taken as a black body. It is easy to show that the water behaves like a black body thanks to the Fresnel coefficient.
- The walls of the pool are adiabatic.
- The ambient air temperature is higher than 21°C.
- The wind speed is less than 5 m/s.
- Energy gains and losses due to swimmers are negligible.
- Density and heat in the water change linearly with temperature.
- Conduction is neglected.
- The flow is laminar and non-compressible, and natural convection is taken into account by Boussinesq's hypothesis.
- The water is homogeneous and isotropic.
- The problem is non-stationary.

2.3 Theoretical Formulation

By adopting the simplifying hypotheses indicated in the previous paragraph, the equations that govern continuity, momentum and heat transfers in a swimming pool are as following :

Continuity equation :

$$\nabla \cdot U = 0 \qquad (1)$$

Momentum conservation equation :

$$\rho \frac{\partial U}{\partial t} + \rho\left(U \cdot \nabla U\right) = \nabla\left[-pI + \mu\left(\nabla U + \left(\nabla U\right)^T\right)\right] + F_b \qquad (2)$$

Energy conservation equation :

$$\rho C \frac{\partial T}{\partial t} + \rho C\left(U \cdot \nabla T\right) = \nabla\left(\lambda \cdot \nabla U\right) \qquad (3)$$

Fb is a volume force that must be added to simulate the buoyancy force causing natural convection. The Boussinesq's approximation is used to highlight this buoyancy force, as follows:

$$F_b = \rho g\left[1 - \beta\left(T - T_m\right)\right] \qquad (4)$$

where :

U: Velocity,
T: Temperature
C: Mass heat capacity,
p: Pressure,
: Thermal conductivity,
: Dynamic viscosity,
: Density,
: Fluid expansion coefficient,
g: Gravity acceleration,
Tm: Initial temperature

2.4 Boundary Conditions

The pool water has several interactions with the environment that must be identified to define the boundary conditions associated with mass and heat transfers. Table 2 shows the essential boundary conditions for simulating the movements of fluids inside the pool [23,24].

3. Results and Discussions

3.1 Temperature Distribution

Figure 1 shows the results of the numerical simulation at different times during the heating process of a swimming pool. It is interesting to note the symmetrical progression of the temperature from two injection points to the two suction points in the pool until the instant t=20000s. After this time, a deviation of the hot water towards the right suction point is observed due to the effect of the natural convection and the buoyancy force. This result is in very good agreement with the literature [25,26].

Table 2. Boundary Conditions

Water flow	Heat Transfer	Border	
U=0 m/s	$-\lambda \frac{\partial T}{\partial n} = 0$	Lateral board	(5)
U=Uinit=1,25m/s	T=Tfin=27°C	Injection point	(6)

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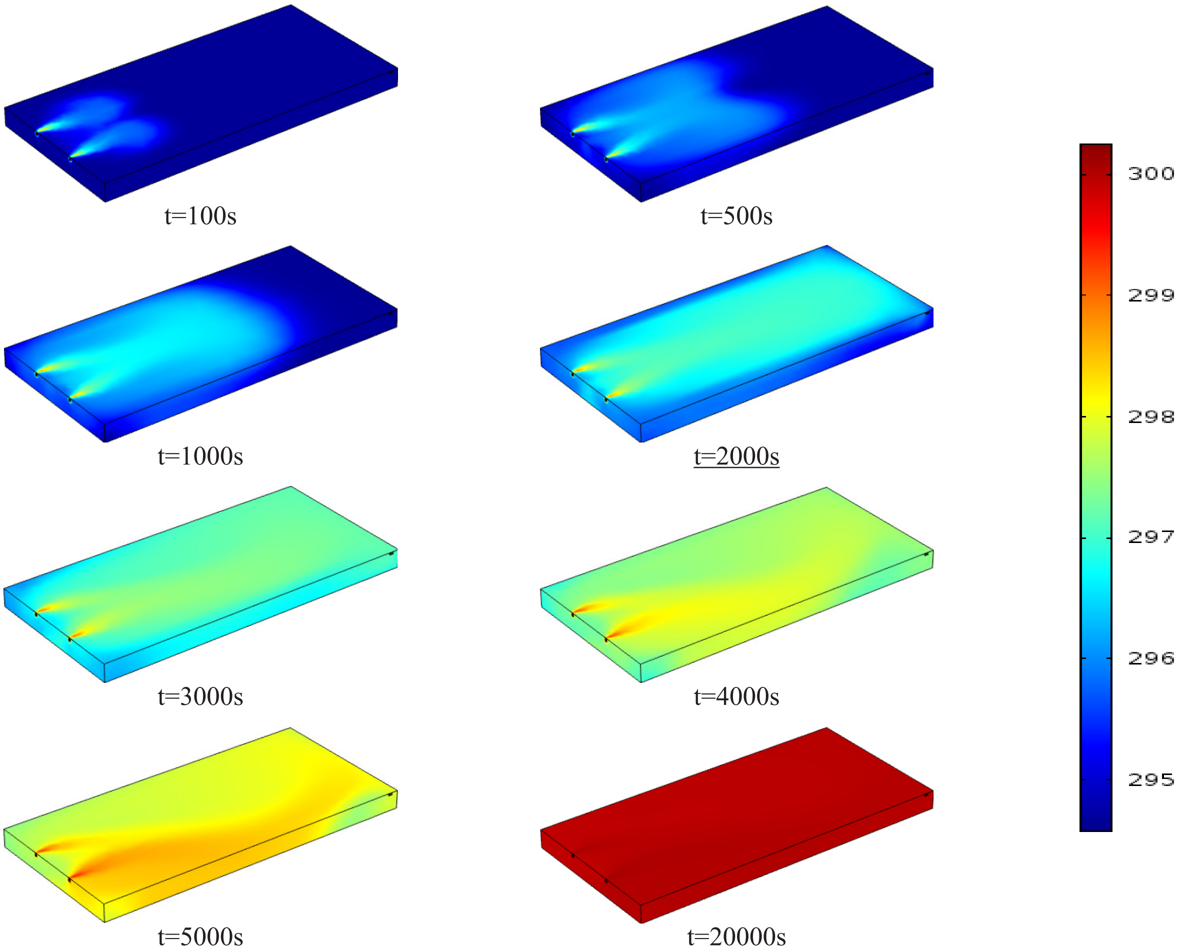

