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Performance analysis cooling tower type induced draft with PVC plate fillingmaterial

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Abstract

In the industry, savings in water use are needed, so that the output water from the condenser will be recirculated for reuse so that it does not need new water. The output of the condenser, which is hot water with a temperature of 45 °C, needs to be conditioned to a normal temperature. So they designed a cooling tower to reduce the temperature of the hot water through direct contact with the air. Filling material is a component that is very influential on the performance of the cooling tower because, in this material, there is direct contact between hot water and dry water in opposite directions. The purpose of this study was to determine the height of the PVC plate filling material that has adequate effectiveness so that the hot water in the cooling process runs optimally. In this study, several tests were carried out that showed the performance of the cooling tower, including range, approach, cooling effectiveness, cooling capacity, and the rate of evaporation of water into the air. So from this research, it was found that the optimal height of fill material is 20 cm, which has the highest relative humidity (RH) of the outgoing air, which is 87.2%, and the lowest exit air temperature of 29.3°C

Keywords:
cooling tower, filling material, relative humidity, temperature

1 Introduction

A cooling tower is a type of heat exchanger that uses contact with air from below or direct contact to cool heated water. Hot water sends a tiny amount of heat to the dry air when it comes into touch with it. A small amount of water is evaporated by this heat, which is then sucked up by the suction fan and released into the atmosphere [1]. In order to utilize the hot water output from the condenser, cooling towers are typically used in the industrial sector [1]. The cooling tower's main job is to remove heat that has been absorbed by the water circulation in the cooling system. A plant that relies solely on circulating cooling water without a cooling tower will release warm water into a nearby lake or river, harming the ecosystem [2].

Cooling towers come in a variety of designs, such as forced and induced draft. In this study, hot air produced in the cooling tower by direct contact with dry air and hot water is drawn to the tower's top and then released into the atmosphere [3].

High-temperature water is utilized in cooling towers to transfer mass and heat energy to cooling air. The filler material does not aid in the cooling of the water, but it does provide a site in the cooling tower where hot or hot and dry water can come into contact with one another. As a result, the filler material must be strong, light, and heat resistant [4]. Performance of cooling towers is frequently discussed in terms of approach and range. The range is the difference in temperature between the cooling tower's hot and cold water, or incoming and outgoing air, while the approach is the difference between the cooling tower's cold water and the ambient air at its wet bulb temperature [4].

The temperature at which wet gauze is applied to the ball is referred to as the "wet bulb temperature." The thermometer will read a lower temperature if water vaporizes from the gauze. Furthermore, a climate-controlled space's temperature, humidity, and airflow are three crucial factors in figuring out how comfortable a cooling system is to use [6]. The cooling tower functions as a kind of heat exchanger by transferring heat from the cooling water of the condenser to the surrounding air [7]. The effectiveness of a heat exchanger is dependent on the type of fluid flow and the fluid that passes through it [8].

The cooling tower with induced draft was evaluated in this study to evaluate its performance before being used. The framework of the cooling tower was built in stages, including the selection of the cooling tower frame, suction fan, and sprinkler pipe, before the performance of the cooling tower in this study was tested. After the cooling tower has been properly built, performance testing and calculation analysis are done to assess how well it will work.

2 Research method

A cooling tower is a heat exchanger that uses water and air as the working fluids. Its function is to cool down the water by coming into direct contact with the air, which causes a little amount of water to evaporation and discharge into the atmosphere [9]. Additionally, the water basin will house the process water. The release of heat and the transfer of heat from water to air are essential for the cooling tower to function. In cooling towers, some water is evaporated into moving air and then released into the atmosphere, significantly cooling the remaining water [10]. The hot water emerges from the spray nozzle holes, sinks to the bottom, and then directly contacts the dry water that has just surfaced as seen in Fig.1.

