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An Efficient Cooling Tower for a Stationary Engine

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Abstract. Cooling tower is a type of heat exchanger used to dissipate the unwanted heat from a medium into the atmosphere. A well-designed cooling tower provides prolong contact time for water with air and breaks down the water to have large surface area to promote the heat transfer rate. In the present work, an induced draft cooling tower is fabricated and used with a stationary IC Engine to minimize the overall usage of water. The performance of the tower with two different bed materials (Jute carpet & Polystyrene balls) with and without wire mesh at three different water flow rates viz., 12, 18 and 30 lpm are studied. The cooling tower parameters such as range, approach, efficiency, effectiveness, heat loss, windage losses, and evaporative losses are calculated from the experimental data. At higher flow rates, jute carpets with wire mesh provided optimal results for the parameters while at low flow rates polystyrene balls are found to provide better results. The experimental results showed that the efficiency of the cooling tower increased by 67% as the flow rate increased from 12 lpm to 30 lpm with jute carpet and wire mesh, whereas the efficiency decreases as the flow rate increases with polystyrene as the bed material. Also, the similar trend is observed for the effectiveness of cooling tower.

1. Introduction

Cooling towers are the very vital part in any thermal power plants, nuclear stations, and HVAC industries since it controls the performance of the plants and hence stands ahead in deciding the economic as well as the environmental aspects of the industries. Based on the type of air movement in to the tower, they are classified as mechanical draft, natural draft and induced/fan assisted draft type cooling towers. Indeed, the cooling towers provide enthralling applications due to its very basic principle in recycling of water through the removal and transfer of heat to the atmosphere and hence preventing large amount of water being wasted [1]. In a cooling tower both heat and mass transfers happen simultaneously which makes the whole system design a complex part. In a wet cooling tower, the heat transport takes place from hot water to the air partially by sensible mode and remaining by evaporative cooling mode (latent heat or mass transfer). Out of which, evaporative cooling is the predominant mode of heat transport which contributes to a maximum thermal efficiency for the cooling tower [2]. The performance of a cooling tower can be increased by minimizing the power



requirement of the fan through some accessories like fluidized beds [3]. Additionally, louvers help in enlarging the contact area at the interface between water and air while fluidized beds enhance mixing of intake air with the water properly thereby increasing the contact time between the phases. In general, louvers are found to be from wood or plastics coated with water repellent paints while the bed materials are of marbles, jute carpets, polystyrene balls. Past studies showed that the configuration of the fluidized beds have a strong influence over the cooling tower performance [4,5]. Also, previous reports claimed that the cross-flow type cooling towers are more efficient than the counter flow type towers [6]. Cooling towers are found to be used for stationary engines for their heat removal in a view of recycling and preserving the coolant water used in the engines. It is imperative that the cooling tower should be of operationally reliable to avoid any breakdowns of such engines and in further to enable its productivity. Owing to its importance for the aforesaid application and limited studies available in the literature, in the present work, a cooling tower is utilized for heat removal from an IC Engine and its performance is studied.

The exergy of water has not been able to completely recovered by the intake air in a cooling tower, during the energy transfer process, which results a quantum of energy to remain with water [1,7]. To this effect, an optimized condition will be achieved through a proper and well-designed cooling tower with an appropriate flow rate (water & air). The load variation which is primarily during the summer conditions when the wet bulb temperature reaches the maximum necessitates a large capacity for a cooling tower and hence influences its performance. A variable speed fan in an induced draft type cooling tower could effectively handle such load variations in the tower [8]. Though the exit water temperature and the ambient air temperature together determine the effectiveness of a cooling tower, the quality of water used in the tower decides its performance over a long run [9]. Poppe method can be used to predict the draft in a geometrically designed tower and the heat transfer rate in the tower can be estimated using e-NTU approach. Additionally, analyzing the performance of a tower is made possible with wire mesh packing in different orientations [10–12]. In circulating water systems, the economic and the technical benefits of cooling tower is directly affected by the loss of quantity of water [13]. Literature shows that any value of liquid-gas ratio between 0.3 and 0.8 would result a better performance for a cooling tower [14]. Also, the inlet temperatures of water and air and the mass flow rates are found to have significant role on the performance of a cooling tower. The tower design must include provision to prevent the backflow of exhaust air in to the tower, which is considered to be harmful causing reduction in cooling capacity in warm condition and icing of intake air in cold condition. In large scale, an improper design parameter and surrounding buildings lead to backflow situations to a cooling tower [15, 16]. Generally, selecting wet cooling towers as the choice of cooling system for any application should consider the power output, industrial type, thermodynamic parameters, and techno-economic conditions [17]. Furthermore, one such tower will be more sensitive to the wind and the sensitivity is proportional to its height. Also, the height of the tower determines the grid structure to ensure the safety and viable situation [18]. Several other parameters such as cooling range required, approach to wet bulb temperature, mass flow rate of water, air velocity also have significant role over the tower design [19]. Furthermore, the heat and mass transfer characteristics that a cooling tower establishes in the contact zone and in the rain zone determine its performance [20].

