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Novel Energy Efficient Design of Water-Cooler for Hot and Dry Climate

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Abstract:
Conventional domestic water coolers found in schools, offices and other public places work on the vapour compression refrigeration system are highly energy-intensive and expensive due to the presence of compressor. An evaporative cooling process is an alternative way to cool the drinking water without the use of external energy in hot and dry weather conditions. This paper illustrates the novel energy-efficient design of water-cooler for a hot and dry climate. The proposed system has lower energy consumptions as compared with the compressor based conventional water cooler. Average drinking water inlet and outlet temperature for the developed system were recorded as 30.5^{0}C and 23.06^{0}C respectively. The average rate of evaporation of water on jute humidifier was found as 3.116 kg/hr with average heat rejection from the drinking water as 339.73 W. The humidifying efficiency of jute humidifier was estimated as 76.8%. The drinking water at temperature 23.06^{0}C was found good for drinking purpose. The coefficient of performance (COP) of the developed system was found as 8.26 with a refrigeration capacity of 0.0968 TR.

Keywords: *Coefficient of performance, Drinking water, Evaporative cooling, Humidifying efficiency, Vapour compression refrigeration system.*

1. INTRODUCTION

Largely electric power is produced through coal-fired power plants. They release certain by-products harmful to the environment. The systems which are electrically driven must be energy efficient. Old and inefficient systems which are in service either should be replaced or re-designed for maximum energy efficiency.

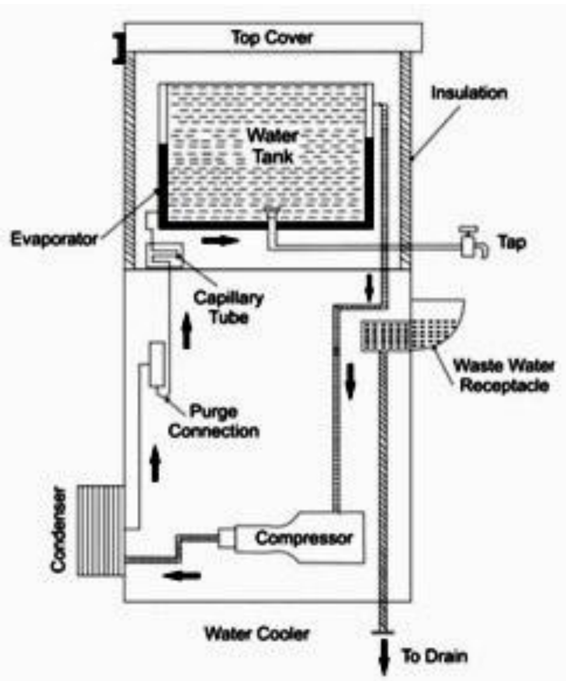

Figure 1: Conventional water cooler

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The water cooler (figure 1) is the popular appliance usually found in schools, colleges, and many public places running on electrical energy. It uses a vapour compression refrigeration system (VCRs) to cool the water. This system employs a compressor which is the high energy-consuming element. Thus, it is required to re-design the water cooler for lower energy consumption.

For a hot and dry climate, evaporative cooling is an attractive method to cool the substance. In the evaporative cooling process, the water is cooled by using its large enthalpy of vaporization. The temperature of the water is dropped significantly through the phase transition of liquid water to water vapour without using external energy. This process is known as an evaporative cooling process, which is widely used in desert cooler (figure 2) to cool and humidify the air in hot & dry climatic condition.

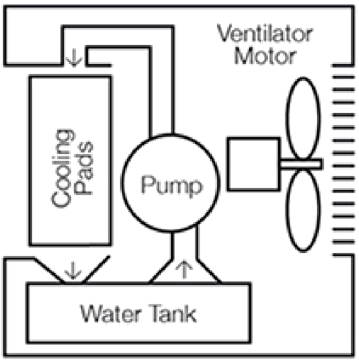

Figure 2: Evaporative cooling process in desert cooler

Cooling by surface evaporation is used by the human from ancient time. Cooling of water in the clay pot (figure 3) is a common application of evaporative cooling which is used at many places where the climate is hot and dry.

