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Analysis on Exergy Efficiency of a Dew Point Evaporative Cooler

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ABSTRACT

In order to evaluate the energy efficiency of a dew point evaporative cooler from the views of "quantity" and "quality" of energy, based on the second law of thermodynamics, the influence of intake air temperature, air flow velocity and relative humidity on the distribution and variation of thermal exergy, chemical exergy, mechanical exergy, and exergy efficiency in the wet and dry channels of the cooler was studied by exergy analysis. The results show that the exergy efficiency of the cooler increases from 10.6% to 36.7% with the increase of the intake air temperature, and decreases from 21.8% to 9.5% with the increase of the relative humidity of the intake air and decreases from 18.2% to 9.1% with the increase of the air flow velocity. By studying the exergy efficiency under different conditions, it is known that the cooler still has a great energy saving potential. Combined with the exergy efficiency, the weak points of energy saving of the dew point evaporative cooler can be clearly known, thereby finding a method for reducing energy loss.

Keywords: dew point evaporative cooler; thermal exergy; chemical exergy; mechanical exergy; exergy efficiency

NONMENCLATURE

C_{pa}	Mass specific heat capacity of dry air, kJ/kg
C_{pv}	Mass specific heat capacity of water vapor, kJ/kg
ω	Moisture content, kJ/kg
ω_{os}	Humidity content of saturated moist air at ambient conditions, kJ/kg
T_0	Environmental temperature, ºC
T	Inlet and outlet air temperature, ºC
p_0	Environmental state pressure, Pa
p	Inlet and outlet air pressure, Pa
ex	Unit quality exergy, kJ/kg
ex_{th}, ex_{ch}, ex_{me}	Unit mass thermal exergy, chemical exergy, mechanical exergy, kJ/kg
η	Exergy efficiency
m_1, m_2	Primary and secondary air mass flow rates, kg/s
Δ	Variation in exergy

1. INTRODUCTION

Energy shortage is a very serious problem for the world nowadays. The development and utilization of renewable energy sources is of great significance. Evaporative cooling technology is a natural refrigeration technology with many advantages, i.e. no compressor, no chemical refrigerant, large fresh air volume, high efficiency and economy, etc. which is driven by the difference between dry and wet bulb temperature [1-3]. The dew point cooling technology represents a new stage of evaporative cooling development which could provide low-temperature product air even close to the air dew point [4].

Most of the literatures evaluate the evaporative cooling performance only in terms of cooling efficiency. It is unable to analyze the nature of energy use and loss. Exergy analysis can remedy this deficiency by identifying the site, size, and cause of energy loss. It can help to find the way to reduce energy losses and maximize the energy efficiency of the dew point evaporative cooler [5].

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2. METHODS FOR EXERGY CALCULATING

2.1 Selection of environmental parameters

In thermodynamics, it is defined that the maximum useful work made by changing reversibly from any state to the state of equilibrium with the environment is called thermodynamic exergy, when the thermodynamic system interacts only with the environment. For exergy analysis of dew point evaporation cooler, the first thing is to determine the zero base point of exergy analysis. It is unreasonable to choose unsaturated wet air as the environmental state. Therefore, the atmospheric temperature and pressure corresponding to saturated wet air state (T_0, P_0, ω_0) are defined as the environmental state [6]. The primary air of the dew point evaporative cooler is unsaturated wet air, which is unbalanced with temperature, pressure and moisture content of environmental state, so it owns the ability to do work. The dew point evaporative cooler could convert more energy to useful energy.

2.2 Method of calculation

When the system temperature is imbalance with the ambient temperature, the useful energy is defined as thermal exergy, and is calculated as follows [7].

$$ex_{th} = (c_{pa} + \omega c_{pv})T_0\left(\frac{T}{T_0} - 1 - \ln\frac{T}{T_0}\right) \quad (1)$$

When the system pressure could not be balanced with the ambient pressure, the useful energy is named mechanical exergy [7].

$$ex_{me} = (1 + 1.608\omega)\ R_a T_0 \ln\frac{p}{p_0} \quad (2)$$

When the moisture content of the system is not balanced with that of the ambient, the useful energy is called chemical exergy [7].

$$ex_{ch} = R_a T_0[(1 + 1.608\omega)\ln\frac{1 + 1.608\omega_{os}}{1 + 1.608\omega} + 1.608\omega\ln\frac{\omega}{\omega_{os}}] \quad (3)$$

