DOI: 10.2507/34th.daaam.proceedings.xxx

CALCULATION OF THE EFFECTIVENESS OF A DEHUMIDIFIER AND INTEGRATION OF A NEW MODEL OF A DESICCANT WHEEL INTO TRNSYS

Haris Lulic, Sadjit Metovic & Almira Softic

This Publication has to be referred as: Lulic, H[aris]; Metovic, S[adjit] & Softic A[lmira] (2023). Calculation of the Effectiveness of a Dehumidifier and Integration of a New Model of a Desiccant Wheel into TRNSYS, Proceedings of the 34th DAAAM International Symposium, pp.xxxx-xxxx, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-xx-x, ISSN 1726-9679, Vienna, Austria
DOI: 10.2507/34th.daaam.proceedings.xxx

Abstract

Rotating wheel dehumidification is a relatively new air cooling technique used in air conditioning, insufficiently researched and applied in practice. The system's effectiveness depends significantly on the desiccant wheel's properties and the moist air operating parameters. Modern software and simulations with defined inputs, can predict process air conditions required for air conditioning as long as each component characteristics of the system are known. In this work, an existing component in TRNSYS was used to simulate the desiccant wheel operation, which for stationary operating conditions and predefined efficiency aligns well with experiments. However, for a time-varying process, significant deviations of the results are observed, i.e. when the entered wheel efficiency does not correspond to every condition of the air entering the wheel. Considering that TRNSYS requires the definition of the desiccant wheel's efficiency before simulation start, treating them as fixed parameters, with the existing model component located in its database, it is impossible to carry out the simulation for time-varying conditions with satisfactory accuracy. A modified desiccant wheel model was developed and integrated into TRNSYS, which allows changing the functions of potential F_1 and F_2 and efficiencies ε_{F1} and ε_{F2} during simulations, for time-varying parameters of the humid air inlet state.

Keywords: Desiccant; Dehumidification; Numerical Simulation; Adsorption; Desorption 228.

1. Introduction

Climate change and increased demands for thermal comfort have caused a greater demand for cooling energy worldwide, not only in areas with tropical climates but also in areas with temperate climates, like most European countries. This results in a significant increase in electricity consumption for the operation of compressor cooling devices, which consequently causes an unwanted increase in the use of fossil fuels and nuclear energy, and threatens the stability of power networks. In their work, Ahmović et al. [1] demonstrated the increase in average annual temperatures in continental climates attributed to climate change. As an alternative to existing conventional cooling systems, new solar cooling technologies are being developed and deployed, especially for comfort air conditioning when the time period required for cooling coincides with the maximum intensity of solar energy. Solar air-condition units work on the principle of desiccant cooling, with the desiccant wheel based on solid desiccant appears as a key component of the system. The primary task of the desiccant wheel is to reduce the incoming air humidity in areas with high humidity, and bring it closer to the projected indoor air levels. On the other hand, in moderate climate, the desiccant wheel has the task of additionally dehumidifying the outside air in order to increase the capacity for an additional humidifier, which at the same time cools the air entering the room.

The process of dehumidification in the desiccant wheel depends both on the construction and composition of the wheel itself, and on the operating conditions of the system: desiccant wheel rotation speed, air flow, outside air temperature and humidity, and regenerative air temperature and humidity. Ma at al. [2], as well as Lulić at al. [3] have shown through their research that in solar cooling systems the greatest destruction of energy occurs at the desiccant wheel. In both papers, it is concluded that optimizing the desiccant wheel‘s working parameters, primarily regenerative air flow and temperature, as well as by improving the characteristics of the solid desiccant, it is possible to significantly increase the efficiency of the system component itself, and reduce the increase in entropy and increase the overall degree of efficiency of the system. The effectiveness of the dehumidifier can be expressed through two coefficients expressed as a function of the temperature and humidity of the air currents before and after the desiccant wheel. The values of the efficiency coefficients, considering the non-ideal system and processes, represent modified functions of potential based on the foundations of mathematical modeling of transport processes in the desiccant wheel. Howe [4] and Jurinak [5] developed these functions of potential in their papers, investigating the propagation of a wave front through the filling of a desiccant rotating wheel. Using the methods of nonlinear algebra [6], functions of potential $F_i(t,x)$ are defined as approximate nonlinear functions of temperature and absolute humidity, applying the same analogy as when modeling a sensible heat exchanger.

Momoi at al. [7], conducting a numerical calculation of the desiccant wheel model, found that using the values of the dehumidifier coefficients, the values of temperature and relative humidity of the air flow at the exit from the desiccant wheel can be predicted for different values of the regenerative air parameters. At the same time Bourdoukan at al. [8] using the experimental results and the results obtained by simulating the operation of the desiccant wheel model established a significant sensitivity of the change in the parameters of the process air depending on the change in the value of the efficiency coefficients of the dehumidifier. The biggest deviations occur in cases of high outdoor air humidity. Similar research was carried out by Norazam at al. [9] who, using a validated numerical method, determined the moisture removal capacity of a desiccant wheel based on solid desiccant and determined its thermal effectiveness and dehumidification effectiveness. The results obtained numerically show satisfactory deviations in terms of predicting the temperature and humidity of the process air (1.05% and 8%, respectively) compared to the experimental results. These studies are of particular importance when using software tools for simulating the operation of solar air conditioning systems (e.g. TRNSYS) that have a predefined component of the desiccant wheel with constant efficiency coefficients.

