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Effect of rotational speed on the performances of a desiccant wheel

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HIGHLIGHTS

- ▶ The performance of desiccant wheels depend on several operational parameters.
- ▶ The rotational speed of desiccant wheels is widely recognized as a key parameter.
- ▶ The desiccant can be regenerated with low-temperature thermal energy (60–70 °C).
- ▶ Optimal speed for dehumidification performance depends on the operating conditions.
- ▶ Sensible energy ratio is monotonically increasing with rotational speed.

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ABSTRACT

In recent years, the boost towards the reduction of electrical loads for air conditioning and the decentralization of energy conversion devices are determining an increasing interest in small scale trigeneration systems fueled by natural gas ("gas cooling"), able to shift energy demand in summer from electricity to gas, at the same time allowing the exploitation of natural gas surplus during the warm season. A technology that meets these requirements is represented by desiccant-based dehumidification systems, in which thermal energy for regeneration can be provided by a small scale cogenerator; the main component of these systems is the desiccant wheel, whose performances, in terms of humidity reduction and process air outlet temperature, depend on several operational parameters. The rotational speed of the desiccant wheel is widely recognized as a crucial parameter: if the wheel rotates too fast, the desiccant material does not have enough time to remove the moisture, while if the wheel rotates too slowly, saturation could occur. As a result, there must exist an optimal rotational speed, depending on the operating conditions, that guarantees the best dehumidification performance. Rotational velocity of the desiccant wheel influences the process air temperature exiting the desiccant wheel too; therefore it should be chosen in order to contemporary obtain a high dehumidification performance and an enough low outlet temperature, to reduce the cooling load on the cooling device, in particular if a conventional vapor compression chiller is used, as often occurs in high humidity climates. In this paper, experimental tests on a silica gel desiccant wheel, in order to highlight the effect of rotational speed on its performance, are shown. The adsorbent material is regenerated by thermal energy up to 65 °C. The experimental results were used to calculate some of the most representative performance parameters for the wheel, that are the dehumidification effectiveness, the dehumidification coefficient of performance (DCOP) and the sensible energy ratio (SER). Finally, the influence of process air inlet temperature and humidity, regeneration temperature and the ratio between the regeneration and process air flow rates on the optimal rotational velocity is discussed. It was found that, for the analyzed desiccant wheel, the velocity that optimizes the dehumidification performances varies in the range 5–10 revolutions per hour, depending on operating conditions, while SER monotonically increases with rotational velocity.

1. Introduction

During last years, air conditioning demand is spreading, both in the tertiary (shops, warehouses, offices, schools, etc.) and in the residential sector. This causes a sensible increase in primary energy consumption in these sectors, especially in industrialized countries, where people spend the major part of the day in confined environments, therefore it is very important to guarantee a high Indoor Air Quality (IAQ) and thermal comfort. In fact, individuals perform more effectively in conditioned than in untreated indoor air environments. The operation of a Heating, Ventilation and Air-Conditioning (HVAC) system is usually required to achieve

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Nomenclature

c_p	specific heat of the air (kJ/kgK)
D	dehumidification capability (kg/kg)
DCOP	dehumidification coefficient of performance (dimensionless)
h	specific enthalpy (kJ/kg)
N	rotational velocity (rev/h)
R^2	determination coefficient (dimensionless)
SER	sensible energy ratio (dimensionless)
t	temperature (°C)
$\dot{V}$	volumetric flow rate (m^3/h)
DW	desiccant wheel

Greek symbols

Δh_{vs}	latent heat of vaporization of water (kJ/kg)
η	effectiveness (dimensionless)
ρ	air density (kg/m^3)
ω	air humidity ratio (kg/kg)

Subscripts

deh	dehumidification
opt	optimal
proc	process
reg	regeneration

comfortable indoor conditions. It has to provide a sufficient amount of fresh air to the occupied zone, remove indoor generated contaminants and maintain suitable indoor air temperature and humidity, by supplying or removing heat and/or moisture to or from the occupied space. However, HVAC systems often consume large amounts of energy. Therefore, it is very important to investigate the possibility of efficiently attaining improved indoor environmental quality, reducing energy consumption and environmental impact with respect to conventional systems, [1].

The increase of the ventilation air flow rate, favouring the dilution of pathogenic agents, is the commonly used strategy to guarantee a hygienic and comforting environment for the occupants. Unfortunately, the increase of ventilation flow rate determines higher air conditioning energy requirements; in fact, ventilation air represents the main source of latent load, especially in humid areas. Moreover, the demand for summer cooling in domestic and commercial sectors is usually satisfied by electrically driven units; this involves high electric peak loads and black-outs.

Finally, the increasingly need to drastically reduce the use of conventional HFC (Hydro Fluoro Carbon) and HCFC (Hydro Chloro Fluoro Carbon) refrigerants should be taken into account, as HFCs provide a considerable global warming contribution and HCFCs have a not negligible ozone depletion potential too.

