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Investigation of Entropy Generation in Cooling Tower System

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Abstract

Entropy generation in cooling towers is critical to their thermal performance and efficiency. However, reducing entropy formation in cooling towers is crucial since it directly affects the cooling tower's efficiency and the system's overall energy usage. Decreased entropy creation results in a more effective cooling process, leading to energy conservation and decreased operational expenses. This study proposes a control volume process that reduces entropy formation insimultaneous heat and mass exchangers. It also aims to investigate the thermal efficiency of a cooling tower system. The experiment uses a Cooling Tower Model HE152 apparatus, uniform PVC packing, and acrylic packing with different water inlet temperatures (35 °C,43°C,50°C) combined with airflow rates of 138 kg/h and water flow rates of 25,50,75,100,125,150, 175 and 200 kg/h. At lower mass flow rates in particular, the system performs best when efficiency and mass flow rate ratio rise; as temperature rises, efficiency falls. In comparing the entropy generation of acrylic and ununiform PVC packing of fill, the study finds that whereas PVC has higher entropy generation because of lower thermal efficiency and higher irreversibilities, acrylic has lower entropy generation, which indicates efficient heat transfer and fewer irreversibilities. The study found that cooling tower efficiency initially increases with mass flow rate but declines beyond this point due to increased turbulence and frictional losses. Acrylic packing shows higher initial efficiency compared with ununiform PVC packing. Entropy generation increased with mass flow rate, reflecting increased irreversibilities due to frictional losses and thermal gradients, particularly at higher temperatures, with acrylic packing exhibiting higher entropy generation.

1. Introduction

The cooling tower's lifespan by reducing mechanical stress on its components, resulting in lower maintenance costs and improved reliability. Overall, managing entropy generation is essential for enhancing the performance, longevity, and environmental impact of cooling tower systems. The process of transferring waste heat to the atmosphere through the cooling of a water stream is accomplished by cooling towers, which are devices that provide heat rejection. Most of the time, cooling towers are utilized for the purpose of chilling the circulating water that is utilized in power plants. The development of the steam engine was the first stage in the process of building cooling towers. This process began in the 19th century, when condensers were utilized in the power generation systems. For the purpose of condensing the steam that was produced by the turbines or cylinders, condensers were utilized [2]. Cooling ponds were utilized in certain regions that had access to vast amounts of space; however, cooling towers were utilized in large cities that had a constraint on the amount of land available.Earlier towers were either built on rooftops or as free-standing constructions. Both options were equally viable. In the year 1901, an American engineer presented a unique design that consisted of a rectangular or circular shell that was almost identical to a chimney stack that had been shortened vertically but had been significantly increased horizontally. There is a collection of distributing troughs located at the very top of the tower. Water is pushed from the condenser to the very top, where it is then allowed to flow down over wooden slats or woven wire screens that comprise the area within the tower. Gerard Kuypers and Frederik van Iterson, two Dutch engineers, were the first to receive a patent for a hyperboloid cooling tower in 1918. The towers were constructed in the same year in Heerlen [2].

2. Methodology

Figure 1 cooling tower diagram illustrates the key elements of the cooling process as well as the flow of water through the tower. The cooling tower system has three different types of fluid flow: airflow, hot water flow, and cold water flow. The movement inside and around the tower, driven upward by a fan, is represented by the airflow. As air moves through the packing material, it enables effective cooling [3]. Water is pumped from the bottom of the tower and evenly distributed throughout the packing material to create the hot water flow. The hot water exchanges heat with the air that is rising as it passes through the packing. The cold-water flow illustrates how hot water in the tower turns into cold water. As the hot water interacts with the wind, it cools down and experiences a reduction in temperature. To keep the system's cooling flow constant, the collected cold water is recycled. Specifically, the assessment will compare the efficiency and entropy generation of acryic packing and PVC packing.