The performance of the entire solar air conditioning system largely depends on the characteristics of the dehumidifier. Nawaz at al. [10] conducted research with the aim of determining the basic characteristics of solid desiccant, specifically silica-aerogel, during system operation in non-stationary conditions (transient behavior/conditions) with different parameters of moist air at the inlet and outlet of the desiccant wheel. The paper emphasized that the adsorption capacity differs from the desorption capacity, and that the adsorption capacity is higher in samples with smaller pores in the structure. Zafar at al. [11] experimentally investigated the characteristics of a desiccant wheel with a solid desiccant (silica gel) at different parameters and ambient air flow. The results indicate that the effectiveness of dehumidification increases with increasing ambient air temperature up to a certain value, and then significantly decreases. In the paper, it is stated that the best characteristics of the desiccant wheel with silica gel filling and constant rotation speed, are shown at inlet air speeds of 3.5m/s with sensible temperature of 34°C. Narayanan at al. [12] in their research showed a change in the efficiency of the dehumidification process depending on the speed of rotation of the desiccant wheel with silica gel filling. In the case of a higher rotation speed, the contact time of moist air with the desiccant is reduced, which results in a higher humidity of the outgoing air. At the same time, higher speeds reduce the time of the regeneration process and result in a reduced performance of the desiccant wheel in the next cycle. On the other hand, low rotation speeds of the desiccant wheel significantly reduce its efficiency.

This paper describes in detail the working principle of a desiccant wheel with solid material filling (silica-gel), as well as a description of the desiccant wheel model given in TRNSYS. The theoretical bases for determining the function of potential as well as the efficiency coefficients of the desiccant wheel are given, as well as their values determined for the known configuration of the desiccant wheel. Data on the characteristics of the desiccant wheel and the tests carried out were taken from the equipment manufacturer. The obtained values of efficiency coefficients are integrated in TRNSYS by modifying the basic component of the desiccant wheel. In this way, during the simulation period, the efficiency values do not remain constant, as is the case with the configuration of the basic component, but change their value in accordance with the changing parameters of the process and regenerative air. The new component has been tested in TRNSYS and shows agreement with the results given by the basic component in operation with fixed values of wheel efficiency for constant values of inlet air parameters.

2. Air dehumidification process using desiccant wheel with solid sorption material

The process of air drying takes place in a rotating wheel, which in design resembles a rotary regenerative heat wheel, with the fact that in this case the filling of the wheel is made of a solid desiccant capable of receiving large amounts of water vapor from moist air. Adsorption material occupies, by volume, the largest part of the interior of the wheel, while only a small part belongs to the structural part of the filling (Fig.1).

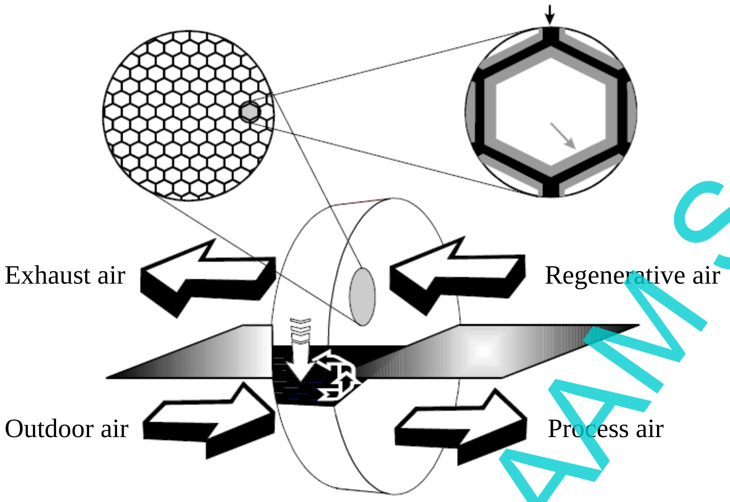

Fig. 1. Schematic of a desiccant wheel with solid sorption material [13]

In the desiccant cooling process, the purpose of the rotating desiccant wheel is to sufficiently dry the outside air so that the evaporative cooler can be used in the continuation of the process. Moisture from the moist air adsorbed in the rotating wheel in the process air stream must be transferred to the waste air on the regenerative side of the rotating wheel, so that the process can proceed without interruption. The temperature of the process air will rise at the exit from the desiccant wheel as a consequence of the adsorption process in the desiccant, i.e. the release of latent heat during phase change of the water vapor in the air. The amount of heat released by adsorption depends on the amount of water present in the desiccant and the amount of heat accumulated in the structural part of the filling of the desiccant wheel. In general, it can be said that a smaller amount of water contained in the adsorption material enables the release of a larger amount of latent heat, i.e. a higher temperature increase of the process air. On the other hand, the accumulated heat in the construction of the wheel increases its temperature, and later the temperature of the process air, which occurs as a result of convection. From this it is evident that both the water content in the dehumidifier and the temperature of the structural part of the wheel largely depend on the regeneration temperature and vice versa. The increase in the temperature of the process air during the drying process in the rotating wheel is the result of the effect of various influencing parameters such as: heat and mass transfer coefficients in the given conditions, specific sorption characteristics of the desiccant, the ratio of the volumes of the active filling and the constructive structure of the wheel, the amount and operating parameters of the air, wheel dimensions and wheel rotation speed. From this it can be seen that the correlation between the dehumidification process and the temperature increase is really complex, posing a challenge in modeling such systems.