A particularly interesting technology that meets these requirements is represented by desiccant-based dehumidification systems, [2]. These systems use a desiccant wheel, that consists of a rotor, filled with a solid desiccant material, in which humid air is dehumidified by the desiccant material, to balance latent loads of the ambient. Desiccant-based air handling unit (that can also use liquid desiccants, [3]) offers an effective means of controlling space humidity while providing an energy-efficient air temperature control. To guarantee continuous operation, the wheel has to be regenerated by a hot air stream. In terms of the overall system performance, the use of solar energy to regenerate the wheel represents a deeply investigated research topic [4–6].

As regards the innovative component of desiccant-based systems, performances of the desiccant wheel (*DW*), for example in terms of dehumidification effectiveness and process air outlet temperature, depend on several parameters, both operational (such as inlet thermal-hygrometric properties and flow rates of process and regeneration air and *DW* rotational speed), and design parameters (such as the rotor thickness, the type of desiccant material, process and regeneration angles).

The rotational speed of the desiccant wheel is widely recognized as a crucial parameter: in fact, if the wheel rotates too fast, the desiccant material in the process side does not have enough time to remove the moisture. Likewise, the moisture contained in the desiccant material cannot be completely desorbed in the regeneration side. On the other hand, if the wheel rotates too slowly, equilibrium is reached while the desiccant material is still in the process section, therefore saturation occurs. As a result, there must exist an optimal rotational speed, depending on the operating conditions, that guarantees the best dehumidification performance [7,8].

Esfandiari Nia et al. [9] simulated the combined heat and mass transfer processes that occur in a solid desiccant wheel with MATLAB Simulink. Using the numerical method, the performance of an adiabatic rotary dehumidifier is parametrically studied, and the optimal rotational speed is determined by examining the outlet adsorption-side humidity profiles. The model allowed to predict the optimal rotational speed at various regeneration temperatures, comparing the simulation results with experimental work.

Several researchers focused on the influence of regeneration temperature on optimal rotational speed of desiccant wheels. Chung et al. [10] for example, showed that, regardless of the outdoor conditions, as the regeneration temperature becomes higher, the optimum time required per one wheel revolution (the inverse of the rotational speed) decreases and then approaches a constant value. Kodama et al. [11] showed the existence of an optimal value of the rotational speed, that minimizes the ratio between outlet and inlet process air humidity ratio; furthermore, the optimal value rises with the regeneration temperature. Ruivo et al. [12] used experimental data derived from the literature to formulate correlations for the adiabatic and dehumidification effectiveness of a desiccant wheel. These correlations were then used to evaluate the effect of the rotational speed of the desiccant wheel, expressed as sorption cycle duration, on process air temperature and humidity ratio at the outlet of the rotor. A comparison with experimental data was also carried out. Both predicted and experimental data show a minimum value of outlet humidity ratio for a given value of the sorption cycle duration; furthermore, this value decreases, hence optimal rotational speed increases, when regeneration temperature rises.

Ahmed et al. [13] developed a numerical model to study and discuss the effect of design and operating parameters, such as wheel speed, and to draw the performance curves of the desiccant wheel to quantify the optimum parameters for certain operating conditions. Also, a test facility for the desiccant wheel is built, and a comparison between numerical and experimental results is carried out. The study showed that there is an optimum wheel speed at which the humidity reduction reaches its maximum value. This speed depends on desiccant wheel geometry, regeneration temperature and air flow rate.

Enteria et al. [14] experimentally investigated the heat and mass transfer of the separated and coupled operations of a desiccant wheel and a heat wheel. As regards the *DW*, they evaluated the Moisture Removal Capacity (MRC) and the Moisture Removal Regeneration (MRR) as a function of rotational speed, for different values of regeneration temperatures and air flow rates.

De Antonellis et al. [15] investigated desiccant wheel performance and optimization. The analysis is carried out through a one-dimensional gas side resistance model which considers developing temperature and velocity profiles along the channels. The model is used to analyze the influence of working conditions on desiccant wheel performance and on the optimal revolution speed.

A different result was presented by Vineyard et al. [16], who investigated the impact of varying some operating parameters on the performance of a desiccant dehumidification system, reporting the results using two quantitative measures, such as latent capacity and latent coefficient of performance. Two desiccant loadings were tested, one at normal production level and the other with 25% more desiccant applied to the wheel. For both desiccant loadings, the latent capacity and Coefficient Of Performance (COP) increased as desiccant wheel speed increased, instead of showing a peak at a certain speed.

However, to the authors' knowledge, studies reported in literature focused only on the effect of rotational speed on dehumidification performance of the desiccant wheel, evaluated by means of different figures of merit, neglecting the effect on thermal performance of the *DW*, for example in terms of process air outlet temperature. This is also a very important effect, as it directly influences the cooling load on cooling device, that typically is an electric activated vapor-compression inverse refrigerating unit.

