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CHARACTERIZATION OF AN ENTHALPY WHEEL TO HELP THE MOISTURE AND TEMPERATURE CONTROL PERFORMED ONLY BY CONVENTIONAL COOLING

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Abstract. *This work was to claim a study of characterization of a adsorptive wheel with passive principles (enthalpy wheel) for the composition of a cooling system in which the weather effects are promoted by both steam compression as by a adsortiva unit. The pretext motivator is based on the attempt to carry out the control of temperature and humidity present in the air conditioned environment using adsorption technology and consequently obtain reductions in expenses involved in the control of these parameters currently only made by compression of steam. In other words, stardom is to reduce energy costs and also the expenses provided by the depreciation of the environment/health man. The results presented in this study showed that in addition to the advantages obtained from the control of humidity and temperature, the union of a adsorptive unit with passive principles also promotes 100% internal air renewal to the air-conditioned environment by eliminating possible short supply of carbon dioxide. The promotion of stable conditions of thermal comfort is also one of the advantages of this system, being achieved by means of heat and mass exchanges in adsorptive unit present in the enthalpy wheel using only air flows from the refrigerated environment itself and the external environment.*

Keywords: *Refrigeration, Heat and mass transfer, Enthalpy wheel, Humidity and temperature control.*

1. INTRODUCTION

In the mid-19th century, it was discovered that the expansion of gases promoted a low-temperature refrigerator effect given by the withdrawal of heat, this effect did arise the steam-compression refrigeration-RCV. This mode to get cooled, currently employed worldwide, not only serves for preserving food but also for the cooling environments and the promotion of human thermal comfort.

Despite its wide use, this method of artificial climate control, presents itself as a strong energy consumer and its potential further worsened in summer times. It is at this time that this system is widely requested. Nevertheless, this system features moisture control deficits and does not promote the total renovation of the indoor air cooled environment.

Currently there are many studies aimed at improving or replacing the steam compression refrigeration. This occurs in order to reduce energy consumption as in the sense of eliminating the refrigerants, do the humidity control, the temperature and promote the total renovation of the air introduced into the air-conditioned environment.

Tolmasquim (2012), states that one of the foundations of the economic sustainability of a country is its ability to provide logistics and energy to the development of its production, safely and on competitive terms and environmentally sustainable.

On that thought and the need to improve the conventional refrigeration with regard to moisture and temperature control with total renovation of indoor air to air-conditioned environment, this work was performed a characterization, i.e. an assessment of climatic effects produced artificially by an enthalpy wheel placed in different conditions of work, using for that climate effects conducted by own conventional steam compression refrigeration and climatic conditions outside the air-conditioned environment.

2. THEORETICAL BASIS

The humidity control, temperature and total air renewal of environments with climates produced artificially, are parameters of great importance when you want to obtain the effects of artificial climate control for public use. Currently the control of these parameters is made directly by the compression refrigeration systems of steam (RCV), without the aid of any other form of air conditioning. These parameters are directly related to human health, the environment, air conditioned and with the energy consumption used to be kept stable and on human thermal comfort conditions.

Excess moisture from an environment, for example, causes damage to facilities, materials, and the existing furniture in the environment, time consuming in its repair or replacement. The harmful effects to health and the discomfort felt by people who frequent such environments, are summed up the damage yet. Not to mention that for the control and/or removal of part of that moisture, it is necessary to increase energy costs involved in such an operation (Medeiros, 2007).

Macagnan (2010), reports that the effect of certain refrigerants used by RCS, including halogenated compounds replacements of CFCs, may have direct effect, when directly are emitted into the environment or indirect, when additional consumption of energy-related data for their inefficiency in the refrigeration cycle. He was also responsible for additional energy production to compensate, which releases more CO_2 in the atmosphere due to the processes of electric power generation.

The National Agency of Sanitary Surveillance -ANVISA, among other measures put forward in resolution No. 176, of October 24, 2000, establishes that for air conditioning for public use, must be provided measures to promote the maintenance of indoor air quality index. Such measures should be related to air treatment process, controlling variables such as: temperature, humidity, speed, particulate matter, biological particles and the concentration of carbon dioxide (CO_2).