3. Existing model of rotating desiccant wheel in TRNSYS

Dehumidifiers are devices that extract moisture from the air using a drying process, without additional cooling of moist air below the dew point temperature, which results in the extraction of water vapor from the air by the condensation process. These devices use the ability of hygroscopic materials (solid desiccants such as silica gel) to adsorb water particles on their surface. In the adsorption process, a thin molecular layer of one substance, in this case water vapor from the process air, is adsorbed on the surface of another substance, that is, a solid dehumidifier (silica gel). Over time, the structure of the dehumidifier becomes saturated, which loses its function and must be regenerated in the drying process. There are two types of dehumidifiers with filling made of solid material, which are most often used in practice. The first appears in the form of a dehumidifier cushion over which moist process air flows until the dehumidifier material becomes completely saturated. Regenerative air is periodically allowed to flow over the cushion with the aim of drying it. In another dehumidifier configuration, process and regeneration air flow simultaneously over a rotating wheel with solid sorption material, drying it on one part of the surface and wetting it on the other. Regenerative air is taken from the environment, in most cases, and heated with the aim of reducing the relative humidity. Therefore, an additional heat source is required for the air cooling process using the dehumidification technique.

For the purposes of performing simulations of the cooling process by dehumidification, a model of a rotating desiccant wheel filled with silica gel was created in TRNSYS, whose characteristics are defined by the functions of potential F_1 and F_2. The model determines the required temperature of regenerative air, which has the same value of absolute humidity as the ambient air, and which should dehumidify the process air at the exit from the rotating wheel to the set value of absolute humidity. The mass flow values of the process and regenerative air are the values set at the beginning of the calculation. Figure 2 shows a schematic view of the rotating desiccant wheel model used in TRNSYS.

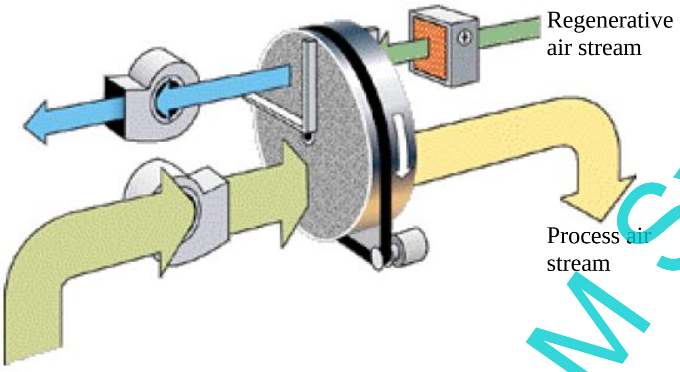

Fig. 2. Schematic of rotating desiccant wheel model in TRNSYS [14]

The ideal adsorption process that takes place from the Pin state to the Pout state is shown in the psychrometric T-x diagram in Figure 3. The process air of a certain state enters the dehumidifier. Due to the fact that water vapor is separated from the process air and adsorbed in the sorption material, the heat released during this process is transferred to the surrounding air stream. The process air leaves the dehumidifier with a lower amount of moisture and a higher temperature than it had at the entrance. In the same diagram (Figure 3), the ideal regeneration process from R_{in} to R_{out} is also shown. It is assumed that the process and regenerative air come from the same environment, that is, they have the same absolute humidity values, and that the regenerative air is heated receiving only sensible heat. Regenerative and process air pass through the rotating wheel in countercurrent. The saturated sorption material is exposed to a stream of warm and relatively dry regenerative air, which receives a certain amount of water from the dehumidifier while releasing a certain amount of heat. Regenerative air leaves the rotating wheel at a lower temperature and with a higher amount of moisture compared to the inlet conditions.

As can be seen in Figure 3, an ideal dehumidifier adiabatically dries the process air and transfers a certain amount of moisture to the regenerative air. The actual sorption and desorption processes do not take place at a constant enthalpy, since the values of humidity, temperature and enthalpy in different layers of the sorption material, contained in the rotating wheel, are transmitted in the form of waves along the depth of the filling, changing their values at the same time. The dehumidifier is expected to be completely dry at the start of each process. The moist air current moves over the filling of the wheel, delivers a certain amount of water vapor and increases the moisture content in the dehumidifier. The first filling layers of the dehumidifier, which are in contact with moist air, become saturated and unable to carry out the process of drying the air, thus the parameters of the exit state of the air from the rotating wheel approach the input parameters. However, the complete filling of the wheel does not saturate at the same moment, but only the first layer, which is in contact with the stream of moist air. Adsorbed water particles from the first layer of sorption filling, in the form of waves, are transported slowly towards the inner layers, i.e. leaving behind always saturated layers of filling, they move towards unsaturated layers. The process of transporting moisture through the sorption material happens faster if there is air flow through the rotating wheel. If there is no process air flow, the air remaining in the dehumidifier reaches an equilibrium state, the process of heat and mass transfer stops, until the dehumidifier is completely dry. Through the flow of process air, "trapped" warm and humid air is released from the dehumidifier. If the dehumidification process is performed with a rotating wheel, the speed of rotation is set to allow maintaining the values of the parameters of the air outlet state within the given limits. If the speed of rotation is lower, the transport of moisture between the filling layers is higher, that is, the speed of the wave front is higher. By increasing the rotational speed of the desiccant wheel, the speed of the wave front decreases and prevents complete saturation of the filling material.

In this regard, during the investigation of the propagation of the wave front through the filling of the dehumidifier, the functions of potential F_1 and F_2 were developed. With the aim of determining the explicit values of the functions of potential, an expression is defined in which the coefficients $a_{i,j}$ determined numerically and valid only for a specific combination of the working medium that is being dehumidified and the sorption material used. The functions of potential are given by the expression:

$$F_j(t,x) = \frac{\left(\frac{T}{273{,}15}\right)^{a_{1,j}}}{a_{1,j}} + a_{2,j}\frac{x^{a_{3,j}}}{a_{3,j}} \tag{1}$$

Using the non-linear regression technique, the coefficients $a_{i,j}$ were determined for the combination moist air-silica gel, and their values are given in Table 1.

