FRI-9.3-1-THPE-12

PERFORMANCE ASSESSMENT OF SORPTION REGENERATOR FOR DEHUMIDIFICATION IN AIR HANDLING UNIT

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Abstract: *Nowadays the studying various solutions to reduce energy consumption has a great importance. Air to air heat exchangers have the potential to increase the energy savings. In particular, interest in desiccant wheels is increasing due to their high effectiveness and possibility to dehumidify. This paper reviews the potential to transfer of heat and moisture in regenerative heat exchangers as a part of air conditioning system in pharmaceutical industry. A comparison of performance between the different types of regenerators is made under different operating parameters.*

Keywords: *Air conditioning, Dehumidification, Desiccant wheel, Efficiency, Energy consumption, Heat and mass transfer, Regenerative heat exchangers.*

INTRODUCTION

The major application of the desiccant wheel also known as a sorption regenerator is to control the humidity of the indoor air. Dehumidification of air is a mass transfer process, which removes water vapor from the air. Usually it is used for application such as food storage, pharmaceuticals, microelectronics, etc. (Rafique, M., 2016). The dehumidification is process, which needs heat energy from an external heat generator.

This paper deals with effectiveness and ability of desiccant wheel for initial air preparation of Heating, Ventilation, and Air conditioning (HVAC) installation, meeting the requirements for cleanliness class ISO8 in Pharmacy.

The subject of the present study is a desiccant wheel, which is an element of a HVAC system, described in (Penev, Y., Zlatev, P., Bobilov, V., 2017). The desiccant wheel has been simulated with computer software through different control parameters. The simulation results are compared with real data, which were collected by a BMS, used to control the whole HVAC system on the analyzed object.

The main aim is to analyse how the ratio between process and regeneration area, the different inlet regeneration temperatures and the rotation velocity affect desiccant wheel performance. A comparison between balanced and unbalanced desiccant wheel has been made in terms of moisture removal capacity (MRC), regeneration, thermal and moisture efficiencies.

EXPOSITION

Desiccant wheel

In principle two different methods exist for dehumidification of humid air. The first one is dehumidification by cooling and condensation and the other one is dehumidification by adsorption and desorption (Rafique, M., Gandhidasan, P., Bahaidarah, H., 2016). A combination of the two methods is used in order to meet the requirements for initial temperature and humidity in pharmacy clean rooms.

The desiccant wheel is divided into two sections. The first section is crossed by the process air and the other one by the regeneration air, while the wheel is rotating at constant speed. It is commonly accepted that 1:1 split between the two sections is generally used at low regeneration temperatures. In that case the desiccant wheel is balanced. On the other hand, for high regeneration temperatures the 1:3 split between regeneration and dehumidification area is used. The rotating wheel is then unbalanced (Chung, J. D., Lee, D. Y., Yoon, S. M., 2009).

In the existing case the wheel is unbalanced, i.e. the process sector area is 75 % and the regeneration area - 25 %. Its rotating velocity is 37 rotations per hour and the regeneration temperature is 140 °C. The constant temperature of the inlet process air is achieved by surface cooler, which is not subject of this paper. Then the process air is transferred to the desiccant wheel, where the process of dehumidification continues (Fig. 1).

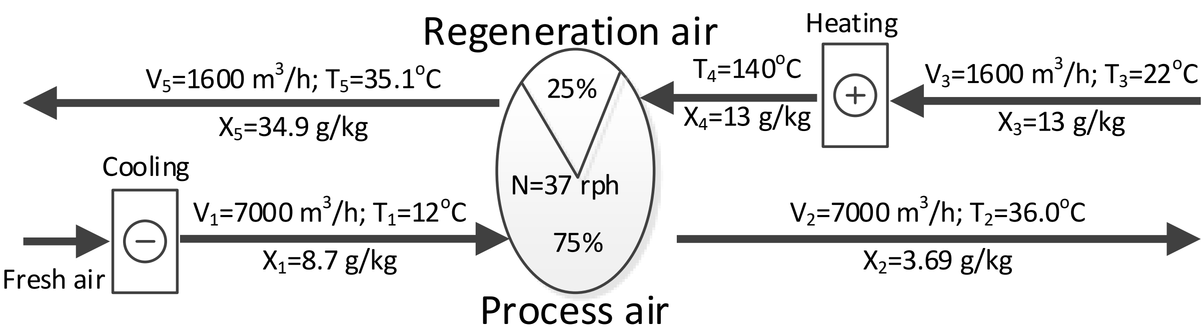

Fig. 1. Design parameters of the desiccant wheel

Desiccant wheel performance indices

The governing equations for energy and mass conservation are expressed by **(**Klein, H., 1988) and (Melikyan, Z.;,Fouda, A., 2010).

The desiccant wheel is assumed as a heat exchanger, because of its heat and mass transfer capability. Therefore, its first performance index is the thermal effectiveness. It is described by the following equation, given by (Mandegari, M.;,Pahlavanzadeh, H., 2009):

$$\varepsilon_t = \frac{T_2 - T_1}{T_4 - T_1} \tag{1}$$

where T_1 and T_2 are the inlet and outlet temperatures [K] of the process air, and T_4 is the inlet regeneration air temperature [K].