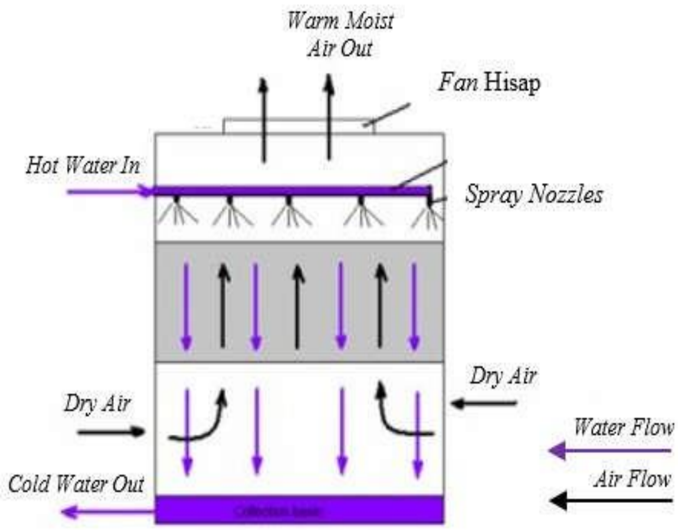

Fig. 1. Cooling Tower

Hot water will transmit part of its heat to dry air when they come into contact, which will then be sucked in by the fan and released into the atmosphere [1]. The Cooling Tower Induced Draft Counterflow Type [11] relies on cooling water flowing against the Cooling Tower's circulation. Cooling Tower has several components such as: fun suction, PLC nano V5.2, pump, water basin, filling material and sprinkler pipe.

2.1 Fan suction

The fan is positioned close to the cooling tower's exit, pulling air from the side, drawing it up the cooling tower, and releasing it into the atmosphere [12].

Since it is in charge of sucking hot air from the exchange of dry air and hot water, the suction fan is the most crucial part of a cooling tower. Air is drawn in and released into the atmosphere by a suction fan. The area for air intake is situated around the tower before the basin water in the prototype induced draft cooling tower type. [1,] Dry air or air is automatically drawn in when the suction fan is turned on.

2.2 PLC Nano V5.2

A PLC Outseal Nano V5.2 serves as the primary controller in the Cooling Tower prototype. For the relay to operate the pump, the PLC sends signals. The controller also works to activate the BTS7960 driver module, which activates the suction fan. Fig.2 shows PLC Outseal Nano V5.2.

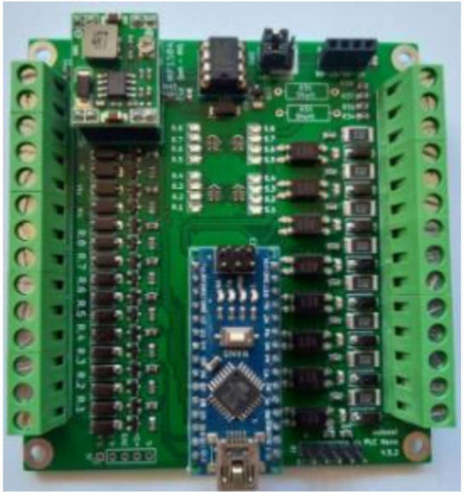

Fig. 2**.** PLC Nano V5.2.

2.3 Pump

In this prototype, fluid is moved from the Hot Water Tank inlet to the Cooling Tower intake using a centrifugal pump with an AC motor driven by AC electrical energy.

2.4 Water basin

Before being used again for the subsequent procedure, the cold water that drips from the fill material is collected in the water basin. Typically, zinc is used to make water basins [1].

2.5 Filling material

In order to maximize air and water contact and slow the velocity of falling water, filler material is employed in cooling towers [13]. The movement of mass and thermal energy from hot water to cool air is necessary for a cooling tower to function. The filler material is not absolutely necessary, but it is a position in the cooling tower that makes it easier for hot or falling water to come into touch with dry water. As a result, the filler material needs to be strong, light, and heat resistant [13].

2.6 Sprinkler pipe

A sprinkler pipe is a conduit that circulates hot water from the condenser to the top of the Cooling Tower so that heat transfer from water can operate successfully and efficiently [1].