A possible solution, with efforts employed in aid of conventional air-conditioning system, referring to the lifting of the internal air quality index to the thermal environment, summarized in making the union a system of processing of air by adsorption to conventionally existing systems. This union, allows using the principles of thermodynamics of adsorption in a porous medium, the air conditions reached by conventional system are kept with attribution of a better quality to the indoor air thermal environment through its total renewal and elimination of possible concentrations of carbon dioxide and other harmful substances both the environment and the health of those who use it.

A adsorptive phenomenon, is one in which when placed in contact with a solid adsorbent and a mixture of fluids, one of the members of this mixture will be retained by the solid. Going on with that an increase of the concentration of the adsorbed no fluid. The adsorption is due to the fact that the surface of any body in a State of tension or non-saturation, which forms a true residual field of surface forces. The natural tendency of reduction of surface free energy is responsible for this phenomenon (Ferrari, 2005).

3. DEVELOPMENT

The development of the present study was to evaluate the effects of artificial climate control by putting a adsortiva cylindrical array that makes up the framework of an enthalpy wheel, working in different conditions of work evaluating the influence of parameters such as temperature, air flows involved, cylindrical array speeds and different flows for air flows.

The performance of this equipment was evaluated taking as means, his ability to maintain a temperature of air direcinado air conditioned environment, as close as possible to that achieved by the existing conventional cooling. The humidity ratio, another very important parameter in environments with climates artificially produced, was also taken as a means to assess the performance of the equipment, she allowed herself to assess the potential that the enthalpy wheel has to keep it as close as possible to the existing thermal environment. For that are assessed the process of heat and mass transfer promoted by adsorption phenomenon in cylindrical array costituída porous adsorbent material.

3.1 Materials

The enthalpy wheel employed in this work is a device in which the main climatic effects are born from the dehumidification of air flow. These matrices have their structures with multiple channels of air passage, being formed by a substrate made of: aluminum, plastic, glass fibre or ceramic base, in which is set a desiccant type material: silica gel, synthetic zeolite (molecular sieves) or synthetic polymer Simonson (1998).

The main characteristics of the equipment used during the experimental study of this work were: diameter of 700 mm, 270 mm thickness, with an area of adsorption/desorption area of 1:1, predominant silica gel desiccant material and aluminum substrate. As a means of promoting initially the artificial climate environment, was used a conventional cooling system by steam compression (RCV) residential size. The idealized weather effects with the use of this enthalpy wheel arose from the existence of two airflows laid across it without any counter-flow interaction between them, Fig. 1. These flows were produced by the installation of two centrifugal fans, one for process air flow, air to be treated, and the other for the return airflow, previously cooled indoor air.

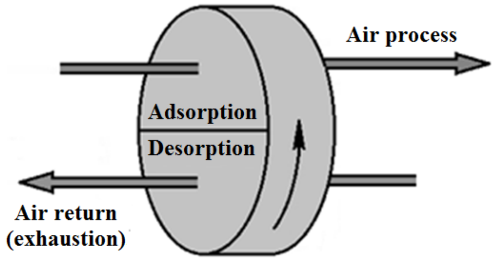
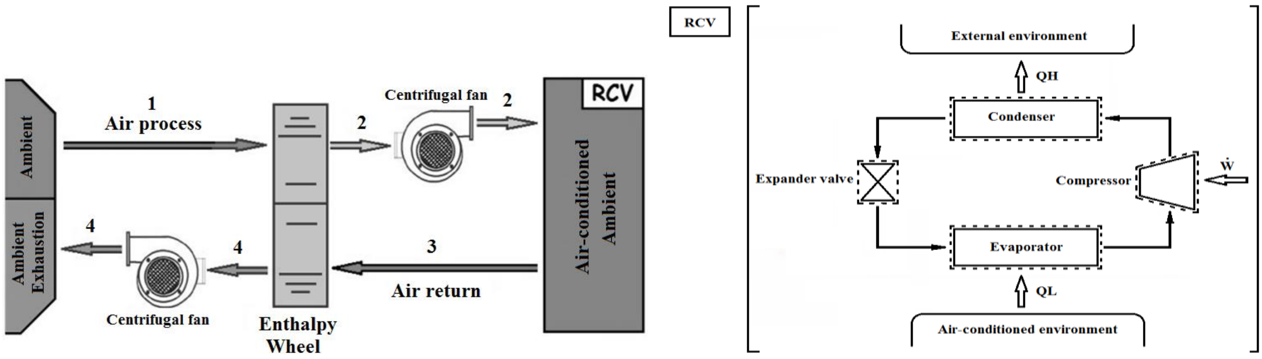


