Effect of Mesh Topologies to Predict Cooling Effect on Evaporative Cooling Duct

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Abstract. This paper examines the effect of different mesh types on a numerical study of evaporative cooling in the chimney. This research is a follow-up study from previous research. The test specimen used is an evaporative chimney design with the addition of a nozzle arrangement in it. The main focus of this research is the study of mesh refinement, namely by applying structured mesh during the simulation process. Three types of mesh with different levels of fineness were used for the specimens. They are coarse (mesh A), medium (mesh B), and fine (mesh C). In addition to differences in mesh, research was also carried out with variations in the level of relative humidity (RH). The RH levels used are 5, 10, and 15%. Two main parameters of evaporative cooling performance are airflow distribution and temperature drop in the chimney. Method for measuring the distribution of airflow and temperature drop in the chimney by making five planes with different heights. The results showed that the simulation with mesh B produced a good agreement data with previous studies than mesh A and C. The RH level that generated the most optimal cooling is found at 5% RH.

Keywords: chimney, evaporative cooling, mesh, numerical study, temperature.

1. Introduction

The comfort level of a building is influenced by several aspects. Among those aspects, one of them is thermal comfort related to air circulation inside it. Nowadays, there are many devices employed to generate good air circulation and environmentally friendly such as windows installation as natural ventilation in the building [1] [2] [3] [4], heating, ventilation and air conditioning (HVAC) [5], and evaporative cooling tower which used to catch airflow around the building [6]. A multi-stage down-draft evaporative cool tower (DECT) is an air conditioning mechanism in buildings with catch the wind flows that pass through the building [7] [8] [9]. DECT is very environmentally friendly and does not require electricity to use [8]. Another technology developed by the researchers is an energy-efficient and pollution-free cooling system, called indirect evaporative cooling (IEC) [10], wind tower [11], and passive cooling system [12].

To create a more optimal cooling effect at the evaporative cooling tower modified by adding other components such as water spray by the nozzle [13]. This water spray gives a better cooling effect. The
nozzle addition as a component of the evaporative cooling has been carried out by many previous researchers both experimentally and computationally [14] [15] [16]. Georges and Buchlin [17] carried experiments using a single nozzle on evaporative cooling in the chimney. A simulation study was conducted by Gant [18] by using a single nozzle in the water misting process. The study focused to observed the thermal energy and momentum transfer that occurs in the surrounding air. The results of Gant’s research were identical to those of Georges and Buchlin. Experiments study also done by Pearlmutter about evaporative cooling with the addition of a water spraying system in the chimney [19] [20]. The results show that the most optimal cooling occurred when the water spray has a little intensity with smooth misting.

The cooling effect is also influenced by the number, type, and nozzles arrangement [21] [22] [23] [24]. Tambur and Guetta [25] conducted research using two types of nozzles, namely BETE PJ32 and TF6. The orifice diameter of each nozzle has been modified by the total modified of it is 16. The results obtained that the PJ32 nozzle produces a better spray than TF6 at the same surface area per unit volume. Sarjito [26] researched the number of nozzles and the arrangement of the nozzle positions for the most optimal cooling effect in the evaporative chimney. The simulation research carried by Sarjito et al. [27] focused on the differences of number and nozzles arrangement to the cooling effect in the evaporative chimney. The results showed that the nozzle configuration with 8 nozzles at the top of the chimney and 3 nozzles with a height of 3.5 m from the bottom of the chimney produced the optimal temperature reduction and mass flow rate. The humidity level also influences of evaporation cooling effect [23].

Referred to research conducted by Sarjito et al. [27], in this study, a refinement mesh study was carried out by applying a structured mesh to evaluate the cooling effect in the evaporative chimney. Two main parameters of evaporative cooling performance are airflow distribution and temperature drop in the chimney. The results of this study are then compared with the founding data carried by Sarjito et al. [27].

2. Methods

The research was conducted in two steps. The first step is to make the geometry of the evaporative chimney, according to Sarjito’s research [27]. The next step is the meshing process of the specimens using the Gambit meshing tools. Then the simulation process is carried out by adopting the structured mesh that has been made before.

2.1. Making the Geometry

This process is carried out to ensure that the test specimens conform to the geometry used in Sarjito’s research. The specimens used in this study are tubular, as shown in Figure 1. Chimney diameter (D) = 3 m, height (Lo) = 4 m, nozzle diameter (do) = 0.00625 m, nozzle length (lo) = 0.05 m, the injection centre is located at 0.01 m from the tip of the nozzle with the nozzle spray angle (θ) is 30 degrees.

Figure 1. The dimensions of evaporative chimney. [27]
2.2. **Meshing Process**

The structured mesh is created using the Gambit meshing tool. Three types of mesh i.e coarse mesh (mesh A), medium (mesh B), and fine (mesh C), were used in this study. The differences between each mesh are shown in Figure 2. The characteristics of each mesh model are shown in Table 1. The use of structured mesh is the main focus of this research. The use of structured mesh provides the same size for each element so that the number of nodes and cells is less than the unstructured mesh. Structured and unstructured meshes have their advantages and disadvantages. The superiority of structured mesh is that we can determine the size of each element so that each cell tends to have the same size. While the limitation of structured mesh is that the meshing process takes a long time compared to unstructured mesh. Hereafter the superiority of unstructured mesh is that the meshing process is so simple. This is because the geometry of the element is automatically determined by the system. While the limitation is that the meshing results have different element sizes and produce many cells when used in complex shapes.