The method employed in this study is a quantitative research method because the gathered data are numerical. Methods of qualitative research place a greater emphasis on the outcomes of experiments or field tool tests [14]. Several stages will be completed in this research, including [4] the following:

1. Determine the airflow capacity of the Fan

By measuring the airflow velocity with an anemometer, the maximum airflow capacity of the fan can be determined. Therefore, the maximum air flow capacity of the fan can be calculated by multiplying the cross-sectional area (A) by the airflow velocity (v). From the findings of an anemometer measurement of air flow velocity. The airflow velocity measured by the anemometer is 5.5 meters per second, and the diameter of the fan is 30 centimeters or 0.3 meters, hence the maximum air flow capacity of the fan may be calculated using by the Eq.(1).:

$$V_{max} = A \text{ x } v = \frac{1}{4} \, x \, \pi \, x \, D^2 \, x \, v \tag{1}$$
$$= \frac{1}{4} \, x \, 3{,}14 \, x \, (0{,}3)^2 \, x \, 5{,}5$$
$$= 0{,}26 \, m^3/s = 572 \, cfm \, (ft^3/min)$$

2. Determine the range of the Cooling Tower

The Cooling Tower prototype is anticipated to be able to cool hot water from 45°C to approximately 38°C. Thus, the highest temperature range determined for this Cooling Tower study is between 38°C and 45°C, or 7°C.

3. Determine the flow rate of the Cooling Tower water distribution

According to the flow rate recorded by the flowmeter placed at the Cooling Tower inlet, the water flow rate for the cooling tower is regulated. The Water Flow Sensor FS300A (Fig.3), which is mounted on the inflow pipe and has a maximum capacity of 30 liters per minute, is utilized in this investigation. Water flow meter sensor FS300A can be seen in the Fig.3.

Fig. 3**.** Water Flow Sensor FS300A

4. Cooling Tower construction design

a. Construction

The design of the Cooling Tower is based on the Induced Draft Counterflow type Cooling Tower construction. The normal upper limit for Cooling Tower Counterflow air velocity is between 1.5 and 3.6 meters per second [15]. In this study, the air velocity within the Cooling Tower is determined to be 2,4 meters per second. So as to calculate the Cooling Tower's base area (Eq. (2)) [2].

$$Q_{tower} = Q_{fan} \tag{2}$$
$$A_{tower} \, x \, v_{aliran\,udara\,Cooling\,Tower} = A_{fan} \, x \, v_{fan}$$
$$A_{tower} \, x \, 2{,}4 \, m/s = \left(\frac{1}{4} \, x \, 3{,}14 \, x \, (0{,}3)^2\right) x \, (5{,}5 \, m/s)$$
$$A_{tower} = 0{,}16 \text{ m}^2 = 1600 \text{ cm}$$

The square base or Water Basin of the Cooling Tower measures 40 cm on each side. When selecting the height of a cooling tower, additional considerations like sprinklers, filling materials, and others are taken into account. For the cooling tower to be able to stand upright, the support frame must be able to stabilize the cooling tower. As a result, the Cooling Tower's structure is made of 3 mm thick angle iron plate. Therefore, the Cooling Tower's height is set at 100 cm. Fig. 4. shows the cooling tower implementation.

Fig. 4. Cooling tower implementation

b. Casing

The selected casing material is a PVC plate with a thickness of 1 mm. The reason for choosing this plate as a casing material is that it has good resistance to all weather and heat resistance.

c. Water basin

To hold water for the cooling tower, this cold-water container is constructed using PVC plate material and angled iron. The Water Basin has dimensions of 40 cm in length, 40 cm in breadth, and 20 cm in height (T). Eq.(3) can be used to compute the maximum water volume in the manner described by Eq.(3). The Water Basin of the prototype temperature control system on the Cooling Tower can be seen in Fig.5.

$$\text{Volume} = p \times l \times h = 40\text{ cm} \times 40\text{ cm} \times 20\text{ cm} \quad (3)$$
$$= 32000\text{ cm}^3 = 0.032\text{ m3} = 32\text{ Liter}$$

