Determining the optimal number of collector layers in fog water harvesting system

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Abstract

Enhancing fog collector efficiency can be achieved by increasing the number of layers in various collectors. This study scrutinized the influence of layers on efficiency for conventional collectors (Raschel and Aluminum mesh) through a meticulous analysis of theoretical relationships and the execution of experimental tests. In the laboratory phase, following the installation of the system, the output flow from the humidifier was directed towards the collecting plate. Subsequently, the efficiency of collectors with 1, 2, 5, and 7 layers was assessed and compared based on the amount of collected water post-fog extraction. The results of the investigation into the theoretical relations governing water extraction from fog revealed a significant trend. As the shade coefficient of the collector increases, aerodynamic efficiency demonstrates an initial increase, peaking at 50-60%, followed by a subsequent decrease. Furthermore, the efficiency of Raschel and Aluminum mesh is intricately linked to the number of layers, with the highest theoretical efficiency observed at 4 and 7 layers, respectively. Experimental findings indicated the highest water collection efficiency for Raschel mesh with 5 layers at 55.3% and for Aluminum mesh with 6 layers at 58.1%. In terms of cost-effectiveness, the optimal number of layers for Raschel and Aluminum mesh is determined to be 2 and 4 layers, respectively.

Keywords: Aluminum mesh, Collector, efficiency, Number of layers, Raschel mesh

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1. Introduction

Water harvesting is a widely recognized method of water supply that has garnered significant attention from researchers in recent years. Various collectors, such as the standard fog collector (SFC), Juvic, and Harp-wire, are utilized for harvesting fog water. The SFC is the most commonly used fog collector, extensively employed in feasibility projects across different regions of the world due to its ease of preparation and operation [1]. Fog collectors are manufactured from a range of materials and shapes, including Raschel mesh, metal mesh, Teflon, and metal wires. Raschel mesh, composed of polypropylene, is a prevalent choice in research and operational projects due to its availability and cost-effectiveness. The efficiency of a collector is determined by a multitude of parameters, including meteorological conditions, geographical location, collector geometry, the shape of the collector element (wire or ribbon), the physical and chemical properties of the collector's surface, and the number of layers. Modifying any of these factors directly impacts the efficiency of the collection system. Increasing the number of layers on the collector plate is a method to enhance collector efficiency. Field research comparing one and two-layer cylindrical collectors has shown that the two-layer collector performs better than the one layer, with a linear relationship between the number of layers and the amount of extracted water [2]. Theoretical research by Regalado and Ritter [3] has indicated that the collection efficiency increases with an increase in the number of layers, peaking at 5 layers before a decline in efficiency is observed.

Considering the absence of comprehensive experimental research to determine the optimal number of layers in various collectors, this study aims to select the optimal layer count by measuring the efficiency of conventional collectors (Raschel and Aluminum) and comparing them with existing theoretical relationships.

2. Methodology

In order to determine the optimal number of fog collector layers to achieve maximum efficiency, a research was conducted in a laboratory condition using Raschel and Aluminum meshes. For this purpose, simulation of fog flow in the laboratory was carried out by four ultrasonic humidifiers model MLH-330. Humidifier modules were placed in a plastic cylindrical chamber, and then using a Turbo vph-15S2S blower fan, which was placed on the chamber, the fog created through a cylindrical tube was directed to the collector. Also, the speed of the output fog near the collectors was measured with a Testo245 digital speedometer. At the beginning of the experiment, the intensity of the fog output and the amount of collected water were measured using two digital scales. Measurements were made for each of Raschel and Aluminum meshes with the number of 1 to 7 layers.

2.2. Theory

Under fog conditions, the theoretical amount of water collected by the collector can be estimated by Equation (1) [4, 5].

$$Q = 3.6 \times LWC \times u \times A \times \eta_{coll} \quad (1)$$

A collector is never able to absorb all passing droplets and store them. Therefore, the efficiency of the collector (ηcoll) is used to determine the amount of droplets absorbed by the collector. ηcoll is defined as the ratio of the amount of water collected per unit area of the collecting plate (q) to the fog passing flux from the cross section (LWC×u). To determine collector efficiency, it is necessary to measure wind speed, LWC and collected water. In this way, the total collection efficiency can be shown by equation (2) [6].

$$\eta_{coll} = \frac{q}{3.6 \times LWC \times u} \quad (2)$$

As mentioned, a collector can only capture a fraction of the total passing droplets and store them in the tank. This decrease in efficiency can be due to the deviation of the path of the fog droplets before reaching the collecting plate (aerodynamic efficiency), the passing of the fog droplets through the empty space and not hitting the solid part of the mesh (impaction efficiency), the dropping of the droplets outside the collecting environment due to the high-speed wind and distortion of the collector plate as well as losses due to leakage in the drainage system (drainage efficiency).