$\mathbf{a_{i,j}}$	**j=1**	**j=2**
$a_{1,j}$	-1,4899998	1,4899998
$a_{2,j}$	3,7463964	-0,0898325
$a_{3,j}$	0,8624176	0,0796875

Table 1. Values of coefficients ai,j for silica gel, [4]

The graphical interpretation of the functions of potential F_1 and F_2 represents the developed curves, which show the smallest deviation from the values of the wavefront propagation characteristics for a given adsorbent. Figure 4 shows the isopotential lines for silica gel in the psychrometric T-x diagram, where the deviation of the isopotential lines in shape compared to the lines of constant enthalpy and relative humidity is clearly seen.

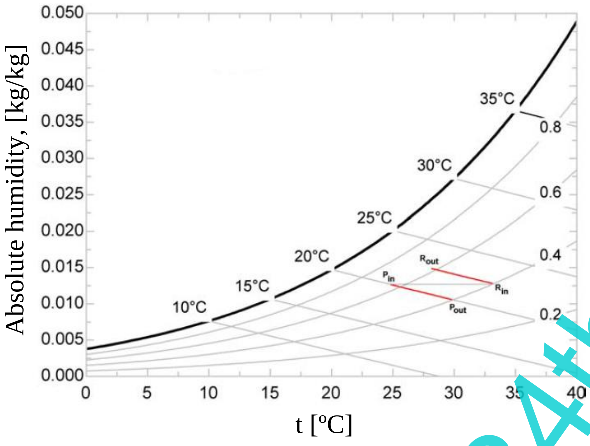

Fig. 3. Scheme of the ideal air dehumidification process using the drying technique

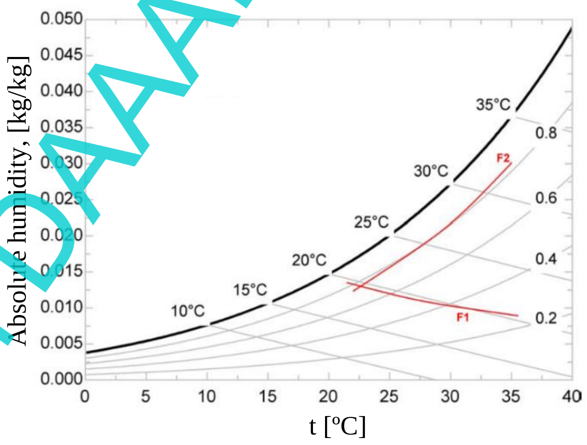

Fig. 4. Graphical representation of the values of the functions of potential F_1 and F_2

According to the expression for F_j and the coefficients given in Table 1, the values of the functions of potential for silica gel are determined according to the expressions:

$$F_{1,j} = \frac{-2865}{T_i^{1{,}490}} + 4{,}344 \cdot x_i^{0{,}8624} \tag{2}$$

$$F_{2,j} = \frac{T_i^{1{,}490}}{6360} - 1{,}127 \cdot x_i^{0{,}07969} \tag{3}$$

In these expressions, air temperature is included in [K], and absolute humidity in [kg/kg]. Using isopotential curves F_1 and F_2, Figure 5 shows a graphic representation, in a psychrometric T-x diagram, of the process of dehumidifying process air using the drying technique in a rotating wheel. The process air enters the dehumidifier with the state marked P, is heated and dehumidified along the potential line F_{1P} and exits the dehumidifier with the state D*. On the regenerative side of the wheel, air enters the dehumidifier with state R, cools and humidifies along the potential line F_{1R}, and leaves the rotating wheel with a state corresponding to the intersection of the potential lines F_{2P} and F_{1R}.

The functions of potential F_1 and F_2 can be further modified, considering the non-ideality of the system and process, with two values of the efficiency coefficients ε_{F1} and ε_{F2}, which, according to [15], are defined as:

$$\varepsilon_{F1} = \frac{F_{1,D} - F_{1,P}}{F_{1,R} - F_{1,P}} \tag{4}$$

$$\varepsilon_{F2} = \frac{F_{2,D} - F_{2,P}}{F_{2,R} - F_{2,P}} \tag{5}$$

where D is the actual state of the outlet air from the rotating wheel, and D* is the state of the outlet air from the dehumidifier in the case of an ideal process.

Figure 6 gives a graphical representation of the actual dehumidification process in a rotating wheel in a psychrometric T-x diagram using isopotential lines. The rotary wheel dehumidifier component model in TRNSYS uses an iterative process to determine the actual state of the outlet air (point D). The dehumidifier is not limited by capacity, which means that the set state of air humidity at the outlet can be achieved whenever the dehumidifier is in operation. The model determines the temperature of regenerative air at the entrance to the dehumidifier, for a defined value of absolute humidity at the exit. As input data in the modeling process of this component, the following values must be provided: mass flow of air streams of process and regeneration air, state parameters of the process air (dry bulb temperature and absolute humidity) at the entrance to the dehumidifier, the desired value of the absolute humidity of the process air at the exit from the rotating wheel and the value of the absolute humidity of the regenerative air at the entrance.

