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# MODELING OF AIR COOLING BY EVAPORATIVE PROCESS

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## Abstract:-
*Air conditioning systems are responsible for increasing men's worke efficiency as well for his comfort, mainly in the warm periods of the year. Currently, the most used system is the mechanical vapor compression system. Furthermore, the higher electricity demand for cooling causes summer peaks, which may lead to high electricity prices and grid connected problems as black-outs. However, in many cases, evaporative cooling system can be an alternative to replace the conventional system, under several conditions, or as a pre-cooler in the conventional systems. Also the remaining cooling demand must be covered with alternative, environmentally friendly cooling technologies.*
*Evaporative cooling operates using induced processes of heat and mass transfer, where water and air are the working fluids. It consists in water evaporation, induced by the passage of an air flow, thus decreasing the air temperature. This paper presents the basic principles of the evaporative cooling process for human thermal comfort, the principles of operation for the direct evaporative cooling system and the mathematical development of the equations of thermal exchanges, allowing the determination of the effectiveness of saturation to determine the convective heat transfer coefficient and to compare with the mathematical model.*

**Keywords: -** *aircooling process or evaporative cooling.*

## 1. INTRODUCTION

Vietnam is located in tropical and subtropical climates, the demand of refrigeration and air conditioning corresponding increasing economic and society growth of the country. Energy consumption for cooling and air conditioning is significant proportion compared to the energy supply for other needs. The process of transformation of renewable energy resource for cooling and air conditioning is shown in figure 1.

Using renewable energy to reduce the costs of energy consumption, contribute to reduce the lack of power in the current period and for the foreseeable future, and reduce the greenhouse effect, improves effective protection of the community living environment. Thereby, people can orient the use of energy-saving and efficiency [1].

Air cooling system that we will recommend is called "Evaporative Cooling and Desiccant", abbreviated DEC. DEC works on the principle of combining dehumidifier to reduce air humidity and moisture to the air freshener in it. Thus the coolant is water that evaporates directly into the atmosphere to reduce its temperature. Air-conditioning system works with solid adsorbent has been studied and many businesses in Europe-American manufactured in commercial. Solid adsorbents used mainly silica gel and zeolite. The capacity of the device is usually calculated by the amount of air through the device. Current devices provide air volume ranges from 5,000 to 50,000 $m^3$/h, corresponding to a capacity of 20 to 300 kW [8].

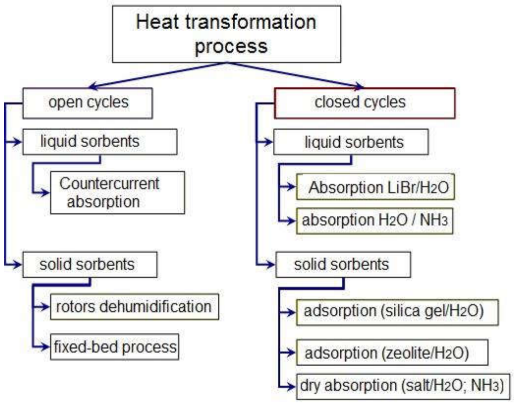


**Figure 1. The method of cooling / airconditioning using renewable thermal energy [4]**

The handling process for air conditioned rooms (mainly temperature and humidity) is done through regulatory division provides thermal energy for that process. Air-conditioning system works with two-cycle periodic rotation: humidifier to lower the air temperature and separate humidity from the adsorbent. When the adsorbent is saturated, it cannot dehumidify anymore, so the need to separate moisture from the adsorbent to the adsorption process is allowed to continue. Then the equipment must perform simultaneous adsorption process and the adsorption separation. Therefore there should be at least two adsorption and desorption (adsorption separation) units working in parallel. For continuous operation equipment, the need is switch function between adsorption and separation unit continuously in order to the air conditioning process operate without interruption. Currently, the rotor is used to rotate the "wheel distribution" in cylindrical shape, in which many adsorbent tank and arrange hot air and cool air from the outside through the chambers circulate it [2]. When the adsorbent in a compartment was "saturated", it was rotated to pick the hot air flow to separate the adsorbent, while outside air through the chamber has been separated for desiccant adsorption, reduce moisture before into humidification chamber. The rotor speed often 8 to 12 cycles/min [3]. Cycle cooling air humidifier is described in the following figure.