Another expression of desiccant wheel's performance is the regeneration effectiveness (Mandegari, M., Pahlavanzadeh, H., 2009):

$$\varepsilon_r = \frac{\dot{m}_{process}\,(x_1 - x_2)h_{fg}}{\dot{m}_{regeneration}\,(h_4 - h_3)} = \frac{\dot{Q}_{latent}}{\dot{Q}_{regeneration}} \tag{2}$$

where $\dot{m}_{process}$ and $\dot{m}_{regeneration}$ are the mass flow rates [kg/s] of process and regeneration air, $\dot{Q}_{latent}$ is the vaporization latent heat rate [kW] , $\dot{Q}_{regeneration}$ is the input heat of regenerated rate [kW], h_{fg} is the latent heat of vaporization [kJ/kg], h_4 and h_3 are specific enthalpy of moist air [kJ/kg], x_1 is the absolute humidity ratio of the process air in the inlet of the desiccant wheel [kg/kg], and x_2 is the absolute humidity ratio of the process air in the outlet [kg/kg].

The effectiveness of air drying in the desiccant wheel is expressed by the following equation (Angrisani, G., Minichiello, F., Roselli, C., Sasso, M., 2012):

$$\varepsilon_x = \frac{x_1 - x_2}{x_1} \tag{3}$$

This definition is very important in the desiccant wheel optimization and usually assumed as objective function.

The primary performance indicator is assessed by the moisture removal capacity (MRC) (Antonellis, S., Joppolo, C., Molinaroli, L., 2010):

$$MRC = \dot{m}_{process}\,(x_1 - x_2), kg/h \tag{4}$$

MRC is more appropriate than ε_x as a performance index in the case of an unbalanced desiccant wheel. An optimal MRC index does not mean a minimum value of the absolute humidity ratio of the process air in the outlet of the desiccant wheel, since the mass of removed moisture can become larger not only by decreasing of outlet humidity but also by increasing of the area of the process section (Chung, J. D., Lee, D. Y., Yoon, S. M., 2009). Because of that the most important parameter, which describes the effectiveness of the desiccant wheel, is the MRC.

Results

The simulation results are represented by diagrams shown in Figs. 2 - 5. The values of the different parameters of the existing system are marked with cross on the figures.

In Fig. 2 and Fig. 3 are given the thermal and moisture efficiency's distributions of the desiccant wheel in terms of temperature of the regeneration air with respect to the rotation speed.

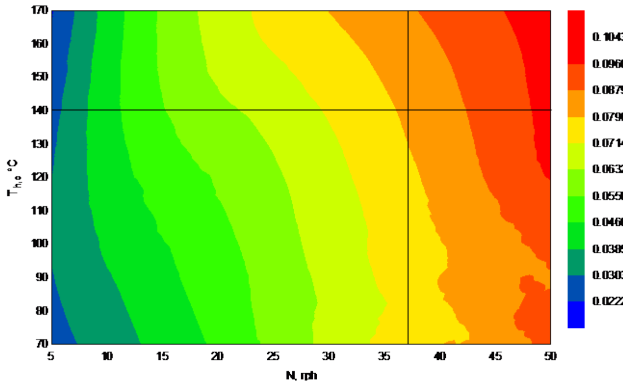

Fig. 2. Thermal efficiency

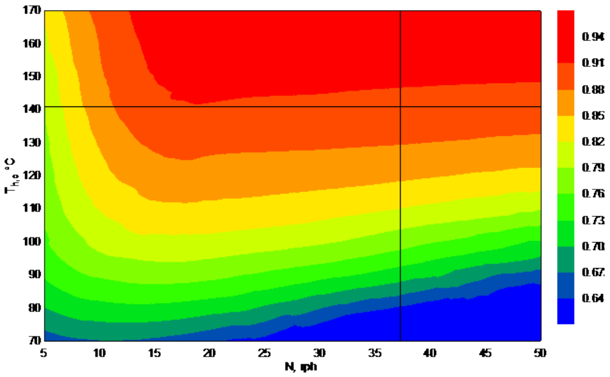

Fig. 3. Moisture efficiency

As it can be seen in Fig. 2, the thermal efficiency could be improved by the increase of the regeneration temperature and the rotation speed. Its value is 8.1 %. If we reduce the rotation speed on 18 rph and keep the regeneration temperature, the thermal efficiency would decrease to 5.8 %.

Table 1. Main parameters of the desiccant wheel

Wheel type	Vol. flow pr. air	Vol. flow reg. air	Wheel vel.	Pr. air out. temp. (T_2)	Pr. air out. hum. (X_2)	Reg. air out. hum. (X_5)	Reg. air in. temp. (T_4)
-	*[m³/h]*	*[m³/h]*	*[rph]*	*[°C]*	*[g/kg]*	*[g/kg]*	*[°C]*
Balanced	7000	3000	37	51.9	1.6	29.50	140
Unbalanced	7000	1600	37	36.0	3.69	34.90	140
Unbalanced	7000	1600	15	33.5	3.21	36.99	140

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On Fig. 3 it is shown that by increasing the regeneration temperature, dehumidification improves because of the better performance of desorption process. By keeping the same value of the regeneration temperature and decreasing of the rotation speed at 18 rph, the moisture efficiency would increase from 90.4 % to 90.63 %. The simulation results are given in Table 1.