![Meshes A, B, and C]  
**Figure 2.** Meshing.

| No | Type mesh | Nodes    | Elements |
|----|-----------|----------|----------|
| 1  | Mesh A    | 63005    | 50000    |
| 2  | Mesh B    | 104091   | 100000   |
| 3  | Mesh C    | 327626   | 312500   |
| 4  | Sarjito et.al | 348068 | 2016345 |

2.3. **Domain and Boundary Conditions**

The domain and boundary conditions used in this study refer to research conducted by Sarjito et al. [27]. The top of the chimney is “opening” with the intake air temperature of 30°C, on the chimney cover is “wall-free slip adiabatic”, and at the bottom of the chimney is “outlet” with a pressure of 0 Pa. The exiting water velocity from the nozzle is 21.57 m/s with a temperature of 10°C. In this simulation k-epsilon, the turbulent model was applied, which represent the average turbulent flow condition the domain and boundary conditions of the test specimen shown in Figure 3.
2.4. Nozzle Configuration
The nozzle configuration used is 8 nozzles at the top of the chimney and 3 nozzles with a height of 3.5 m from the bottom of the chimney. The nozzle configuration is shown in Figure 4.

2.5. Measurement Position
A total of five planes with different heights were used as measurement positions to analyze the airflow distribution and temperature drop in the evaporative chimney. The five measurement positions are shown in Figure 5.

3. Results and Discussion
3.1. Mesh Validation
The mesh validation is shown in Figure 6. The simulation results used in mesh B produce consistent data with the results conducted by Sarjito et al. [27]. It is shown by the identical trend graph, while the
simulation results are under prediction from previous studies. The discrepancy between the prior research was 0.093%.

The simulation results using mesh A and C do not match with the reference data by the previous researcher. In measurement positions, 1 and 2 occurred “under-prediction”. At measurement positions 4 and 5 occurred “over-prediction” only at measurement position 3 has the same value as the reference data. The difference in simulation results using mesh A and C against the previous studies was 0.094% and 0.083%, respectively. Based on the results, it shows that the difference in level mesh smoothness affected the simulation results. Furthermore, mesh B was used to analyze the cooling performance in the evaporative chimney.

![Figure 6. Temperature distribution.](image)

3.2. Airflow Velocity Distribution in the Chimney

Figure 7 shows the velocity distribution of the airflow in the chimney at each measurement position. Mesh B gave consistent data with reference data conducted by Sarjito et al. [27]. Similar trends occurred at positions 1 to 4 only at position 5 occur striking diversity. The discrepancy with prior research is 20.55%.

The simulation results with mesh A and C produce a similar trend. The results obtained an "under-prediction" to the reference data. The discrepancy to the reference data is 24.27% (mesh A) and 28.96% (mesh C).

![Figure 7. Velocity distribution.](image)

3.3. The Effect of RH level on Evaporative Cooling Performance

The difference in RH level affect the evaporative cooling performance. In this study, the RH levels used 5, 10 and 15%. RH can be calculated using the following equation.

$$RH = \frac{P(H_2O)}{P'(H_2O)} \times 100\% \quad (1)$$
Table 2 shows the data from the calculation of RH levels with variations in temperature differences.

**Table 2. RH level calculation.**

| Temperature (°C) | RH 5%    | RH 10%   | RH 15%   |
|------------------|----------|----------|----------|
| 0                | 0.0002   | 0.0004   | 0.0006   |
| 5                | 0.0003   | 0.0005   | 0.0008   |
| 10               | 0.0004   | 0.0008   | 0.0011   |
| 15               | 0.0005   | 0.0010   | 0.0016   |
| 20               | 0.0007   | 0.0014   | 0.0022   |
| 25               | 0.0010   | 0.0019   | 0.0029   |
| 30               | 0.0013   | 0.0026   | 0.0039   |

Figure 8 shows the effect of RH differences on the temperature distribution inside the evaporative chimney. Based on the results, the differences in RH levels affect the temperature distribution. RH level of 5% with the highest temperature of 303.14 K (29.99°C) and the lowest temperature of 300.49 K (27.34°C), there was a decrease in temperature in the lowest plane of 2.65°C. RH level of 10% with the highest temperature of 303.14 K (29.99°C) and the lowest temperature of 300.59 K (27.44°C), there was a decrease in temperature in the lowest plane of 2.55°C. RH level of 15% with the highest temperature of 303.14 K (29.99°C) and the lowest temperature of 300.69 K (27.54°C), there was a decrease in temperature in the lowest plane of 2.45°C. Based on this analysis, it can be seen that the cooling effect decreases with increasing RH. This is because the higher RH indicates the water vapour content in the air is high. Hence the impact of water spray from the nozzle is less influential because there is a natural temperature drop of air in the chimney.

**Figure 8.** Effect of RH

4. Conclusion
The mesh refinement study on cooling simulations in the evaporative chimney has been completed. The temperature drop and airflow cooling distribution in the evaporative chimney are the focus of this research. The three types of mesh produced different simulation results. Based on the validation results, mesh B provides consistent data with the results of previous studies, both in temperature drop and airflow distribution in the chimney. Of all the mesh types used, it can be concluded that mesh B produces good agreement results to the previous data compared to mesh A and C. The study of mesh refinement on evaporative cooling in the chimney gave consistent results with the data of previous
researchers. In the future, this research can be developed by varying the position and direction of the nozzle spray, i.e. horizontal, diagonal or setting a certain angle.

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