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Full Length Research Paper

Determination of the relationship among air velocity, cooling efficiency and temperature decrease at a cellulose based evaporative cooling pad

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The aim of this study is to determine the relationship between air velocity, cooling efficiency and decrease of the temperature of the air passing the pad, at a cellulose based evaporative cooling pad and to gain handy information for the persons working on this subject. In the study, cellulose based evaporative cooling pad (CELdek R 7060-15) was handled as material. As for the velocity of air passing through the pad 0.5, 1.0 and 2.0 ms^{-1} values were selected. Based on the measurement results, cooling efficiency and provided decrease of the temperature of the air passing the pad, were calculated. As a result of the research, cooling activities calculated between 3 different air velocities were found significant in the statistical sense ($p < 0.01$) for the measurement periods except II. measurement periods. As for the temperature decrease, the difference between other measurement periods except II. and III. measurement periods, were also found significant. The highest cooling activity and temperature decreases were reached at 0.5 and 1.0 ms^{-1} air velocities. It can be said that according to statistical data, optimal air velocity for the Mediterranean climatic conditions should be between 0.5 and 1.0 ms^{-1}, among the selected air velocities.

Key words: Evaporative cooling pad, cooling efficiency.

INTRODUCTION

Evaporative cooling systems are widely used in poultries and greenhouses in hot climates, for mitigating the negative effects of heat at inner environment. The performance characteristics of these cooling systems change depending on relative humidity of the air passing through the pad, passing velocity and the flow rate of water used for wetting the pad, apart from the construction material and structural features of the pad (Anonymous, 1983; McNeill et al., 1983; Koca et al., 1991; Simmons and Lott, 1996). Many studies were carried out about functional features of evaporative cooling pad systems in different climate conditions. Some of these studies are mentioned as follows.

Benham and Wiersma (1974) set an experiment for determining the optimum thickness and airflow rate of vertically and horizontally positioned pads, that were made from poplar sawdust. Buffington et al. (1978) compared evaporative cooling pads made of four different materials because of cooling efficiency. Koca et al. (1991) assessed the functionality of three different cellulose pads in an experiment set they developed. Simmons and Lott (1996) studied the effect of wetting water temperature on cooling efficiency of a pad evaporative system. Dağtekin et al. (1998) carried out a study in Çukurova Region (Adana, S. Turkey), for deter-mining the most suitable pad material for evaporative cooling system by comparing pads made of poplar sawdust, nutshell and cellulose.

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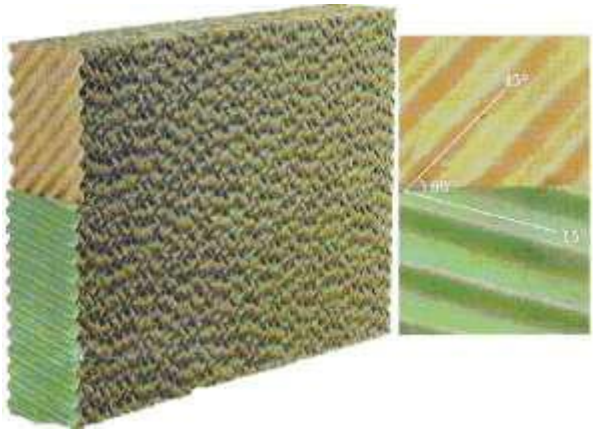

Figure 1. CELdek R 7060-15 pad method.

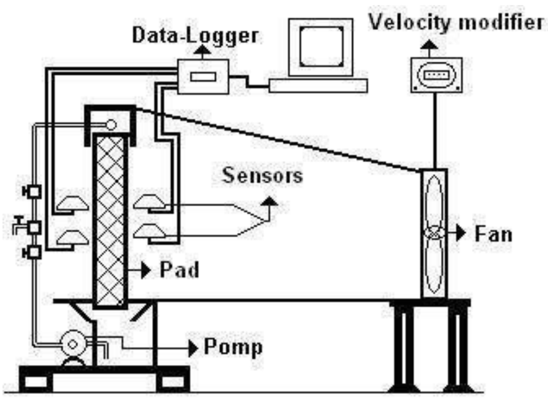

Figure 2. Experimental set.

Cruz et al. (2006) evaluated three different pad material efficiencies at different temperatures and air velocity in a study conducted in Evora – Portuguese. Dağtekin et al. (2009-a) examined some performance characteristics of an evaporative pad cooling system in a broiler poultry house at Mediterranean climate conditions. Dağtekin et al. (2009-b), examined the temperature distribution at long axis in a broiler poultry house in Mediterranean climate conditions.