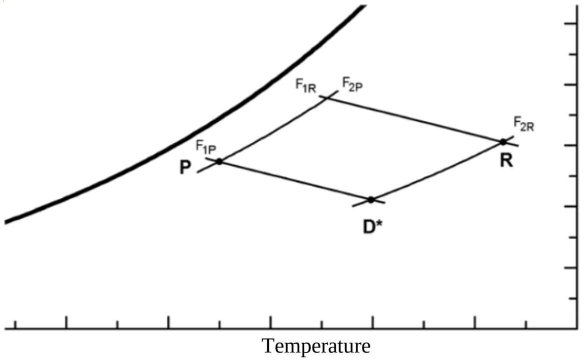

Fig. 5. Graphic representation of the dehumidification process using isopotential lines

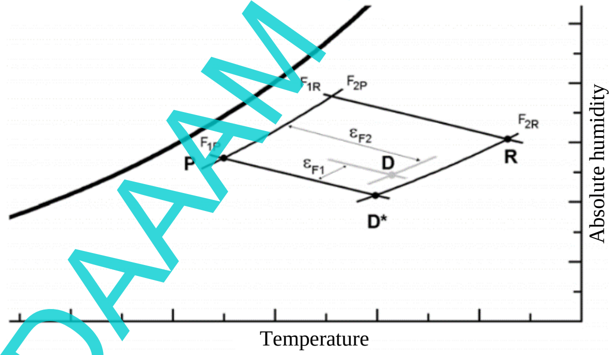

Fig. 6. Efficiency of the functions of potential F_1 and F_2 during the actual dehumidification process

The model first calculates the values of the functions of potential F_1 and F_2, for the input state of the process air. Considering that the value of the function of potential F_1 is the same for states P and D*, the output state of the process air is completely determined. When the value of the temperature for the state D* is known, the value of the function of potential F_2 at the point D* can be determined. Given that points D* and R are connected by an isopotential line, which means that the function of potential F_2 has the same value at points D* and R, the required temperature of the regenerative air can be determined. Based on the known values of the efficiency coefficients of the functions of potential (ε_{F1} and ε_{F2}), modified values of air parameters of state D* are calculated, which correspond to the function of potential at point D.

Using the obtained values for the functions of potential at point D, the model determines the appropriate value of the absolute humidity of the process air at the exit from the dehumidifier by an iterative procedure. The next procedure in the process of modeling this component of the system is the determination of the exit temperature of the process air, based on the achieved required value of absolute humidity. The condition of the regenerative air at the exit from the rotating wheel is determined using the mass balance of the air currents entering the dehumidifier and the new calculated values of the parameters of the process air at the inlet and outlet, as well as the input state parameters of the regenerative air.

4. Determination of efficiency and functions of potential F_1 and F_2 according to known characteristics of rotating, desiccant wheel

The dehumidification capacity for a specific rotating wheel depends on several factors, primarily on the production characteristics of the wheel itself, operating conditions, and mass flow of process and regenerative air. The most important characteristics of a dehumidifier in the form of a rotating wheel, which must be known before the modeling procedure, are certainly: the type and characteristics of the sorption material, the ratio of active and inactive filling structures, physical characteristics of the wheel structure and its dimensions, recommended rotation speeds at which the best cooling effect and dehumidification for given conditions and amounts of process and regenerative air is achieved. In this work, a desiccant wheel with characteristics given in Table 2 was used during the modeling of the solar air conditioning system.

For different operating conditions occurring during simulations of the created model, the values of the functions of potential and their efficiencies were determined. The data used in calculations were taken from the equipment manufacturer. The results are presented tabularly and graphically in Mollier's i-x diagram. Table 3 gives the calculated values of the functions of potential F_1 and F_2, as well as the efficiencies ε_{F1} and ε_{F2}, for the dry bulb temperatures of process and regenerative air of 19ºC and 80ºC, with variations of the absolute humidity of the process air at the inlet.

Sorptive material – active part of the wheel infill		Silica gel
Wheel filling structure		Honeycomb
Load-bearing part of the wheel infill – the inactive part of the infill		Fiberglass
Wheel thickness	mm	200
Surface of the front of the wheel	m^2	2,25
Percentage of the area through which the process air flows	%	58
Percentage of the area through which the regenerative air flows	%	42
Wheel housing width	mm	2010

Table 2. Characteristics of the desiccant, rotating wheel

Air stream			**t**	**x**	**Functions of potential**		**Efficiency**	
			[ºC]	[g/kg]	F_1	F_2	ε_{F1}	ε_{F2}
Process air	a	in	19,0	6,00	-0,5545	-0,0080	0,0856	0,6186
Process air		out	35,2	2,41	-0,5362	0,1067		
Regenerative air		out	51,2	21,40	-0,3618	0,0371		
Process air	b	in	19,0	7,00	-0,5470	-0,0173	0,0865	0,6115
Process air		out	36,4	2,86	-0,5292	0,1018		
Regenerative air		out	49,1	22,40	-0,3605	0,0257		
Process air	c	in	19,0	8,00	-0,5396	-0,0254	0,0871	0,6012
Process air		out	37,4	3,36	-0,5224	0,0965		
Regenerative air		out	47,3	23,30	-0,3592	0,0160		
Process air	d	in	19,0	9,00	-0,5324	-0,0326	0,0889	0,5935
Process air		out	38,4	3,89	-0,5154	0,0920		
Regenerative air		out	45,6	24,10	-0,3584	0,0070		
Process air	e	in	19,0	10,00	-0,5260	-0,0392	0,0913	0,5854
Process air		out	39,3	4,46	-0,5085	0,0876		
Regenerative air		out	44,1	24,80	-0,3578	-0,0008		
Process air	f	in	19,0	11,00	-0,5183	-0,0451	0,0936	0,5772
Process air		out	40,1	5,06	-0,5017	0,0833		
Regenerative air		out	42,7	25,50	-0,3570	-0,0082		
Process air	g	in	19,0	12,00	-0,5114	-0,0506	0,0959	0,5689
Process air		out	40,8	5,69	-0,4951	0,0791		
Regenerative air		out	41,4	26,20	-0,3560	-0,0151		
Process air	h	in	19,0	13,00	-0,5045	-0,0557	0,0985	0,5599
Process air		out	41,4	6,36	-0,4885	0,0748		
Regenerative air		out	40,2	26,80	-0,3554	-0,0214		
Process air	i	in	19,0	13,80	-0,4991	-0,0595	0,1022	0,5538
Process air		out	41,9	6,92	-0,4830	0,0717		
Regenerative air		out	39,3	27,20	-0,3553	-0,0259		

