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Cooling tower fog harvesting in power plants – A pilot study

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ABSTRACT

Fresh water shortage is a major global problem of this century. Estimates have shown that a large part of the human population will not have access to clean drinking water in a couple of decades from now. Collection of fog can be a useful solution to this concern. Fog, a large source of potable fresh water, has potentials to substitute traditional sources. Attempts have been made over the last few decades to capture fog from nature by installing large fog water collectors along coastal mountains and highlands. However, fog harvesting from artificial fog generators were not envisaged in these studies. In this pilot study, we have explored the possibilities of fog capture from CT (cooling tower) plume in a thermal power plant; CT plume accounts for one of the major sources of industrial water losses. Our study shows that a recovery of about 40 percent water from the drift loss – amounting to a saving of nearly 10.5 m^3 of water per hour from a 500 MW unit – could be achieved using the proposed fog harvesting strategy. Unlike the natural fog harvesting schemes where the fog laden flow is predominantly horizontal, fog flow stream in a cooling tower rises against the gravity. Three parameters are found to influence the collection efficiency predominantly: the shade coefficient of the mesh, effective dripping length of water droplets along the fog net, and angle of inclination of the mesh with respect to the vertically rising fog stream. The observed collection efficiency is more than twice as compared to those of other globally operational fog collectors. Results offer the design bases for full-scale fog harvesting systems that can be deployed in power plant cooling towers and a wide range of other artificial fog generators.

1. Introduction

Fresh water is essential not only for household living, irrigation, feedstock but also for several industries and is vital for sustaining urbanization. With increasing contamination of fresh water the concern for global water crisis is rising. Currently, 90% of energy production relies on intensive and non-reusable water models, which are not sustainable [1]. To recognize this concern for global water crisis, UNESCO has recently launched the International Year for Water Cooperation 2013 [2] and the UN declared the period 2005–2015 as the International Decade for Action “Water for Life” [3]. Research for new alternative sources of adequate fresh water supply has gained impetus in the last two decades [4]. Fog is found to be one of the potential alternate sources of good quality fresh water with a very low-cost collection system. As a result, many fog collection initiatives have been attempted in more than 17 countries including the coastal deserts of Peru, Sultanate of Oman, Namib desert, Yemen, and in the hills of Nepal [5,6]. Reviews show that the projects till date have mostly been installed in regions of low precipitation and droughts [7]. These projects face a common limitation of seasonal fogs or limited number of fog days (parameters that are dependent on the climatic and topographic location of the project site).

Standard fog collector consists of a large screen held by support structures like poles or frames, perpendicular to the direction of the wind driven fog (Fig. 1(a)). The screen acts as an obstacle to the fog carrying wind stream when a fraction of the droplets present in this wind stream hits the mesh fibers and gets deposited for collection. A typical fog consists of water droplets ranging from 1 to 30 μm [8]. As the fog-laden air passes through the mesh, the smaller droplets

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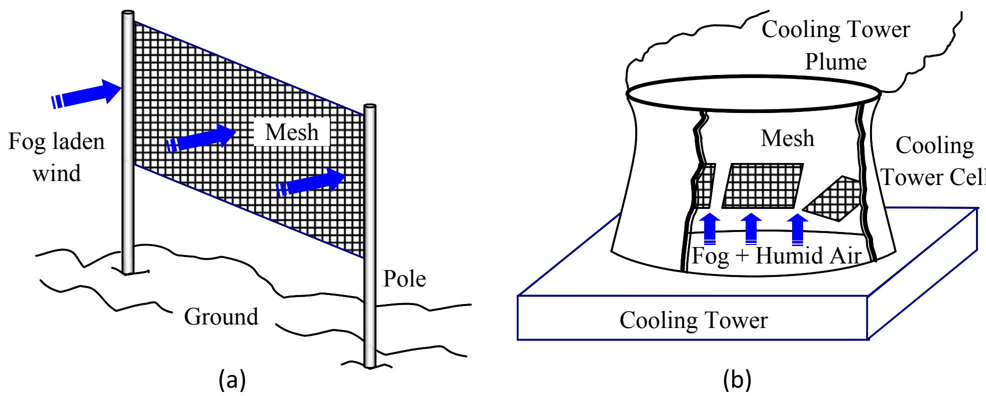

Fig. 1. Schematics of (a) standard atmospheric fog collector, (b) cooling tower fog collector.

may easily flow through the openings of the mesh, thus escaping capture. Therefore, the screen is able to collect only a fraction of the droplets present in the fog laden wind [9]. The deposited droplets coalesce and flow down the mesh fibers by gravity to the collector. This fraction of droplets hitting the mesh is also seen to be indirectly dependent on the amount of openness of the mesh, as well as the droplet distribution in fog. Two types of screens are commonly used [6], the SFC (standard fog collector) of 1 m^2 area and LFC (large fog collector) of 40–50 m^2. When a site is identified for fog harvesting, preliminarily the SFC is used to find the measure of fog water collection, while the LFC is installed at established sites with enough space for installation.