Until now the investigations on the reliability of cooling towers for stationary engines are limited. Henceforth, the present work aims at designing and studying the operational reliability of a cooling tower with an IC Engine and to understand the significance of various parameters on the cooling tower performance. For the experimental investigations, a small-scale cooling tower is designed and fabricated following the rules adapted in literatures.

2. Experimental Methodology

To investigate the effectiveness of a cooling tower for a stationary engine, an experimental setup (cooling tower) is built and utilized for cooling an 8 HP internal combustion (IC) Engine. The schematic of the experimental arrangement of the compact cooling tower with its water loop is shown in Figure 1 and its specifications are provided in Table. 1. The hot water at the engine outlet is collected at first, in a tank, which is then pumped at the top of the tower through connection pipes. The hot water is sprayed on to the tower louvers through nozzles which help in breaking down the liquid and increasing the contact surface area of the liquid water, thereof. As the hot water trickles down, it contacts with the air which is in the inhalation by the fan, fixed at the top of the tower. Since the average temperature of the inlet water of the tower is 55°C, portion of water is believed to be evaporated along with the air, which is also conformed during the experiments.

Table 1: Specifications of the cooling tower

Part	Specification
Frame	Mild Steel/ 20 mm sq. tube/ (800 x 700 x 800)mm
Louver Hangers	Mild Steel/ 16 no's/ 10 mm sq. rod, 5 mm Strip (800 mm & 700 mm)
Collection tank	Galvanized Iron/ 2 mm sheet/ (800 x 700 x 200) mm
Louvers	Plywood/ 16 no's/ Plywood coated with water repellent
Exhaust Fan	9"/ Sweep: 230 mm/ 2500 rpm/ 100 W
Pump	0.5 HP/ 2800 rpm/ Head: 25 m/ 1620 lph
Pipes	20 mm Plastic Pipes
Bean Balls	6-8 mm Diameter Balls
Jute Carpets	2 no's/ (900 x 550) mm
Digital Thermometer	Range: -50 to +110°C/ $\pm 1^\circ\text{C}$ / 0.01°C
IR Thermometer	Range: -30 to +500°C/ $\pm 1.5^\circ\text{C}$ / 0.1°C

Henceforth, makeup water is supplied to the loop at constant interval. One-inch MS square tubes are used to construct the frame using MIG welding process. GI sheet is welded at the bottom of the tower to collect the cold water. The wooden louvers are coated with water resistant paints to minimize the corrosion effects of water. Louvers help to make the interaction between the water molecules and ambient air longer; thereby it enhances the convection heat transport and reduces water temperature further. The water circuit is made across the tower with PVC pipes of 20 mm size. The ambient air is pulled inside the tower and towards the top using an exhaust fan of 230 mm sweep, installed at the tower top.