Table 3. Calculated values of efficiency and functions of potential

Figure 7 shows a graphic representation of the dehumidification process using the drying technique in a rotating wheel, the characteristics of which are given in Table 2 and which works with the state parameters of the process and regenerative air shown in Table 3. In the calculation, a constant value of the absolute humidity of the regenerative air of 15 g/kg was taken, that is, the maximum value of the absolute humidity that appears in the given climatic conditions during the summer period of operation of the dehumidifier. The diagram clearly shows the deviation of the actual drying process in the rotating wheel from the adiabatic, isoenthalpic process.

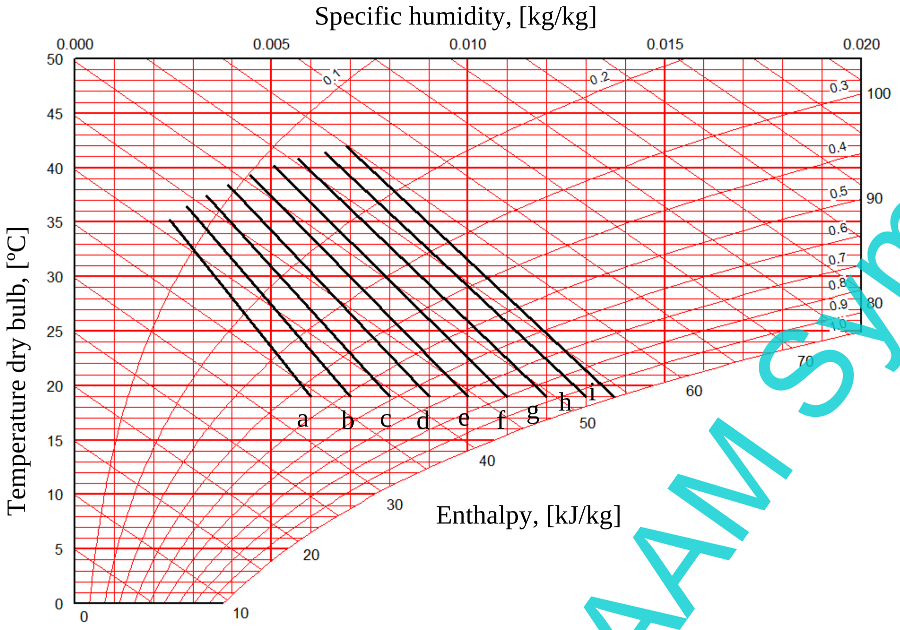

Fig. 7. Graphic representation of the dehumidification process for different input parameters of the process air

5. Modification of an existing TRNSYS component of a rotary desiccant wheel

When simulating the desiccant rotating wheel, more precisely the component of TRNSYS named Type683, as a fixed data that must be entered at the beginning of the calculation is the value of the efficiency ε_{F1} and the efficiency ε_{F2}, which remain unchanged during the entire simulation time, regardless of the change in the parameters of the state of the moist air in front of and behind the wheel. Considering that the efficiencies are defined by the functions of potential F_1 and F_2, which are directly dependent on the temperatures of the process and regenerative air, the simulation of the model at constant values of the efficiency of the rotating wheel gives satisfactory results in the case of constant parameters at the entrance to the dehumidifier. However, if it happens that outside air directly enters the desiccant rotating wheel, the simulation results show a certain deviation from the expected values of the output parameters of the process and regenerative air. For this reason, in this paper, a modification of the existing TRNSYS component of the desiccant rotating wheel was made, which during the simulation can change the efficiency values depending on the input state parameters of the moist air and maintain the values of the output properties within the limits of satisfactory accuracy. The calculated efficiency values are entered into the new model, which during the simulation interpolates the entered data and assigns to the rotating wheel the values of efficiency that belong to the parameters of the process air at the inlet.

5.1 Integration of the modified rotating wheel component in TRNSYS

Preparing and creating a new component in TRNSYS consists of two phases. The first phase involves modeling the actual processes that occur in the operation of the component and defining the mathematical model, while the second phase mainly refers to the collection and use of fixed data obtained from the equipment manufacturer, with the aim of better describing the characteristics of the given component. In this case, the first phase was already done when creating the basic component, and the modification of the component was connected to the second phase of component creation in TRNSYS and followed the existing constitutive relations and supplemented the model. The goal was to establish a component that will work equally with other TRNSYS components. The program that defines the mode of operation of the new component was written in FORTRAN and compiled for TRNSYS. The component has been tested in TRNSYS and shows agreement with the results given by the base component in operation with fixed wheel efficiency values.

The new component enables the change of the efficiency value of the desiccant wheel during the simulation, and for the given parameters of the process air during the simulation it assigns the rotating wheel the corresponding values, while the basic model of the component works with the same efficiency values for the entire simulation period, and at the same time the parameters of the state of the process air are variable. Figure 8 shows the change in the efficiency of the desiccant rotating wheel that works according to the new model during the process of simulating the operation of solar air conditioning. It can be seen from the diagram that the efficiency values are not constant, but vary depending on the changes in the parameters of the state of the process and regenerative air.