3. Results and Discussion

The investigation initiated by employing theoretical principles to explore the relationship between collection efficiency and the number of collecting layers. Figure 1 illustrates the variations in aerodynamic and impaction efficiencies concerning the layer count in Raschel and Aluminum collectors. The expansion of the droplet collision surface with an increase in collector layers allows for enhanced droplet collection. The theoretical impaction efficiency escalates from 39% and 22% to 100% and 95% for Raschel and Aluminum meshes, respectively, with 12 layers (Figure 1-a). Conversely, the rise in layers results in decreased aerodynamic efficiency, transforming the collectors into nearly impenetrable barriers that alter the flow of fog. Figure 1-b demonstrates the decrease in aerodynamic efficiency as the number of layers increases in Raschel and Aluminum meshes. The theoretical aerodynamic efficiency for Raschel mesh and Aluminum decreases from 24% and 16% with one layer to 12% and 9% with 12 layers, respectively. This escalation in layers transforms the collectors into nearly impenetrable barriers, causing a deviation in the flow of fog.

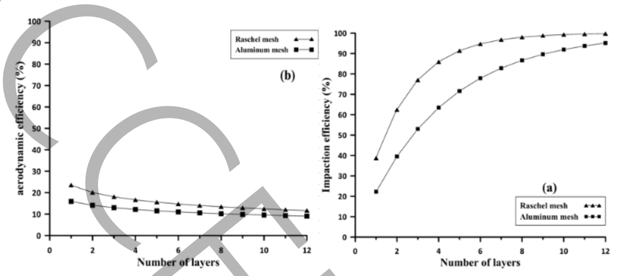

Figure 1. Variations of impaction (a) and (b) aerodynamic efficiencies with the number layers in Raschel and Aluminum meshes

In the next part of the research, the results of the experimental test were compared with the values obtained from the theoretical relationships. Figure 2 shows the changes in the total efficiency of Raschel and Aluminum meshes according to both theoretical relationships and experimental data. Theoretical methods suggest that the highest efficiency for Raschel mesh is achieved with 4 layers at 14.3% and for Aluminum mesh with 7 layers at 8.8%. However, experimental results show that Raschel mesh's highest efficiency is at 5 layers (55.3%) and Aluminum mesh at 6 layers (58.1%). The significant difference between theoretical and experimental values indicates that theoretical models do not account for many factors affecting collection efficiency in real conditions. This observation is also supported by Rivera's studies [6]. It can be concluded that while theoretical models are useful for determining the optimal number of layers in collector design, modifications and increased accuracy in efficiency estimation can be achieved through laboratory measurements and numerical simulations.

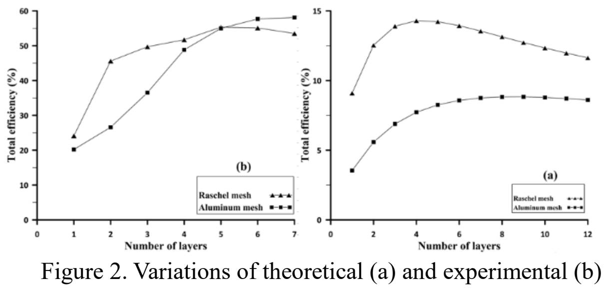

Figure 2. Variations of theoretical (a) and experimental (b) efficiencies with the number of layers in Raschel and Aluminum meshes

Moreover, to ascertain the most cost-effective number of layers for a large-scale fog water extraction system (LFC), the expenses associated with implementing the system and the cost per unit of extracted water were carefully evaluated. As a result, it was determined that the optimal number of layers for Raschel and Aluminum mesh were 2 and 4 layers, respectively. Also, the unit cost of the extracted water was calculated to be 141.25 thousand Rials per liter for Raschel and 377.76 thousand Rials per liter for Aluminum mesh.

4. Conclusion

Increasing the number of collector layers is a method to enhance water extraction efficiency in various collectors. This research utilized theoretical methods from fog extraction literature and laboratory measurements to determine the optimal number of layers for Raschel and Aluminum mesh collectors. The results indicated that as the number of Raschel and Aluminum mesh layers increased from 1 to 12, aerodynamic efficiency decreased by 12% and 7%, respectively, while impaction efficiency increased by 61% and 73%, respectively, highlighting a significant improvement in impaction efficiency compared to aerodynamic efficiency.

The laboratory measurements also revealed that increasing the number of layers in Raschel mesh up to 5 resulted in improved total efficiency (due to the increased droplet collision surface), but beyond that point, not only did efficiency not increase, but air flow permeability decreased. This led to fog diversion and an overall efficiency reduction. Economically, the most appropriate number of layers for Raschel and Aluminum mesh is 2 and 4 layers, respectively. However, regardless of economic considerations, the optimal number of layers in Raschel and Aluminum collectors was found to be 5 and 6 layers, respectively.

5. References

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