Therefore, the aim of this paper is to experimentally analyze, by means of adequate indices (dehumidification effectiveness, DCOP and SER), the dehumidification and thermal performance of a silica-gel desiccant wheel. The performance of the desiccant wheel has been experimentally evaluated by varying the rotational speed in the range from 2 to 33 rev/h. Furthermore, the effect of several operational parameters (process air inlet humidity ratio and temperature, regeneration temperature and ratio between regeneration and process air flow rates) on the optimal rotational speed has been investigated too.

2. Test facility

The test facility is located at "Università degli Studi del Sannio" in Benevento, a town in the South of Italy. In Fig. 1, only the *DW* section of the test facility is shown, crossed by process and regeneration air flows, both drawn from the outdoor (state 1 in Fig. 1, shown only for process section). The *DW* is a part of a more complex small scale polygeneration system, as it is contained in a desiccant-based air handling unit interacting with a microcogenerator and an electric chiller: the former provides thermal energy for regeneration (up to a regeneration temperature t_3 = 65 °C), while the latter provides cooling energy for sensible cooling of the process air exiting the desiccant rotor. In [17–20], a more detailed description of the test facility can be found. Further experimental analyses on the performance of both the silica gel rotor ([19,20]) and the whole polygeneration system ([17,18]) were published by the authors. This paper is a part of the research activity on *DW* performances, addressing the effect of rotational speed.

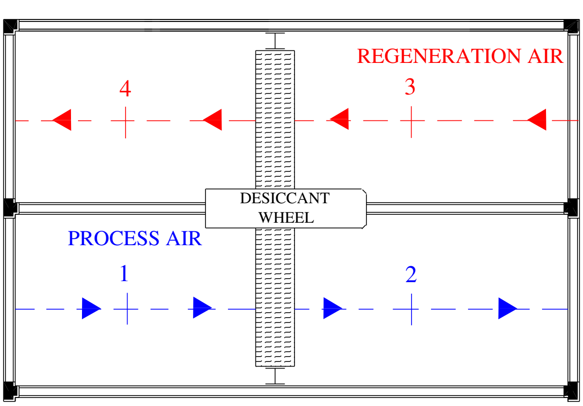

Fig. 1. A zoom on test facility section for experimental investigation of desiccant wheel.

Temperature, relative humidity and velocity of process and regeneration air are experimentally measured by means of the following sensors: Pt-100 type for air temperature (accuracy ±0.15 °C), capacitive hygrometer for air relative humidity (accuracy ±2%), immersion stem for air velocity (accuracy 0.2 m/s + 3% of measured value).

3. Methodology

To evaluate the performance of the desiccant wheel as a function of the rotational speed (*N*), the following performance parameters have been analyzed (refer to Fig. 1 for process and regeneration air state points):

(1) the dehumidification effectiveness, η_{deh}, that represents the ratio between the humidity reduction across the wheel and the inlet humidity ratio, [21]:

$$\eta_{deh} = \frac{(\omega_1 - \omega_2)}{\omega_1} \quad (1)$$

(2) the DCOP. It is the ratio between the thermal power due to air dehumidification and the regeneration thermal power, [8]:

$$\mathrm{DCOP} = \frac{\rho_1 \dot{V}_{proc} \Delta h_{vs}(\omega_1 - \omega_2)}{\rho_1 \dot{V}_{reg}(h_3 - h_1)} = \frac{\dot{V}_{proc} \Delta h_{vs}(\omega_1 - \omega_2)}{\dot{V}_{reg} c_p (t_3 - t_1)} \quad (2)$$

where the latent heat of vaporization of water, Δh_{vs}, is evaluated by means of the following empirical function [22]:

$$\Delta h_{vs} = -0.614342 \times 10^{-4} t_1^3 + 0.158927 \times 10^{-2} t_1^2 - 0.236418 \times 10 t_1 + 0.250079 \times 10^4 \quad (3)$$

As already said, regeneration air is taken from outside, therefore the enthalpy difference $h_3 - h_1$ represents the specific regeneration thermal power;

(3) the SER, that is the ratio between the thermal power due to the process air heating through the wheel and the regeneration thermal power [23]:

$$\mathrm{SER} = \frac{\rho_1 \dot{V}_{proc} c_p (t_2 - t_1)}{\rho_1 \dot{V}_{reg} c_p (t_3 - t_1)} = \frac{\dot{V}_{proc}(t_2 - t_1)}{\dot{V}_{reg}(t_3 - t_1)} \quad (4)$$

While higher values of η_{deh} and DCOP represent better dehumidification performances, a higher value of SER is unfavourable, as it means a higher increase of the process air temperature through the wheel and therefore a higher cooling load on the cooling device.

In Eqs. (2) and (4), the ideal gas model with constant specific heat has been assumed.

