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# The applicability of nebulizing solar heated water for conditioning evaporator inlet air in solar-assisted air source heat pump

Kutbay Sezen[1]

[1] ALTSO Vocational School of Higher Education, Alanya Alaaddin Keykubat University, Turkey

*(kutbaysezen@gmail.com) Email of the corresponding author

***Abstract*** – Air-source heat pumps are energy-efficient, cost-effective, and easily applicable heating systems. The ability to support these systems with renewable and clean solar energy in the simplest way possible will contribute to the widespread adoption of solar-assisted heat pumps and ultimately facilitate the transition to more environmentally friendly and sustainable heating systems. In this study, the extent to which the air temperature and relative humidity change when the evaporator inlet air of an air-source heat pump is mixed with nebulized solar heated water was investigated. The potential benefits or harms of varying the properties of the evaporator inlet air for the system were determined. Even though the evaporating water droplets are 43°C hotter than the air, they lead to a decrease in the air temperature within the airflow. It was found that the increase in relative humidity resulting in an increase in COP does not compensate for the decrease in COP caused by the temperature drop, resulting in a predicted performance loss for the system.

*Keywords – Solar Assisted Heat Pump, Performance, Evaporator Inlet Air, Solar, Nebulized Heated Water*

## I. INTRODUCTION

Solar-assisted heat pump (SAHP) systems have garnered increasing interest in recent years due to their ability to provide environmentally friendly, sustainable, and efficient heating solutions by integrating solar energy into the system [1]. Building energy consumption constitutes approximately 40% of the total energy usage, with heating applications accounting for the largest portion. In the United States, heating represents 55% of building energy consumption, while in China and Europe, the figures rise to 70% and 80%, respectively [2].

Solar energy, being a renewable, clean, and readily available energy source, has the potential to significantly contribute to environmentally friendly and sustainable energy management in buildings, especially for heating purposes [3]. Meanwhile, heat pumps offer energy-efficient heating solutions as they can transfer heat from colder environments to warmer ones with reduced input work compared to the heat transferred [4].

Given these factors, the development of appropriate methods for solar energy integration in heat pump systems becomes crucial in order to achieve more environmentally friendly and efficient heating solutions.

In this study, the potential of supplying hot water heated by solar energy in a nebulized form into the evaporator inlet airflow was investigated to determine if it can enhance the performance of a solar-assisted air-source heat pump (SA-ASHP). Using correlations based on the model developed in the author's previous work [5], the variations in evaporator inlet air temperature and humidity ratio were determined, and their impact on the ASHPs coefficient of performance (COP) was evaluated using the developed correlation.

## II. MATERIALS AND METHOD

Air-source heat pumps are heating systems that transfer heat from the outdoor air to the indoor space by incorporating compressor power. The energy exchange and heat transfer between the refrigerant flow and the air throughout the cycle are illustrated in Figure 1.

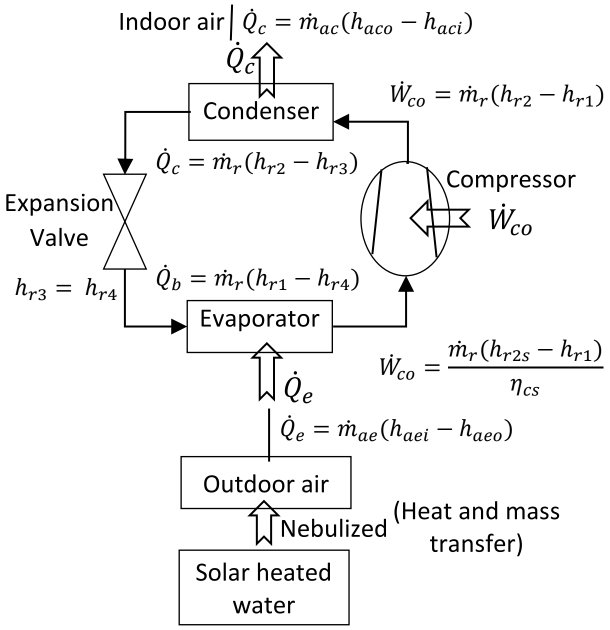


Fig. 1 Energy exchanges of refrigerant and air in ASHP cycle

A model is developed using energy equations and logarithmic mean temperature differences in the heat exchangers to determine the effect of the evaporator inlet air temperature and relative humidity on the COP. In order to facilitate the practical application of the model results, correlations are also established. The detailed methodology of the model and correlations can be found in the previous study [5]. The correlation applicable for the fixed heating power, utilized in this study is provided below.