Fig. 5. Water basin Cooling Tower

5. Sprinkler selection

The Cooling Tower prototype's sprinkler contains a feature that distributes hot water that will be cooled. The functional features were taken into consideration when selecting the springs that will be used in the cooling tower. The accompanying illustration shows the sprinklers that were installed on the cooling tower (Fig. 6)

Fig. 6. Sprinkler Cooling Tower

6. Planning for filling materials

Because it offers a sizable surface area for heat evaporation and mass transfer from hot water to ambient air, the filler material used in cooling towers is essential. The filler material, specifically its thermal performance, which accounts for 70% of the heat dissipation capacity, is said to have an impact on the efficiency factor, according to a prior study [3]. A 20 cm tall, 0.5 mm thick PVC plate is utilized as the filler material for the prototype temperature control system in this cooling tower. The Water Basin of the Cooling Tower can be seen in the Fig. 7.

Fig. 7. Filling Material Cooling Tower

3 Results and discussion.

To evaluate the performance of the induced draft Cooling Tower by adjusting the height of the filling material until the optimal height for lowering the temperature of the hot water is determined.

Considering the pump's parameters, the optimal height of the filling material is then used to determine the maximum water capacity that can be cooled. With the following details: temperature water in is 45℃, temperature water out is 38,16℃ and range 7℃

For this reason, the performance of the cooling tower design is very good affected by the ambient temperature. The parameter which affects the performance of the cooling tower, namely: ambient temperature is the ambient temperature (dry bulb and wet bulb) that will affect heat transferor performance in the cooling tower[16]. The research was carried out in the following environmental air conditions: RH_{in} = 82,2% - 75,7 %, $T_{db.in}$ = 28,4-32,8 and $T_{wb.in}$ = 25,9- 29.

The results of this test were carried out at a constant flow of 20 l/min by adjusting the valve opening at the cooling tower inlet. So that the test results can be obtained as a whole shown in Table 1[4].

The relative humidity and temperature of the outgoing air were measured using the UNI-T UT333 hygrometer thermometer, and the online psychrometric chart was used to calculate the wet bulb temperature. In addition, the air flow rate is determined by multiplying the airflow velocity by the cooling tower's mining area

.Table 1. Overall Filling Material Height Test Result

Height of filling material (cm)	RH Outlet (%)	T air outlet (°C)	T wet bulb (°C)	*T water basin* (°C)	Airflow speed (m/s)	Airflow rate (m^3/s)
16	84,8	32,4	30,1	36,89	5,7	0,91
18	86,3	31,4	29,3	37,53	5,5	0,88
20	87,2	29,3	27.4	38,04	5,4	0,86
22	84,6	30,8	28.5	39,44	5,1	0,81
24	83,9	31,2	28.8	40,33	4,8	0,7

After determining the best filling material height, it is used to determine the maximum hot water discharge that can be cooled by the Cooling Tower by modifying the Cooling Tower's valve opening until the maximum water discharge that can be cooled is determined. The overall test results are shown in Table 2.

RH_{in} = 67,4% - 63,8 %,
$T_{db.in}$ = 30,2^{0}C-32,8^{0}C and,
$T_{wb.in}$ = 25,2^{0}C- 26,9^{0}C.

Table 2. Overall Water Discharge Test Results

Water Discharge (ℓ/min)	RH Outlet (%)	T air outlet (°C)	T wet bulb (°C)	T *water basin* (°C)	Airflow speed(m/s)	Air flow rate (m^3/s)
20	87,2	29,3	27,4	38,04	5,4	0,86
25	86,9	31,4	29,4	38,04	4,9	0,78
30	84,5	31,9	29,6	38,18	4,5	0,72
34	89,8	30,6	29,1	39,05	4,1	0,65

From the acquired test results, various analyses and calculations can be performed to derive the following cooling tower performance parameters[4].

1. Approach

Based on the difference between the Cooling Tower cold water outlet temperature of 38.18℃ and the wet bulb temperature of 29.6℃. So that the approach value is calculated by Eq. (4).