Furthermore, the effect on optimal rotational speed (N_{opt}) of inlet process air temperature (t_1) and inlet humidity ratio (ω_1), regeneration temperature (t_3) and ratio between regeneration and process air volumetric flow rates ($\dot{V}_{reg}/\dot{V}_{proc}$), has been investigated.

All the experimental results refer to the nominal value of both process and regeneration volumetric air flow rates (800 m^3/h). Contrariwise, when the effect of $\dot{V}_{reg}/\dot{V}_{proc}$ is analyzed (Figs. 8 and 9), the process air flow rate is kept constant at 800 m^3/h, while varying the regeneration air flow rate.

In each test (duration 200 min), 10 rotational velocity have been investigated (2, 5, 7.5, 10, 12.5, 15, 20, 25, 30 and 33 rev/h), each one for 20 min and with an acquisition time of 1 s. Therefore each curve is composed of 12,000 experimental point. However, to improve clearness of charts, only the trend curve are shown, while to highlight the dispersion of the experimental point, the R^2 value (determination coefficient) for each curve was calculated.

4. Results

In Fig. 2, η_{deh} as a function of the rotational speed for different outdoor air humidity ratio is shown. The rise in ω_1 causes an increase of the *DW* dehumidification capability ($D = \omega_1 - \omega_2$); in fact, when process air is more humid, a higher difference of vapor partial pressure between process air and the surface of the desiccant material establishes, and this determines a higher diffusion of water droplets from the former to the latter. Nevertheless, η_{deh} reduces with higher inlet humidity, due to the increase of ω_1 itself (see Eq. (1) and [20]). Furthermore, N_{opt} slightly increases from 7 to 10 rev/h when ω_1 increases from 8.63 g/kg to 11.1 g/kg. The mass transfer capacity on the process side is improved with higher outdoor air humidity ratio, as the adsorption rate increases. Hence, the time for achieving equilibrium state is shortened, which results in higher optimal rotational speed. This result is also confirmed by Ge et al. [8], in which the authors state that an increase in process air inlet humidity ratio determines an increase of the optimal rotational velocity to maximize the dehumidification capability of the rotor.

In Fig. 3, DCOP (left vertical axis) and SER (right vertical axis) as a function of the rotational speed for different outdoor air humidity ratio are shown. As regards DCOP, the increase in ω_1 causes an increase in *D* (as already said for Fig. 2), with a constant regeneration

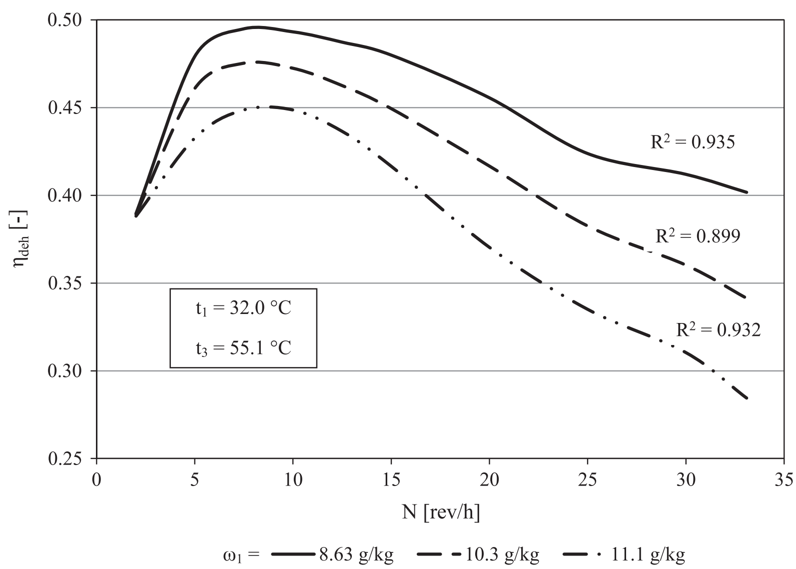

Fig. 2. η_{deh} as a function of the rotational speed for different outdoor air humidity ratios.