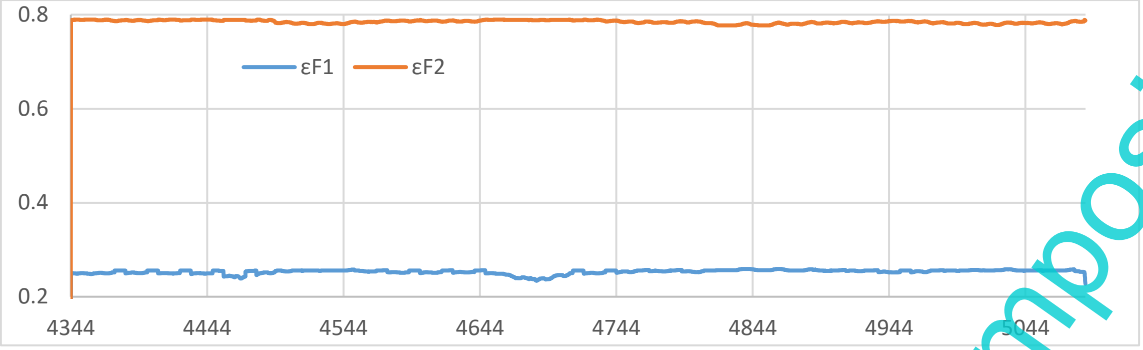

Fig. 8. Values of the efficiency functions of the desiccant rotating wheel during the simulation period

5.2 Validation of operation of the modified component of the desiccant rotating wheel

For the evaluation of performance and verification of calculated values using the new component in TRNSYS, a simple and limited simulation was employed. To test the new component, individual simulations of the existing component were conducted for 18 different combinations of process and regenerative air input parameters, with constant values for the wheel efficiency. In doing so, the idea was to show the agreement of the output parameters of the state of the air from the desiccant rotating wheel obtained during the simulation with the experimental values during the operation of the wheel in stationary conditions, i.e. for one set of input parameters of the state of the process and regenerative air and the corresponding values of the wheel efficiency (Figure 9).

The obtained simulation results were compared to the results of dynamic simulation of the new component, and they proved to be identical. It's worth noting that in the simulation of the new component, the input data set was formatted in the form of temperature and absolute humidity of the process air at the wheel's inlet, which change over time, with each time interval representing one of the mentioned 18 combinations of moist air state parameters. The printouts after a certain time interval showed that, for the given values of the parameters of the state of the process air in that interval, the assigned values of the efficiency of the wheel coincide with the values of the fixed parameters entered before the start of the individual simulations on the existing model for the same values of temperature and absolute humidity of the process and regenerative air. It should be emphasized that the new model performs interpolation of the data values at its disposal with the aim of determining the efficiency of the wheel as accurately as possible in each time period of the simulation.

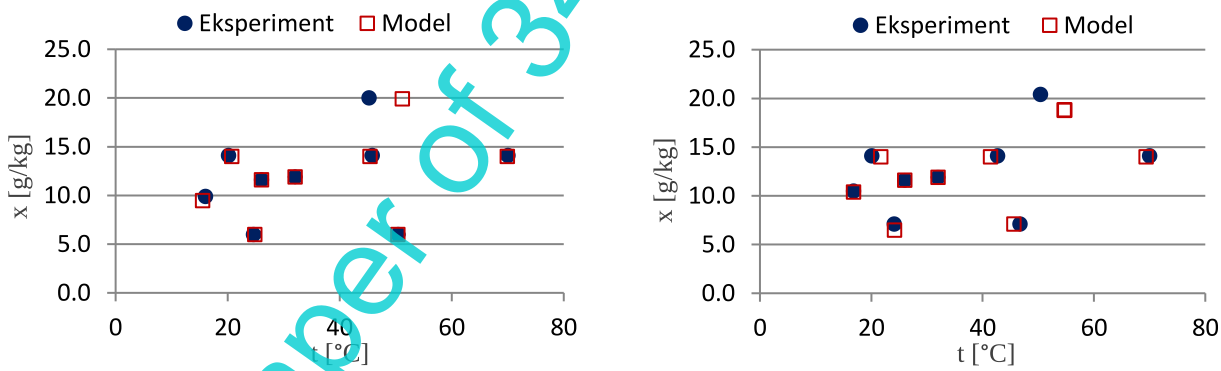

Fig. 9. Deviations between the simulation results obtained in TRNSYS and the values obtained through experiments, according to [16] (left) and [17] (right).

6. Conclusion

In the process of modeling a solar air conditioning system using the dehumidification process, the most challenging step is modeling the rotating wheel and determining the efficiencies ε_{F1} and ε_{F2}, whose values describe the cumulative effect of various influential parameters in the complex and simultaneous heat and mass transfer process. Considering that the values of ε_{F1} and ε_{F2} represent the efficiencies of the functions of potential F_1 and F_2, which are directly dependent on the input parameters of the process and the regenerative air, it can be concluded that special attention should be directed to the accurate input of these values when developing a model for a solar air conditioning system.

The results obtained by simulating basic models of solar cooling by dehumidification under steady-state conditions represent various values of the state parameters of moist air during the process and show good agreement with experimentally determined values of air parameters for the same conditions. During the simulation of the model under time-varying input parameters, there was a deviation in the output parameters of the process and regenerative air from the rotating wheel, as the simulation program TRNSYS uses a component that works with fixed parameters of the functions of potential F_1 and F_2, as well as the efficiencies ε_{F1} and ε_{F2}. The new desiccant wheel model developed in this work and integrated into the TRNSYS database allows for changes in the wheel efficiency values depending on the variation of the moist air state parameters at the inlet over time, thereby increasing the accuracy of the simulation.