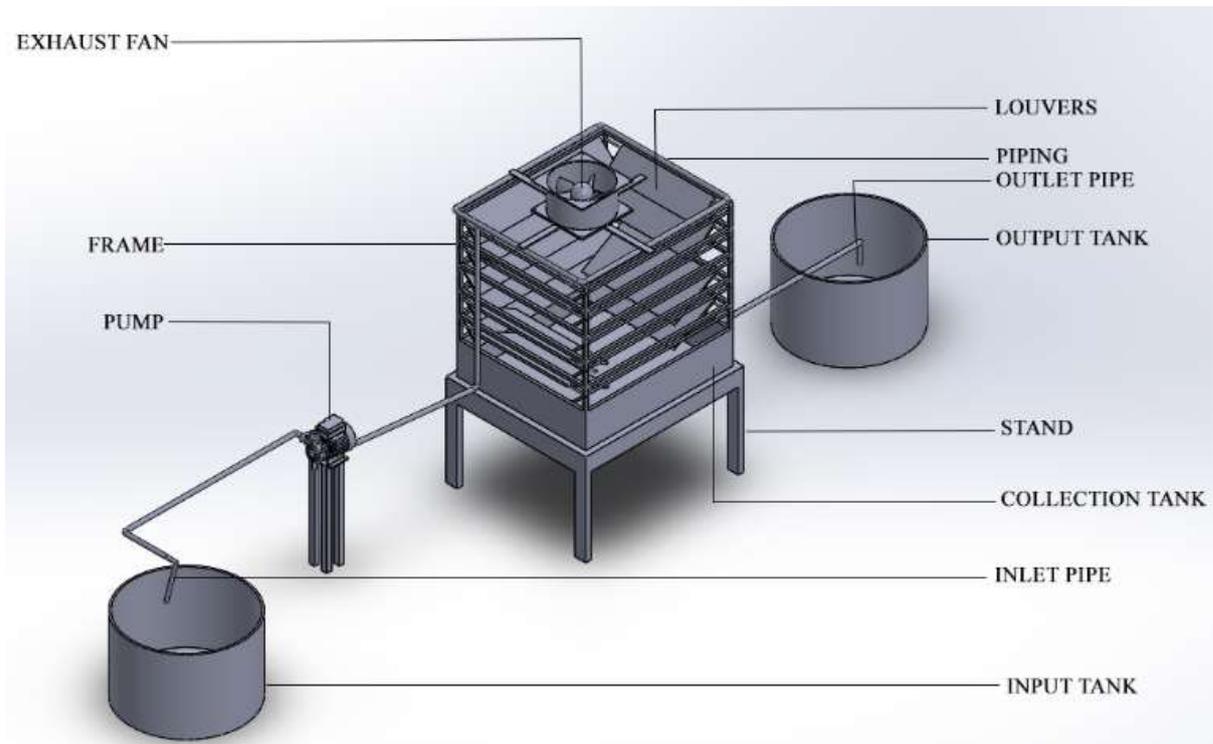


Figure 1: Schematic of the experimental setup

In the present study, the mass flow rates of water (12, 18 and 30 lpm) and air are assumed to be of constant, neglecting small variations in their magnitudes. Jute carpets and Polystyrene balls are used as the bed materials to filter the water and the accumulated cold water is transferred to the sump through pipes by means of gravity.



Figure 2. Experimental setup (Cooling Tower)

Temperatures at various locations are measured using a digital non-contact IR gun thermometer. Figure 3. shows the graphical representation of the experimental method followed in the present work.