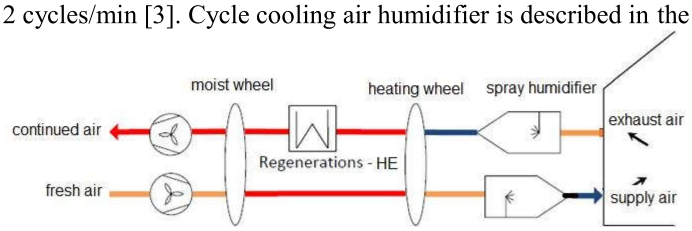


**Figure 2. Diagram of open-cycle air conditioning equipment [7]**

The outstanding advantage of this system is the heat resource to regenerate the adsorbent (adsorption separation process) with temperature from 45°C to 95°C [6]. This heat resource can be provided through the solar collector with the simplest form is flat or it may use the excess waste heat at low temperatures. Currently, the liquid absorbent is being studied and the equipment is improved (add or remove several components) to make the equipment operate more complete [4].

Principle working of evaporative cooling is: Evaporative cooling operates using induced processes of heat and mass transfer, where water and air are the working fluids. It consists, specifically, in water evaporation, induced by the passage of an air flow, thus decreasing the air temperature. When water evaporates into the air to be cooled, simultaneously humidifying it, that is called direct evaporative cooling (DEC, as described above) and the thermal process is the adiabatic saturation. When the air to be cooled is kept separated from the evaporation process, and therefore is not humidified while it is cooled, it is called indirect evaporative cooling (IEC). The main characteristic of this process is the fact that it is more efficient when the temperatures are higher, that means, when more cooling is necessary for thermal comfort. It has the additional attractiveness of low energy consumption and easy maintenance. Due to use total airflow renewal, it eliminates the recirculation flow and proliferation of fungi and bacteria, a constant problem in conventional air conditioning systems. Schema of indirect evaporative cooling is in following figure.

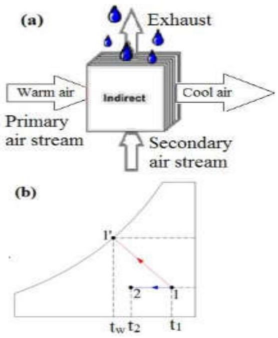


**Figure 3. Indirect evaporative cooling. (a) Typical configuration of indirect evaporative cooling system, (b) Psychrometric chart representation [9]**

## 2. DIRECT EVAPORATIVE COOLING

Due to increase in the awareness of environmental problems resulting from greenhouse gas emissions, various applications of evaporative cooling have been extensively studied and used for industrial and residential sectors, such as: humidifier, cooling tower and evaporative cooler. Direct and indirect evaporative cooling systems are used to produce low temperature medium fluid (i.e., water, air, etc.). Direct evaporative cooling system adds moisture to the cool air, which also makes conditions more uncomfortable for humans as air humidity increases.

The principle underlying direct evaporative cooling is the conversion of sensible heat to latent heat. Non-saturated air is cooled by heat and mass transfer increases by forcing the movement of air through an enlarged liquid water surface area for evaporation by utilizing blowers or fans. Some of the sensible heat of the air is transferred to the water and becomes latent heat by evaporating some of the water. The latent heat follows the water vapor and diffuses into the air. Figure 4 shows a schematic direct evaporative cooling system [9].

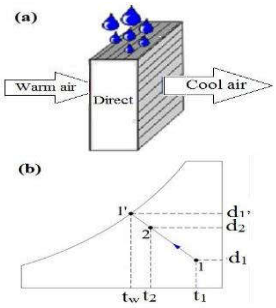


**Figure 4. Direct evaporative cooling. (a) Typical configuration of direct evaporative cooling system, (b) Psychrometric chart representation [9].**

In a direct evaporative cooler (DEC), the heat and mass transferred between air and water decreases the air dry bulb temperature (DBT) and increases its humidity, keeping the enthalpy constant (adiabatic cooling) in an ideal process. The minimum temperature that can be reached is the wet bulb temperature (WBT) of the incoming air. The effectiveness of this system is defined as the rate between the real decrease of the DBT and the maximum theoretical decrease that the DBT could have if the cooling were 100% efficient and the outlet air were saturated.