$$COP_{ratio} = 0.6007(10^{-3})T_{\mathrm{aei}}{}^2 + 0.0113T_{\mathrm{aei}} + 0.8871 + (0.3442\varphi_{\mathrm{aei}} - 0.2061)0.0556T_{\mathrm{aei}} \quad (1)$$

The changes in air properties when hot water is mixed with the evaporator inlet air as nebulized droplets have been determined using the model developed in the previous study [5]. The methodology for this model is provided in the previous study. In this study, the following correlations, which describe the changes in air temperature and relative humidity, were used based on the model results.

$$t_{std} = (d_d/30)^2\exp(-2.694\mathrm{x}10^{-6}\dot{m}_{ratio}{}^2 + 0.00431\dot{m}_{ratio} - 0.539\varphi_{ai}{}^2 + 2.437\varphi_{ai} + 0.183\mathrm{x}10^{-3}T_{ai}{}^2 - 0.0335T_{ai} - 0.957) \quad (2)$$

$$T_{ao} = \mathrm{a}(t_{ratio})^2 + \mathrm{b}(t_{ratio}) + \mathrm{c}$$
$$\mathrm{a} = \exp(-9.709\mathrm{x}10^{-7}\dot{m}_{ratio}{}^2 + 3.664\mathrm{x}10^{-4}\dot{m}_{ratio} - 0.299\varphi_{ai}{}^2 + 0.356\varphi_{ai} - 6.260\mathrm{x}10^{-5}T_{ai}{}^2 + 8.349\mathrm{x}10^{-3}T_{ai} + 1.721$$
$$\mathrm{b} = 7.655\mathrm{x}10^{-7}\dot{m}_{ratio}{}^2 + 7.257\mathrm{x}10^{-3}\dot{m}_{ratio} + 8.35\varphi_{ai}{}^2 - 1.699\varphi_{ai} - 1.355\mathrm{x}10^{-3}T_{ai}{}^2 - 0.172T_{ai} - 12.53$$
$$\mathrm{c} = T_{ai} \quad (3)$$

$$RH_ç = \mathrm{a}(t_{oran})^2 + \mathrm{b}(t_{oran}) + \mathrm{c}$$
$$\mathrm{a} = \ln(2.803\mathrm{x}10^{-7}\dot{m}_{oran}{}^2 - 1.78\mathrm{x}10^{-4}\dot{m}_{oran} + 0.122RH_g{}^2 - 0.437RH_g - 1{,}639\mathrm{x}10^{-4}T_{hg}{}^2 + 0.0147T_{hg} + 0.653)$$
$$\mathrm{b} = -3.19\mathrm{x}10^{-7}\dot{m}_{oran}{}^2 - 8.442\mathrm{x}10^{-5}\dot{m}_{oran} - 1.107RH_g{}^2 + 1.247RH_g + 2.722\mathrm{x}10^{-4}T_{hg}{}^2 - 0.0257T_{hg} + 0.878$$
$$\mathrm{c} = RH_g \quad (4)$$

$$t_{ratio} = t/t_{std} \quad (5)$$

$$\dot{m}_{ratio} = \dot{m}_{air}/\dot{m}_{water} \quad (6)$$

## III. RESULTS AND DISCUSSION

A 4 kW capacity ASHP operating under the following conditions was studied: indoor temperature of 20°C, outdoor temperature of 7°C, and outdoor relative humidity of 50%. The ASHP has a COP value of 4.17 under these conditions. The evaporator air flow rate is 37 kg/min and flow velocity is 2,5 m/s. Hot water is added to airflow 1 m before evaporator entrance. The effect of mixing nebulized hot water, with a temperature of 50°C and a diameter of 20 μm, into the evaporator inlet air at mass mixing ratios $\dot{m}_{ratio}$ of 100, 500, and 1000 were investigated. The changes in evaporator inlet air temperature, relative humidity and the change in in COP according to $\dot{m}_{ratio}$ were determined (Figure 2).