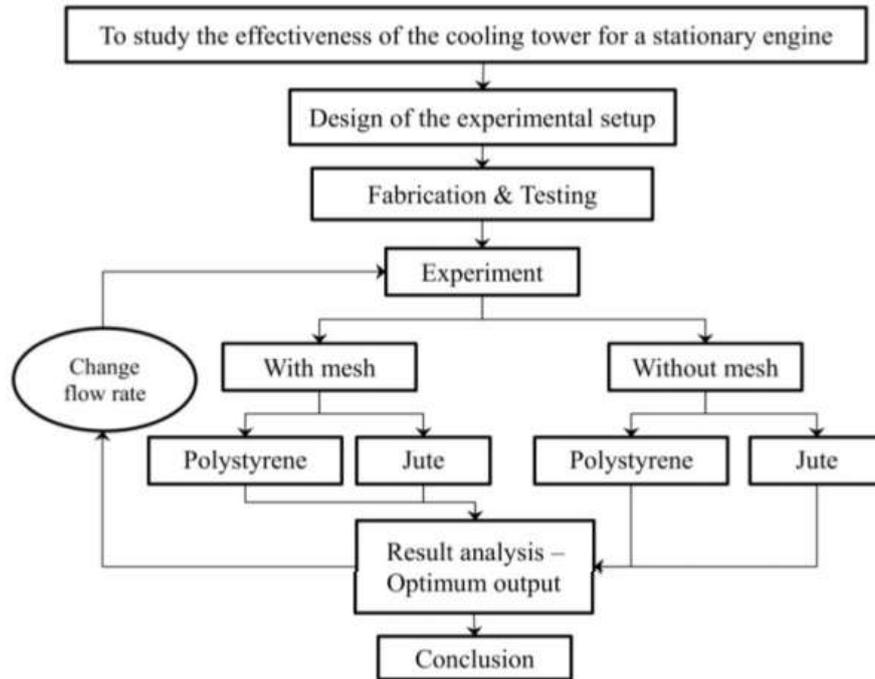


Figure 3. Schematic of the experimental procedure followed in the work

3. Results and Discussion

The experiments are conducted for various flow rates and materials. Three different flow rates in 4 configurations (2 different materials with and without wire mesh) are analyzed. Water inlet, outlet, air intake and wet bulb temperatures are measured for each combination of flow rate and material. Then windage losses, evaporative losses, range, approach, efficiency, effectiveness and heat loss by water are calculated.

3.1. Measured Values

Table 2 shows the measured values of water and air temperatures at various flow rates and materials of the cooling tower. The results shown below contains both inlet and outlet temperatures of the water of cases like using Jute carpet and Polystyrene balls and both these materials used with and without mesh.

Table 2: Temperatures measured during the Experiment

S. No	Flow rate (lpm)	Entity		Temperature (°C)			
				Water Inlet	Water Outlet	Air Inlet	Wet Bulb Temp
1	30	With mesh	Jute	57	43.6	33	30
2			Polystyrene balls	58.8	46	33	30
3		Without mesh	Jute	55	46	33	30
4			Polystyrene balls	57	49.8	33	30
5	18	With	Jute	55	46.1	33	30

6	12	mesh	Polystyrene balls	55	45.8	33	30
7		Without mesh	Jute	55	47.5	33	30
8			Polystyrene balls	55	46.9	33	30
9		With mesh	Jute	55	47.5	33	30
10			Polystyrene balls	55	46.5	33	30
11		Without mesh	Jute	55	47.2	33	30
12			Polystyrene balls	55	46.5	33	30

Low flow rate shows no significant effect on reduction in temperature either with mesh or without mesh. Medium flow rate shows marginal temperature drop for both materials without mesh but shows better performance with mesh compared to without mesh in both the cases. High flow rate shows better temperature drop and jute material with mesh shows highest temperature drop among 4 combinations.

3.2. Windage losses and Evaporative losses

Windage loss is loss of water to the atmosphere due to exhaust air. Windage loss is assumed to be of 0.5% loss of the flow rate of water, which is independent of materials used. Windage loss and evaporative loss for the present experiment conditions are estimated using Eqns (1) and (2) and the values are provided in Table 3.

$$\text{Windage loss, } W_L = 0.005 \times m_{w1} \tag{1}$$

$$\text{Evaporative loss, } E_L = 0.00085 \times m_{w1} \times (T_1 - T_2) \tag{2}$$

Where, m_{w1} is mass flow rate of water in kg/hr, T_1 is inlet temperature to cooling tower and T_2 is outlet temperature from cooling tower.

Table 3: Windage and evaporative losses

S. No	Flow rate (lpm)	Entity		Windage Losses (kg/hr)	Evaporative Losses (kg/hr)
1	30	With mesh	Jute	9	20.502
2			polystyrene Balls	9	19.584
3		Without mesh	Jute	9	13.77
4			polystyrene Balls	9	11.016
5	18	With mesh	Jute	5.4	8.1702
6			polystyrene Balls	5.4	8.4456
7		Without mesh	Jute	5.4	6.885
8			polystyrene Balls	5.4	7.4358
9	12	With mesh	Jute	3.6	4.59
10			polystyrene Balls	3.6	5.202
11		Without mesh	Jute	3.6	4.7736
12			polystyrene Balls	3.6	5.202