Practically, wet porous materials or pads provide a large water surface in which the air moisture contact is achieved and the pad is wetted by dripping water onto the upper edge of vertically mounted pads. Typic schema of the direct evaporative cooling is shewed in figure 5.

In this process, energy consumption mainly for the separation of moisture from the saturated moisture adsorbent. This energy can be supplied by renewable energy such as thermal solar energy, biomass, biogas or waste heat in industrial production. Thus the process is completely environmentally friendly [4].

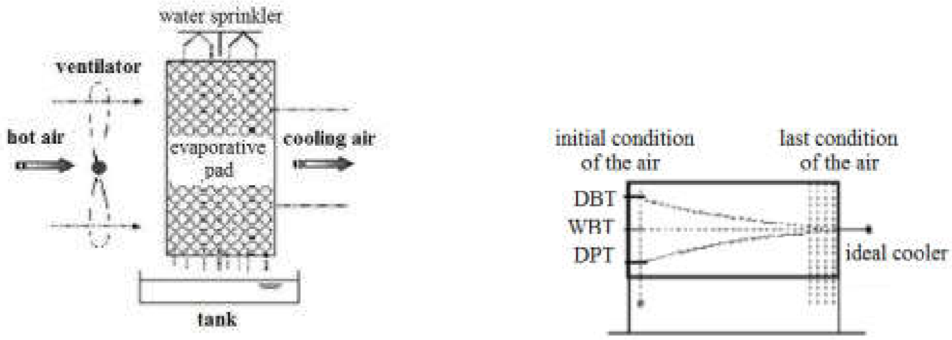


**Figure 5.An element of the direct evaporative cooler and typical variationof air dry bulb, wet bulb and dew point temperatures through it**

**3. Mathematical model**

In the study of the psychrometric process dry air is considered as a single gas characterized by an average molecular mass equal to 28.9645 kg/kmol [6]. In this work the humid air is considered as a mixture of two gases: the dry air and water vapor. Considering the flow of humid air close to a wet surface, according to Fig. 6, the heat transfer will occur if the surface temperature $t_s$ is different from the draft temperature t. If the absolute humidity (concentration) of the air close the surface $d_s$ is different from the humidity of the draft d, the mass transfer will also occur. The elementary sensible heat is:

$$\delta Q_s = \alpha_c dA(t_s - t) \qquad (1)$$

where $\alpha_c$ is the convective heat transfer coefficient, A is the area of the heat transfer surface, $t_s$ is the surface temperature and t is the bulk temperature.

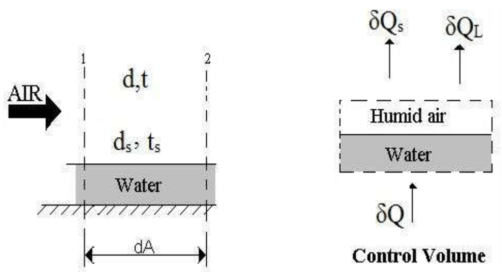


**Figure 6. Schematic flowchart of evaporative**

The coefficient $\alpha_c$ is determined from the Nusselt number (Nu) expressed as a function of the Reynolds number (Re) and Prandtl number (Pr). In a similar way the rate of water vapour transfer $dm_V$ between the draft and the air close to the surface will be

$$dm_V = h_m \rho_a dA(d_s - d) \qquad (2)$$

where $h_m$ is the mass transfer coefficient by convection and $\rho_a$ is the density of the water. By analysis of the interface air-liquid, the latent heat $\delta Q_L$ is determined by the energy conservation law.

$$\Delta QL = \delta Q - \delta Q_s = i_{Lvs} dm_v \qquad (3)$$

where $\delta Q$ is the flow of total heat and $i_{Lvs}$ is the specific enthalpy of vaporization of the water at surface temperature. Rearranging Eqs. (1), (2) and (3), the total differential heat flow is

$$\delta Q = [\alpha_c (T_s - T) + \rho_a i_{Lvs} h_m (d_s - d)]dA \quad (4)$$

Equation (4) indicates that the total heat transfer is the result of a combination of a portion originating from temperature difference and other portion originating from the difference of the absolute humidities. The total heat is caused by two potentials and these potentials can be combined by the Lewis relationship so that the total heat flow will be expressed by a single potential that is the enthalpy difference between the air close to the wet surface and the air free current.