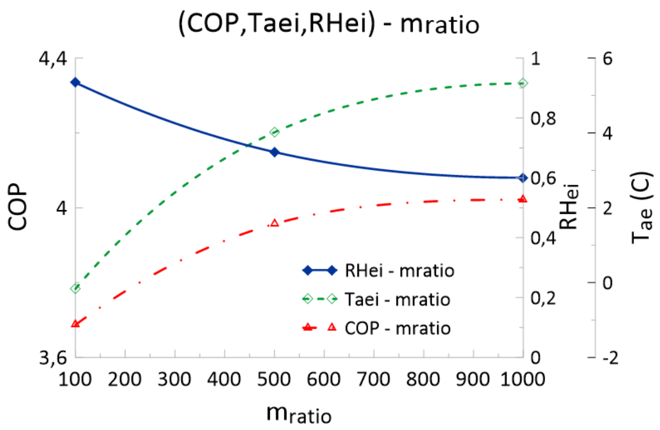


Fig. 2 The changes in COP, $T_{aei}$, $RH_{ei}$, depending on $\dot{m}_{ratio}$

Even though the water droplet introduced into the air is 43°C hotter than the air, due to the latent heat it absorbs during evaporation, it causes a decrease in the air temperature and an increase in relative humidity. As the ratio of air mass to the mixed water decreases, the mass of water that can evaporate within the limited time period decreases, thus limiting the increase in relative humidity. At $\dot{m}_{ratio}$ of 100, 500, and 1000, the temperature of the air entering the evaporator decreases from 7°C to -0.2°C, 4.0°C, and 5.3°C, respectively, while the relative humidity increases from 0.5 to 0.92, 0.69, and 0.60, respectively. Although the increase in relative humidity contributes to the COP value, the COP variation caused by the decrease in temperature is more significant, resulting in a decrease in performance of the system under all conditions (Figure 3).

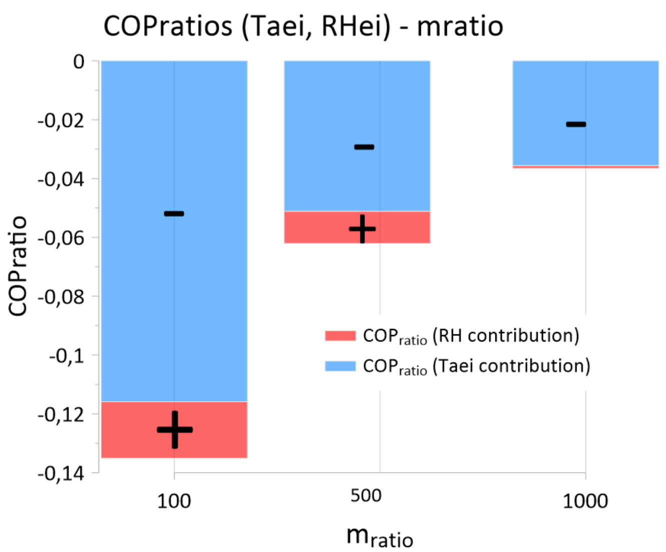


Fig. 3 The contributions of temperature $T_{aei}$ and relative humidity $RH_{ei}$ changes of evaporator inlet air to COP ratio according to $\dot{m}_{ratio}$

## IV. CONCLUSION

This study aimed to investigate the effect of washing the evaporator inlet air with nebulized hot water heated by solar energy on the performance of an air source heat pump (ASHP) system. Correlations developed to analyse changes in ASHP performance were utilized. The results revealed two key observations when the initially 7°C outdoor air was washed with hot water droplets of 20 μm in diameter and 50°C in temperature at mixing ratios ranging from 100 to 1000. Firstly, the air temperature consistently decreased for each mixing ratio. Secondly, this process led to an increase in relative humidity of the air. However, it is observed that temperature decrease occurred across all mixing ratios and the temperature-driven decrease in COP counteracted the humidity-induced increase in COP enhancement under all conditions.

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