3.3. Range and Approach

In the present work, the performance assessment of the cooling tower is done by determining the metrics such as the range, approach, efficiency and effectiveness of the tower and it is estimated using Eqns (3) to (6).

$$\text{Cooling Tower Range, } CTR = T_1 - T_2 \tag{3}$$

$$\text{Cooling Tower Approach, } CTA = T_2 - T \tag{4}$$

$$\text{Efficiency, } \eta = \frac{T_1 - T_2}{T_1 - T} \tag{5}$$

$$\text{Effectiveness, } \varepsilon = \frac{T_1 - T_2}{T_1 - T_a} \tag{6}$$

Where, T is wet bulb temperature and T_a is atmospheric temperature

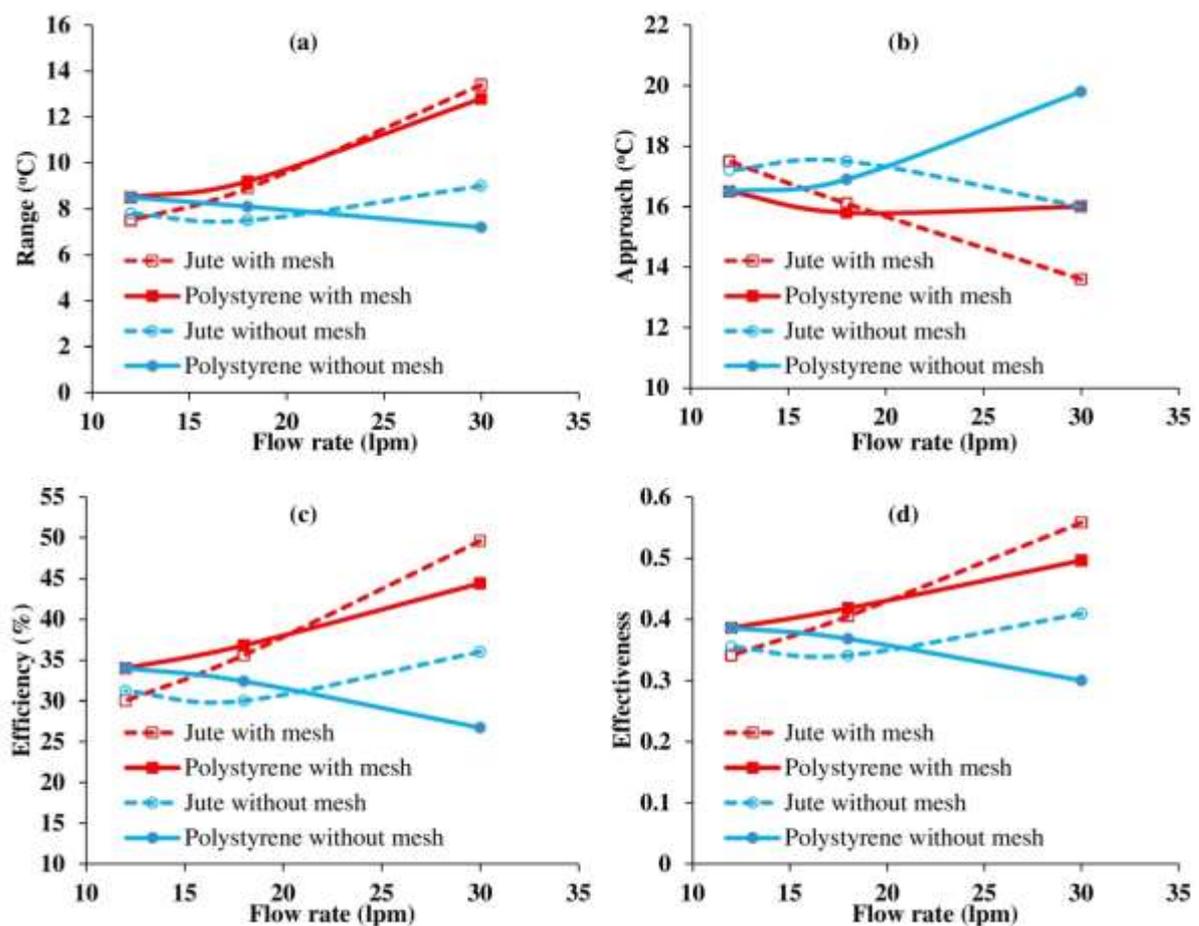


Figure 4. Influence of water flow rate on Range, Approach, Efficiency and Effectiveness