Approach (℃) = Outlet water temperature (℃) – wet bulb temperature (℃) (4)
and the result is approach (℃) = 38.16 – 29.6 = 8.5℃

2. Cooling effectiveness

Effectiveness is the ratio between the range and the ideal range. Effectiveness can be calculated by the following Eq. (5).

$$\text{Effectiveness (\%)} = 100 \text{ x } \left(\frac{\text{Range}}{\text{Approach}}\right) \quad (5)$$

$$\text{Effectiveness (\%)} = 100 \text{ x } \left(\frac{6{,}84}{8{,}5}\right) = 80 \text{ \%}$$

3. Specific water discharge

By the Cooling Tower cross-sectional area of 0.16 m^2, it can be calculated the specific water discharge for each increase in air-water discharge using Eq. (6). With the same calculation method, the specific water discharge price for each increase in water discharge is shown in the Table 3. The graph of the relationship between the increase in water discharge and the specific cooling tower water discharge obtained from the test results can be seen in Fig. 8 .

$$\dot{m}_{sp} = \frac{\dot{m}}{A_{tower}} \quad (6)$$

$$= \frac{20}{0{,}16} = 125\ \ell/min/m^2$$

Table 3. The relationship between the increase in water discharge and the specific water discharge of the cooling tower

Water Discharge (ℓ/min)	Face Velocity (m/s)
20	125
25	156,25
30	187,5
34	212,5

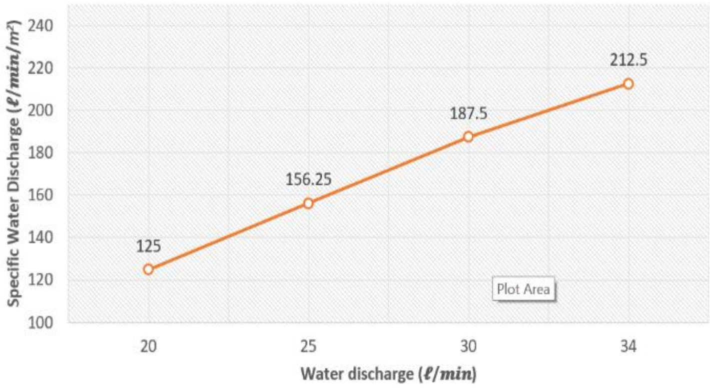

Fig. 8. The relationship between the increase in water flow and the specific cooling capacity of the Cooling Tower

4. Cooling capacity of the Cooling Tower

The cooling capacity of a Cooling Tower can be calculated by
$\dot{m}$ = 20 $\ell/menit$ = 0,34 Kg/s

ΔT= 45 ℃ – 38,16 ℃ = 6,84 ℃

$T_{average} = \frac{45 + 38{,}16}{2} = 41{,}58$

Specific heat of water (C_P)= 4200 J/Kg. K = 4,2 KJ/Kg.℃

So that the price of cooling capacity is obtained as Eq. (7).

$$Q = \dot{m}\ C_P\ \Delta T \quad (7)$$

Q = 0,34 Kg/s x 4,2 KJ/Kg.℃ x 6,84 ℃

Q = 9,76 KJ/s = 9,76 kW

Then the specific cooling capacity per unit cross-sectional area of the Cooling Tower can be calculated by Eq.(8). With the same calculation method, the price of cooling capacity for each increase in water discharge is shown in the Table 4.

$$Q_{Sp} = \frac{Q}{A_{tower}} \quad (8)$$

$$= \frac{12{,}92}{0{,}16} = 80{,}75 \text{ kW/m}^2$$

Table 4. The relationship between the increase in water flow and the specific cooling capacity of the cooling tower.

Water Discharge (ℓ/min)	Water Discharge (m/s)	*Q (kW)*	*Q_{SP} (kW/m^2)*
20	0,34	9,76	61
25	0,43	12,35	77,18
30	0,51	14,65	91,56
34	0,58	16,66	104,12

5. Air requirement

Table 5 listed Cooling Tower air demand is the actual air flow rate per unit of Cooling Tower cross-sectional area (facial velocity). It also depicts relationship between the increase in water outflow and face velocity.