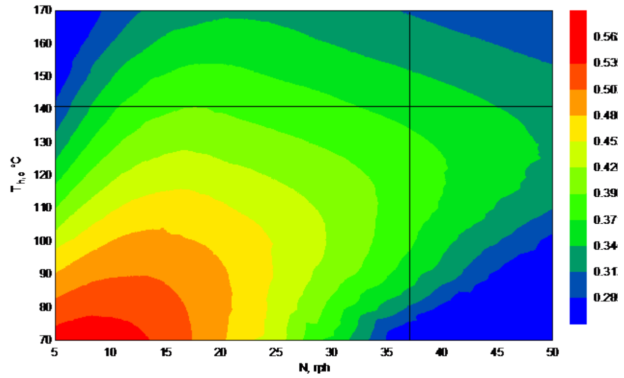

Fig. 4. Regeneration effectiveness

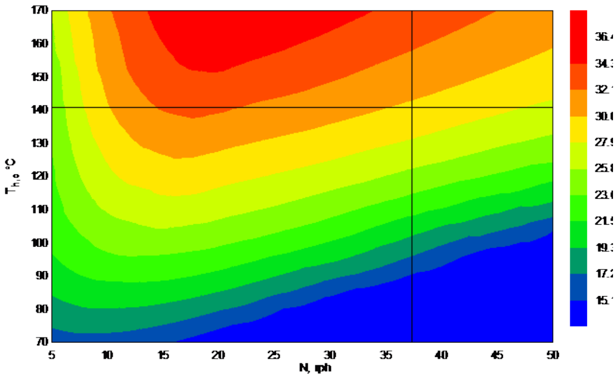

Fig. 5. Moisture removal capacity

On Fig. 4 it is given the regeneration effectiveness distribution and its current value, which is 36.3 %. This parameter rises with the decrease of the regeneration temperature and the rotation speed. As higher its value is, as bigger would be the energy efficiency of the process.

But the increasing of this parameter leads to reduction of the dehumidification capacity of the wheel, as it can be seen in Fig. 5. Here is shown the main parameter, which characterized the desiccant wheel. This is the ability of the wheel to adsorb the moisture in the air. In the present case the MRC of the wheel is 29.6 kg/h. Its optimum value could be found at higher regeneration temperatures and at speed between 15 and 20 rph. The figure shows that at the same regeneration temperature, the decrease of the rotation velocity would improve the dehumidification process. At 18 rph and 140 °C regeneration temperature the MRC is 32.3 kg/h, shown in Table 3.

The same MRC as the current case would be achieved at 24 rph and 130°C regeneration temperature. This leads to increasing of the regeneration effectiveness, because of the reduction of the primary energy for the regeneration, as seen in Table 2. This means more energy efficient process in comparison with the present case.

Table 2. Regeneration energy with respect to the rotation speed at T_4 = 140 °C

Heater Output, kW	63.4	63.4
Proc. Sens. Heat Gain, kW	56.3	51.4
Wheel Speed, rph	*37*	*18*

In the case of balanced rotor, it is necessary to increase the air flow of the regeneration air to 3000 m3/h. This leads to increase of the heat energy for regeneration up to 118.5 kW, which reduce the energy efficiency of the process. This makes the use of balanced rotor in this case inappropriate.

Table 3. Performance indices of the desiccant wheel

Wheel type	**Vol. flow pr. air**	**Vol. flow reg. air**	**Wheel velocity**	**Thermal efficiency**	**Moisture efficiency**	**Regener. efficiency**	**MRC**
-	*[m³/h]*	*[m³/h]*	*[rph]*	*[-]*	*[-]*	*[-]*	*[kg/h]*
Balanced	7000	3000	37	20.2%	98.1%	29.7%	43.03
Unbalanced	7000	1600	37	8.1%	90.4%	36.3%	29.60
Unbalanced	7000	1600	15	5.8%	90.6%	39.7%	32.29

CONCLUSION

The heat and mass exchange processes in the report are stationary, i.e. the stability of the input and output values is a condition for the equilibrium of the exchanged heat and humidity.

The results show that if we keep the regeneration temperature at 140 °C and decrease the rotation velocity from 37 to 18 rph, the MRC would be increased by 2.7 kg/h, also the moisture efficiency would be increased by 0.23 %.

Reduction of the rotation speed leads to decrease of thermal efficiency by 2.3 %, which in this case has a positive effect on the performance of the whole HVAC installation.

The results shown in Table 2 indicate that only by decreasing of the rotation velocity, the regeneration efficiency improves with 8.66 % and energy consumption for regeneration decreases.

In comparison with the existing case, the reduction of regeneration temperature to 130 °C and rotation speed to 24 rph keeps values of all efficiency parameters and leads to longer operation period of the wheel.

In this case balanced desiccant wheel is not appropriate because of increasing of energy consumption.

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