Figure 1. Air treatment in the areas of adsorption/desorption.

As can be seen in Fig. 1, the areas of adsorption and desorption of the equipment, are responsible for creation and maintenance of a adsortivo cycle. Without them, there is no possibility of obtaining the desired climate conditions. The adsorption area, is responsible for the process on a solid surface retention of all or part of one of the constituents of a mixture of fluids, in this case, water steam/air. The area of desorption, is responsible for the process of elimination of constituent of the mixture of retained fluids by the same solid. As much as for adsorption desorption occur of joint way, i.e. to a adsortivo cycle happens to the exploitation of their maximum efficiency it is necessary that both processes occur at the same time (Melo, 2015).

3.2 Experimental Procedures

In Figure 2, the enthalpy wheel presents itself within the experimental design as a means of promoting the control of humidity, temperature and total renovation of air thermal environment. As was mentioned in the previous section, experimental design features an airflow crossing the adsortiva array and directed to the thermal environment, and another being taken out of that environment with their conditions previously created by system RCV, passing in a matrix of adsorption counter-flow and directed to the external environment.



(a) (b)

Figure 2. Experimental design (a), (b) RCV conventional system.

Figure 3 below, can be used for a better understanding of the process of treatment of air by enthalpy wheel. She represents the array of adsorption that throughout the process is put at constant speed around its central axis, allowing the completion of the cycle responsible for adsorption/desorption processes. In point 1, the process air picked up the environment is forced to traverse the array impregnated by the adsorbent material. The air in this bridge has room temperature and high humidity ratio. In point 2, due to the heat and mass exchanges promoted by adsorption phenomenon in the array, the air must have low temperature and low humidity ratio. After entering the thermal environment the air is forced to return, 3 point, still possessing low temperature and low humidity ratio. The return air, crossing the adsortiva array, point 4, must then have virtually the same air conditions picked up initially in point 1. From point 4, the air must be eliminated in the external environment at a point different from the point of initial capture.

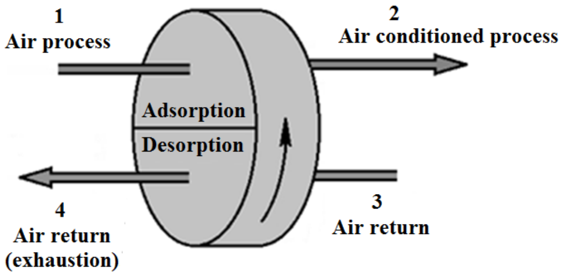


Figure 3. Enthalpy wheel in characterization.

In Figure 3, the air in point 2, process air Treaty, must present virtually the same conditions of return air coming from the air conditioned environment, point 3. In other words, this air must possess the same ability to promote thermal comfort with increased thermal environment's health, since the concentrations of harmful substances such as CO_2 were eliminated because of the total renovation of the air.

3.3 Mensurement of Efficiency of Enthalpy Wheel

The mathematical equations used in this work were simply to show the effectiveness of the enthalpy wheel in process air treatment. The effectiveness is a dimensionless parameter used to assess the degree of performance of the equipment when it is being crossed by countercurrent air flow. It can be evaluated as to the ability to exchange heat, and is taken in this case as sensitive effectiveness (ε_s), and can be assessed as well as for mass changes, and in this case is taken as latent effectiveness (ε_l).