This study is aimed at evaluating the relationship between the velocity of air passing the pad, the cooling efficiency and the temperature decrease of air passing through the pad statistically and to obtain data that might guide people involved in production and using evaporative systems.

MATERIALS AND METHODS

Materials

In the study, cellulose based pad (CELdek R 7060-15, Munters AB, Kista, Sweden) which is used commonly in the region, was dealt with as material. Pad's thickness is 0.1 m with 45° to 15° chamfer angle (Figure 1)

The study was carried out at Çukurova University, Faculty of Agriculture, Department of Agriculture Machinery. The experimental set given in Figure 2 was employed in the study. The set is constructed by forming a 2.5 m long tunnel supported by metal construction. The adjacencies of the roof supported with metal construction were encompassed with canvas cloth.

A fan with 0.95 m diameter (EM-30 Munters) was installed at one tip of the tunnel and a pad with 1.2 x 1.2 m surface area was installed to the other tip. The airflow rate of the fan was 15,000 m^3h^{-1} and activated by 0.5 kw electrical engine. An electronic circuit was used for changing air velocity, which eases setting of the selected air velocity.

The metal framed pad's bottom was built as a water reservoir. Water drawn from the reservoir by pump was poured to the pad surface via perforated pipe. The excess water, which was not vaporized, was collected to the water reservoir by chamfers, found below the pad.

At the experiments, flow rate of pad wetting water was kept stable (at 4 Lm^{-1}). At the study for the velocity of air passing through the pad 0.5 ms^{-1}, 1.0 $ms^{-1}$and 2.0 ms^{-1}values were chosen. These values are within the limits prescribed by previous studies (Anonymous, 1983).

The dry bulb temperature at inlet and outlet points of the pad, along with relative moisture values were measured by a DL2e (Delta-T Devices Ltd., Cambridge, UK). The air velocity was measured by a portable OMEGA HHF710 anemometer (OMEGA Engineering, Stamford, CT, USA) with ± 0.01 ms^{-1} sensitivity.

The air temperature and relative humidity were measured at 1 min intervals and averages were calculated every 5 min.

The dry bulb temperature and relative humidity values measured on the outer surface of the pads were analyzed, as the wet bulb temperature of the air entering into the pad was determined, from a psychometric diagram. By placing values in Equation 1, the cooling efficiency was calculated (Timmons and Baugman, 1984; Koca et al., 1991; Scarborough et al., 1988).

$$\eta = \frac{t_{kd} - t_{ki}}{t_{kd} - t_{yd}} \; 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where η is cooling efficiency(%) and tkd , tki, tyd are the dry bulb temperature of the air entering the pad, the dry bulb temperature of the air exiting the pad and the wet bulb temperature of the air entering the pad (°C), respectively.

The evaporated cooling systems in Mediterranean climate are generally operated between June and September. Thus, the experiment was initiated in the first week of June and completed in the last week of September. A total of 6 data sets were obtained by 15-day interval measurements. Air and water flow rate measurements were performed between 8:30 am and 5:30 pm.

The experiment was planned as completely randomized factorial experimental design and conducted with thirty-three replications;

$$Y_{jki} = \mu + F_i + T_j + FT_{ij} + e_{ij} .$$

Where, Y_{ijk} is observation value (i. period treatment, j. velocity, k. cooling efficiencies); μ is the overall mean; F_i is the effect of the ith period treatment (I. Period = 6-7-8 July 2008, II. Period = 23-24-25 July 2008, III. Period = 4-5-6 August 2008, IV. Period = 20-21-22 August 2008, V. Period = 7-8-9 September 2008, VI. Period = 24-25-26 September 2008; T_j is the effect of the jth velocity (1 = 0.5 ms^{-1} air velocities, 2 = 1.0 ms^{-1} air velocities, 3 = 2.0 ms^{-1} air

Table 1. Statistical analysis relating to different measurement period and cooling efficiencies calculated at different air velocities.

Source	Df	Mean square
Intercept	1	3884382.771**
Period	5	2382.056**
Velocity	2	2113.483**
Period × velocity	10	396.538**
Error	576	25.489**

** P < 0.01.

velocities); FT_{ij} is the effect of interaction between period and velocity; e_{ij} = residual error. DUNCAN Multiple Range Test was then utilized to comprehend these differences (Minitab V 13.20, 2000). Also, Pearson' correlation values were estimated for determining the relationship of the air velocity with the cooling efficiency.