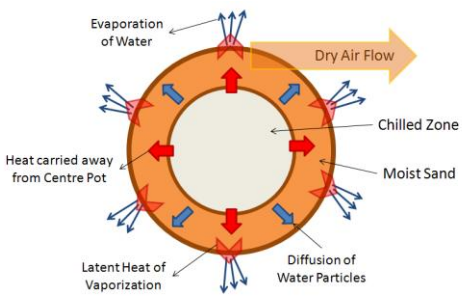

Figure 3: Surface evaporation from a clay pot

Many researchers have used the evaporative cooling process for cooling air and other substances. Patil *et al.*, [1] said that the evaporative cooling systems are useful for dry and hot climates. These systems are energy-efficient and environmentally clean as they do not make use of any chemical or refrigerant. Jain *et al.*, [2] concluded that regenerative evaporative cooler is advantageous for providing more cooling compared to an ordinary direct evaporative cooler. Kulkarni *et al.*, [3]depicted that the effectiveness of evaporative cooling is a function of dry-bulb temperature (DBT) and wet bulb temperature (WBT) of outside air. The effectiveness was found in the range of 0.55 to 0.72. The system can be effectively used to provide comfort conditions for hot and dry weather with a net energy saving of 65 %. Gohane *et al.*, [4] stated that wet media is a mandatory part of an evaporative cooler. Various kinds of porous materials such as metal and plastic foams, zeolite and carbon fibres can be used as wet media for heat and mass transfer in evaporative cooling systems. Aviv *et al.*, [5] demonstrated that building components must be parametrically designed to yield optimal cooling effects. Chakrabarti *et al.*, [6] developed a theoretical approach for simultaneous heat and mass transfer for the air washer. De Antonellis *et al.*, [7] investigated a new indirect evaporative cooling system including the effects of secondary air humidification in the inlet plenum. The indirect evaporative cooling system can provide a significant reduction in primary air temperature. Duan *et al.*, [8] found that the saturation efficiency of triangular cooling media was higher than the other developed cooling media. Lin *et al.*, [9] said that under most simulation conditions, the cooled air exergy was 70% to 85% of the total exergy input. The exergy efficiency ratio of the dew point evaporative cooler was above 1.0 under most simulation conditions, indicating that it was a highly efficient and economical approach to cool the air sensibly. Chopra *et al.*, [10] concluded that cooling efficiency was improved by 20.43% using semicircular shaped khus cooling pad. Celdek was preferred cooling pad

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material followed by coconut, bamboo fibre and khus material. Sachdeva *et al.*, [11] observed that for different thickness of cooling pads, the second law efficiency did not change, but wet bulb saturation efficiency had been changed. Xiea *et al.*, [12] demonstrated an indirect evaporative air cooler system and indirect evaporative chiller system. The indirect evaporative cooling system to produce cold water was found better than to produce cooling air in both electricity consumption and heat transfer area input. Zakari *et al.*, [13] developed an evaporative cooling system for the preservation of fresh vegetables. Suramwar *et al.*, [14] stated that water cooler can be easily developed using adiabatic saturation process.

From the literature, it is found that many investigators proved that evaporative cooling process is the best cooling process without the use of any external energy for hot and dry outdoor conditions. But very few investigators have tried to develop the water cooler working on the evaporative cooling process. Keeping this forethought, work on the development of water cooler with evaporative cooling was undertaken. This paper demonstrates an experimental investigation on the novel energy-efficient design of water-cooler working on the evaporative cooling process.

2. THE NOVEL ENERGY-EFFICIENT DESIGN OF WATER-COOLER

The proposed water cooler is shown in figure 4. It has a base frame of stainless steel with a height of 1524 mm, the width of 1066 mm and a length of 762 mm. The system consists of two insulated stainless steel tanks of 15 litres capacity each. One tank is used to store the water from the filtering unit while the other tank is used to store the cold water coming from the copper tube for drinking purpose. The water which is to be cooled flows through the copper tube of 15 mm diameter and 15240 mm length with thermal conductivity of 385 W/m k. Copper tube is externally covered with jute material to accomplish the evaporation of water on its surface. Jute is long, shiny, soft vegetable fibre primarily produced from the plant. It has a great ability to hold the water. To provide continuous water supply on jute, two water trays with a depth of 75 mm, the width of 915 mm and a length of 610 mm are provided. The upper tray is spraying water on jute covered copper tube and the lower tray collects excess water falling from the copper tube. DC pump of the rating of 12V, 8W is used to circulate water from lower to upper tray. The air is circulated over the jute using 12V, 33W, D.C. exhaust fan. Figure 5 shows a photograph of the developed water-cooler.