The equations described in this work and used in (Klein *et al.*, 1990), are defined in the following ways:

Equation (1), representative of the sensitive effectiveness,

$$\varepsilon_s = \frac{\dot{m}_{pr}\left(T_{pr,inlet} - T_{pr,outlet}\right) + \dot{m}_{ex}\left(T_{ex,outlet} - T_{ex,inlet}\right)}{2\dot{m}_{min}\left(T_{pr,inlet} - T_{ex,inlet}\right)} \tag{1}$$

Equation (2), representative of the latent effectiveness,

$$\varepsilon_l = \frac{\dot{m}_{pr}\left(W_{pr,inlet} - W_{pr,outlet}\right) + \dot{m}_{ex}\left(W_{ex,outlet} - W_{ex,inlet}\right)}{2\dot{m}_{min}\left(W_{pr,inlet} - W_{ex,inlet}\right)} \tag{2}$$

where, $\dot{m}_{pr}$ - air mass flow of process [kg/s]; $\dot{m}_{ex}$ - mass flow rate of exhaust air (return) [kg/s]; $\dot{m}_{min}$ - lower mass flow between process air and return air [kg/s]; $T_{pr,inlet}$ - process air temperature at the inlet enthalpy wheel [K ou ℃]; $T_{pr,outlet}$ - process air temperature at the exit enthalpy wheel [K ou ℃]; $T_{ex,inlet}$ - exhaust air temperature (return) at the entrance of the enthalpy wheel [K ou ℃]; $T_{ex,outlet}$ - exhaust air temperature (return) at the exit enthalpy wheel [K ou ℃]; $W_{pr,inlet}$ - air humidity ratio of process at the entrance of the enthalpy wheel [$g_{steam\ water}$ /$kg_{air\ dry}$]; $W_{pr,outlet}$ - air humidity ratio of process in the output of the enthalpy wheel [$g_{steam\ water}$ /$kg_{air\ dry}$]; $W_{ex,inlet}$ - humidity ratio of exhaust air (return) at the entrance of the enthalpy wheel [$g_{steam\ water}$ /$kg_{air\ dry}$]; $W_{ex,outlet}$ - humidity ratio of exhaust air (return) at the exit enthalpy wheel [$g_{steam\ water}$ /$kg_{air\ dry}$].

4. RESULTS AND DISCUSSION

Table 1 presents the results for the enthalpy wheel performance, assessed in the conventional refrigeration using two pairs of flows and two different rotations. The results of this study were calibrated using the respective pairs of flows (515-511) [m³/h] and (806-811) [m³/h] where, the pair represent [process-exhaustion (return)]. The rotation set for the array of adsorption enthalpy wheel were 10 and 25 [rpm], and air temperatures and return process were kept close to 29 and 23 ℃ respectively.

Table 1. Results for the characterization of the enthalpy wheel.

Rot. (rpm)	$Q_{pr^{(1)}}$ (m³/h)	$Q_{ex^{(2)}}$ (m³/h)	Process				Return (exhaustion)				Ef. Lat. (%)	Ef. Sen. (%)
			Inlet (Point 1)		Outlet (Point 2)		Inlet (Point 3)		Outlet (Point 4)			
			$T_{pr^{(1)}}$ (°C)	$W_{pr^{(1)}}$ (g/kg)	$T_{pr^{(1)}}$ (°C)	$W_{pr^{(1)}}$ (g/kg)	$T_{ex^{(2)}}$ (°C)	$W_{ex^{(2)}}$ (g/kg)	$T_{ex^{(2)}}$ (°C)	$W_{ex^{(2)}}$ (g/kg)		
10	515	511	28.90	18.92	23.90	12.52	22.60	12.15	27.70	17.79	89.56	80.78
25			28.10	18.59	23.00	12.24	22.40	12.14	27.10	17.84	94.02	86.53
10	806	811	28.70	18.60	23.80	12.46	22.70	12.19	27.90	17.14	87.62	85.40
25			28.30	18.16	23.60	12.24	22.70	12.17	27.60	17.22	93.66	86.91

