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A study on the heat pump system for removing white plume of cooling tower and recovering water vapor

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Abstract

A study on the system applying a heat pump technology to remove the white plume from a cooling tower and recover the water vapor is carried out. The proposed system firstly cools the discharged humid air stream (38 °C, RH 95%) from a cooling tower by using a cool outside air and secondly cools the humid air stream by the evaporator of the heat pump system to recover water vapor. The recovered water is re-supplied to the cooling tower's water basin. The thermal energy absorbed in the evaporator is released to the condenser of the heat pump system. The condenser is located at the final stage of the cooling tower to heat the air stream discharging into the atmosphere. The final discharging air stream is cooled by the cold outside air as soon as it is released, but the probability of white plume generation is significantly low, owing to the thermal buffer which is provided by the condenser of the heat pump.

Keywords: Cooling tower; White plume; Abatement; Heat pump; COP

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1. Introduction

A Cooling tower is an important facility in various industrial fields such as power generation and air conditioning that can supply a heat sink at 28~32 ºC by using the latent heat of water evaporation [1]. The cooling tower discharges heat energy into the atmosphere by evaporating the fresh water under forced direct-contacted convection. The humid air which is discharged from the upper part of the cooling tower in fall or winter generates the form of cloud, usually called white plume. The white plume from a cooling tower can pose several issues. It may affect visibility and safety as well as public perception [2]. Even though the cooling tower plume is made up of water vapor, a community may perceive it as unwanted or smoke-related. This may affect the use of nearby land or decrease property values.

Another issue about recent cooling tower technology is related to the huge consumption of fresh water for cooling. The water consumption in cooling towers may lead to lower efficiency of facilities and a decrease in industrial production in certain seasons especially when drought occurs. Large inland power plants with cooling towers generating electricity by using water supplies in large quantities should pay high attention to water saving in drought season.

Water conservation is highly related to energy conservation. It takes a considerable quantity of water to generate electricity [3]. Likewise, it takes a considerable amount of energy to produce fresh water and to treat wastewater. This article discusses a water-saving modification using a heat pump in the upper part of the cooling tower. The heat pump condenses the water vapor discharged from the cooling tower for the recovery of fresh water and heats the final discharging flow to reduce white plume.

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2. System schematic and experimental results

2.1. System schematics

Fig. 1 shows a schematic diagram of the heat pump dehumidification system for a cooling tower. The humid air flow at DB (dry-bulb) 36 °C – RH (relative humidity) 95% is generated in a duct system by using a thermo-hygrostat and additional humidifiers. The air flow rate was 1000 CMH. The heat pump system makes hot and cold water circulating for heat exchangers. In order to simplify the system configuration and to consider the actual installation conditions of the cooling tower, the cold and hot water stream are separately circulated. For better performance, it is necessary to adopt a method of direct heat exchange of the refrigerant with the humid air, so further studies are currently underway. The temperatures of the cold water and hot water were 24 °C and 61 °C, respectively.