Figure 1. Temperature distribution during the injection process of warm water

P=0 Pa	$-\lambda\frac{\partial T}{\partial n}=h\left(T-T_{amb}\right)$	Skimmer	(7)
Un=0	$-\lambda\frac{\partial T}{\partial n}=h\left(T-T_{amb}\right)$ $-\lambda\frac{\partial T}{\partial n}=\varepsilon\sigma\left(T_{amb}^{4}-T^{4}\right)$	Top board	(8)
U=0 m/s	T=Tinit=21°C	Initial time	(9)

3.2 Flow Velocity Distribution

Figure 2 shows the evolution of the field of flow velocity inside the pool during the heating process. Near the injection points, the flow velocity is horizontal with a slight downward deflection due to the effect of forced convection caused by the injection flow. However, by moving away from the injection sites, the decrease in the effect of forced convection compared to the effect of natural convection is noticeable. The position of the injection points of the heated water flow in the pool can affect natural convection; this is the reason why it has been considered useful to study the influence of the injection and suction points on the heat transfer and the temperature distribution of the flow.

3.3 Temperature Evolution

Figure 3 shows the evolution of the temperature of the water flow of the pool as a function of time for different positions of the injection and suction points. For two injection points at the bottom, the homogeneity of the temperature is reached faster than in the case where the two injection points are placed at the top. This can be explained by increasing the effect of natural convection in the case where the two injection points are placed downwards.

