IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

International Journal of Heat and Technology
Vol. 42, No. 4, August, 2024, pp. 1427-1433
Journal homepage: http://iieta.org/journals/ijht

Numerical Simulation and Experimental Analysis of the Behavior of Portland Cement Cooling Towers

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https://doi.org/10.18280/ijht.420432

Received: 5 January 2024
Revised: 9 March 2024
Accepted: 18 March 2024
Available online: 31 August 2024

Keywords:
cooling tower, dry air, cold air, efficiency, energy balance

ABSTRACT

The Behavior of Cement Portland Cooling Tower was evaluated numerically and experimentally**.** The three-dimensional simultaneous governing equations of the fluid flow, heat transfer and mass transfer were discretized and solved numerically, and the result of simulation were compared with measured data from the cement factory and with the available published result on the internet. Solid software was used as numerical software tool to predict the performance characteristics of cooling tower in Portland cement factory such as the velocity, temperature, stress and strain were simulated and compared with compute experiment. Experimentally the temperature, and pressure of gaseous and its emission across the cooling tower in White Portland cement factory were measured. The agreement seems acceptable between the numerical and experimental results.

1. INTRODUCTION

The most common material utilized for contemporary infrastructure is cement.

Approximately 5% of all anthropogenic CO_2 emissions worldwide are attributed to the cement industry, one of the highest polluting industrial sectors and an energy-intensive industry where energy expenditures account for 40% of overall production costs The cement mill can cut its energy usage by thirty percent [1].

Huge concrete chimneys are used in natural draft designs to introduce air through the media.

It uses big fans to push air through water that is being circulated. The water flows over fill surfaces at a downward angle, which helps prolong the water-air contact period.

The purpose of the counterflow cooling tower is to cool hot water that exits the compressors and blowers' heat exchangers and then recycles the water to cool the components once again [1-3].

Figure 1. Cooling tower model

Both mechanical and natural drafts cooling tower are utilized to drive air through circulating water and it employed for humidification operations to introduce air through the media. As seen in Figure 1, the water falls downhill over fill surfaces that aid in lengthening the water-air contact period [1].

1.1 Cross flow

Figure 2 illustrates a crossflow design, in which the air flow is oriented perpendicular to the water flow [2].

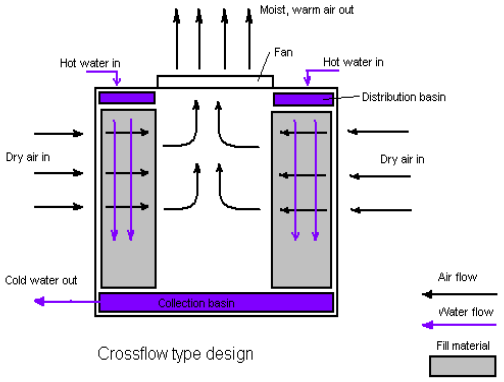

Figure 2. Cross flow [2]

1.2 Counter flow

Figure 3 illustrates how the air flow in a counterflow system is exactly opposite the water flow. After first entering a gap under the fill material, air is pulled up vertically. Water is sprayed by pressure nozzles and travels against the flow of air through the fill, falling downhill [3].

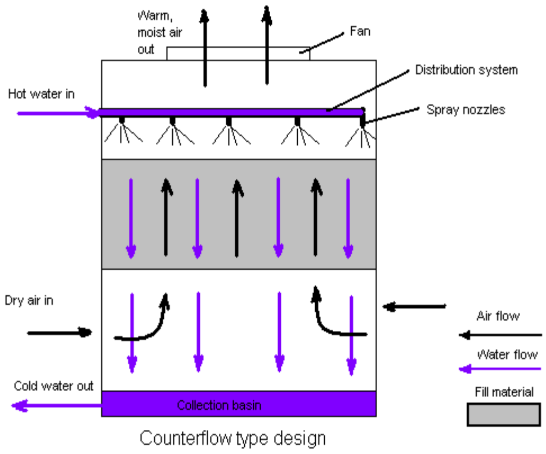

Figure 3. Counter flow type design [3]

2. LITERATURE REVIEW

There isn't a single mathematical model that can faithfully replicate every facet of the tower's simultaneous mass and heat transmission operation [3, 4].