RESULTS AND DISCUSSION

In this study, cooling efficiencies calculated at 6 measurement periods and three different selected air velocities, tested according to completely randomized factorial experimental designs and the obtained results are given in Table 1.

As seen on the table, effects of cooling efficiencies calculated in 6 measurement periods, at 3 different air velocities and together, effects of cooling efficiencies between air velocity and measurement periods, turned out to be quite important at statistical understanding. In this study, results showing which measurement period and velocities were affected by this importance, are given in Table 2.

As it is seen on the table, calculated cooling efficiencies between 3 different air velocities were found significant for other measurement periods except II measurement period, in a statistical sense ($p < 0.01$). A negative relationship between cooling efficiencies calculated at I, III, IV and V measurement periods and air velocities was observed.

In other words, as the air velocity increased, the cooling efficiency was decreased. This situation is in accordance with literature (Albright, 1989; Anonymous, 1983; Benham and Wiersma, 1974). In the VI period, however, an adverse situation occurred. It is considered that this situation, which is contrary to the scientific data, was caused by the difference at outer environment air temperature and relative humidity values, on the days measurements were taken.

The cooling efficiencies calculated at 0.5 and 1.0 ms^{-1} air velocities in 6 different measurement periods showed a similar change. The cooling efficiencies calculated at these two air velocities were found higher than 2.0 ms^{-1} air velocity. As a result of statistical analysis, for the cooling efficiencies calculated at 0.5 and 1.0 ms^{-1} air velocities, between I, III, IV and V periods, a statistically significant difference was not found.

However, the difference between II, VI and these periods was found significant. At the 2.0 ms^{-1} air velocity, difference between II, IV and V periods was insignificant, while the difference between those three periods and other periods was found significant ($p < 0.01$). Statistically, the highest cooling efficiency was reached at 0.5 and 1.0 ms^{-1} air velocities in the I, III, IV and V periods, however at the 2.0 ms^{-1} air velocity, it was reached only in the III period.

As a reason for the calculated cooling efficiencies at 0.5 and 1.0 ms^{-1} air velocities in VI period being lower than the other five periods, climatic changes (increase of air relative humidity and decrease of air temperature) beginning in this region, in this period (September) might be shown.

Also, the calculated cooling efficiencies at 0.5 and 1.0 ms^{-1} air velocities (in I, III, IV and V periods) were found higher than the values calculated at 2 ms^{-1} air velocity. In evaporative cooling pad systems, as the velocity of the air passing through the pad increases, the contact period of the air with wet pad surface shortens and air leaves the pad before reaching full saturation level.

Therefore, cooling efficiency of the system also decreases (Albright, 1989; Anonymous, 1983; Benham and Wiersma, 1974). The relationship between air velocity and cooling efficiency obtained in this study, is in consistence with the literature. Statistical analysis results of decreases of the temperature of air passing through the pad, occurred in different periods and air velocities made according to completely randomized factorial experimental design and the obtained results are given in Table 3.

As seen on the table, effects of temperature decreases calculated in 6 measurement periods, at 3 different air velocities and together, effects of temperature decreases between air velocity and measurement periods were found rather significant. In this study, results showing which measurement period and velocities were effected by this importance, are given in Table 4.

As it seen in the table, temperature decreases between three different air velocities for other measurement periods except II. and III. measurement periods were found statistically significant ($p<0.01$). The highest temperature decrease occurred at 2.0 $m\ s^{-1}$ air velocity when the VI. period excluded.

As for the provided temperature decrease of air passing through the pad in six measurement periods at 0.5 ms^{-1} air velocity, the difference between II, III, IV and V periods, was insignificant at 1.0 ms^{-1} air velocity, the difference between I, III, IV and V periods was insignificant, at 2.0 ms^{-1} air velocity, however, the difference between I, II, IV and V periods, was insignificant in itself but for their difference with other periods was found significant ($p < 0.01$). The highest decrease occurred at the

Table 2. Cooling efficiencies calculated at different air velocities.

