A NOVEL METHOD FOR DESIGNING AND PREDICTING THE PERFORMANCE OF MIST COOLING SYSTEM USING MITIGATION TECHNIQUE

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ABSTRACT

By harnessing the heat of water evaporation, a process that uses very little water and energy and only produces tiny amounts of water and energy, a cooling system that sprays tiny water droplets may be effective in reducing temperature rises in metropolitan areas. On hot days, spraying water mist in a semi-outdoor setting, such one covered by a canopy, could help the environment. Nevertheless, there is not much information available for the design or management of such systems. We address variations in cooling effects in the context of water mist particle size distribution in order to suggest a way for planning and forecasting the performance of a water mist system. The findings of the numerical fluid analysis revealed that the temperature decrease for different particle sizes is not significantly different. However, the water particles remained in a lower position with larger particles.

Keywords- Mitigation technologies; natural sinks; passive cooling; heat dissipation

INTRODUCTION

To regulate the space's humidity and temperature, the air conditioning system consumes the most energy in both household and industrial applications. Around 50% of the energy used globally is consumed by the construction industry, which is a major energy consumer. A typical air conditioning system uses 30% of the power in a home or business. In order to increase the energy efficiency and cooling capacity, much research is being done on evaporative cooling techniques as direct evaporative cooling, indirect evaporative cooling, combined direct and indirect evaporative cooling, different types of cooling media and materials, etc. To forecast the outflow, Hsieh et al. [6,7] created a numerical model for a direct evaporative cooler with a compact metallic air/water interface. The predicted and experimental results are compared and observed with 1.33% maximum error. Mzad et al. [8] have theoretically investigated the exchange of energy and concentration among the air stream and water mist particles and proposed the simplified correlation to find the cooling efficiency. Nakayama et al. [9] have analyzed the effect of performance parameters as frontal air velocity, inlet air temperature and incoming water temperature on the cooling effect produced by the system. An empirical correlation is also developed between the frontal air velocity and the cooling effect produced by the system. Qiang [10] had optimized the factors which are affecting the performance of the cooling process by developing a mathematical model and obtained the results as the saturation efficiency with respect to WBT is 0.9 to 1.0.

LITERATURE REVIEW

1. Abdalla et al [1] aimed to review the recent developments concerning evaporative cooling technologies that could potentially provide sufficient cooling comfort, reduce environmental impact and lower energy consumption in buildings. Air-conditioning plays an essential role in ensuring occupants thermal comfort.
2. However, building’s electricity bills have become unaffordable. Yet the commercially dominant cooling systems are intensively power-consuming ones, i.e. vapor compression systems. An extensive literature review has been conducted and mapped out the state-of-the-art evaporative cooling systems. The review covers direct evaporative cooling, indirect evaporative cooling and combined direct-indirect cooling systems. The indirect evaporative coolers include both wet-bulb temperature evaporative coolers and dew point evaporative coolers have been of particular interest because of high thermal performance. The dew point evaporative coolers have shown great potential of development and research opportunity for their improved efficiency and low energy use.
3. Celata et al [2] used pump for supplying water required to moisten the evaporative cooling surface was eliminated. The system was constructed and tested under varying temperature, relative humidity and air flow rates. Results showed significant temperature reduction accompanied with acceptable increase in relative

humidity. Temperature drop of (6-10) oC between the inlet and outlet temperatures of the product or supply air was recorded. Increase in relative humidity of the supply air was (6 –10) % less than the working air.

4. Holman et.al.[3] aims to analyze the influence of some operation parameters, such as the reactivation temperature of the adsorbent, and the relationship between the reactivation air flow and the process air flow (R/P) on the performance of the system. In addition, this paper presents an application of a proposed system in different climate characteristics of several tropical and equatorial cities.
5. Hamlin et.al. [4] carried out experimental device to study thermal performance of the evaporative coolers, their studies concentrate on changing pack thickness. The increase in pack thickness from (5.5cm) to (13cm) leads to effectiveness more than (51%). Also they studied possibility to develop water distribution system and water pump power. The results indicate that the use of these modifications together leads to effectiveness of more than (90 %).
6. Hosoz et al [5] drip evaporative cooling method was constructed with simple materials and used for the preservation of fruits and vegetables. It consists of a simple low cost cavity wall evaporative cooler constructed from bricks and termed as “Improved Zero-Energy Cool Chamber” in India.