Many researchers used finite difference and CFD approaches to study the fundamental equations for mass and heat transmission both computationally and experimentally the most important aspects of the cooling tower in various dimensions [5-12].

Zargar et al. [13] studied numerically the heat and mass transmission inside wet counter cooling towers under various climatic circumstances using a one-dimensiona.

On other hand, A new approach for evaluating measured data of cooling tower performance was provided by Smrekar et al. [14]. It makes it possible to research how local anomalies in CT affect the power production of the plant. Poppe model is offered for cooling tower applications on a local basis. An empirical model is created that links the temperature of the cooling water to the power production.

Qureshi and Zubair [15] was introduced the fouling model to look at the cooling tower's risk-based thermal performance. For the specified fouling model, the efficacy has decreased by around 6.0%. They looked into the cooling tower's sensitivity analysis for rating and design calculations for various mass flow rate ratio values.

Berndt [16] looked at ways to shield concrete from the acid that sulfur-oxidizing bacteria in geothermal power plants release. He discovered that the best protection was provided by calcium aluminate cement mortar, epoxy coatings, and silica fume.

Ahamed et al. [17] studied the energy recovery of the Grate coolers which used in cement industries.

Klimanek [18] forecast the performance of natural draft wet-cooling towers using demonstrated a CFD model.

In order to establish the minimal energy objectives for production and suggest strategies to increase energy efficiency, Boldyryev et al. [19] examined the energy consumption of a specific cement mill in Croatia.

A numerical model grounded on wet cooling towers has been combined with a numerical plume model that accounts for the potential for condensation as well as the condensation event itself [20].

Using a multiparametric numerical simulation and a CFD model, Zhelnin et al. [21] examined the effects of tower separation and crosswind speed on two cooling towers.

Using the Finite Element Method, Ansys software, Kumar et al. [22] modeled hyperbolic cooling towers. The results demonstrate how the behavior of Hyperbolic Cooling towers during earthquakes is considerably altered by the soil-structure interaction effect.

The mass and heat transport within a natural wet cooling tower under various operating and crosswind circumstances have been quantitatively explored by Al-Waked and Behnia [23]. Both the Lagrangian and the Eulerian approaches have been used in the current simulation for the air and water phases, respectively.

The literature has a number of numerical models that explain the fundamentals of cooling tower operation: Sutherland models, Fujita and Tezuka, Webb, Jaber and Webb, ESC code, FACTS, VERA2D, and STAR [3, 4].

Every model uses a slightly different set of presumptions. As a result, each model's heat-mass transfer coefficient computations provide different findings.

In the present study the Solid flow numerical model was used to simulate the performance of the cooling tower of Portland cement factory [24].

3. COOLING TOWER THEORY

The motion of the water droplet is as shown in Figure 4:

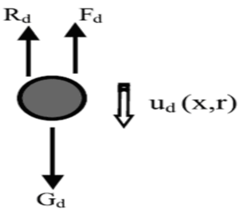

Figure 4. Free body of water droplet

$$M_d \frac{du_d}{dt} = G_d - F_d - R_d$$

Heat is transferred from water drops to the surrounding air by the transfer of sensible and latent heat as shown in Figure 5.

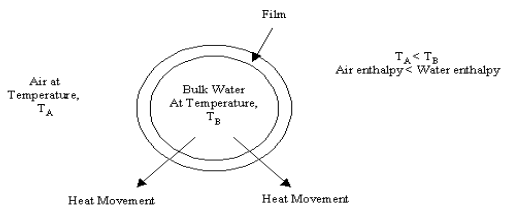

Figure 5. Interfacial film of water droplet

The heat removed from the water must be equal to the heat absorbed by the surrounding air [25]:

$$q''' = ka\left(h_{sw} - h_a\right) \tag{1}$$

$$\dot{m}_v''' = ka\left(w_{sw} - w_a\right) \tag{2}$$

The tower characteristic value can be calculated by solving Eq. (1):

$$\frac{\mathrm{KaV}}{\mathrm{L}}=\int_{T_2}^{T_1}\frac{\mathrm{dT}}{h_w-h_a}=\frac{T_1-T_2}{4}\left(\frac{1}{\Delta h_1}+\frac{1}{\Delta h_2}+\frac{1}{\Delta h_3}+\frac{1}{\Delta h_4}\right) \tag{3}$$