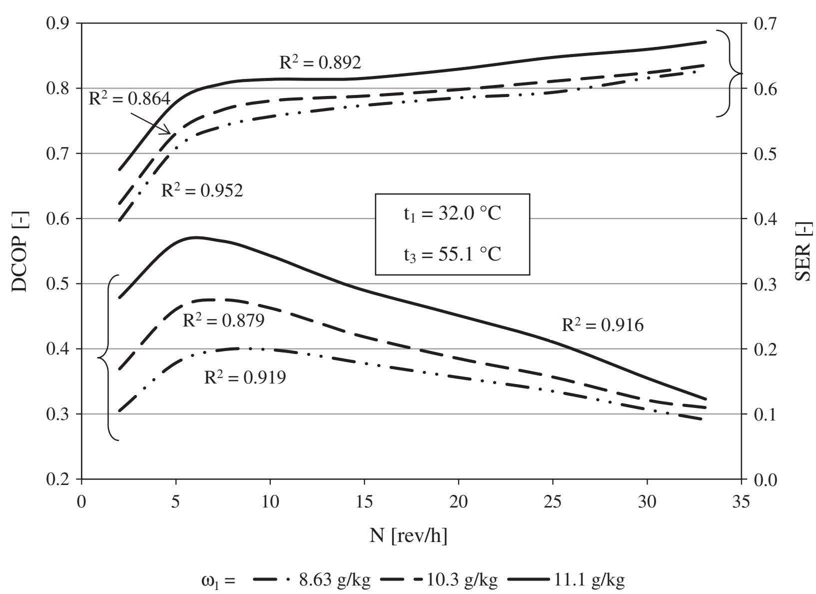

Fig. 3. DCOP and SER as a function of the rotational speed for different outdoor air humidity ratios.

thermal power; therefore DCOP increase with inlet humidity [8]. In terms of the effect of rotational velocity, N_{opt} has a slightly increasing value, from about 6 to about 8 rev/h, when ω_1 reduces.

As regards SER, t_2 strongly increases with ω_1, as the wheel catches a greater quantity of water vapor. Therefore, t_2 rises due to the increase in the released adsorption heat, while t_1 and t_3 are constant: thus, SER increases with inlet humidity. In terms of rotational velocity, an increasing monotonic trend was obtained; in fact, as N rises, the hot side of the rotor (the regeneration section) is more quickly moved in the cold side (the process section) and there is a shorter time for process air to cool the rotor, therefore both t_2 and SER increase. A more quick increase of SER was experimentally obtained for N lower than about 10 rev/h.

In Fig. 4, η_{deh} as a function of the rotational speed for different outdoor air temperature is shown. The adsorption process is exothermic, so it enhances with low temperatures [24]; therefore, the rise in t_1 causes a decrease in D, [19,20]; consequently, as ω_1 is constant, the dehumidification effectiveness reduces when t_1 rises, as confirmed by [9,21]. As regards the effect of rotational speed, N_{opt} decreases from about 8 to about 6 rev/h when t_1 rises from 25.6 °C to 34.3 °C. In fact, the adsorption rate of the desiccant wheel is higher at a lower process air inlet temperature, therefore the optimal rotation speed increases to lead the desiccant material away from the equilibrium state. In other words, with higher t_1, the adsorption process is thwarted, hence a longer adsorption time is required.

In Fig. 5, DCOP and SER as a function of the rotational speed for different outdoor air temperature are shown. As regards DCOP, the increase in t_1 causes a slight reduction of both D and the latent heat of vaporization of water, but, above all, an increase in inlet enthalpy; therefore the thermal power needed to achieve a fixed regeneration temperature significantly reduces with inlet temperature, and DCOP rises. In terms of the effect of N, the three curves show a similar trend, with an optimum value at nearly the same rotational velocity (about 7 rev/h).

As regards SER, the three curves show very similar trends and values, as the increase in inlet process temperature does not cause a significant change in SER ([20]). As seen for Fig. 3, they initially

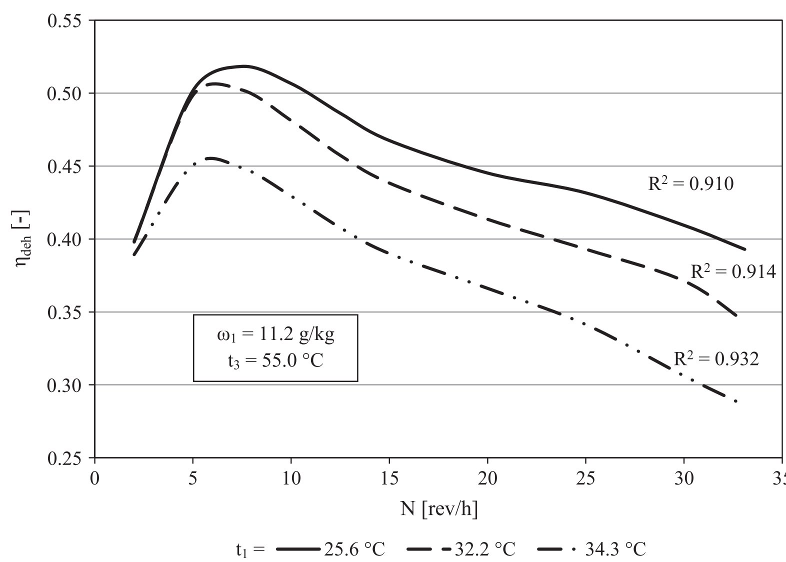

Fig. 4. η_{deh} as a function of the rotational speed for different outdoor air temperatures.

