EXPERIMENTAL STUDY FOR A HEAT PUMP USED FOR THE DRYING OF FRUIT

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Abstract. *The present work shows the development, construction and tests of a fruit dryer operating with slightly warmed up air at low humidity levels. The main purpose of it is to obtain a better quality product than that obtained by means of the traditional dehydration methods that make use of higher temperatures. We have decided on a heat pump that makes the external air be dehumidified after being insufflated by the evaporator in order to be heated up immediately afterwards when passing through the compressor from where it dry and hot flows out at favorable thermodynamic conditions to carry out the drying process. A hermetic compressor of 1C.V. was used to make the present prototype, which has been equipped with both temperature and pressure transducers at various points of the* higher and lower pressure layers so as to maintain the thermodynamic characteristics of a thermo machine. To secure the thermodynamic quality of the process, air thermometers, hygrometers and anemometers are used. These are placed at the front and rear sections of both the condenser and evaporator. The evaporator is mounted on a tray in order to collect the condensed water that spills out from a drain into a test tube. It was possible to adjust the heat pump so that the processing air could be ejected out of it at a temperature of 50ºC and a relative humidity of 15%. The COP system – considering the energy consumed during the air dehumidification – was calculated as being of the order of 2.6, confirming once again the viability of the pump.

Keywords*: heat pump, dehumidification, dryers, refrigeration*

1. INTRODUCTION

Drying food is the oldest method of food preservation which it was known (Cohen and Yang, 1995). It is a process which can use a combination of convection and radiation or conduction to conduct the heat to the product which was being dried. That is a complex process and it involves the removal of water from a product by evaporation and at same time heat and mass are transferred. It is necessary to supply heat to evaporate the water from the product and a means of transportation to remove the water vapor which was formed in the surface of the product to be dried, which is usually the air (Travaglini et al., 1993). Currently, equipment has been studied to provide heat efficiently, with to reuse of heat that could be rejected to the environment. The heat pump is an example of it, because it is a thermal machine that operates according to a thermodynamic cycle where it works receiving work and transferring heat from the cold source (the reservoir of low temperature) for the hot source (high-temperature reservoir). The application of this energy from the source of warm is what makes the difference between the heat pumps and the refrigerate equipment, where the energy is wasted or released to the external environment. Although heat pumps are extensively used in industry for many years, drying of food researches are relatively recent. According to Chua et al. (2002), those heat pump dryers offer several advantages over the conventional ones, such as greater efficiency, control of accurate characterization of the drying air, quality of product, better performance and reduced operational cost. Also Pereira et al. (2004) justified the addition of a system of heat pump that can put more energy than it consumes as also higher energy efficiency and the conservation of organoleptic properties and the opportunity of to operate independently from environmental conditions without environment aggressions with gases in the atmosphere. Adapa et al. (2002) have been studied the performance of a cabinet dryer with recirculation of air to dry alfalfa sprouts. This study evaluates the potential of a heat pump designed and built to investigate the air characteristics in the dehumidifying process. This heat pump provides a dehumidified and heated air which dries the food.

2. EXPERIMENTAL APPARATUS AND PROCEDURES

2.1. Experimental apparatus

Equipment which was designed, constructed and used in the tests consists of two parts: the first one is the heat pump for steam compression which works like a domestic refrigerator. The second part is the drying chamber where the product dehydration process occurs. The system can work with two configurations: a closed loop with the air circulating many times and as an opened cycle where the air is cast to the environment. This last on is the configuration used to characterize the heat pump under study and which is shown in the Figure 2. On it we can verify the installation of two PVC (***P**olyvinyl* ***c**hloride*) pipes in the entrance and in the exit of air of the equipment for a laminate flow to come into contact with the speed and temperature sensors whose are installed in it.

Figure 1. Drying System

Figure 2. Heat pump researched

The heat pump, shown in Figure 3 consists basically of an evaporator (1), an expansion valve (2), a compressor (3), a condenser (4) and a fan (5) that makes the circulation of the air. The condenser and evaporator are heat exchangers. The power used in the compressor was 900W and for the fan was 80W. Tests were performed into two of the available fan speeds: 5.7 and 6.1 m / s. With the air circulating in the system in velocity of 5.7 m/s, the internal pressure in condenser and evaporator were respectively, 380 Psi (2721.326 kPa) and 68 Psi (570.162 kP). At the speed of 6.1 m/s they were respectively 375 Psi (2686.859 kPa) and 70 Psi (583.958 kPa). The refrigerant fluid used in heat pump was the R-22.