where,

$$\begin{gathered}\Delta h_1=h_w\text{-}h_a \text{ at } T_2+0.1(T_1\text{-}T_2)\\ \Delta h_2=h_w\text{-}h_a \text{ at } T_2+0.4(T_1\text{-}T_2)\\ \Delta h_3=h_w\text{-}h_a \text{ at } T_2\text{-}0.4(T_1\text{-}T_2)\\ \Delta h_4=h_w\text{-}h_a \text{ at } T_2+0.1(T_1\text{-}T_2)\end{gathered} \tag{4}$$

3.1 Transport equation [24-31]

Figure 6 shows the geometric shape of the tower.

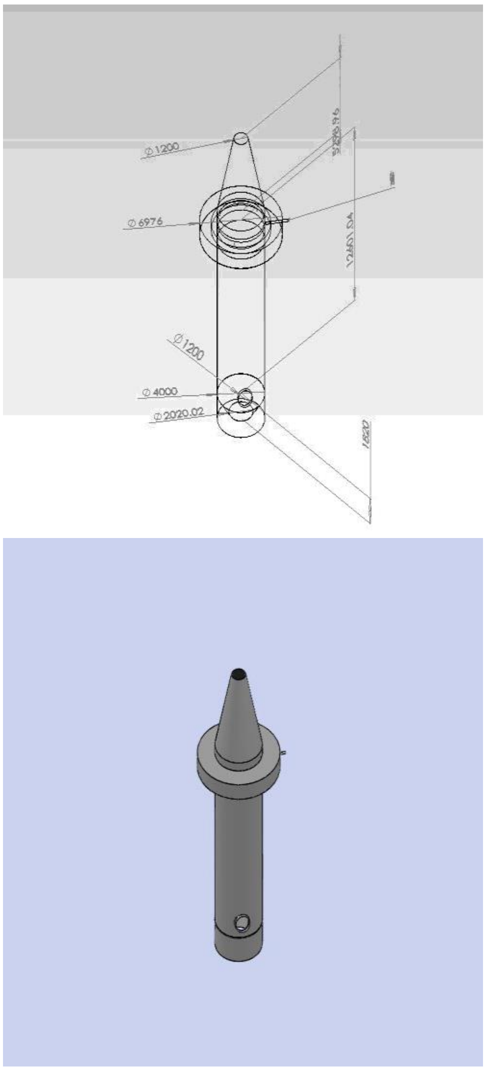

Figure 6. Cooling tower dimension

The governing equations are:

Continuity of moisture air:

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

Continuity of water:

$$\frac{\partial(\rho_w u_w)}{\partial x}=m_v$$

The air momentum equation in x direction:

$$\begin{aligned}&\frac{\partial}{\partial x}(\rho uu)+\frac{1}{r}\frac{\partial}{\partial r}(\rho r v u)+\frac{\partial}{\partial x}\left(\mu_{eff}\frac{\partial u}{\partial r}\right)\\ &-\frac{1}{r}\frac{\partial}{\partial r}\left(r\mu_{eff}\frac{\partial u}{\partial r}\right)=\frac{\partial p}{\partial x}-f_x-(\rho-\rho_{amb})g\end{aligned}$$

The air momentum equation in r direction:

$$\frac{\partial}{\partial x}(\rho uu)+\frac{1}{r}\frac{\partial}{\partial r}(\rho r v v)+\frac{\partial}{\partial x}\left(\mu_{eff}\frac{\partial v}{\partial r}\right)-\frac{1}{r}\frac{\partial}{\partial r}\left(r\mu_{eff}\frac{\partial v}{\partial r}\right)=\frac{\partial p}{\partial r}-f_r$$

Energy conservation of air:

$$\frac{\partial}{\partial x}(\rho u h)+\frac{1}{r}\frac{\partial}{\partial r}(\rho r v h)+\frac{\partial}{\partial x}\left(\Gamma_{eff}\frac{\partial h}{\partial x}\right)-\frac{1}{r}\frac{\partial}{\partial r}\left(r\Gamma_{eff}\frac{\partial h}{\partial r}\right)=q_v$$