Measurement period	Cooling efficiency (%) Air velocity (ms^{-1})		
	0.5	1.0	2.0
I	86.57±3.75Aa	83.69±3.58 aB	75.62±3.05 cC
II	78.67±6.52Ba	80.76±5.45bA	78.36±2.94 bA
III	89.34±5.20Aa	85.24±6.93aB	80.31±6.33 aC
IV	89.36±5.88aA	83.11±4.05abB	77.22±2.82bcC
V	88.41±6.79aA	85.06±5.84aB	77.47±3.70bcC
VI	70.31±2.98cB	71.08±4.11cB	73.06±4.05dA

a,b,c: DUNCAN multiple range test for columns; A,B,C: DUNCAN multiple range test for lines. I - II periods (July 2008), III - IV periods (August 2008), V - VI periods (September 2008).

Table 3. Statistical analysis relating to decreases at the temperature of air passing through the pad occurred in different periods and air velocities.

Source	Df	Mean square
Intercept	1	22467.180**
Period	5	212.646**
Velocity	2	62.285**
Period × velocity	10	76.420**
Error	576	1.249**

** : $P < 0.01$.

Table 4. Temperature decreases of the air passing through the pad at different air velocities.

Measurement period	Temperature decrease (°C) Air velocity (ms^{-1})		
	0.5	1.0	2.0
I	6.49±1.16bB	5.70±0.7bC	6.83±0.46dA
II	5.04±1.08cA	4.86±0.82cA	4.74±0.78dA
III	5.67±1.47cA	5.49±1.11bA	5.81±1.42bcA
IV	5.04±1.20cC	5.80±0.59bB	6.42±0.99aA
V	5.53±1.18cB	5.90±1.03bAB	5.88±1.40abA
VI	12.5±1.67aA	9.12±1.31aB	5.53±0.94cC

a,b,c: DUNCAN multiple range test for columns; A,B,C: DUNCAN multiple range test for lines.

temperature of the air passing through the pad at 0.5 ms^{-1} air velocity and VI period. This was followed by IV and V periods, at 2.0 ms^{-1} air velocity. For the reason of higher temperature decrease which occurred at 0.5 and 1.0 ms^{-1} air velocities in the VI measurement period, outer environment air relative humidity being low in that period might be shown.

There is a negative relationship between velocity of air passing through the pad and temperature decrease of air passing through the pad in evaporative pad cooling systems. In these systems, as the velocity of air passing through the pad increases, the contact period of air passing through the pad with wet pad surface shortens and air leaves the pad before reaching its saturation level. Therefore, the dry bulb temperature of air passing through the pad becomes lesser.

Otherwise, since the air would contact longer with the wet pad surface, it would leave the pad in a relative humidity closer to saturation level. Therefore, higher decreases are achieved at the dry bulb temperature of the air passing through the pad (Albright, 1989; Anonymous, 1983; Benham and Wiersma, 1974). In the trials performed at selected air velocities with 6 repetitions, this event did not appear distinctly. It is considered that this situation contrary to the literature was caused by the outer environment air temperature

