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Numerical evaluation of dry-cooling towers interaction in different arrangement

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Abstract

The effect of wind on the performance of dry indirect cooling towers in different arrangements is investigated in the present paper. Thus, there are two cases to solve the problem: At first, solving various arrangements in free convection state, and then when exposed to wind (forced convection). Let consider a wind of 5 m/s velocity in order to compare different results obtained in forced convection state in various arrangement. For the case of free convection, towers are considered as two parallel towers, two successive towers, three towers in triangular arrangement and four towers in rectangular arrangement at equal distances. Then, velocity and pressure field are compared in different arrangements and phenomena such as chocking of tower flow due to presence of wind and interactions of various towers on each other's suction capacity in case of wind blow are investigated. Navier-Stokes equations are used in this work.

Keywords

Dry cooling tower, numerical simulation, wind effect, chocking, flow rate of tower suction.

Introduction

The main objective of this study is to simulate cooling tower of indirect dry type numerically. One significant advantage of this type in compare with the wet type is low consumption of water. Performance of these systems is strictly bounded to the ambient weather conditions like coldness, warmth, etc. which have been investigated broadly

by many researchers. In addition, the effect of wind on the performance of cooling tower is another concern of theirs. Works carried out in [1, 2, 3] are good samples of this tendency.

Governing Equations

Governing equations of flow filed of cooling towers and its surroundings are equations 1, 2 and 3 which have to be analyzed and solved through numerical methods.

- 1- Continuity equation in cylindrical coordinate,

$$\text{equation 1: } \frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{1}{r} \frac{\partial}{\partial r} (r \rho v) = 0$$

(1)

- 2- Three momentum equations for example in r direction, equation 2:

$$\frac{\partial (\rho u)}{\partial t} + \frac{\partial}{\partial x} (\rho u u) + \frac{1}{r} \frac{\partial}{\partial r} (\rho r v u) =$$

$$\frac{\partial P}{\partial x} - (\rho - \rho_{eff}) g_x + \frac{\partial}{\partial x} (\mu_{eff} \frac{\partial u}{\partial x}) + \frac{1}{r} \frac{\partial}{\partial r} (r \mu_{eff} \frac{\partial u}{\partial r}) \quad (2)$$

Where $\mu_{eff} = \mu + \mu_t$, which is the sum of turbulent and physical viscosity of fluid.

- 3- Another equation to be solved along with previous equations is energy equation, equation 3:

$$\frac{\partial (\rho h)}{\partial t} + \frac{\partial}{\partial x} (\rho u h) + \frac{1}{r} \frac{\partial}{\partial r} (\rho r v h) =$$

$$\frac{\partial}{\partial x} \left(\Gamma_{eff} \frac{\partial h}{\partial x} \right) + \frac{1}{r} \frac{\partial}{\partial r} \left(r \Gamma_{eff} \frac{\partial h}{\partial r} \right) + q_s \quad (3)$$

Geometry, mesh and numerical adjustment

Boundary conditions are of special importance in modeling, since they indicate the amount of heat and flow on boundaries of physical model. We

have used the following boundary conditions in this analysis:

- 1- Velocity inlet, 2- radiator, 3- wall, 4- symmetry, 5- pressure exhaust

A schematic of computational solving field, mesh and its boundary conditions is shown in Fig. 1-a. Different arrangements that have been simulated in addition to the single tower are shown in Fig. 1-b. Wind flow direction is specified through an arrow.

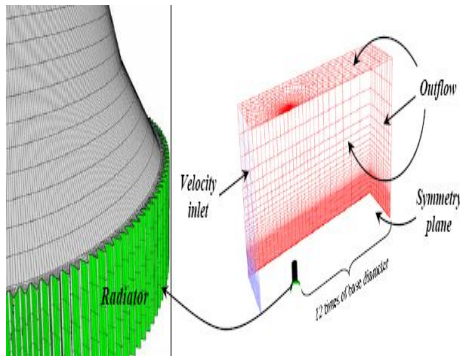


Figure 1-a

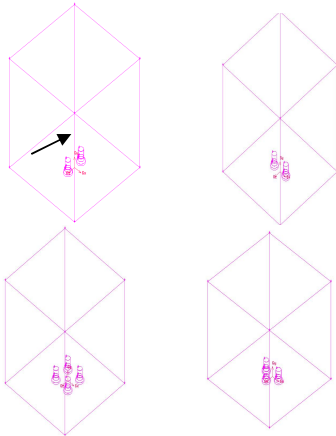


Figure 1-b

Figure 1.1-a: solving field, mesh and boundary condition. 1-b: different arrangement of towers

The distance between center of towers is always $2d$ where d is the diameter of tower base.