Mass conservation of moisture in the air:

$$\frac{\partial}{\partial x}(\rho u f)+\frac{1}{r}\frac{\partial}{\partial r}(\rho r v f)+\frac{\partial}{\partial x}\left(\Gamma_{eff}\frac{\partial h}{\partial x}\right)-\frac{1}{r}\frac{\partial}{\partial r}\left(r\Gamma_{eff}\frac{\partial f}{\partial r}\right)=m_v$$

Energy conservation of water:

$$\frac{\partial}{\partial x}(\rho_w u_w h_w)=q_v$$

3.2 Cooling tower efficiency

Cooling tower thermal efficiency can be calculated as:

$$\eta_{CT}=\frac{T_{wi}-T_{wo}}{T_{wi}-T_{WB}}$$

The power water input of cooling tower ($P_{input\ (water)}$) is:

$$\begin{gathered}P_{in}=P_{out}+P_{input(water)}\\ P_{in}-P_{out}=P_{input(water)}\\ m_{air}\,C_p\,(T_{in}-T_{out})=m_w\,(h_{out}-h_{in})\end{gathered}$$

The efficiency is:

$$\eta=P_{input(water)}/(P_{in}-P_{out})$$

The humidity ratio is:

$$W=m_w/m_{air}$$

where, m_w=mass flow rate of water; m_{air}=mass flow rate of air; C_p=specific heat at constant pressure of air; P_{in}=power input of cooling tower; P_{out}=power output of cooling tower; V=Volumetric flow rate.

$$V=25\mathrm{m}^3/\mathrm{h}\longrightarrow m_{air}=1.2*25=30\ \mathrm{kg\ h\text{-}1}$$

From Eq. (2):

$$30*1.0004*250=m_w(501.73)$$
$$m_w=14.95\text{ kg h-1}$$
$$\eta=7503/7953.18=94.339\%$$
$$W=14.95/30=0.4933$$

4. NUMERICAL INVESTIGATION CFD

Solid flow CFD was used to graphical solution of the equations of mass, momentum, and energy.

"Materials and Methods"

The discretized and numerically solved three-dimensional simultaneous governing equations of mass, heat, and fluid flow were then compared with the simulation's output and observed data from the cement factory and published results from the internet .

In order to anticipate the performance characteristics of the cooling tower in the Portland cement industry, solid software was utilized as a numerical software tool. Variations in temperature, velocity, stress, and strain were simulated and compared with computing experiments.

Experimental procedures used.

Experimentally the temperature, and pressure of gaseous and its emission across the cooling tower in White Portland cement factory were measured.

"Numerical Simulation Methods" section

The temperature distribution inside the cyclone separator: - 0-700 C

The SolidWorks Software Suite gives scientists a powerful and effective means to assess data for applications while enabling optimum speed and flexibility for all types of research needs. SolidWorks analyzes a three-dimensional meshed CAD model to solve a system's flow using the finite element method.

5. RESULT AND DISCUSSION

5.1 Temperature distribution

Figures 7, 8 show the temperature distribution inside the cooling tower. As shown the temperature within the cooling tower depends on the amount of unburned fuel.