CONSTRUCTIONAL DETAIL

This system works by air evaporation of water droplets. Misting system work so effectively because of sufficient water supply. The reserve water through ¼" nylon/steel lines to brass mist nozzles, producing microscopic droplets of water. The fine mist of water droplets droplets hits the hot air and flash evaporates to cool the surrounding space up to 15degrees. When evaporation occurs, temperature drops. The outdoor heat, necessary to cause evaporation, actually draws from the air temperature and cools the surrounding area within seconds. Our misting system do this by atomizing high-pressure water via specialized misting nozzles that produce a fine mist/fog that is perfectly sized for evaporation. The lower the relative humidity, the better the evaporative cooling effect. This system works by air evaporation of water droplets.

Diagram of a Simple Pick and Place Robot:

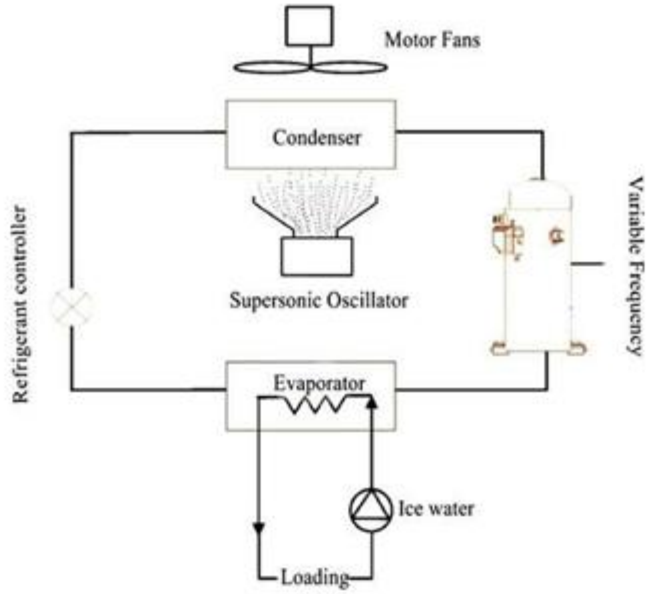

Fig.1 Flow chat of water-cooled chiller components

A variable frequency control was employed to eliminate the frequent starting and stopping of the compressor. It is capable of controlling the temperature, as well as providing a power saving operation and allowing the supersonic atomizer system to adjust the volume of atomization in coordination with the compressor loading status. Because supersonic atomization has mostly been used in the cooling of electronic ships and small components, and the literature has shown that atomization is capable of carrying away a large amount of heat through the vaporization of water mist, this study was intended to design an experiment platform to measure the data and compare the atomization efficiency with that of traditional air-cooled water chillers.

The design of the supersonic vaporization chiller is shown in Fig. 2(a) and a photograph of its implementation is shown in Fig. 2(b). Fig. 2(a) also shows the experiment platform of the air-cooled water chiller. Its components are (1) a fan; (2) a con- denser; (3) a water-mist spray outlet; (4) a Man–machine inter-face/circuitry assembly; (5) a Refrigerant controller; (6) supersonic atomizer; and (7) a compressor.

Their main functions are as follows:

- Fan: driving water mist to distribute it evenly over the condenser surface.

- Condenser: exchanging heat with air (heat dissipation), using the air to carry heat away from the refrigerant inside the condenser so that the high-temperature and high-pressure gaseous refrigerant transforms into a hyper-cooled high-pressure liquid refrigerant of normal temperature.