The total energy per unit mass of wet air is composed of thermal, chemical, and mechanical energy, calculated as follows [7-8]:

$$ex = ex_{th} + ex_{me} + ex_{ch} \quad (4)$$

The efficiency is the ratio of the profit exergy to the total input exergy, and the energy conversion efficiency is evaluated in terms of work capability, calculated as:

$$\eta = \frac{m_1 \Delta ex_{th1}}{m_1 \Delta ex_{me1} + m_2(\Delta ex_{ch2} + \Delta ex_{me2})} \quad (5)$$

2.3 Data sources

The data in this paper are all from published experimental tests, as shown in Fig. 1 [3].

Fig. 1 Experimental rig for dew point evaporative cooler

3. EXERGY TRANSFORMATIONAL

In order to study the exergy transformation relationship between the dry and wet channels in the dew point evaporative cooler. The dry channel is defined as primary thermal exergy and primary chemical exergy, and the wet channel as secondary thermal exergy and secondary chemical exergy. To simplify the calculation, the fan and pump power are considered as the mechanical exergy that is input to the dew point evaporative cooler. Exergy changes in the dry and wet were tested when the outdoor air temperature of 25°C, 30°C and 35°C, and the results are shown in Table 1.

Table 1 Exergy transformational relationship

Temperature(°C)	25°C	30°C	35°C
Primary energy exergy(kJ/kg)	112.0	156.1	206.7
Secondary energy exergy(kJ/kg)	0.7	0.2	0.2
Secondary chemistry exergy(kJ/kg)	-354.8	-385.9	-414.0
Mechanical exergy(kJ/kg)	-320.7	-322.8	-324.8

The outlet chemical exergy in wet channel is less than the inlet chemical exergy. The reason is that a part of the air in the dry channel enters the wet channel and continuously exchange heat and moisture with the wetting evaporation surface. The moisture content in the wet channel keeps increasing until approaching saturation. The unbalance between the moisture content in the wet channel and the saturated moisture content gradually decreases. The ability to do work is reduced and the chemical exergy decreases. At the same time, the process of heat and moisture exchange between water and air causes irreversible chemical exergy loss. Therefore, the wet and dry channels are studied as a whole system.

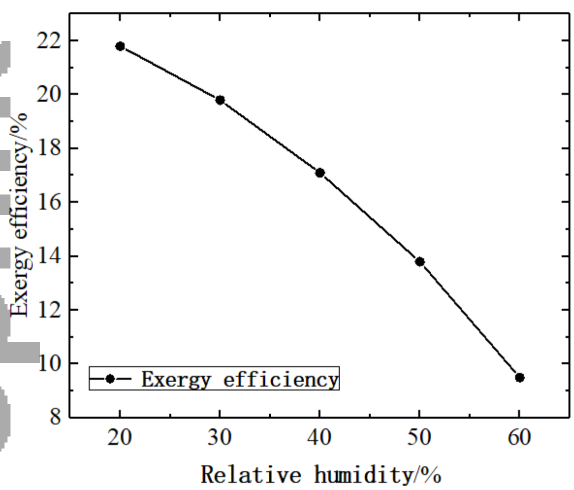

Fig. 3 Influence of inlet relative humidity on exergy distribution and parameter efficiency.

4. *INFLUENCE OF PARAMETERS ON THE EXERGY DISTRIBUTION AND EFFICIENCY*

4.1 Impact of inlet air temperature

Fig. 2 shows the trend curve of the dew point evaporative cooler's exergy efficiency as the inlet air temperature increases. It can be seen that the exergy efficiency increases from 10.6% to 36.7% as the inlet air temperature increases from 20°C to 40°C. The results show that the rapid increase in thermal energy storage is the key factor influencing the exergy efficiency increase with increasing air inlet temperature. The reason is that with the inlet air temperature increases, the grade of the air heat source increases and therefor the useful energy increase correspondingly. The increase in thermal exergy is greater than the decrease in chemical exergy and mechanical exergy. As the temperature difference between the dry and wet bulb increases, the evaporative cooling potential increases, the irreversible exergy loss between the air in the wet channel and the wetted evaporative surface decreases, and the exergy efficiency increases.