(1) process, (2) exhaustion, [g/kg] = [$g_{steam\ water}/kg_{air\ dry}$], Ef. = Efficiency, Lat. = Latent, Sen. = Sensitive, Q = Flow rate

Observing the results presented in table 1, to the smallest pair of flows, evaluated at two speeds, were obtained for process air temperatures ranging from 23 and 24 °C, showing a good approximation of the temperature of the return air coming from the environment initially ranging from temperature-controlled 22 and 23 °C. As can be noticed, the two rotations showed respectively reductions in process air temperature 5 and 5.1 °C.

Analogously, for the smallest pair of rated flow rates in two speeds, were obtained for process air, moisture reasons ranging from 12.54 and 12.24 [g/kg], showing a good approximation of the reasons of return air humidity coming from the environment initially air-conditioned and with reasons of moisture between 12.14 [g/kg] and 12.13 [g/kg]. As can be noticed, for the two speeds there were respectively reductions in air humidity ratio of process 6.4 and 6.35 [g/kg].

For the biggest pair of rated flow rates in two speeds, the enthalpy wheel showed similar behavior, i.e., were obtained for the temperatures process air ranging from 23 and 24 °C, also showing a good approximation of the temperature of the return air coming from the environment initially ranging from temperature-controlled 22 and 23 °C. As can be noticed in the two rotations there were respectively reductions in process air temperature 5 and 5.1 °C.

With respect to humidity ratio, the largest pair of rated flow rates in two speeds, were obtained for process reasons of air humidity ranging between 12.46 [g/kg] and 12.24 [g/kg], showing again a good approximation of the reasons of return air humidity coming from the environment initially air-conditioned and with reasons of moisture between 12.19 [g/kg] and 12.17 [g/kg]. As can be noticed in the two rotations there were respectively reductions in air humidity ratio of process 6.14 [g/kg] and 5.92 [g/kg].

According to the equations for the effectiveness of the enthalpy wheel, Table 1 shows the relationship of efficiencies relating to mass and heat exchange, i.e. latent efficiencies and sensitive. One can see that in the smallest pair of flows with the speed from 10 to 25 [rpm], latent efficiency suffered an increase of 4.46%, that is, its went from 89.56 to 94.02%. Similarly, to the extent that increased rotation, sensitive efficiency went from 80.78 to 86.53%, i.e. increased 5.75%.

To the biggest pair of flows with rotation also of 10 to 25 [rpm], latent efficiency suffers an increase of 6.04 %, that is, the matter of 87.62 to 93.66%. Similarly, the sensitive efficiency suffers a small increase from 85.40 to 86.91%.

5. CONCLUSION

Investigating the influence of rotations on the efficiencies of the equipment, it was noted that the increase of this parameter for each pair of flows, there was an increase in both the latent efficiency as sensitive efficiency. What sets a better heat and mass transfer within the array of adsorption. As the influence of the flow on these same efficiencies, it was found that with the increase of this parameter by keeping constant rotation, there was a decrease of latent efficiency and an extra sensitive efficiency, that is, less mass transfer and heat transfer more.

The equipment was considered an excellent ally to be used in conjunction with conventional cooling. Evaluated as experimental procedures, he allowed the process was sent to the air-conditioned environment with practically the same air conditions existing in the return air conditioned environment with 100% renewal leaving you with 0% of harmful gases.

The enthalpy wheel, through its array of adsorption, proved to be a crucial importance for the control of humidity and temperature of the process air. This was evidenced both by the values obtained for the efficiencies, according to the equations used and the characteristics of this air in the output of the equipment (point 2), in which, for every combination of speed and flow rates remained virtually the same as the return air at the entrance of the equipment (point 3).

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