Figure. 4 shows the variations of all these aforementioned metrics with the water flow rate in the tower. The range, which is the difference of water temperatures between inlet and exit, is otherwise a measure of how much a tower is effective in bringing down the water temperature. As shown in Figure. 4 (a), at low flow rate (12 lpm) the range of the tower is unaltered much either by material or by mesh types; whereas, at high flow rate (30 lpm) the mesh type has significant role over the range. At high flow rate, the water temperature in the tower is witnessed to be reduced significantly in the presence of mesh on the louvers, which is possibly expected to have enhanced the contact surface area for heat transfer. Sequentially, this phenomenon is confirmed with low value for range at the same flow rate without the presence of wire mesh. Furthermore, it is observed from the figure that the type of material imparts less significance on the range value even at high flow rate.

The water discharged from the pump on the tower top starts hitting the louvers with high velocity as the flow rate increases, which in further breaks the water jet into more droplets and thereby enhances the heat exchange between air and water. At such a higher flow rate, jute, which is the mesh of tight jute fibers, develops more air bubbles in the bed. Whereas the polystyrene balls easily allows the water to escape through their stacked layers which hinders the effective heat transfer between air and water. At lower flow rates, the water moves steadily and stagnates in case of jute material. However, polystyrene balls make uniform dispersion of the water around them at low flow rates and resulted with an enhanced heat exchange process.

The approach of the cooling tower at the three different flow rates are determined and plotted as shown in Figure 4(b). The approach of a tower helps to understand how closely a cooling tower reduces the exit water temperature to the ambient wet bulb temperature. Larger the value of approach of a tower, more the number of cycles of water circulation is required to attain equilibrium with ambient temperature. As observed from Figure 4(b), increase in the flow rate positively reducing the approach value for both the bed materials (jute and polystyrene) but with wire mesh condition. Presence of wire mesh favours the conduction mode of heat transfer, while increasing the flow rate inherently invites irregular flow of water molecules which in further enhances the convection phenomenon. Heat transfer between the water and the ambient air in the tower is found to be not prominent without the wire mesh and henceforth the approach of the tower increases with flow rate in the absence of wire mesh. This trend is in line with the phenomenon observed with the range as shown in Figure 4(a). Type of materials has a strong influence on the approach value as observed from Figure 4(b), where, Jute material has an approach of 3°C lesser than the Polystyrene material at the flow rate of 30 lpm.

The efficiency of a cooling tower is an essential metric to indicate the viability of the tower in any industry. In further, the efficiency is not only depends on the water temperatures at entry and exit but it is limited by the atmospheric wet bulb temperature. Since no significant variation is found with the range value across different input conditions at low flow rate (12 lpm) (Refer Figure 4(a)), a 4% variation is obtained in the efficiency of the tower among the cases (Refer Figure 4(c)). At high flow rate, the jute material with mesh provided 50% efficiency while the polystyrene material without mesh corresponds to 25% efficiency. Moreover, increase in flow rates increases the efficiency of the tower in case of jute material with or without wire mesh. However, the efficiency increases in case of polystyrene material with mesh while it decreases without the mesh. This result from the present work shows that Jute material provides better efficiency for the tower at large flow rate of water. Also, for the above-mentioned reasons, the tower is found to be more effective for the cooling purpose of a stationary engine with Jute as bed material including wire mesh as shown in Figure 4(d).

3.4. Heat loss

The total energy loss in the cooling tower is given by heat loss and it is calculated using Eqn (7)

$$H_L = m_{w1} \times C_{pw} \times (T_1 - T_2) \tag{7}$$

Where, C_{pw} is specific heat for water at constant pressure.

The Figure 5 shows the variations of heat loss nature of different materials for various flow rates. Jute and polystyrene with mesh show high heat loss capability due to the reasons mentioned in section 3.3. This heat loss is high at high flow rate and negligible at low flow rate of water.