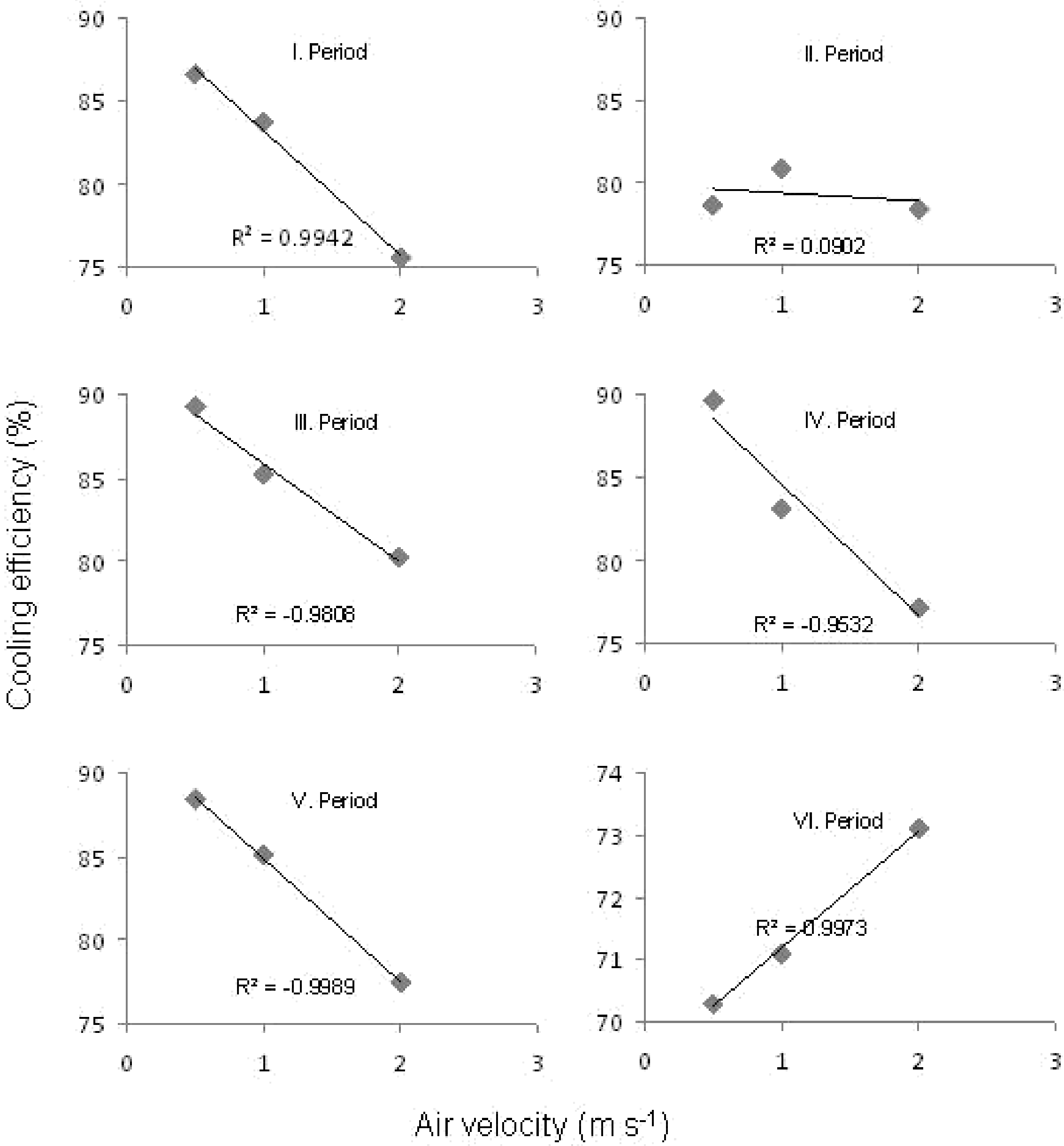

Figure 3. Correlation values about the relationship between velocity of air passing through the pad and calculated cooling efficiency in different periods.

and relative humidity values, similarly not showing any change on the days the measurements were taken.

Correlation value relationships of air velocities with cooling efficiencies in different periods were given in Figure 3. As seen in the figure, there is a high relationship between cooling efficiency and velocity of air passing through the pad. Cooling efficiency changed negatively, depending on the air in the periods except the VI period. The negative relationship between the velocity of air passing through the pad and cooling efficiency is rather significant in I, III, IV and V periods, in the II period however, it is not much significant. It is thought that this situation was caused by the outer environment relative humidity being a little higher in this measurement period, especially on the days the air velocities 0.5 and 1.0 ms^{-1} were tried.

Outside environment relative humidity in VI measurement period, was rather low compared with other periods. Outer environment air with low relative humidity, left the pad before getting fully saturated. Therefore, the calculated cooling efficiency values in this period was determined lower than the values taken in other periods. In this measurement period, there was a positive relationship between velocity of air passing through the pad and the calculated cooling efficiency, contrary to other periods. It was considered that the situation contrary to the known facts (Albright, 1989; Anonymous, 1983; Benham and Wiersma, 1974) was caused by the change at outer environment relative humidity for three different air velocities, on the days the measurements were made.

Conclusion

Calculated cooling efficiencies between 3 different air velocities were found significant for other measurement periods except II measurement period, in a statistical sense ($p < 0.01$). Temperature decreases between three different air velocities for the measurement periods except II and III measurement periods, were found statistically significant ($p < 0.01$). The highest cooling efficiency and temperature decrease is reached at 0.5 and 1.0 ms^{-1} air velocities. It can be said that among the selected air velocities, the most appropriate air velocity for Mediterranean climate conditions should be 0.5 and 1.0 ms^{-1}.

In the study, the measurements at selected air velocities were made on different days. Therefore, it is inevitable that the changing climate characteristics would affect the measurement results and have different effects on calculated values. For this reason, it was tried to ignore the effects of climatic data difference on calculated values. It was thought that repeating this study at the same air temperature and relative humidity conditions would be useful, to consolidate the accuracy of the results to be achieved.

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