Table 5. The increase in water outflow and face velocity

Water Discharge (ℓ/min)	Face Velocity (m/s)
20	5,4
25	4,9
30	4,5
34	4,1

The graph of the relationship between the increase in water discharge and the flow of air per unit cross-sectional area of the Cooling Tower obtained from the test results can be seen in Fig. 10.

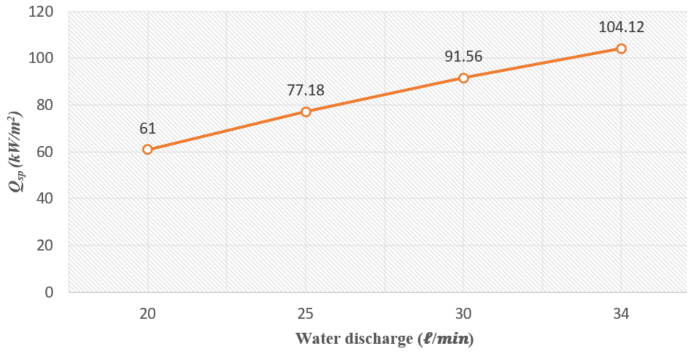

Fig. 10. The relationship between the increase in water

6. The rate of evaporation of water into the air

The rate of water evaporation into the air can be calculated based on fluctuations in the increase in water discharge and cooling tower air flow. Using an online psychrometric chart, the price of the air humidity ratio and the specific volume of ambient air may be calculated based on the conditions of the air entering and exiting the Cooling Tower, as illustrated in Tables 6 and 7:

Table 6. Ambient Air Specific Volume

Water Discharge (ℓ/min)	RH_1 (%)	T Air_2 (°C)	Vol. spec air Ambien (m^3/kg)	Airflow discharge (m^3/s)
20	87,2	29,3	0,888	0,86
25	86,9	31,4	0,898	0,78
30	84,5	31,9	0,9	0,72
34	89,8	30,6	0,896	0,65

Table 7. Cooling tower inlet and exit humidity ratio

Water Discharge (ℓ/min)	RH_1 (%)	T air_1 (°C)	ωh_1 (Kg)	RH_2 (%)	T air_2 (°C)	ωh_2 (Kg)
20	63,6	32,1	0,01934	87,2	29,3	0,022717
25	63,5	32,8	0,02111	86,9	31,4	0,025647
30	63,1	33,2	0,020449	84,5	31,9	0,025657
34	63,4	32,9	0,020195	89,8	30,6	0,025309

From the data above, the price of the evaporation rate of water is obtained using the following Eq. (9). It is known that the density of water (ρ) = 0,99285 kg/ ℓ. So, the rate of evaporation of water (ℓ /min). With the same calculation method, the rate of evaporation of water is then shown in the Table 8.

$$(\omega h_2 - \omega h_1) x \frac{\dot{v}}{\rho\, x\, v_1} x\ 60 \quad (9)$$

The rate of evaporation of water (ℓ /min):

$$(0{,}022717 - 0.01934) x \frac{0.86}{0.99285\ x\ 0.888} x\ 60 = 0.197644 l/mim$$

Table 8. The relationship between increase in water discharge and the rate of evaporation of water on the cooling tower.

Water Discharge (ℓ/min)	The rate of evaporation of water (ℓ/min)
20	0,197644
25	0,238152
30	0,251784
34	0,224199

The graph of the relationship between the increase in airflow and the rate of evaporation of cooling tower water obtained from the test can be seen in the Fig. 11.

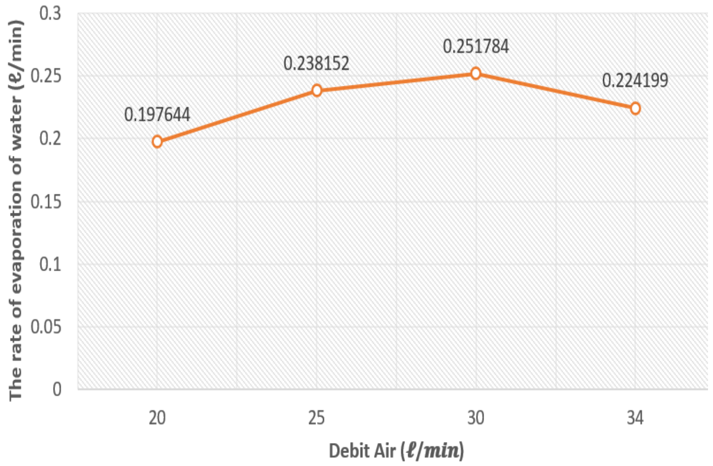

Fig. 11. The relationship between the increase in water discharge and the rate of evaporation of water on the Cooling Tower