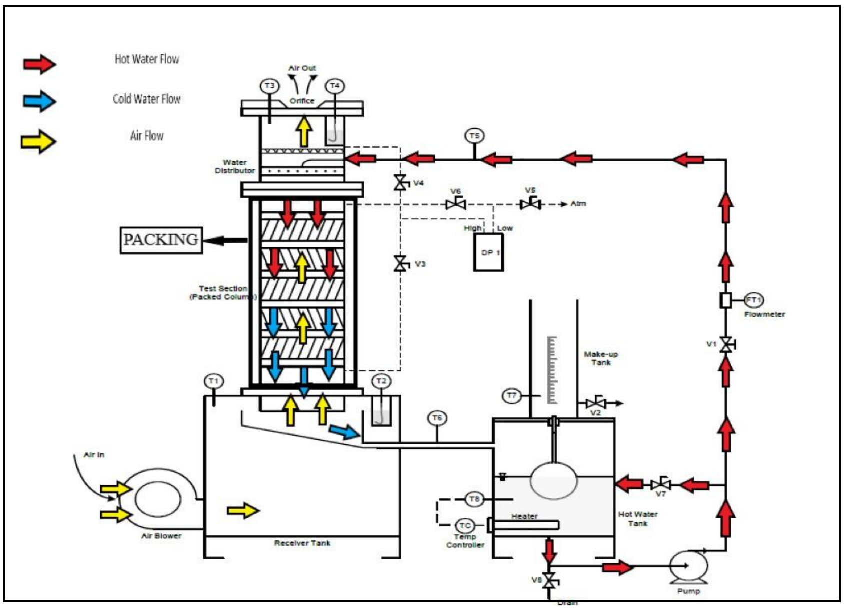


Fig. 1 *Cooling Tower Model HE152[3]*

Hence the exxperiment involves two different of materials packing Figure 2:

i. Acrylic packing.

ii. Ununiform PVC packing.

(a)Ununiform PVC Packing (b)Acrylic Packing

Fig 2 Two different packing (a) Ununiform PVC Packing, (b) Acrylic Packing

3. Equations

In achieving these objectives, an experimental cooling tower setup will establish a controlled environment for conducting the required experiments and measurements. The cooling tower used in this study is a cooling tower model HE152[3]. It aims to increase the contact area between the air and water, making heat and mass transfer more efficient. The tower has a fan that pushes the air upwards, creating an upward flow inside the tower. The setup of the cooling tower also includes a pump that circulates hot water from the bottom to the top, allowing for heat and material exchange between the upward-flowing air and the downward-flowing water. The collection tanks in the setup draw water from a reserve tank, ensuring a consistent water level during the experiments. The following equations represent conservation of energy for a cooling tower with a counterflow. It is presumed that neither the hot nor the cold fluid streams undergo any phase transition, and that the cooling tower does not let any heat escape into the surrounding environment. This equation(1) describe the energy conservation principles applied to a counterflow heat exchanger. It is assumed that both the hot and cold fluid streams remain in their respective phases throughout the process, and that the heat exchanger maintains insulation, preventing any heat loss to the surrounding environment [4].

$$Sgen = m_a\,(s_{2,a} - s_{1,a}) + m_w\,(s_{1,w} - s_{2,w}) \tag{1}$$

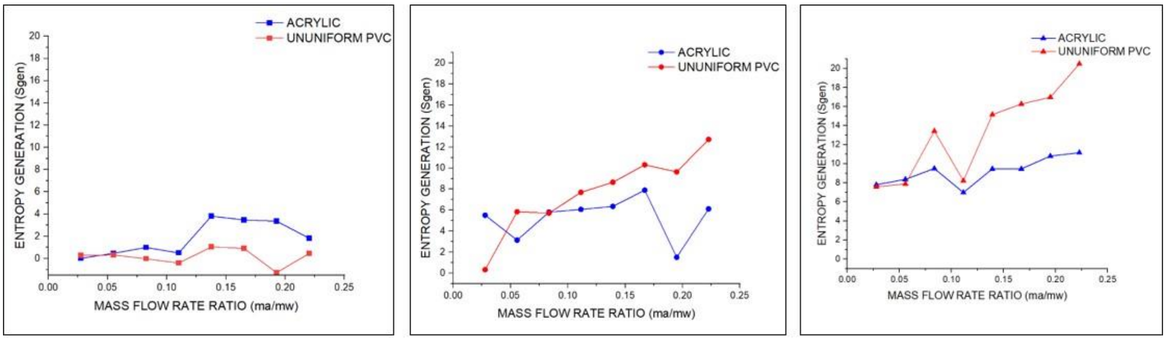
In the cooling tower analysis, it is important to determine the efficiency of these systems. To clarify this, it can be referred to equation (20, which is a fundamental result obtained through previous research. Where T_{in} is the inlet water temperature (hot temperature), T_{out} is the outlet water temperature (cold temperature) and the T_{wb} is the wet bulb temperature.