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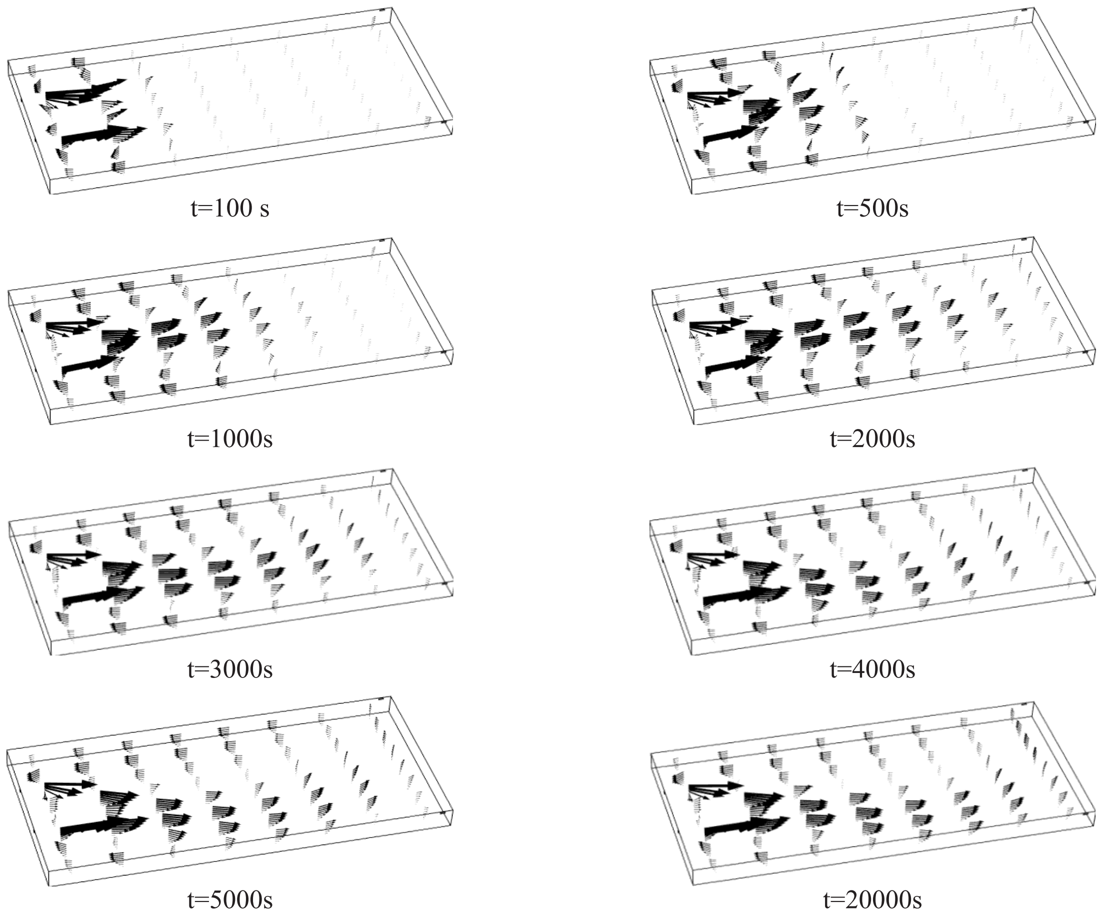

Figure 2. Flow velocity distribution at different times

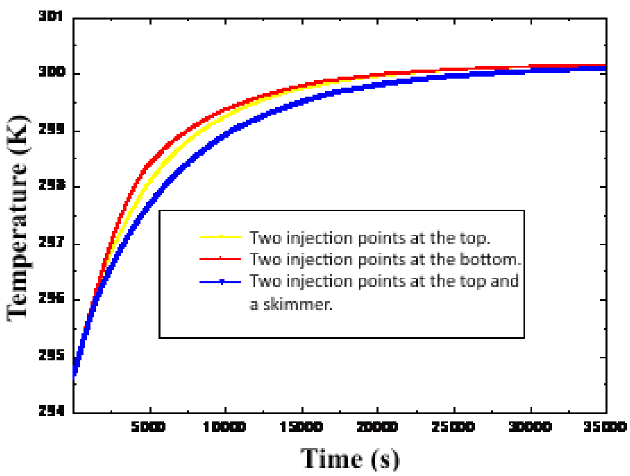

Figure 3. Temperature change

4. Conclusion

The paper deals with the CFD modeling of swimming pools without swimmers for improving their designs and managements. It is best known that the design has a great influence on the hydrodynamic behavior (velocity field, mixing characteristics, and residence time distribution), the thermal behavior (temperature distribution) and disinfectants spread in a swimming pool. The hydrodynamic and thermal behaviors depend on others characteristics than pool geometry such as feed rate, number, and position of water inlets and outlets. All that should be efficient in order to eliminate microorganisms and prevent the formation of water dead zones.

In this way, the COMSOL Multiphysics software with appropriate boundary and initial conditions was used. The COMSOL Multiphysics software has proved to be an interesting tool to help in the design of domestic, municipal and tourist pools. Thanks to the software, we have been able to better understand the process of homogenization of the distribution of temperature within a swimming pool. And subsequently act at the design level to accelerate the homogenization time. Also, based on the simulations carried out, it is crucial to avoid the positioning of the injectors on distant opposite sides as this reduces the turbulence by generating a relatively high velocity field on the periphery of the pool, but low in the central zone, which

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delays the homogenization of the temperature. In perspective, as a follow-up to this work a study by modeling will be performed to make a comparison with the simulation conducted here.

Afterwards, the CFD modeling with turbulence models has to be applied to describe the hydrodynamic behavior with precision. The results will certainly show the hydrodynamic problems of a swimming pool like non-renewable and weak mixing zones, which can reveal disinfectant lacking and microorganisms development. Long-time characteristic chemical phenomena can also be studied, which would be particularly useful for kinetic applications, including the prediction of concentrations of chemical species in the pool. Priority will be given to the study of rapid processes such as the reaction scheme for the chlorination of ammonia water or the chlorination optimization and the daily renewal of water.

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