- Water-mist spray outlet: outputting required mist for cooling and with a function of preventing from mist leaked out of the effective heat-exchangeable area of condenser.
- Man–machine interface/circuitry assembly: viewing the status of machine operation, including chilled water temperature, condenser temperature, and operation load.
- Refrigerant controller: regulating the flow rate of refriger- ant entering the evaporator, so that the quantity of liquid refrigerant entering the evaporator equals the quantity of vaporized refrigerant in the evaporator. Another function is to maintain the system pressure difference between the high-pressure side and low-pressure side, to provide the low-pressure required in the evaporator and the high-pressure required in the condenser. The unit uses a capillary as the controller

WORKING OF MACHINE

Supersonic atomizer: water is atomized into mist through supersonic vibration and spreads in the air. This apparatus includes a set of supersonic transducers and controllers, via tuning the alternating voltage of relatively high frequency, which can effectively adjust the volume of mist. This was the basic cooling setup of the study.

Compressor: The system uses a volute-type compressor, mainly for compressing the refrigerant to generate the high-pressure and low-pressure necessary for the refrigeration cycle. The low-pressure and low temperature gaseous refrigerant is compressed to form high-pressure and hyper-heated refrigerant vapor, which is delivered into the condenser to perform heat- exchange.

Evaporator: performing heat exchange of the refrigerant and the water chiller system. Evaporators commonly used in water chillers are the dry expansion type and flooded type. Structurally, heat-exchangers can be categorically divided into shell, pipe, and plate types. This unit uses a plate heat exchanger.

A rapid water flow occurs when a vibrator produces a super- sonic wave in water. The liquid at the surface exerts a supersonic beam focusing effect, and forms a supersonic fountain. Because of the rapid water flow, the pressure of the liquid temporarily decreases, forming small bubbles. Internal pressure is consider- ably low, pulling liquid fission and forming hollowing. When the water pressure is restored, the bubbles move inward and fission collapses. A considerably small blast occurs, but the effect is a con- siderably large shockwave. The force from the moment of impact causes the liquid to diverge into particles and form a mist. The latent heat required to evaporate a kilogram of water (2430.5 kJ at 30 °C) is equal to the heat required to melt 7 kg of ice. The high pressure sprays droplet sizes of 15–40 µm; the supersonic produces a micro mist diameter in the range of 3–5 µm. The larger the surface area in contact with air, the greater the cooling effect.

In this study, ambient air was drawn or blown through a porous wetted surface where the air stream is cooled by water mist, and its dry bulb= temperature drops to approach its wet bulb temperature. Where, DO-1 to DO- 4 represents the control switches of compressor, ice water pump

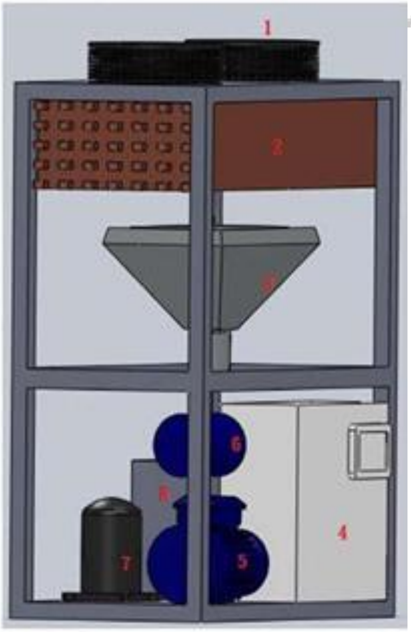

Fig.2 Supersonic vaporization chiller system

Fig. 3 is a diagram of the closed-loop system. Its main controls are a supersonic oscillation driving circuit (SOD), a pulse-width modulation (PWM) control circuit, and a dual-effect fuzzy control (DEFC). The main functions of the controls are as follows:

1. SOD: producing the frequency of the supersonic atomizer.
2. PWM: adjusting the volume of water misting by controlling the frequency of the supersonic vibrator.
3. DEFC: determining the size of the PWM control signal.