Figure 3. Heat pump from side view: (1) Evaporator, (2) Expansion Valve,
(3) Compressor, (4) Condenser e (5) Fan

2.2. Stages of Drying

The heating and dehumidifying which pass the air come from the following stages: dehumidifying, heating and pumping. Dehumidifying occurs when the humid air from the environment is extracted by the fan system, passing through the evaporator which is at a temperature below the temperature of dew when it condenses the steam of water steam in the air. This condensed water is collected in a tray which has a drain and flows into a graduated container. This dehumidifying process promotes the reduction of the absolute humidity from the air and increases its relative humidity and a decreasing in the temperature. In the heating the air from the first stage, passes throw a heating it was caused by energy in the form of heat which was rejected by the compressor body and thereupon by the condenser. The function of this stage is to cause the increase of air temperature. In the pumping stage the fan are extracting the heat air from the heating process and releasing it to the environment. The air released in the process of pumping is dehumidified and heated at the appropriate temperature for drying food.

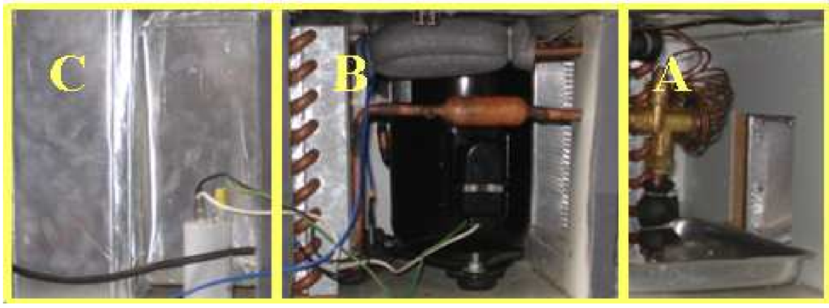

Figure 4: Heating Process: (A) Dehumidifying; (B) Heating; (C) Pumping

2.3. Instrumentation System

Temperature sensors of the type PT100Ω were used to measure the temperatures of dry and wet bulb. They are located at the entrance and exit of equipment and between the evaporator and condenser. Data were collected using a *data logger*. Two anemometers are used to measure the air speed and they are located at the entrance of the evaporator and the condenser exit. Measurements were manually obtained. The rotation of the fan from the heat pump was not changed during the test. The effective power of the compressor was making by measurements of its voltage and current functioning. The vapor of condensed water quantity in the evaporator was measured using a beaker. Details of instrumentation are in Table 1.

Table 1: Instrumentation used during the tests

Instrument	Manufacturer	Scale	Uncertainty
Anemometer	Digital Instruments	0.8 a 12m/s	± (2% + 0.2 m/s)
Beaker	Laborglas Brasil	0 a 1L	*NA
Data logger	Spider 8 (600 Hz)	*NA	*NA

* Not Applied

2.4. Procedures

Equipment set up in open loop and without the chamber attached was connected includes the entire apparatus of instrumentation. The following variables were recorded: the temperature of dry bulb and wet bulb whose were been described above, the pressure at the entrance and exit of the compressor, the speed, the temperature of the surface of the tubing on the refrigeration cycle, the power of the fan and compressor and the volume of condensed water. Temperature of dry bulb and wet bulb were measured by temperature sensors whose were shown in the figure below. The others air properties were obtained.

3. RESULTS AND CONSIDERATIONS

Results obtained in this work were focused on the performance of heat pump (Figure 3), which will be studied linking to the chamber for drying of food which was shown in Figure 1. The experiments were performed by the Laboratory of Solar Energy from Federal University of Paraiba. Tests were performed in different situations with variation of temperature and absolute air humidity. The influence which the environment exerts on the heat pump has been verified, although the air used in this research is not being processed in a closed loop. Among all the tests were selected the best ones to represent the processes which are in the air and in the refrigerant fluid, performed at two speeds (5.7 and 6.1 m/s), which are available on the equipment. Comparing the two speeds, it appears that with the decrease in speed, the flow of dry air and condensed water flow reduced. The air in the processes 1 to 4 was considered as a mixture of dry air and water steam. The temperature of condensed water was taken as 284.65 K in of 5.7 m/s 285.65 K, the velocity of 6.1 m/s, being the average temperature and dew point of the fins the evaporator. The experimental data concerning values and air temperatures of R-22, and the absolute and relative humidity of the drying air are arranged in tables 2 and 3, respectively at speeds of 5.7 and 6.1 m/s.

Table 2: Experimental data of the heat pump at the speed 5.7 m/s

Mass flow			
$\dot{m}_{dryair}$ (kg/s)		$\dot{m}_{H2Ocond}$ (kg/s)	
0.04731		0.0003023	
Air temperature		**Air temperature of the surface of heat exchangers**	
T_0	302.37 K	T_A	374.70 K
T_1	302.37 K	T_B	328.25 K
T_2	291.69 K	T_C	279.55 K
T_3	303.52 K	T_D	288.95 K
T_4	326.37 K		
Absolute humidity of air (w)		**Relative humidity of air (Ø)**	
w_1	0.1748 $kgH_2O/kgdryair$	$Ø_1$	68.25 %
w_2	0.1220 $kgH_2O/kgdryair$	$Ø_4$	13.48 %