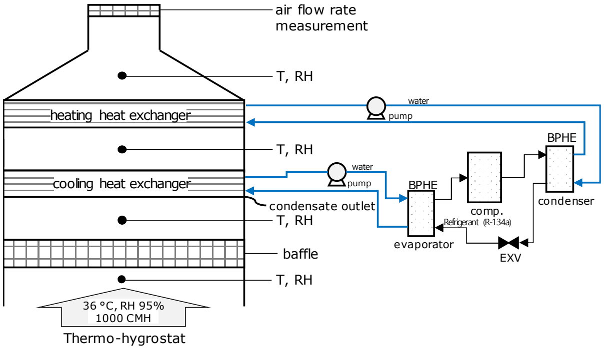


Fig. 1. Schematic of the cooling tower test system with a heat pump dehumidifier

2.2. Experimental Results

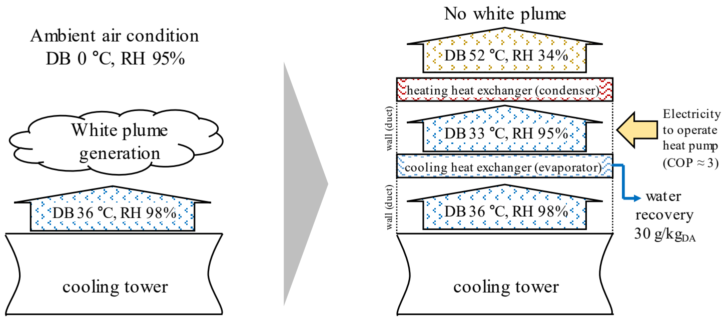
Table 1 presents the experimental results of the targeted system. Approximately 18% of water vapor was recovered by the heat pump system from the humid air flow. The final air flow was heated by the heat pump condenser to DB 52 °C and RH 34%. This final state of the air flow does not cause white plume even under the conditions of the outside DB 0 °C and RH 95%.

Table 1. Performance results of the heat pump system for a cooling tower discharging flow

Evaporator inlet	Evaporator outlet	Water recovery	Condenser outlet	Heat pump capacity	Power consumption of heat pump
DB 36 °C RH 98%	DB 33 °C RH 95%	30 $g \cdot kg_{DA}^{-1}$ (-18.1%)	DB 52 °C RH 34%	Evaporator: 3.2kW Condenser: 4.5kW	1.46kW

Energy is required to condense the water vapor in the air. The energy recovered by the heat pump as water vapor condenses into the water can be used to abate the white plume as in this study, or it can be used for the purpose of supplying hot water for district heating. In order to apply the recovered heat from the water vapor for the district heating system, it is necessary to consider the cost-effectiveness of the electric power consumption of the heat pump system versus the fuel cost to operate a separate peak boiler in a conventional district heating system.

It is difficult to secure economical effectiveness in recovering the water vapor by the heat pump system to simply reduce the water usage cost. The presented approach should be recognized as a disaster response technology that can cope with serious water depletion, desertification or frequent occurrence of drought. In terms of socioeconomic costs of whit plume problem in cooling towers, the presented technology must ensure compatibility in the operation of public infrastructure.



[without water recovery system] [equipped with water recovery heat pump system]

Fig. 2. Schematic of the heat pump system to remove white plume from cooling tower outlet

2.3. Economic Analysis

The power plant that produced 100MW of electricity with 40% efficiency generates 150MW of heat. Assuming a capacity factor of 80% and the plant is cooled by evaporating 15 °C of water, the annual cooling water requirement is estimated at 1.44 million tons. South Korea's industrial water cost is approximately $0.34 per ton. Assuming the additional flow rate for the drain of the cooling tower is 80% of the absolute coolant requirement, the annual cooling water cost is expected to be $927,280. There is sewage fee for drainage of the cooling tower, which is $0.487 per ton of water. Sewage rate of cooling tower is estimated by $563,000 annually. Therefore, annual cooling water usage costs are estimated to be $149 million, taking into account sewage rates. However, this figure is an absolute small cost of $0.002, calculated as the cost of cooling tower in power generation costs per kWh.

From an operator's point of view, unless there is an absolute shortage of water, there seems to be a lack of factors to try to reduce the use of cooling tower with additional investment. It may be better to have an infrastructure with high externalities that can draw water to prepare for an emergency case. This aspect suggests that various technical options should be considered from a policy perspective.

3. Conclusions

In this study, we propose a dehumidification system using a heat pump to recover water by condensing from the humid air discharged from a cooling tower. The experimental results are as follow.

1. As the heat pump system operates in the condition of COP 3 for the cooling tower exhaust air flow (DB 36 °C, RH 95%), 28.5% of water was condensed and recovered from the incoming air-water mass flux.
2. The latent heat which is absorbed from the heat pump's evaporator was utilized for producing hot water by the heat pump, so the final exhaust humid air flow can be in a state of DB 51 °C and RH 31%.
3. The proposed approach can effectively recover water by condensation and prevent a white plume in cold air conditions, but consumes energy required for driving the heat pump. A follow-up study will be conducted to ensure optimum performance of the heat pump in response to various cooling tower exhaust flow and ambient conditions.

Acknowledgements

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