$$\varepsilon = \frac{T_{in} - T_{out}}{T_{in} - T_{\omega b}} \tag{2}$$

4. Result And Discussion

This chapter discusses the results and discussions about using acrylic materials packing in cooling tower applications. The main objective is to evaluate the entropy generation and efficiency of acrylic material when used as a packing material in cooling towers, compared to traditional materials such as PVC. The parameters for this study have been obtained from previous studies, ensuring an accurate and validated method for the results obtained. The study examines the impact of two important factors, specifically the mass flow rates ratio (L/G) and airflow rates at maximum velocity, 10m/s, operation of a cooling tower. To help understand the results, a graph depicting the correlation between efficiency and mass flow rate ratio (L/G) for acrylic packing arrangements at both air mass flow rates and entropy generation were produced in the cooling tower systems.

The results of entropy generation (Sgen) versus mass flow rate ratio (ma/mw) from Figure 3 shown using acrylic material are compared with those using PVC material at an air flow rate of 10 m/s and temperatures of 35, 43, and 50°C. The patterns observed in the data for both materials are analyzed and discussed in this section. the comparison of entropy generation between acrylic and PVC materials at different temperatures and mass flow rates reveals that acrylic generally results in lower entropy generation, indicating more efficient heat transfer and fewer irreversibilities. The higher entropy generation observed with PVC material highlights its lower thermal efficiency and greater complexity in flow dynamics, leading to increased irreversibilities. These findings underscore the importance of material selection in cooling tower systems to optimize efficiency and minimize entropy generation. The theoretical understanding of heat and mass transfer processes and the material properties' impact on these processes provide a comprehensive explanation for the observed differences between acrylic and PVC materials. Overall, the patterns observed in the entropy generation data align with theoretical principles of heat and mass transfer in cooling tower systems. Higher mass flow rates and temperatures generally lead to increased entropy generation due to enhanced transfer rates but also greater irreversibilities within the system. This is more pronounced with PVC material, which shows higher entropy generation across all temperatures and mass flow rates compared to acrylic. The differences between acrylic and PVC materials can be attributed to their distinct thermal and physical properties. Acrylic has higher thermal conductivity, which enhances heat transfer efficiency and reduces thermal resistance. This leads to lower entropy generation as the system experiences fewer irreversibilities. On the other hand, PVC, with its lower thermal conductivity, higher thermal resistance, and possibly different flow dynamics, results in higher entropy generation due to increased irreversibilities and less efficient heat transfer.