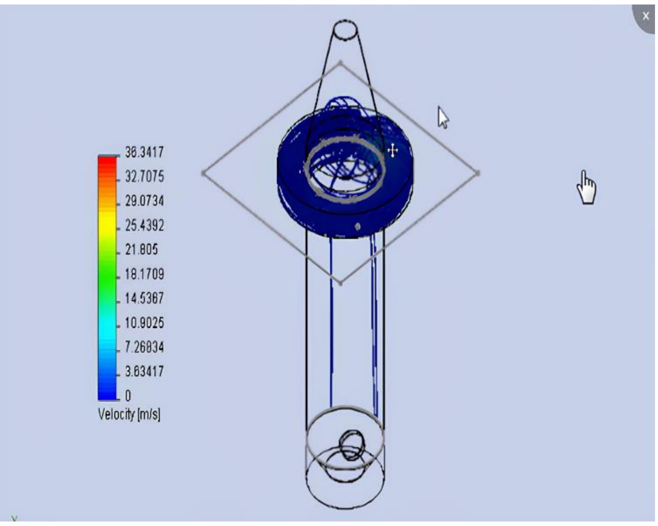

Figure 7. Water circulation inside cooling tower

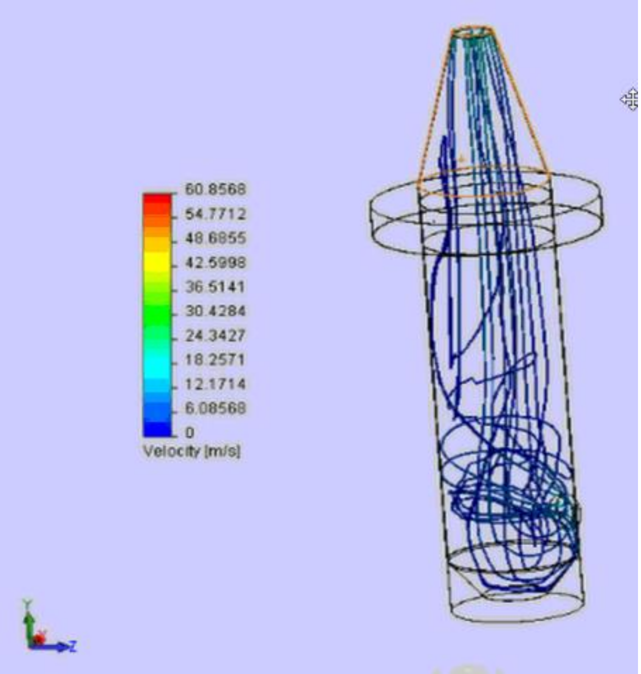

Figure 8. Streamline of air velocity

Gases from the combustion process in the furnace is pulled by (Hot Gas Exhauster) through the heat exchanger is then the distribution of these gases to the mill of raw materials, dried and gases in excess of that goes to the cooling tower which includes a cooling tower seven spraying water (spray) in the included order to cool the gas, where water comes to the cooling tower cooled by cooling tower last no near room for pumps, the cooling water going to the cooling tower of the main works to cool the gas where it is pushing the water up and compressed to be leaving an aerosol pump water multiple stages and as a result of an spray water on these gases (including some dust) is deposited to the bottom and the descent, where the process of regulating the descent of material spiral conveyor to convey these materials to either (Rotary Gate), which in turn long-dried material to the director.

The cooling characteristic coefficient rises with an increase in the temperature of the incoming water and falls with an increase in the water-air mass flow ratio.

At higher water temperatures and mass flow rates, the cooling tower rejects more heat from the process cooling water.

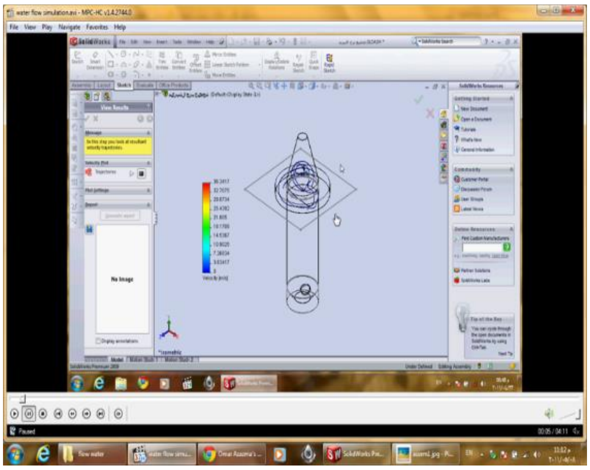

Figure 9. Water circulation inside cooling tower

5.2 Water flow simulation

Figures 7, 9 and 10 show the circulation water inside the cooling tower.

Higher air mass flow rate, lower water mass flow rate, or higher intake water temperature will all result in the optimal water cooling.