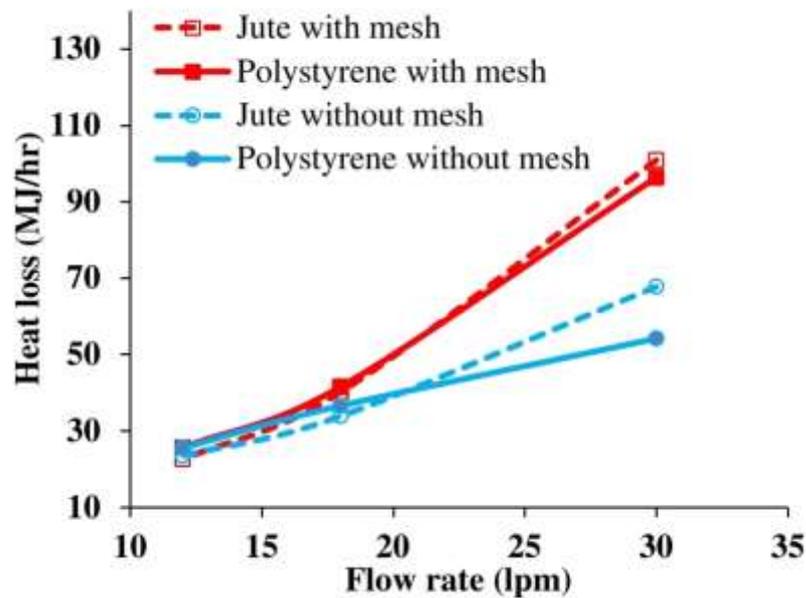


Figure 5. Influence of water flow rate on heat loss

3.5. Number of Cycles

The temperatures of both inlet and outlet of the cooling tower for each cycle of operation are measured and provided in Table 4.

Table 4: Number cycles for Jute with mesh

S. No	Entity	Cycles of operation			
		1 st cycle	2 nd cycle	3 rd cycle	4 th cycle
1	Inlet Temperature of Tower (°C)	57.8	43.4	40.0	36.7
2	Outlet Temperature of Tower (°C)	43.9	40.1	36.7	35.5
3	Range (°C)	13.9	3.3	3.3	1.2
4	Approach (°C)	13.9	10.1	6.7	5.5

5	Efficiency (%)	50	24.6	37	15.7
6	Effectiveness (%)	56.04	31.7	47.14	26.08

From the above values listed in the Table 4, the Range in the 4th cycle is nearly 1°C i.e., the temperature difference between the inlet and outlet water is minimal. Therefore, from the experimental analysis considered above, it is observed that a minimum of 3 cycle operations are required to reduce the temperature from 58°C to 36°C (for DBT of 33°C). As the operation cycles increase, the efficiency of the cooling tower decreases. However, the diesel engine requires high intake cooling water temperature for better performance. Since high intake water temperature reduces ignition delay and reducing knocking tendency. Henceforth, the achievement obtained in the first cycle of operation is considered to be sufficient for the present application.

4. Conclusion

In this study, experiments are conducted to examine the performance of a cooling tower used for a stationary IC engine, with different bed materials at three different flow rates. From the experiments, it is evident that at higher flow rates jute carpets with mesh show better cooling, while coming to lower flow rates polystyrene balls perform better. At low flow rates, it is clear that the usage of mesh does not influence the cooling process. At high flow rate, the jute material with mesh provided 50% efficiency while the polystyrene material without mesh corresponds to 25% efficiency. The present research work established the significance of a cooling tower in a small scale for industrial applications through the determination of various performance metrics of the tower.

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NOMECLATURE

SYMBOL	FULL FORM	UNITS
m_{w1}	Mass flow rate of water	kg/ sec
T_1	Inlet temperature of water	°C
T_2	Outlet temperature of water	°C
T	Wet bulb temperature	°C
T_a	Air inlet temperature	°C
CTR	Cooling Tower Range	°C
CTA	Cooling Tower Approach	°C
H_L	Heat Loss by Water	kJ/hr
C_{pw}	Specific Heat of water at constant pressure	kJ/kg-K
η	Efficiency of Cooling Tower	%
ε	Effectiveness of Cooling Tower	-
W_L	Windage losses of water	kg/hr
E_L	Evaporative losses of water	kg/hr