In future research, activities should be focused on improving the characteristics of the desiccant wheel and reducing the regeneration temperature. This primarily refers to the invention of new sorption materials with a higher degree of adsorption and a lower production price. In this way, the efficiency of the desiccant wheel and the entire system will increase, and the price reduction will enable the application of multi-stage dehumidification, which reduces the regeneration temperature.

7. References

[1] Ahmovic, I.; Dzaferovic, E. & Hadziahmetovic, H. (2018). Analysis of Temperature Data in the Area of the City of Sarajevo (Bjelave) in Period From 2000-2010, Proceedings of the 29th DAAAM International Symposium, pp.0260-0266, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-20-4, ISSN 1726-9679, Vienna, Austria, DOI: 10.2507/29th.daaam.proceedings.037

[2] Ma, Z.; Ren, H. & Sun, Z. (2019). Energy and exergy analysis of a desiccant cooling system integrated with thermal energy storage and photovoltaic/thermal-solar air collectors, Science and Technology for the Built Environment, Online First, 1-16

[3] Lulić, H.; Metović, S. & Softić, A. (2023). Exergy analysis of a solar assisted desiccant cooling system, 14th Days of BHAAAS in Bosnia and Herzegovina, International Conference on Innovative and Interdisciplinary Applications of Advanced Technologies – IAT 2023, Tuzla, Bosna and Hercegovina, June, in press

[4] Howe, R.R. (1983). Model and Performance Characteristics of a Commercially-Sized Hybrid Air Conditioning System Which Utilizes a Rotary Desiccant Dehumidifier, MS Thesis, University of Wisconsin – Madison

[5] Jurinak, J.J. (1982). Open Cycle Desiccant Cooling – Component Model and System Simulations, PhD Thesis, University of Wisconsin – Madison

[6] Banks, P.J.; Close, D.J. & Maclaine-Cross, I.L. (1970). Coupled Heat and Mass Transfer in Fluid through Porous Media – an Analogy with Heat Transfer, Proceedings of the fourth international heat transfer conference, 1970., Versailles, vol. VII, pp. 1-10. Elsevier publishing company, Amsterdam

[7] Momoi, Y.; Yoshie, R.; Satake, A. & Yoshino, H. (2010). Calculation of Dehumidification Coefficients for Numerical Simulation of Desiccant Wheel, Proceedings of the 31st AIVC Conference, Seoul, Korea, https://www.aivc.org/sites/default/files/3B-2.pdf

[8] Bourdoukan, P.; Wurtz, E.; Joubert, P. (2010). Comparison between the conventional and recirculation modes in desiccant cooling cycles and deriving critical efficiencies of components, Energy, Volume 35, Issue 2, Pages 1057-1067

[9] Norazam, A.S.; Kamar, H.M.; Kamsah, N. & Alhamid, M.I. (2018). Simulation of adsorption process in a rotary solid desiccant wheel, The 10th International Meeting of Advances in Thermofluids, 16–17 November 2018, Bali, Indonesia (IMAT 2018), AIP Conference Proceedings, Volume 2062, Issue 1, Print ISSN 0094-243X, AIP Publishing, 2019, https://doi.org/10.1063/1.5086547

[10] Nawaz, K.; Abdelaziz, O. & Jacobi, O. (2021). Characterization of Solid Desiccant for Dehumidification Applications, 18th International Refrigeration and Air Conditioning Conference at Purdue, May 24-28, 2021., Proceedings from 2021., Paper 2217, pp 2694, Page 1-9, https://docs.lib.purdue.edu/iracc/2217

[11] Zafar, A. & Taliv, H. (2022). Experimental Analysis and Performance Evaluation of Solid Desiccant Dehumidifier Using Silica Gel, International Journal of Analytical, Experimental and Finite Element Analysis, Volume 9, Issue 1, March 2022, pp 1 – 8, https://doi.org/10.26706/ijaefea.1.9.20211202

[12] Narayanan, R.; Saman, W.; White, S. & Goldsworthy, M. (2010). Modeling and parametric analysis of silica-gel desiccant wheels. Refrigeration Science and Technology Proceedings 2010-2, ISBN-139781617387845, 9th IIR-Gustav Lorentzen Conference on Natural Working Fluids 2010, Sydney, Australia, 12-14 April 2010, https://hdl.handle.net/10018/1023729

[13] Lindholm T. (2000). Evaporative and Desiccant Cooling Techniques, Ph.D. Dissertation, Department of Building Services Engineering, Chalmers University of Technology, Goeteborg, Sweden, ISBN 91-7197-904-2

[14] TRNSYS user's manual (2004)., Solar Energy Labs, University of Wisconsin, Madison

[15] Schultz K.J. (1983). The Performance of Desiccant Dehumidifier Air-Conditioning Systems Using Cooled Dehumidifiers, MS Thesis, University of Wisconsin – Madison

[16] Hofker G. (2001)., Desiccant Cooling with Solar Energy, Ph.D. Thesis, Institute of Energy and Sustainable Development, De Montfort University Leicester, Department of Building Physics, Fachhochschule Stuttgart, Hochschule fur Technik

[17] Maalouf C.; Wurtz E. & Allard F. (2006). Evaluation of the cooling potential of a desiccant evaporative cooling system using the SimSPARK environment, UTAP, University of Reims, Campus du Moulin de la Housse, Reims, France, Published 2008