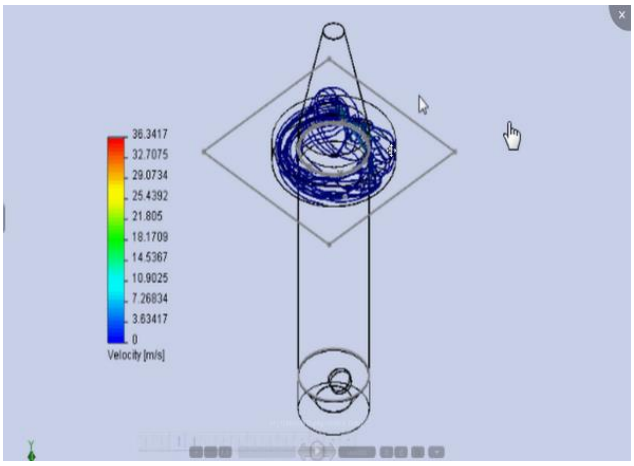

Figure 10. Water circulation inside cooling tower

5.3 Streamline for air

Figures 8, 11-13 show different view of air velocity.

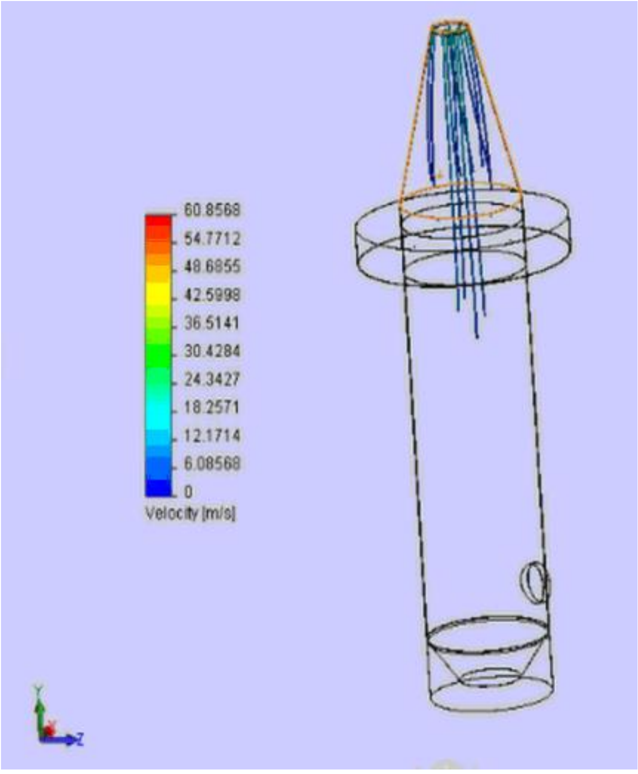

Figure 11. Streamline of air velocity

5.4 Cooling tower measurement

The temperature, pressure, and emission of gaseous matter throughout the cooling tower were measured using the portable emission analyzer Testo 350 S/M/XL, as seen in Figure 14.