The screen materials commonly used are generally of locally available type, like double layered Raschel mesh (made of polyethylene fibers) or single-layered mosquito mesh [6]. Double layer of Raschel mesh with 35% openness that covers approximately 60% surface area of the collector [10] is used most predominantly worldwide for fog collectors. However, there is a large variability in water collection and airflow correlation data reported in the literature. Some studies reports [11] improvement of collection over Raschel mesh with other mesh types. For example, indoor greenhouse aluminet shade net was found to achieve the same collection efficiency as the aforementioned Raschel mesh at lower mesh density. In the present case stainless steel wire mesh with 20% and 33% shade coefficients are used.

Mesh type and pattern directly influence the fog harvesting behavior on the woven wire mesh. Park et al. [5], showed that the fog collection efficiency of a mesh depended on two dimensionless variables: (i) the ratio of the radius of the fog droplets (r_{fog}) to the radius of the mesh wire (R) i.e., $R^* = (r_{fog}/R)$ and (ii) a geometric groups variable, termed the shade coefficient (*SC*), which denotes the fraction of mesh projected area occupied by the mesh fiber material. It is intuitive that a large value of *SC* would imply a greater physical interception of oncoming stream by the wires/fibers. Thus a larger fraction of the oncoming fog would be intercepted by the mesh fiber, facilitating collection. However, this does not necessarily mean an overall increase in fog interception by the mesh, since a higher mesh *SC* also causes a “shielding” effect by the mesh. An increased *SC* results in large flow impedance offered by the mesh, causing a greater diversion of wind stream past the mesh structure and a drop in overall incidence of fog droplets on mesh. The optimum value of *SC* would depend on the structure (e.g., wire mesh or filament) and layout (e.g., triangular or orthogonal weaving) of mesh, as well as the geometry and orientation of fog collector.

The overall collection rate of a fog collector depends on the water content in the fog, average wind velocity and the fog collection efficiency of the nets. Among the ongoing projects [7], Peru has recorded a fog water collection of 11.8 Lm^{-2} per fog day, Chile a highest of 7.8 Lm^{-2} per fog day, South Africa 7 Lm^{-2} per fog day and Oman (only for a period of two months annually) has a maximum collection of 30 Lm^{-2} per fog day. Despite moderate to good collections, the commonly used fiber meshes have serious sustainability issues. Strong winds either tear the mesh fiber elements or cause collapsing of supporting structures [12]; the damage of mesh elements may be prevented by replacing polymer fibers with corrosion resistant commercially available metal wire fibers. These metal wire mesh may act as a better element for fog water capture than the commonly used polyethylene fibers, particularly when the metal surface is tuned with appropriate wetting characteristics [5]. Attempts are being made for improving the fog collection technology through modification of the physical and chemical characteristics of fog collecting surfaces of wires/fibers by taking cues from the natural fog harvesting capability of a few desert animals and plants. The adaptive bio-mimicry seen in the darkling Namib Desert beetle [13], a species of desert grass (*Stipagrostis sabulicola*) [14] and the sticky spider webs [15] have contributed significantly to design the fog capture, transport and collection devices.

Although systematic efforts in the area of atmospheric fog capture have started over a couple of decades ago, there has not been any formal report on extending the philosophy to industrial fog capture. This paper proposes to explore potential alternative fog harvesting resources that are also economically feasible and renewable but is not dependent on the climatic or topological factors for installation. The present work aims at characterizing water harvesting potential of fog nets installed in the cells of cooling tower (see Fig. 1(b)) and evaluating its potential as a source for sustainable fresh water supply. Power plant cooling towers are known to produce dense fog plumes that arise due to the evaporative cooling of the CW (circulating water). The cooling tower fog is looked upon as a technical hazard for the outdoor electrical installation (e.g., in the plant switchyard) and has recently attracted concerns from environmental perspective too [16]. The CW required by a typical 500 MW unit of a power plant [17] is approximately 54,000–60,000 $m^3\ h^{-1}$. Evaporative cooling of CW in a cooling tower incurs water losses in the form of vapor, drift (unevaporated tiny water droplets carried along with the vapor plume) and blow down. The amount of makeup water to compensate these losses is about 900 $m^3\ h^{-1}$, which includes approximately 27 $m^3\ h^{-1}$ of drift loss, for a single 500 MW unit. This huge amount of fresh water needs to be replenished from the local rivers, adding to the scarcity of the fresh water available for consumption. In recent past, many global and national organizations like Electric Power Research Institute, Central Electricity Authority (New Delhi, India) have started promoting innovative techniques to minimize