Applied Thermal Engineering 96 (2016) 632–639

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Experimental study of unstructured porous media inserts for water recovery in a reduced scale, crossflow cooling tower

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HIGHLIGHTS

- Potential water recovery experiments in wet cooling towers.
- Non-structured porous media condensation layer inserts.
- Reduction of cooling water expenditure in power systems.

ARTICLE INFO

Article history:
Received 29 April 2015
Accepted 11 November 2015
Available online 2 December 2015

Keywords:
Cooling tower
Water recovery
Thermosyphon
Porous media

ABSTRACT

The objective of this paper is to report the experimental performance of a novel water recovering system applied to a crossflow cooling tower. For that, a lab-scale experimental setup was built such that it closely resembles the detailed geometry of an actual cooling tower and operates based on identical transport phenomena processes and regimes. To recover the process water evaporated by the cooling air, the experimental apparatus designed, which was 1:20 of a real cooling tower, was assisted by an array of copper tubes installed on both sides of the tower, where cold fluid was circulated by an independent loop. Therefore, immediately after cooling the heated process water, saturated air is forced through the cooled copper tubes partially condensating the process water present in it, which was then reintroduced to the process water loop, returning the cooling air back to the ambient with a lower water content. The experimental setup was tested with four different configurations: (i) without condensating copper tubes, namely "benchmark" configuration, (ii) with copper tubes, (iii) with copper tubes surrounded by a non-structured porous media (i.e., metal foam), which serves as surface area enhancer and (iv) with finned copper tubes surrounded by a non-structured metal foam. The results obtained clearly show that, on average, up to 10% of process water can be recovered through direct condensation. Furthermore, the results also indicate that the use of a non-structured porous media such as tape-like metal foams can significantly improve the water recovering process.

1. Introduction

Over the past ten years or so, a great deal of attention has been given to sustainable energy production as well as to its rational utilization. For instance, fuel-efficient vehicles and low energy consumption appliances have become the standard for most general consumers. While many reasons can be associated to this societal trend, the understanding of the importance of sustainability can arguably be regarded as one of its key aspects. While this trend is certainly positive, sustainability can have a significantly broader meaning than that foreseen by the general population. This concept becomes clear, for example, if considering the production chain process of widespread consumables. In that sense, and defining sustainability as the essentials needed to sustain life in a non-environmentally depleting way, it is somewhat acceptable to consider energy and freshwater related, e.g., Refs. 1 and 2.

The relation between energy and water becomes obvious by realizing that, while water covers the vast majority of the Earth's surface, only a small percentage of that can be classified as fresh or drinkable water. Therefore, while seawater can be certainly converted into freshwater, which would lead to the erroneous assumptions that water is in fact a nearly unlimited resource, that would suggest the need for significant amounts of energy. While many countries have experienced for decades the difficulty in obtaining freshwater, Brazil, which has one of the World's largest freshwater supplies, is currently going through a major drought in localized areas [3].

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http://dx.doi.org/10.1016/j.applthermaleng.2015.11.039
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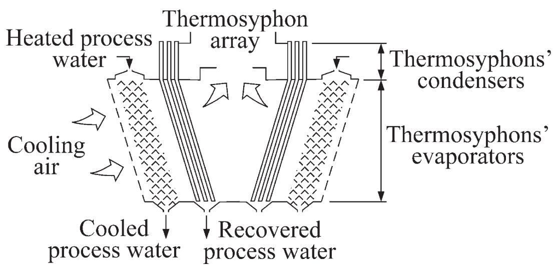

Fig. 1. Sketch of a cooling tower assisted by an array of thermosyphons.

Among the major freshwater consumers, household usage represents approximately 1% of the water consumption in the US, while power plants' expenditures are responsible for 45% according to Ref. 4. Within the numerous industrial segments that draw water from the environment, process cooling is certainly one of the main applications. For example, cooling towers, dry or wet, are a requirement in any thermal power generation process, e.g., Refs. 5–7. Obviously, wet cooling, which often uses ambient air to cool down process water through the direct cross- or counter-flow mixing of both streams, is the preferred technique, e.g., Refs. 8 and 9. Intrinsic of the method, however, is the humidification of the air stream, which inevitably implies in a process water loss to the ambient. While the amount of process water lost to the ambient strongly depends on aspects such as air stream temperature and absolute humidity, it is reasonable to conceive that this loss can be significant.