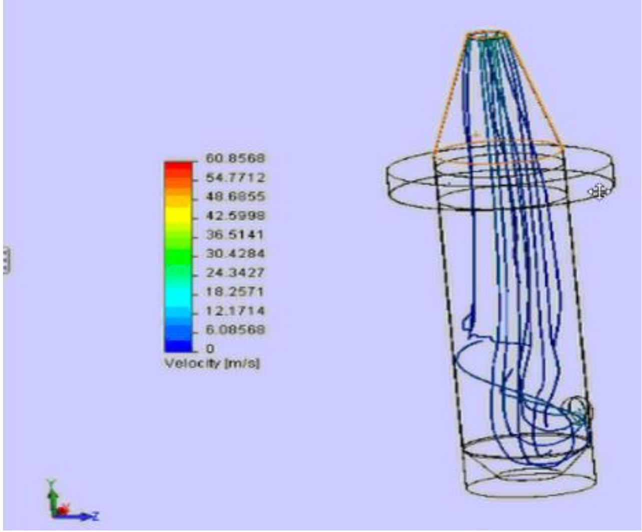

Figure 12. Pipe distribution of air velocity

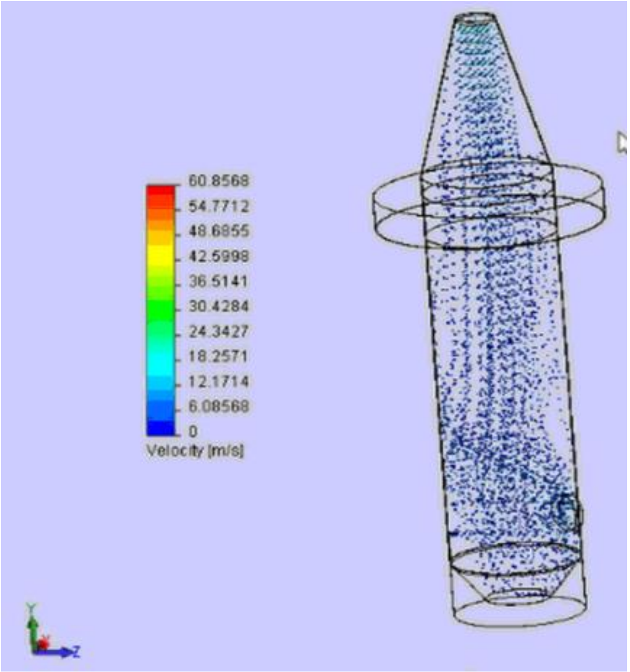

Figure 13. Sphere distribution of air velocity

Figure 14. Testo 350 S/M/XL portable emission analyzer

Finally Figures 15-17 show the measured gas temperature and pressure along the cement Portland factory.

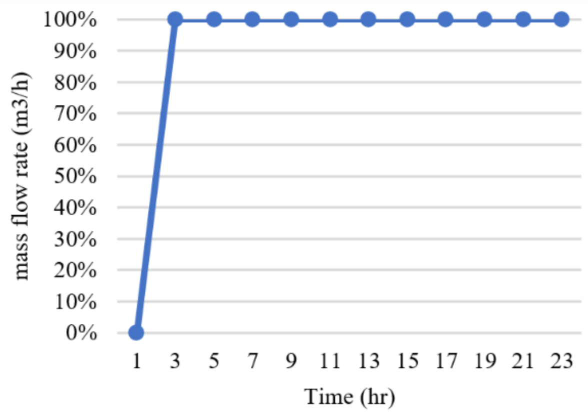

Figure 15. Mass flow rate across the cooling tower

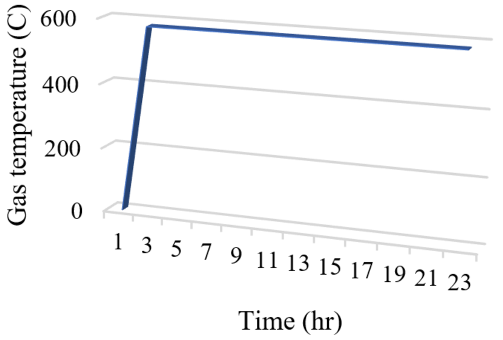

Figure 16. Gas temperature across the cooling tower

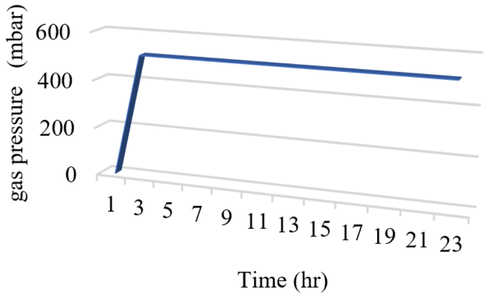

Figure 17. Gas pressure across the cooling tower

6. CONCLUSIONS

Solid flow numerical model CFD was used to simulate cooling tower performance (temperature, pressure and mechanical properties stress and strain). The following were obatined:

As air and cooling water flow rates rise, so does the overall heat transfer capacity; however, the cooling efficiency is the inverse.

As the input temperature rises, so does the cooling tower's overall heat transfer and thermal efficiency.

As the water-air mass flow ratio rises, the cooling water range and cooling tower efficiency fall, and as the intake water temperature rises, they both rise.

The result of this simulation was compared with measured data that was taken from cement factory. In general, very good agreement was obtained.

The limitations of the model & Recommendation:

- Using different type of CFD model.
- Implement an energy audit on the cooling tower to increase the whole efficiency of the Portland cement factory.
- Apply advanced environmental technique to reduce the emission gaseous increasing environmental awareness.
- Simulation of different cooling tower shape.

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NOMENCLATURE

m_w	mass flow rate of water
m_{air}	mass flow rate of air
C_p	specific heat at constant pressure of air
P_{in}	power input of cooling tower
P_{out}	power output of cooling tower
V	volumetric flow rate