7. Water to air ratio

The value of the water-air ratio can be obtained. It is known that the cross-sectional area of the suction fan = 0.07 m^2. So, that the ratio value can be obtained, Water-air ratio = $\frac{125}{737142{,}857}$ = 0.000224651. With the same calculation method the value of the water to air ratio shown in the Table 9. The graph of the relationship between the increase in water discharge and the Cooling Tower air-air ratio obtained from the test results can be seen in Fig. 12

Table 9. The relationship between the increase

Water Discharge (ℓ /min)	Air Discharge (ℓ/min	Specific water discharge (ℓ/min/m^2)	Specific air discharge (ℓ /min/m^2)	Water to-air ratio
20	51600	125	737142,857	0,00016957
25	46800	156,25	668571,428	0,00023370
30	43200	187,5	617142,857	0,00030381
34	39000	212,5	557142,857	0,00038141

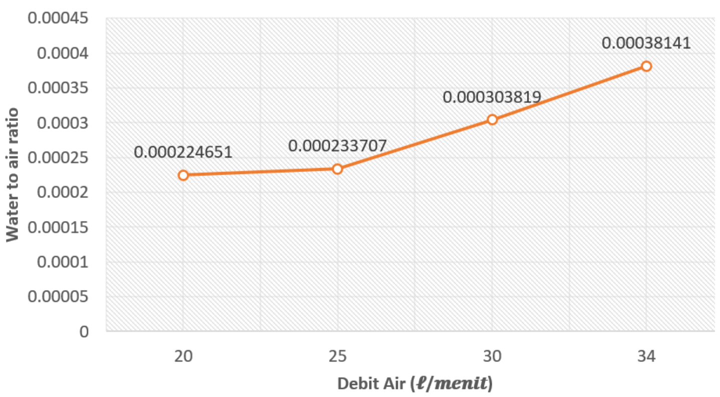

Fig. 12. The relationship between the increase in water discharge and the water-air ratio.

One of the elements that has a big impact on how well the tower refrigerant works is a filler or fill. In order to optimize the interaction between the air and the water, filler is useful for facilitating heat transmission. The filler material's shape and makeup are currently evolving to provide a reasonable level of cooling efficiency at a low production cost. Since the testing results show that the cooling tower can function well, using PVC as the filler material is appropriate. The best material height for the cooling tower is 20 cm since it offers the lowest air outlet temperature of 29.3 oC and the maximum relative humidity (RH) oultet of 87.2%. According to the test, the cooling tower can only handle 30 liters of hot water per minute since this produces the lowest approach (8.5) and cooling effectiveness (80%). Since evaporation is the main process of a cooling tower in cooling water, the rate of water evaporation into the air is one of the most important performance variables for cooling towers. The optimal rate of water evaporation into the air in the cooling tower is 0.251784 liters per minute.

3. Conclusions

1. According to tests conducted on the cooling tower, the best material height for the cooling tower is 20 centimeters because it generates the maximum relative humidity (RH) of 87.2% and the lowest temperature air outlet of 29.3oC.
2. The test reveals that the maximum amount of hot water that may be cooled by the cooling tower is 30 liters per minute, as it creates the lowest approach (8.5) and cooling effectiveness (80%).
3. Because evaporation is the fundamental mechanism of a cooling tower in cooling water, the rate of water evaporation into the air is one of the most important factors affecting cooling tower performance. The cooling tower's ideal rate of water evaporation into the air is 0.251784 liters per minute.

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