Table 3: Experimental data of the heat pump at the speed 6.1 m/s

Mass flow			
$\dot{m}_{dryair}$ (kg/s)		$\dot{m}_{H2Ocond}$ (kg/s)	
0.05079		0.0002682 kg/s	
Air temperature		**Air temperature of the surface of heat exchangers**	
T_0	301.65 K	T_A	375.35 K
T_1	301.65 K	T_B	327.65 K
T_2	289.84 K	T_C	278.55 K
T_3	302.16 K	T_D	286.25 K
T_4	327.87 K		
Absolute humidity of air (w)		**Relative humidity of air (Ø)**	
w_1	0.1774 $kgH_2O/kgdryair$	$Ø_1$	72.17 %
w_2	0.1135 $kgH_2O/kgdryair$	$Ø_4$	11.68%

Figures 6 and 7 show the evolution of the temperature sensors of the type EN 100Ω. We find there clearly the evolution of the temperature of Section 4, the output of the capacitor until it be in steady state. Several tests were performed and, on average, the cycle enters in steady state around two hours for the two speeds.

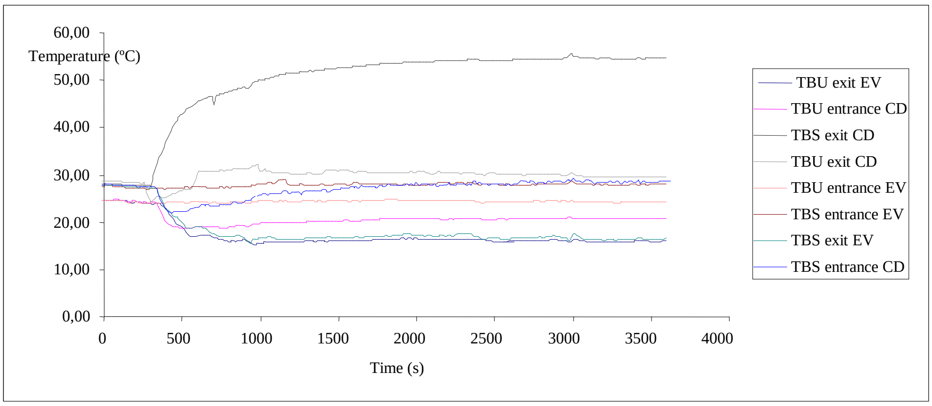

Figure 5: Evolution of the temperature of process air at the speed 5.7 m/s

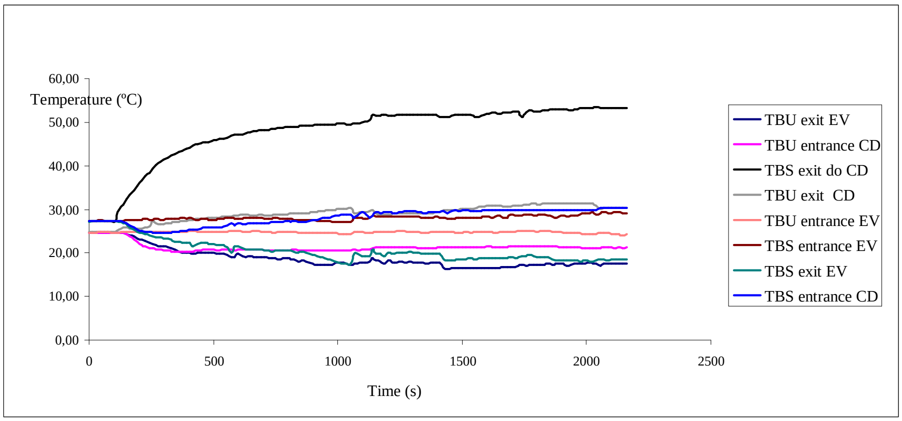

Figure 6: Evolution of the temperature of process air at the speed 6.1 m/s

4. CONCLUSIONS

This present work consists of experimental research and testing of a prototype of a heat pump that uses as a source of heat extraction from the air. It purposes to dehumidify and to heat the air for using in drying of food process. However, the experiments which are made just involved the processing of air and they were not including the drying of food. This study presents the compressor to the internal compartment, taking the heat that would be lost if this was the environment. The use of heat pump dehumidifying and heating the ambient air was shown to be feasible, in that they produce air with a low absolute humidity and a temperature around 50ºC which allows the drying of foods providing a better conservation of its organoleptic properties in comparison with other conventional drying equipment.

5. ACKNOWLEDGEMENTS

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6. RESPONSIBILITY NOTICE

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UNITS AND NOMENCLATURES

CD	Condenser
EV	Evaporator
$\dot{m}$	Mass flow [kg / s]
w	Absolute humidity [kg H2O / kg arseco]
TBS	Dry Bulb Temperature
TBU	Wet Bulb Temperature

Greek letters

Ø	Relative humidity [%]

Subscripties

0	Reference Temperature
H2Ocond	Condensed Water
Dry air	Dry air
A	Point A
B	Point B
C	Point C
D	Point D
1	Point 1
2	Point 2
3	Point 3
4	Point 4