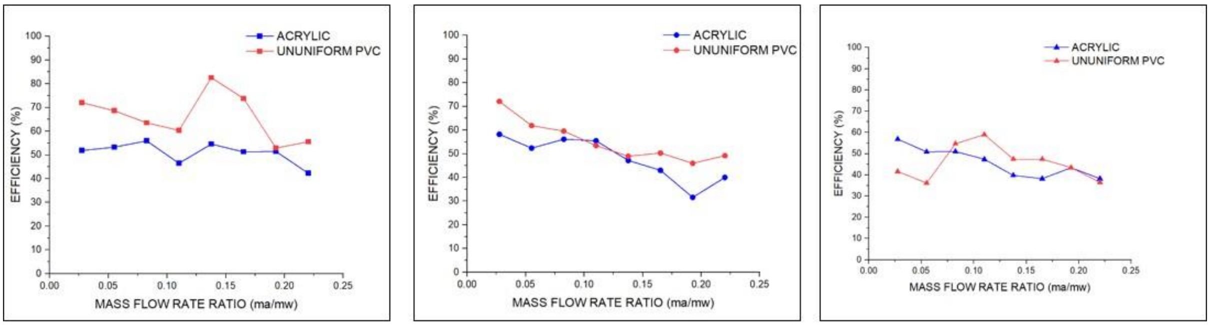


a) Temperature 35 °C b) Temperature 43 °C c) Temperature 50 °C

Fig. 3 Comparison of results of entropy generation acrylic and Ununiform PVC materials at (a) Temperature 35 °C, (b) Temperature 43 °C and (c) Temperature 50 °C

Figure 4 shown the comparison between the efficiency of cooling towers using acrylic and PVC materials at different temperatures of 35, 43, and 50°C and mass flow rate ratios reveals distinct patterns and significant differences. The efficiency data for both materials are analyzed, highlighting the trends and potential reasons based on theoretical principles of heat transfer and material properties. For acrylic material at 35°C, the efficiency (%) varies between 42.28% and 55.95% across different mass flow rates. Specifically, efficiency startsat 51.90% at mass flow rate ratio of 0.0275, peaks at 55.95% at 0.0826, and then fluctuates before reaching 42.28% at 0.2203. In contrast, for PVC material, the efficiency ranges from 52.94% to 82.61%, starting at 72.06% at the mass flow rate ratio of 0.0278, reaching a peak of 82.61% at 0.1392, and then decreasing to 55.56% at 0.2227. For an operating temperature of 43 degrees Celsius, acrylic material shows an efficiency range from 31.58% to 58.20%. The efficiency decreases from 58.20% at mass flow rate ratio of 0.0275 to 31.58% at 0.1927, showing a notable decline as the mass flow rate increases.

For PVC material, efficiency ranges from 45.98% to 72.11%. The efficiency starts at 72.11% at mass flow rate ratio of 0.0278, then decreases to 45.98% at 0.1949, before slightly recovering to 49.17% at 0.2227. The greater decline in efficiency for acrylic material at higher mass flow rates compared to PVC suggests that while acrylic initially provides better efficiency, its performance diminishes more rapidly as the flow rate increases. At 50°C, acrylic material's efficiency decreases from 56.85% to 38.23% with increasing mass flow rate, indicating a decline in performance as flow rate rises. PVC material shows more variability, with efficiency ranging from 36.19% to 58.99%, peaking at a mass flow rate ratio of 0.1114 before fluctuating and then decreasing. The wider fluctuation in PVC's efficiency is likely due to its increased thermal resistance and different heat transfer characteristics, leading to less predictable performance at higher temperatures and flow rates.



a) Temperature T6 35 °C b) Temperature T6 43 °C c) Temperature T6 50 °C

Fig. 4 Comparison of results of cooling tower efficiency using acrylic and PVC materials at (a) Temperature 35 °C (b) Temperature T6 43 °C and (c) Temperature T6 50 °C

5. Conclusion

In Conclusion, The objective of this final year project was to develop a control volume procedure that minimizes entropy generation in simultaneous heat and mass exchangers, and secondly, to investigate thermal efficiency in a cooling tower system. The study successfully obtained reliable results that provided clear insights into the relationship between mass flow rate, entropy generation, and thermal efficiency.The analysis revealed that cooling tower efficiency initially increases with mass flow rate up to an optimal point, beyond which it declines due to increased turbulence and frictional losses. This trend was consistently observed across temperatures of 35, 43, and 50 degrees Celsius. At higher temperatures, overall efficiency decreased, likely due to increased thermal resistance. Comparatively, acrylic packing showed higher initial efficiency but deteriorated more rapidly at higher flow rates than PVC, which maintained a stable efficiency profile. Entropy generation (Sgen) analysis indicated that Sgen increased with mass flow rate, reflecting greater system irreversibilities due to enhanced frictional losses and thermal gradients, especially at higher temperatures. Acrylic packing exhibited higher entropy generation compared to PVC, highlighting a trade-off between enhanced heat transfer efficiency and increased irreversibilities.

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