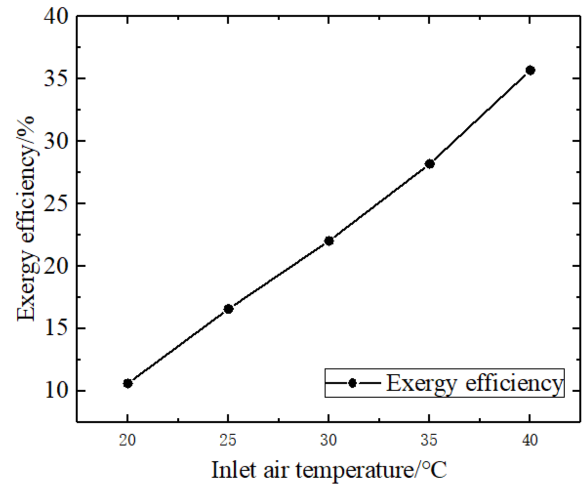

Fig. 2 Influence of inlet air temperature on exergy distribution and exergy efficiency

4.2 Impact of inlet relative humidity

Fig. 3 shows the exergy efficiency trend of the dew point evaporative cooler as the relative humidity of the inlet air increases. It can be seen that the exergy efficiency decreased from 21.8% to 9.5% with increasing relative humidity. The results show that the reduction of chemical exergy in the wet channel is the key factor influencing the reduction in exergy efficiency. When the inlet temperature remains unchanged and the relative humidity increases, the chemical exergy in the wet channel air and wetting evaporation surface heat and moisture exchange process decreases, and the thermal exergy transferred to the dry channel through heat exchange decreases. The thermal exergy reduction is greater than the chemical exergy and mechanical exergy reduction, so the exergy efficiency decreases.

4.3 Impact of airflow velocity

Fig. 4 presents the exergy efficiency trend curve of the dew point evaporative cooler as the airflow speed increases. It can be seen that the exergy efficiency decreases from 18.2% to 3.1% as the airflow speed increases. The results show that a significant decrease in mechanical exergy is a key factor in reducing the efficiency of refrigerating operations as the air velocity increases. Analysis of the causes shows that as the air velocity increases from 0.5 m/s to 2.5 m/s, the fan power increases, the mechanical reduction increases, and the losses due to flow resistance increase, so the amount of air passing through the wet and dry channels increases.

However, due to the insufficient thermal mass exchange between the air in the wet channel and the wetted evaporating surface, irreversible losses increase.

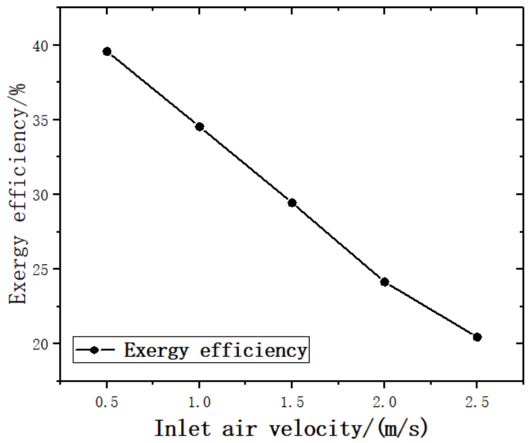

Fig. 4 Influence of airflow velocity on exergy distribution and exergy efficiency.

5. CONCLUSIONS

(1) When the inlet air temperature is increased from 20°C to 40°C, the efficiency of the dew point evaporative cooler increased from 10.6% to 36.7%. The rapid increase in thermal energy exergy is a key factor in increasing the exergy efficiency. It can be improved by promoting evaporative cooling of air and water, reducing irreversible losses in heat and moisture transfer processes, and reducing the resistance of air flow through the channels.

(2) When the relative humidity of the inlet air is increased from 20% to 60%, the exergy efficiency rapidly reduced to a maximum of 21.8%. The rapid reduction of the chemical exergy is the key factor for reducing the exergy efficiency. In hot and humid areas, it is advised to install an air dryer at the dry channel inlet to increase the exergy efficiency.

(3) When the air velocity is increased from 0.5 m/s to 2.5 m/s, the exergy efficiency reduced rapidly to a maximum of 18.2%. Therefore a reasonable airflow velocity should be kept to ensure the exergy capacity for maximizing the energy efficiency.

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