The dual-effect fuzzy control system is used to cover the entire system. The atomization volume output control used the PWM to adjust the supersonic frequency in response to actual demand.

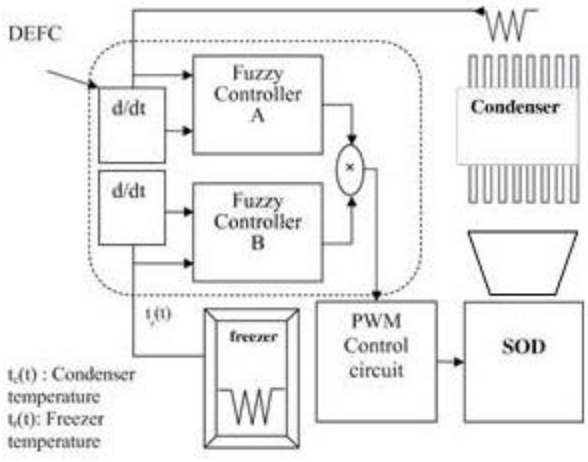

Fig.3 Closed loop system

COP calculation

In this study, the chiller COP was calculated from the measured variables but directly measured. First, the chiller load EL can be obtained by (1), then the chiller COP, using the chiller load divided by the measured variables, including the chiller power and supersonic atomizer power. Besides, chiller power includes the compressor power and condenser fan power, can be found and shown in (2).

$$EL = mW \cdot CP\ (Tchwr - Tchws) \qquad (1)$$

$$COP = EL\ (Ech + Esa) = mW \cdot CWP\ (Tchwr - Tchws)/(Ecc + Ecf + Esa) \qquad (2)$$

where, mw is chilled water flow rate (m^3 /s), CWP is the specific heat capacity of water (4186 J/kg °C), Tchws and Tchwr are temperatures of supply and return chilled water (°C), Ech is chiller power (kW), Esa is supersonic atomizer power (kW), Ecc is compressor power (kW), and Ecf is condenser fan power (kW).

Results and discussion

Based on head pressure control, the air-cooled chiller is operated and studied. In order to examine the performance of the air-cooled chiller with or without water-mist cooling system, experiments under a representative range of ambient temperature (Tdb: 22.8–36.5 °C), relative humidity (RH: 33.4%–91.1%) and part load ratios (PLRs: 0.1–1.2) in the local climate of Tainan, Taiwan were conducted over a period of 3 months from July to September 2014.

The temperature distribution was observed using an infrared photo-detector after the air-cooled water chiller was run for 2 h. The condenser temperature was approximately 45.6 °C without supersonic atomization, as displayed in Fig. 5(a). The condenser temperature was approximately 40.2 °C with supersonic atomization, as displayed in Fig. 5(b). The difference was approximately 5.4 °C. The experiment indicated that the studied fixed-frequency air-cooled water chiller consumes 4.249 kW on average, whereas the chiller, equipped with a variable-frequency mist-cooled sys- tem, consumes 3.716 kW on average. In addition, through (6) and (7) and using the experimental variables which were measured and logged in every 20-min intervals over the experimental period, the COP values of with/without water-mist cooling system were found. Here, as the studied chiller with mist-cooled system a COP value of 4.34 was obtained. Concluding above results knows that the variable-frequency air-cooled water chiller was 25% more energy efficient.

CONCLUSION

The green industry is becoming increasingly mainstream and people are searching for methods that save power, are energy efficient, and do not pollute the environment. This study established an experimental platform for conduct- ing tests, observing cooling efficiencies, and calculating power saving statuses. Regarding the application's cooling efficiency, a temperature difference of 5.4 °C was observed before and after the application, which is substantial regarding efficiency caused no environmental pollution or water accumulation in its surroundings. When compared with fixed frequency air-cooled water chillers, a 25% energy saving was observed, which is excep- tional regarding power saving. The newly developed supersonic mist-cooled water chiller is an effective solution to the problem of rising water and electricity fees.

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