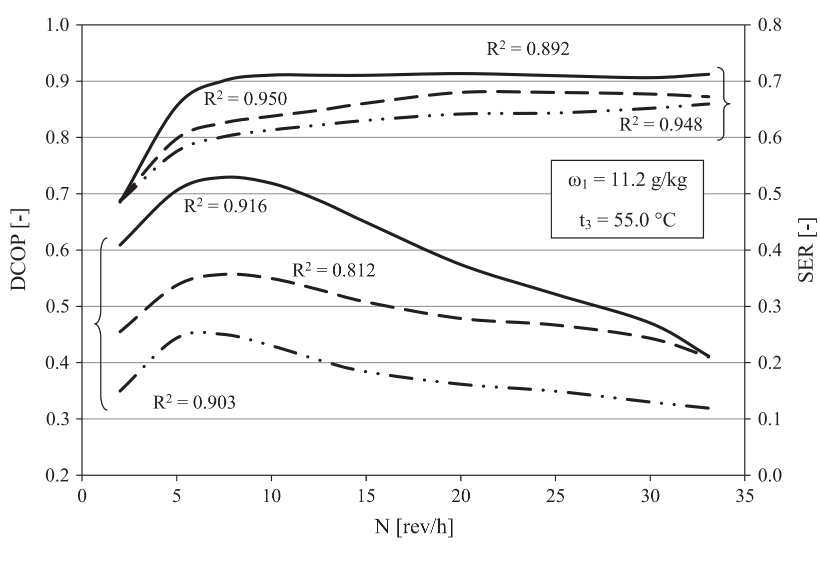

Fig. 5. DCOP and SER as a function of the rotational speed for different outdoor air temperatures.

show a very rapid increase, up to about 8 rev/h, after which the SER assumes a nearly constant value up to the maximum value of N (33 rev/h).

In Fig. 6, η_{deh} as a function of N for different regeneration temperature is shown. When t_3 increases, the DW dehumidification capability rises ([24]), and thus η_{deh}, in agreement with [9,21]. Optimal rotational speed, N_{opt}, rises with t_3, from 6 rev/h for t_3 = 45.0 °C, to 10 rev/h for t_3 = 65.0 °C; in fact, with higher regeneration temperatures, the moisture adsorbed in the desiccant is much easier to be desorbed, therefore the rotational speed should be increased to make the well desorbed desiccant rotate out of the regeneration section in time. This result is also confirmed in [8] and [10–12].

In terms of DCOP, Fig. 7, the increase in D with regeneration temperature is not enough to balance the rise in the regeneration thermal power per unitary mass flow rate ($h_3 - h_1$, with h_1 constant), so DCOP decreases with an increasing regeneration temperature. As regards the effect of rotational speed, also in this case a value of N that maximize the DCOP can be found for each curve, however this value is almost not affected by t_3, as it is equal to about 7 rev/h for the three values of regeneration temperature; a similar consideration was done for Fig. 5.

In terms of thermal performances of the wheel, process air outlet temperature rises with t_3, because of the increased heating of the desiccant material in the regeneration section and consequently in the process section, when the wheel rotates from the former to the latter; but the increase in t_3 itself causes a reduction of SER, as expected looking at Eq. (4). Furthermore, the trend of SER as a function of N is very similar to those of Figs. 3 and 5.

In Fig. 8, η_{deh} as a function of the rotational speed for different $\dot{V}_{reg}/\dot{V}_{proc}$ (the regeneration temperature is constant) causes a rise in the available regeneration thermal power, so the drying process of the desiccant matrix is enhanced, [8,20,25], and η_{deh} rises; N_{opt} increases from 5 to 9 rev/h when the ratio between regeneration and process air flow rates increases from 0.50 to 1.11. In fact, with higher regeneration flow rates, the moisture adsorbed in the desiccant is much easier to be desorbed, therefore the rotational speed should be increased to avoid that the well desorbed desiccant material remains too much time in the regeneration section.

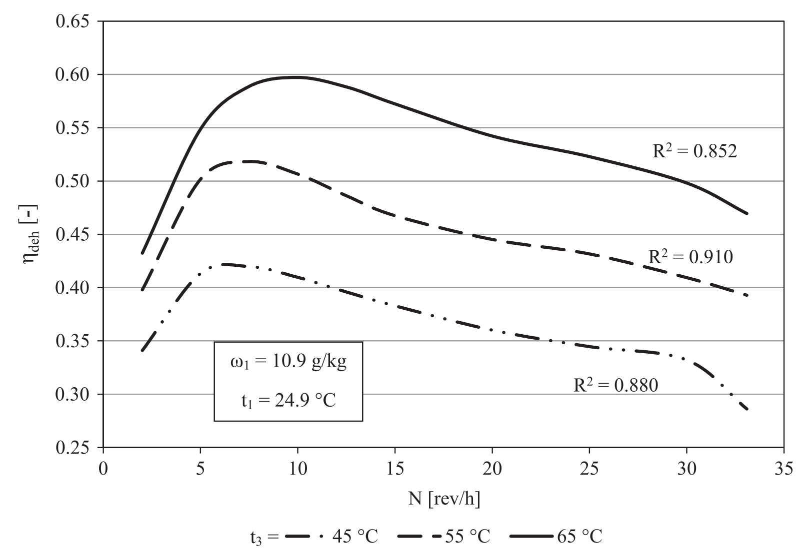

Fig. 6. η_{deh} as a function of the rotational speed for different regeneration temperatures.