Using the specific enthalpy of the mixture as the sum of the individual enthalpies gives:

$$i_s - i = (i_{sa} - i_a) + (d_s i_{vs} - d i_v) \qquad (5)$$

where $i_{vs}$ is the vapor enthalpy at surface temperature, $i_{sa}$ is the enthalpy of the leaving air, $i_a$ is the air enthalpy and $i_v$ is the vapor enthalpy. With the hypothesis that air and vapor are perfect gases it follows that

$$i_s - i = c_{pu}(t_s - t) + i_{vs}(d_s - d) \qquad (6)$$

where the humid specific heat is $c_{pu}$ = cpa + dcpv
$c_{pa}$ is the constant pressure specific heat of the air and $c_{pv}$ is the constant pressure specific heat of the vapor.

In the standard environmental conditions $c_{pa}$ = 1,006 kJ/kgK and $c_{pv}$ = 1,805 kJ/kgK [2]. Therefore

$$t_s - t = \frac{(i_s - i) - i_{vs}(d_s - d)}{c_{pu}} \qquad (7)$$

Combining Eq. (4) and Eq. (7) gives

$$\delta Q = \frac{\alpha_c dA}{c_{pu}}[(i_s - i)\frac{(d_s - d)}{R_{Le}}(i_{Lvs} - R_{Le} i_{vs})] \qquad (8)$$

In the above deduction the density of the humid air was approximated by the density of the dry air. Taking the Lewis relationship as being unitary, gives $(i_{Lvs} - i_{vs}) \approx i_{Ls}$. It is also verified that the term $(d - d_s)i_{Ls}$ is usually negligible in the presence of difference of the specific enthalpies $(i_s - i)$, so that only the first term inside brackets is significant. In the same way, the total heat flow is caused by the difference of specific enthalpies of the air and of the saturated air close to the wet surface and is given by following:

$$\delta Q = \frac{\alpha_c dA}{c_{pu}} \qquad (10)$$

The sensible heat transferred is:

$$\delta Q_s = m_a c_{pu} dt \qquad (11)$$

Where ma is the air mass flow.
There by combining Eq. (11) with Eq. (1) gives

$$\alpha_c dA(t - t) = m_a c_{pu} dt \qquad (12)$$

Which can be integrated resulting in following equation:

$$\frac{\alpha_c}{m_a c_{pu}} = \int_0^A dA = \int_{t1}^{t2} \frac{dt}{(t_s - t)} \qquad (13)$$

The integration yields

$$1 - \frac{t_1 - t_2}{t_1 - t_s} = \exp(-\frac{\alpha_c A}{m_a c_{pu}}) \qquad (14)$$

The effectiveness of a direct evaporative cooling equipment is defined as

$$\varepsilon = \frac{t_1 - t_2}{t_1 - t_s} \qquad (15)$$

$$\text{Then } \varepsilon = 1 - \exp(-\frac{\alpha_c A}{m_a c_{pu}}) \qquad (16)$$

Analysing the Eq. (15) it is verified that an effectiveness of 100% corresponds to air leaving the equipment at the wet bulb temperature of entrance. This requires a combination of large area of heat transfer and a high heat transfer coefficient and low mass flow.

It is also observed that the effectiveness is constant if the mass flow is constant since it controls directly and indirectly the value of the parameters on the Eq. (16).
Anisimov S., Pandelidis D., Maisotsenko V. [8] presents a correlation to determinate the convective heat transfer coefficients in a rigid cellulose evaporative media:

$$Nu = 0,10(\frac{l_e}{l})^{0,12} \mathrm{Re}^{0.8} \mathrm{Pr}^{1/3} \quad (17)$$

Where $l_e$ is the characteristic length and l is the pad thickness

$$l_e = \frac{\psi}{A} \quad (18)$$

Where ψ is the volume occupied by the cellulose media and A is the total wetted surface area. The following air properties are used:
k = 0.0263W/ (mK); Pr = 0.708; $c_{pu}$ =1033 J/kgK and ν =15.7x$10^{-6}$$m^2$/s [10].
Table 1 shows the resulting convective heat transfer coefficient for several air velocities calculated from Eq. (16).