Based on the above, researchers have tried to improve the performance of cooling towers. More recently, a novel passive dehumidification technique has been proposed [10]. The idea is to passively create a cold surface to condensate as much as possible the water vapor present in the air stream before it exits the wet cooling tower, which is then reintroduced to the process water main stream. For instance, according to Ref. 10, an array of vertical or slightly tilted thermosyphons [11] might be a good option considering that the evaporators are placed inside the cooling tower, while the condensers are exposed to external ambient conditions – a sketch of the method is shown in Fig. 1. From a conceptual standpoint, the technical viability of the method was proven valid in a previous study, which used a series of copper tubes, in which cold water was internally circulated, assisted by an unstructured porous medium (stainless steel metal foam) to condensate water from the saturated air stream [12,13]. The condensate recovery rate reached over 40% for some of the cases tested.

Following this line of research, the present study reports the experimental results for the process water recovery technique described above applied to an actual crossflow, wet cooling tower. For that, a reduced scale cooling tower was built and tested under several conditions. The cooling was designed such that it could run under steady state conditions and the amount of the condensate water could be precisely measured. Three types of condensation structures were tested: bare copper tubes, copper tubes assisted by an unstructured porous medium, and finned copper tubes assisted by unstructured porous media. The experimental results report the percentage of the process water recovered.

2. Experimental setup

The laboratory-scale cooling tower setup built for the present investigation, which is shown in detail in Fig. 2, has the following key parts: (i) an air flowing system, (ii) an open loop for the process heated water, and (iii) a closed loop for the cold water. Generally speaking, the operational principle of the scaled cooling tower is identical to an actual system, where an air stream at ambient temperature is flown through the tower while serving as a heat sink to the down flowing process heated water, which needs to be cooled. Therefore, given the direct contact between air and the process water, the latter exists the tower with a reduced temperature and the air stream has its temperature and water content significantly raised. However, in order to reduce the process water loss, an additional sub-system is added downstream the process water cooling area, represented here by the third subsection listed above (i.e., a closed loop for the cold water). In this case, cold water is circulated through a series of copper tubes, forcing part of the water vapor present in the air stream to condensate such that it can be eventually returned to water process loop. However, because one of the main objectives of the present study is to precisely quantify the amount of condensate water recovered from the humidified air stream, the condensate produced will be directed to a vertically positioned beaker assisted by a scale such that a reliable measurement can be obtained.

So, as can be seen in Fig. 2, the air stream is pulled through the tower by a 1.76 kW axial ventilator located on top of the tower. The heated water, which mimics the process water, is stored in a 300 liter tank then pumped through a heating section before entering the tower – the heating section is composed of a nearly 20 kW electrical heater. The red circuit in Fig. 2 shows the process water path through the setup. In the tower, the heated water is dispensed in a showerhead (i.e., perforated plate), which distributes the water

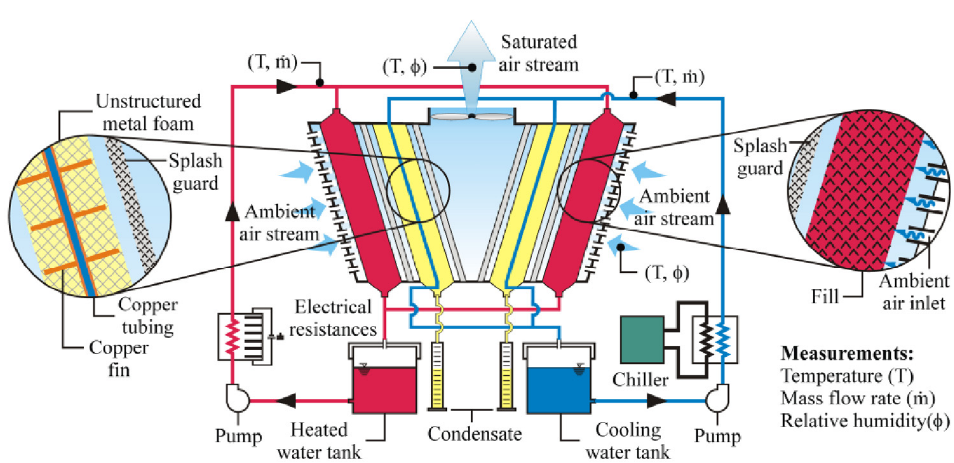

Fig. 2. Experimental setup – the tower alone, without any peripherals, measures 0.58 m × 1.26 m × 0.99 m.