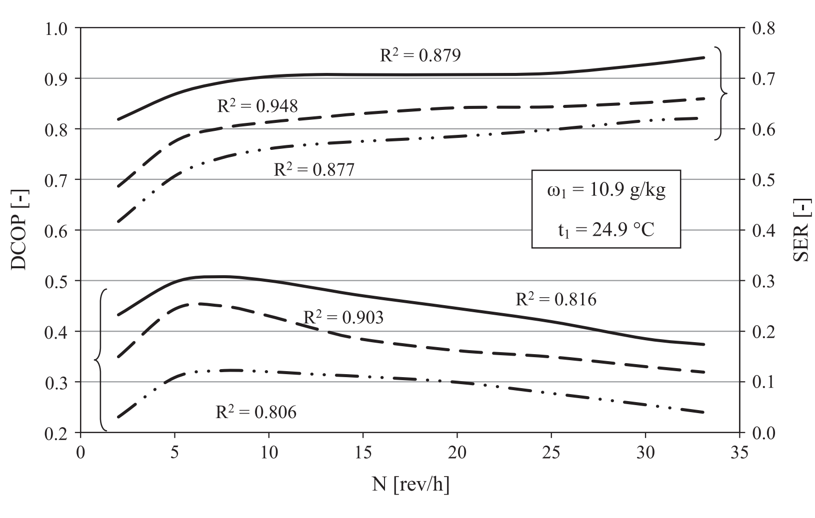

Fig. 7. DCOP and SER as a function of the rotational speed for different regeneration temperatures.

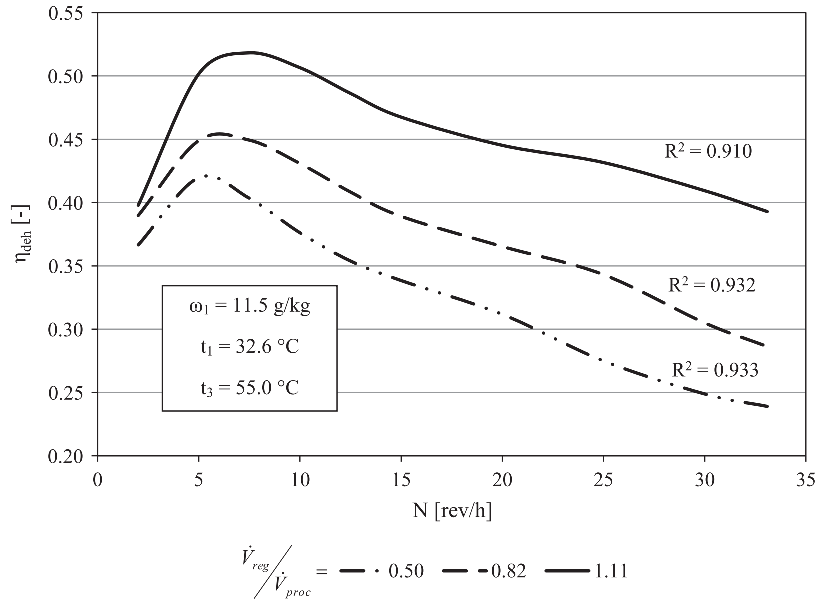

Fig. 8. η_{deh} as a function of the rotational speed for different ratio between regeneration and process air volumetric flow rates.

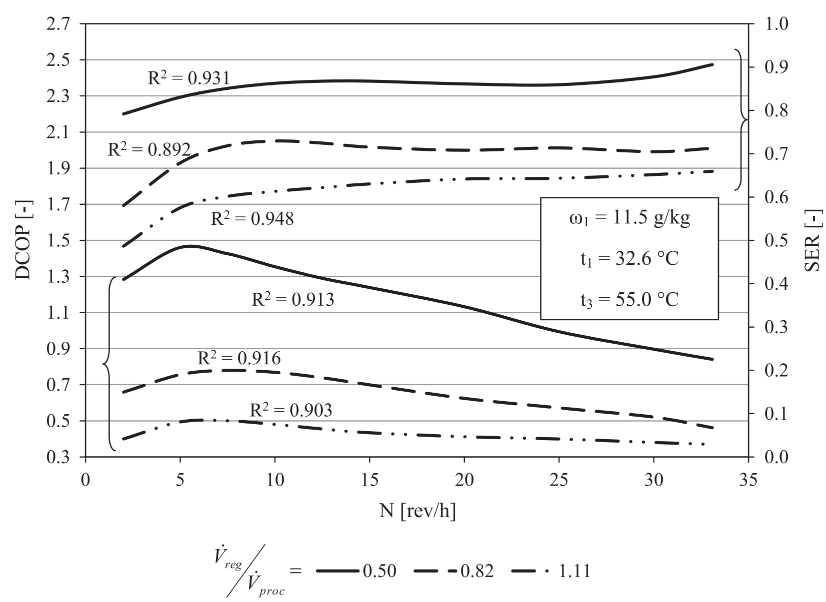

Fig. 9. DCOP and SER as a function of the rotational speed for different ratio between regeneration and process air volumetric flow rates.