Numerical simulation includes two fundamental steps:

- 1- Analyzed solve field (mesh).
- 2- Analyzed governing equations.

In fact, the main idea of finite volume methods in computational fluid dynamics is to meet conservation laws through the whole solve field. As system of equations governing flow field is a system of differential equations coupled to each other thus the proper approach to solve flow field is to apply this system of equations in smaller sections of the field called cell in order to convert partial differential equation into algebraic system of equations. Grid generating is supposed to be the first step in numerical simulation of fluid flow which has attracted much research over the last two decades. But, system under consideration in this paper is a complex industrial system which requires much more concern in compare with academic ones. Generating disordered grid could eradicate many obstacles in regard to grid generation in complex and disordered geometry, especially in industry. Applying three dimensional elements of prism and pyramid type based on concepts of grid generation is much useful. Furthermore, in order to make use of advantages of disordered hexagonal elements, a combination of hexagonal, pentagon and square elements together could be utilized as hybrid network.

Finite volume methods are selected as well-suited methods to discrete Navier-Stokes equations, as they completely satisfy conservation laws all over the solve field. 300000 organized meshes are used to solve our problem numerically in order to obtain independent results. In regard to the works of other researchers suitable boundary conditions and computational area with proper intervals are considered in order to remove upstream obstacles on boundaries [2, 3]. At first equations is solved using first order finite volume method and in the form of decoupled in order to insure convergence and after convergence, second order solution and couple algorithm are selected to obtain higher accuracies. In this work, K- ϵ turbulence model is chosen and RNG is used to solve the problem.

Velocity profile considered for the case of wind blowing is:

$$V(z) = V_g \left(\frac{z}{\delta} \right)^\alpha$$

Where $V(z)$ is velocity at Z altitude. V_g is velocity at δ altitude (δ is the thickness of atmosphere boundary layer) and α is a coefficient related to the altitude and turpitude around the tower which can vary in accordance with local conditions. In the present paper, value of the parameters is selected according to reference [1].

Results

In figure 2, velocity vectors are shown for double towers in the case of free convection.

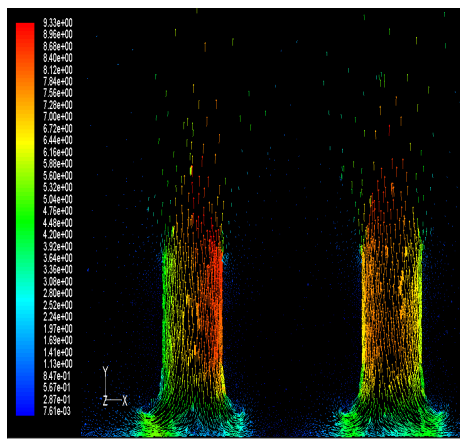


Figure 2 .Velocity vectors for double towers

Then simulation is carried out for other arrangements and the results of various cases and comparison mass flow rates in suction of towers and between in single tower shown in table 1.

Arrangement of towers	Mass flow rate in suction	Percent reduction of mass flow rate in compare single tower
One tower	24723.3	
Two towers	24352.1	1.50
Three towers	24211.4	2.07
Four towers	24108.1	2.48

Table 1.Mass flow rate of different arrangement for free convection

It is shown that mass flow rate is reduced in regard to the case of single tower which is due to interactions of tower on each other's suction rate.

In figure 3, velocity vectors inside and around the tower is shown from top view in the case of wind blowing.

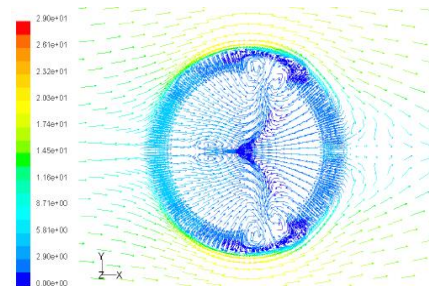


Figure 3.velocity vectors inside and around the tower from top view

Air enters cooling tower through radiators mounted in the base part of tower. It is shown that around the tower due to increase in velocity, reduced pressure of suction of radiators in this part is decreased in compare with the case without wind blowing. Since pressure is higher in the radiators in direct contact with wind blowing, their mass flow rate is higher. Radiators in rear face of tower are in subject to reverse flows. Thus, natural suction is also affected here. This phenomenon leads to disturbing balance and symmetry of flow inside the cooling tower which affects the rising axial flow that eventually results in velocity, as shown in figure 4.