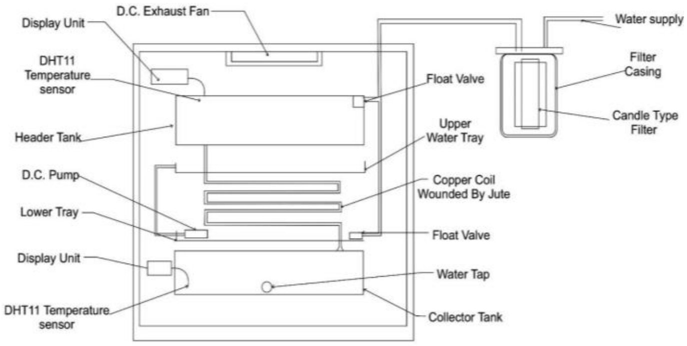

Figure 4: Experimental setup of the proposed water cooler

Figure 5: Photograph of the developed water cooler

The cooling effect created by the evaporation of water on jute material is transmitted to the drinking water through the copper tube and thus the cold

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water for drinking is obtained. It is stored in the lower tank.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental setup was fabricated and tested during the months from January to March 2019 at S. B. Jain Institute of Technology, Management and Research, Nagpur, Maharashtra, India (21.1458° N, 79.0882° E). Figure 6 shows the average experimental observation during the period of testing of the newly designed water cooler. Average drinking water inlet and outlet temperature were recorded as 30.5^{0}C and 23.06^{0}C respectively. The average rate of evaporation of water on the jute surface was found as 3.116 kg/hr with average heat rejection from drinking water as 339.73 W.

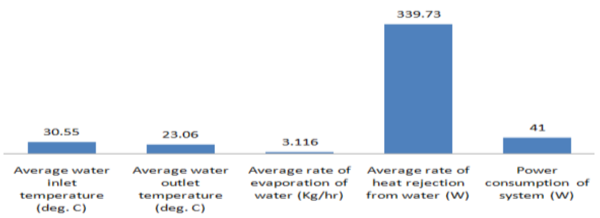

Figure 6: Average experimental results

Figure 7 shows the variation between the inlet and outlet temperature of the drinking water. The average temperature drop of 7.44^{0}C was recorded during the cooling process. The drinking water at temperature 23.06^{0}C was found as good for drinking purpose.

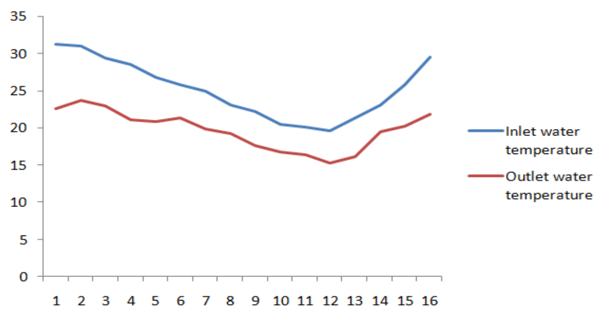

Figure 7: Variation in water inlet and outlet temperature

Figure 8 shows the variation between atmospheric temperature and outlet drinking water temperature. It was found that the average water temperature was 10.6^{0}C less than the atmospheric temperature.

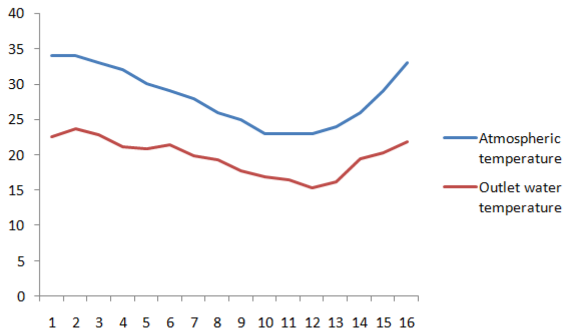

Figure 8: Variation in outlet water temperature and atmospheric temperature

Figure 9 shows the variation in water evaporative coefficient on jute surface and heat rejected by drinking water during its cooling inside the copper tube. It shows that evaporative coefficient was changing gradually; however, heat rejected by the drinking water was varying drastically due to variation in inlet psychrometric properties of air throughout the day.