**Table 1. Convective heat transfer coefficient for several air speeds**

| v[m/s] | m[kg/s] | Re | $\alpha_c$[W/mK] |
|---|---|---|---|
| 0.96 | 0.203 | 153 | 35.28 |
| 1.12 | 0.233 | 178 | 35.49 |
| 1.42 | 0.297 | 226 | 43.05 |
| 2.02 | 0.419 | 322 | 57.12 |
| 2.21 | 0.458 | 353 | 61.132 |
| 2.32 | 0.480 | 370 | 63.81 |

Figure 7 shows the comparison between the effectiveness calculated from the Eq. (15) and Eq. (16) as function of the Reynolds number.

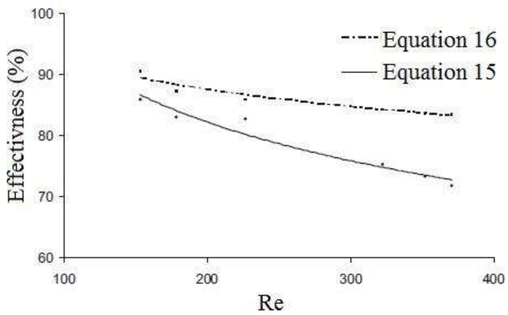


**Figure 7. Relation between Effectiveness and Reynolds number**

## 4. Discussion

This paper presents a mathematical model for a direct evaporative cooling air conditioning system that is obtained by writing the energy conservation equation for an elementary control volume and analyzing the heat and mass transfer between the humid air and the water. The resulting equation allows to determine the DEC effectiveness and compares it with the experimental results, according to Fig. 7 which the curve concerning to the Eq. (15) was determined by the temperature values in the inlet and outlet air flow and the curve referring to the Eq. (16) was determined using the mass air flow and the convective transfer coefficient obtained from the Eq. (17). This is only theoretical calculations. For application in practice should develop the test models for specific application where climate survey.

## 5. Conclusion

In the context of depletion of fossil fuels, using them will cause the greenhouse effect and nuclear energy can cause disaster for humanity, the renewable energy is an abundant energy resource, available in natural, an inexhaustible and "clean" energy resource and no harm to the environment. Exploitation and use of renewable energy is a research direction is worldwide concern. The research results will contribute to the development of sustainable energy, maintain energy security for the community.

This paper also presents a mathematical model for a direct evaporative cooling air conditioning system that is obtained by writing the energy conservation equation for an elementary control volume and analyzing the heat and mass transfer between the humid air and the water.

## References


[1]. Wolkenhauer, Henning, Franzke, Albers, Hindenburg Energieeinsparung durch Einbeziehung solarunterstützter Klimatisierung in zukünftige Planungsprozesse, FIA Bericht Nummer **68** (2002).

[2]. Beck E. - Energieverbrauch, einsparpotenzial und -grenzwerte von Lüftungsanlagen, FIA Bericht Nr. **86**, (2000)

[3]. Amer, O., Boukhanouf, R., & Ibrahim, H. G., A Review of Evaporative Cooling Technologies. International Journal of Environmental Science and Development, **6**(2) (2015) 111.

[4]. Uli Jakob and Ursula Eicker - Betrieb und Simulation von Diffusions Absorptionskaeltemaschinen zur solaren Kuehlung, Luft- und Kaeltetechnik **11** (2005).

[5]. Y. Fan, L. Luo, B. Souyri - Review of solar sorption refrigeration technologies: Development and applications, Renewable and Sustainable Energy Reviews **11** (2007).

[6]. Verdunstungskühlung auch für Gebäude; Hubert Sturies, Jens Panenberg CCI 5/2006.

[7]. Anisimov S., Pandelidis D., Maisotsenko V., Numerical analysis of heat and mass transfer processes through the maisotsenko cycle, 10th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics, 14 – 26 July (2014), Orlando, Florida

[8]. Xu Jia - Fundamental design and study of an evaporative cooling system, department of mechanical engineering, thesis of master of engineering at national university of Singapore (2014).

[9]. Hans Dieter Baehr, Karl Stephan - Waerme- und Stoffuebertragung, Springer Heidelberg Dordrecht London New York, (2011).

[10]. Hans Dieter Baehr, Karl Stephan - Waerme- und Stoffuebertragung, Springer Heidelberg Dordrecht London New York, (2011).