Proceeding Paper

Experimental and Numerical Analysis of Regenerative Indirect Evaporative Coolers [†]

Francisco Comino ^{1,*} , María Jesús Romero-Lara ² and Manuel Ruiz de Adana ²

¹ Departamento de Mecánica, Escuela Politécnica Superior, Campus de Rabanales, Universidad de Córdoba, Antigua Carretera Nacional IV, km 396, 14071 Córdoba, Spain

² Departamento de Química-Física y Termodinámica Aplicada, Escuela Politécnica Superior, Campus de Rabanales, Universidad de Córdoba, Antigua Carretera Nacional IV, km 396, 14071 Córdoba, Spain; p42rolam@uco.es (M.J.R.-L.); manuel.ruiz@uco.es (M.R.d.A.)

* Correspondence: francisco.comino@uco.es; Tel.: +34-626285994

[†] Presented at the Innovations-Sustainability-Modernity-Openness Conference (ISMO'21), Bialystok, Poland, 14 May 2021.

Abstract: Regenerative indirect evaporative cooling (RIEC) systems are an interesting alternative to conventional air-cooling systems. In the present work, the main objective was to experimentally determine the performance of a RIEC air-cooling system under different inlet air conditions. Moreover, a mathematical RIEC model based on a modified ϵ -NTU numerical method was developed and validated. The experimental RIEC results showed a high cooling capacity, with dew point effectiveness values up to 0.91. The accuracy obtained of the mathematical model was more than acceptable. Therefore, it can be used properly to study the global behavior of a RIEC.

Keywords: dew-point temperature; cooling system; heat and mass exchanger; effectiveness-NTU method; experimental and numerical investigations

Citation: Comino, F.; Romero-Lara, M.J.; Adana, M.R.d. Experimental and Numerical Analysis of Regenerative Indirect Evaporative Coolers. *Environ. Sci. Proc.* **2021**, *9*, 21. <https://doi.org/10.3390/environsciproc2021009021>

Academic Editors: Dorota Anna Krawczyk, Iwona Skoczko, Antonio Rodero Serrano and Ewa Szatylowicz

Published: 29 October 2021

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1. Introduction

Development of very low energy consumption heating, ventilation and air conditioning HVAC systems are required in the European frame of nearly zero energy building (NZEB). Evaporative cooling systems could be an effective alternative to conventional technologies, due to their high efficiency and reduced primary energy consumption [1]. There are two main types of evaporative coolers: the direct evaporative cooler (DEC), and the indirect evaporative cooler (IEC) [2,3].

Different experimental and numerical research works have been carried out in order to study the operational parameters that influence the overall performance of regenerative indirect evaporative coolers (RIEC) [4]. Experimental results established that RIEC systems could achieve high COP values [5–7]. Other experimental studies of RIEC showed high cooling capacities [8,9].

The main objective of this study was to experimentally determine the performance of a RIEC air-cooling system under different inlet air conditions. Moreover, a mathematical RIEC model based on a modified ϵ -NTU numerical method was developed and validated.

2. Materials and Methods

2.1. Experimental Test Rig

An experimental test rig was built to study the performance of a regenerative indirect evaporative cooler (RIEC) under different working conditions. A schematic representation of the experimental setup is shown in Figure 1. The inlet temperature, relative humidity and air flow rate of process stream were set using cooling and heating coils (CC, HC), a steam humidifier (SH) and a variable speed fan (F), located upstream of the RIEC. The

data of temperature, humidity and air flow rate were measured and recorded for each experimental test. The sensor locations are shown in Figure 1.

The RIEC system consists of a counter-flow heat and mass exchanger, a water distributing system and an outer casing. The primary air of the device, T_{in} , is cooled along the dry channels without moisture increase and subsequently discharged (supply air), T_{out} . Through the perforations located at the end of channels, a portion of the primary air is diverted into the adjacent wet channels. Flowing in counter direction to the primary air in dry channels, the secondary air of wet channels is humidified, heated and finally exhausted to outside. A damper was used to regulate the discharge air pressure and control the supply air flow.

Figure 1. Layout of the test facility of the regenerative indirect evaporative cooler.