In Fig. 9, DCOP and SER as a function of the rotational speed for different $\dot{V}_{reg}/\dot{V}_{proc}$ are shown. The increase in $\dot{V}_{reg}/\dot{V}_{proc}$ (or, equivalently, the reduction of $\dot{V}_{proc}/\dot{V}_{reg}$) causes a reduction in DCOP; in fact, even if the dehumidification capability rises (see Fig. 8), the increase in $\dot{V}_{reg}$ causes a proportional rise in regeneration thermal power; then, DCOP decreases. The optimum rotational velocity is about 6 rev/h for the three different ratios.

As regards SER, the increase of $\dot{V}_{reg}$ determines a rise in D, therefore an increase in the adsorption heat and process air outlet temperature, [25]; however, the increase in $\dot{V}_{reg}/\dot{V}_{proc}$ predominates and determines a reduction in SER. As for the previous operating conditions analyzed (inlet temperature and humidity and regeneration temperature), an initial increase of SER with N occurs, with a nearly constant value of the parameter after about 10 rev/h.

Generally, very high values of the determination coefficient R^2 have been obtained in almost all cases.

5. Conclusions

The performance of a silica gel desiccant wheel regenerated by low-temperature (65 °C) thermal energy has been obtained by means of an experimental investigation carried out in Southern Italy (Benevento, summer reference conditions of outdoor air: temperature = 32 °C, humidity ratio = 15 g/kg). Outdoor air enters both process and regeneration sections of the desiccant wheel.

This paper particularly focuses on the effect of rotational speed on dehumidification and thermal performance of the wheel, aiming to determine the optimal rotational velocity and to evaluate the effect on it of operating conditions (process air inlet temperature and humidity, regeneration temperature and the ratio between regeneration and process air flow rates). Some performance parameters of the wheel (dehumidification effectiveness, DCOP and SER) were experimentally calculated.

Optimal rotational speed to maximize dehumidification effectiveness depends on the operating conditions; it increases:

- from 7 to 10 rev/h when inlet process humidity ratio rises from 8.63 to 11.1 g/kg;
- from 6 to 10 rev/h when regeneration temperature rises from 45 to 65 °C;
- from 5 to 9 rev/h when ratio between regeneration and process air flow rates rises from 0.50 to 1.11;

while it reduces from 8 to 6 rev/h when inlet process temperature rises from 25.6 °C to 34.3 °C. The maximum dehumidification effectiveness is in the range 0.50–0.60 and it is obtained with low inlet process humidity ratio and temperature, and high regeneration temperature and flow rate.

Optimal rotational speed in terms of DCOP is nearly not influenced by the operating conditions: in fact, N_{opt} remains almost constant (about 6–7 rev/h for the analyzed system) even if inlet thermal-hygrometric conditions or flow rates change. The maximum DCOP is in the range 0.50–1.50 and it is achieved with high inlet process humidity ratio and temperature, and low regeneration temperature and flow rate. Therefore, the operating conditions that maximize DCOP are opposite to those that maximize η_{deh}.

As regards SER, it monotonically increases (in the range 0.40–0.90) with rotational speed of desiccant wheel, independently from the other operating conditions; in terms of thermal-hygrometric conditions, SER increases when inlet process humidity ratio and temperature rise and when regeneration temperature and flow rate decrease.

To the authors' knowledge, studies reported in literature did not analyze the effect of rotational speed on thermal performance of the desiccant wheel, for example in terms of process air outlet temperature or SER. This is also a very important effect, as it directly influences the load on the cooling device, that is an electric activated vapor-compression inverse refrigerating unit in hybrid desiccant-based air handling unit, and therefore the thermo-economic and environmental performance of the overall system. For example, if the rotor is working at optimal speed in terms of η_{deh} and there is the need of reducing dehumidification effectiveness (as a result, for example, of a reduced ambient latent load), it is convenient to reduce, rather than increase, the velocity of the wheel, as it determines a reduction of SER and, therefore, of the load on the cooling device. Furthermore, turning the rotor slower, the electric motor energy consumption, even if quite low, also reduces.

Future research activities could be useful with reference to desiccant wheel analysis, as optimal modes of automatic control and determination of a suitable model for performance prediction.

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