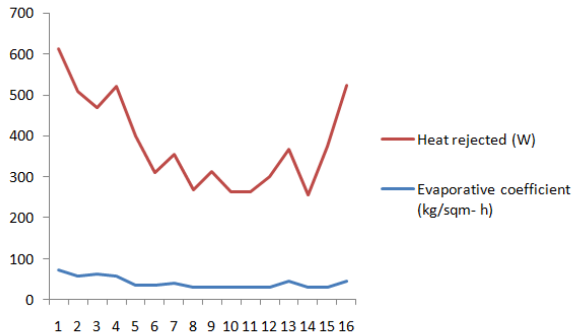

Figure 9: Variation in evaporative coefficient and heat rejected by the water

Figure 10 shows the representation of the evaporative cooling process occurring on the surface of the jute covered on the copper cooling coil. Average humidifying efficiency of the jute humidifier was recorded as 76.8%. The system energy consumption was recorded as 41W. System coefficient of performance (COP) was estimated to be 8.26 with cooling capacity of 0.0968 TR. By considering conventional VCRs based water cooler

COP as 2.5, the developed water cooler COP was found 230% higher due to its lower input energy consumption. The expenditure on fabrication was Rs. 23600 which was found much lower as compared with commercially available water cooler of the same capacity.

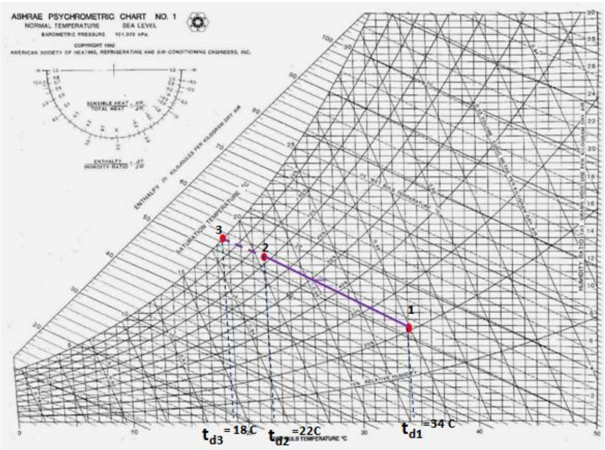

Figure 10: Cooling and humidification process of air

4. CONCLUSION

The presented work referred to a novel energy-efficient design of water-cooler for hot and dry climate operating on the evaporative cooling process. The proposed system has only two energy-consuming devices, fan and pump; they consume much less energy as compared with the compressor used in the conventional water cooler. Hence the developed system is found economical with low energy expenditure.

Average drinking water inlet and outlet temperature were recorded as 30.50C and 23.060C respectively. The average rate of evaporation of water on jute surface was found as 3.116 kg/hr with average heat rejection from drinking water inside the copper tube as 339.73 W. Humidifying efficiency of jute humidifier was estimated as 76.8%. The drinking water at temperature 23.060C was found suitable for drinking purpose. The system energy consumption was recorded as 41 W with a coefficient of performance (COP) of 8.26. The system cooling capacity was found as 0.0968 TR. The developed water cooler COP was found 230% higher due to its lower consumption of input energy as compared with the conventional water cooler. The developed system has a low initial cost due to the absence of a compressor, low maintenance cost since there are no such materials which get wear-off. As the system does not use any type of coolant or chemical for cooling or no use of CFCs and HCFCs, hence there is no emission of any harmful substance to the environment.

The cold drinking water received from the developed cooler is found gentle on the throat and beneficial for people suffering from cough or cold since water from the fridge can be too cold to consume. It is found perfectly cold to quench thirst.

For the places with a hot and dry climate, the developed system is very effective. It is useful for domestic as well as large scale applications in schools, colleges, shopping malls, railway stations and many other public places.

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