A total of 25 experimental tests of the RIEC system were performed for the study and validation of the mathematical RIEC model. The ranges of the experimental test carried out are shown in Table 1. The input variables were the inlet air primary temperature, T_{in} , inlet air primary humidity ratio, in , primary air flow rate, V_{in} , and ratio of secondary air flow rate to primary air flow rate, R . Each state point was taken under steady-state conditions and all the measured values were average values over a period of 20 min with sampling time steps of 5 s.

Table 1. Ranges of the experimental tests carried out.

Range	T_{in} [°C]	in [g/kg]	V_{in} [m³/h]	R [-]
Lower value	33	8.5	3000	0.3
Upper value	43	13	4500	0.7

2.2. Mathematical Model of the Indirect Evaporative Cooler

A mathematical RIEC model based on modified ε -NTU numerical method to determine the optimal geometrical and operating parameters was developed. The main equations of the model are expressed by (1)–(3).

$$NTU = U^* dA / C_{min,i} \quad (1)$$

$$U^* dA = \left(a \cdot \left[\frac{1}{\alpha_{d,i}} + \frac{\delta}{K} + \frac{\delta_w}{K_w} \right] + \frac{1}{\beta_i} \right)^{-1} \cdot N_{ch} \cdot W \cdot dx \quad (2)$$

$$\varepsilon = f(NTU, C_{r,i}) \quad (3)$$

2.3. Validation and Evaluation of the Indirect Evaporative Cooler

The validation of the mathematical model and the performance study of the RIEC were carried out in terms of variations in primary air temperature, T , and of dew point effectiveness, ε_{dp} . Such indexes were defined through the following equations:

$$\Delta T = T_{in} - T_{out} \quad (4)$$

$$\varepsilon_{dp} = \frac{T_{in} - T_{out}}{T_{in} - T_{dp,out}} \quad (5)$$

where T is dry bulb temperature and T_{dp} is dew point temperature.

3. Results and Discussion

The experimental and numerical results of variation of primary air temperature, T , and of dew point effectiveness, ε_{dp} , are shown in Figure 2, corresponding to the 25 tests that were carried out. As shown in Figure 2, there is a very good agreement between numerical and experimental primary air temperature variations, being that the deviation was always within 0.45 °C (see Figure 2a). The accuracy of the dew point effectiveness results was also been found to be appropriate, with deviations of less than 0.025 (see Figure 2b).

The experimental results showed high T values, up to 26.5 °C for values of T_{in} , V_{in} and R equal to 43 °C, 8.5 g/kg, 4000 m³/h and 0.5, respectively, see Figure 2a. The ε_{dp} results showed that the supply air conditions were close to the dew point. The highest ε_{dp} value was 0.91 for values of T_{in} , V_{in} and R equal to 43 °C, 13 g/kg, 3000 m³/h and 0.35, respectively (see Figure 2b).

Figure 2. Parity plots of experimental and numerical results of (a) primary air temperature variations, ΔT , and (b) dew point effectiveness, ε_{dp} .

The validated model allowed to obtain the temperature, enthalpy and humidity distributions inside the exchanger. The air conditions of the primary and secondary air flows for each computational element of the exchanger are shown in Figure 3. For this example, 100 computational elements were used for the numerical modelling.

Figure 3. Psychrometric chart with the primary and secondary air flows for each computational element.

4. Conclusions

The experimental results showed that the studied RIEC system reached high cooling capacity. Therefore, the device can be considered as a serious alternative to conventional air-cooling systems composed of direct expansion units. The numerical results suggested that the proposed mathematical model can be valid to study the air-cooling system in detail, achieving suitable accuracy. The maximum deviations of T and d_p were always within $0.45\text{ }^{\circ}\text{C}$ and 0.025 , respectively. Moreover, the model allowed to obtain the temperature, enthalpy and humidity distributions inside the exchanger.

Author Contributions: F.C. conceived and designed the experiments, analyzed the data, and wrote the paper; M.J.R.-L. performed the experiments; M.R.d.A. contributed to the development of the numerical model and analyzed the data. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: The authors acknowledge the financial support received by the European Regional Development Fund and the Andalusian Economy, Knowledge, Enterprise and University Council, Spain, through the research project HICOOL, reference 1263034, and the Postdoctoral Fellowship of the University of Cordoba, Spain, and by European Union's Horizon 2020 research and innovation programme, through the research project WEDISTRICT, reference H2020-WIDESPREAD2018-03-857801.

Conflicts of Interest: The authors declare no conflict of interest.

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