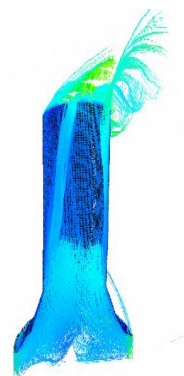


Figure 4.vortex flow in tower

Asymmetry inside the tower according by instability and curvature in rising flow and in flow leaving the towers also wind blowing outside the tower lead to back flow to the tower that is called chocking.

Chocking, however can reduce mass flow rate in suction of tower, figure 5.

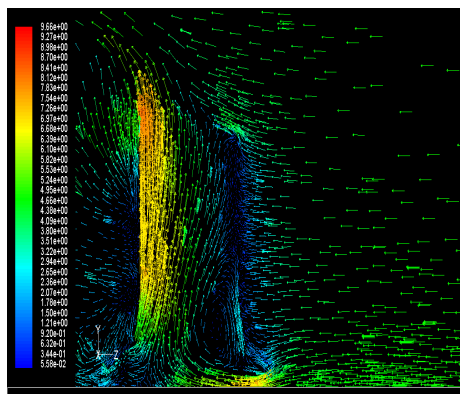


Figure 5. Chocking of tower

Another important issue studied is the effect of towers on each other's performance in the presence of wind (forced convection).

A wind with velocity of 5m/s is used to compare suction rate in different arrangements.

In figure 6, velocity vectors due to presence of wind is shown in the following arrangement: two successive towers, two parallel towers, three towers in triangular arrangement and four towers in rectangular arrangement.

In order to investigate the rate of changes in tower suction due to the presence of wind, mass flow rates of two successive towers, one in front and the other in the back of each arrangement, are presented in table 2.

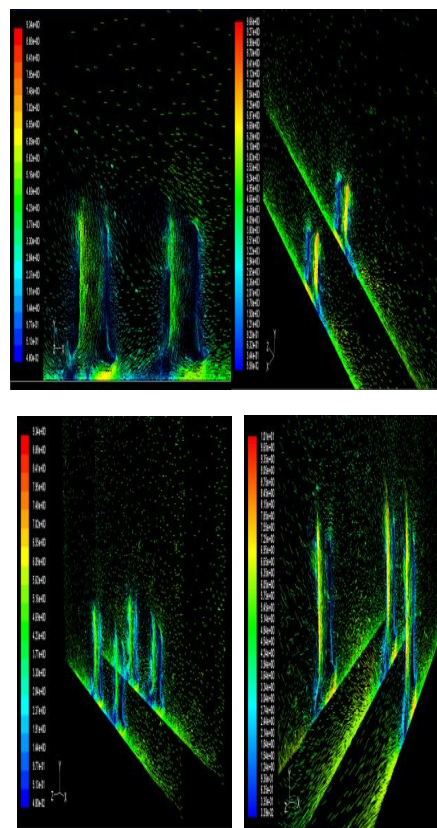


Figure 6. velocity vectors for different arrangement in forced convection

Arrangement	Mass flow rate of first row towers	Mass flow rate of second row towers
two parallel towers	11505	
two successive towers	7550	11053
three towers	9617	11754
four towers	5410	10850

Table 2. Mass flow rate of different arrangement for forced convection

It is shown that, when two towers are located in parallel situation, tower interactions and wind effect will result in a four percent reduction in mass flow rate of suction air in compare with the case of

single tower. When placing two towers in series, positive effects of wind on the mass flow rate of second tower is shown which is due to the reduction of undesirable effects of wind, since first tower function as an obstacle for the second one.

The arrangement of four towers is a combination of above mentioned case which includes said negative effects on mass flow rate of tower suction. When using triangular arrangement these negative effects are reduced.

Conclusion

In the present paper, it is shown that the presence of wind has a negative effect on the suction rate of tower and subsequently system efficiency. Furthermore, this negative effect increases as wind velocity increases. It is also found out that in the case of four towers, in addition to interactions of towers, front towers function as an obstacle against negative effects of wind on back ones.

Thus, undesirable effects of wind should be minimized.

References

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