ENCIT-2018-0390
SELECTION OF HEAT EXCHANGER FOR USE IN
INDUSTRIAL DRYING PROCESS

Andrade, André J. C.
Guimarães, H. B.
Programa de Pós-Graduação em Engenharia Mecânica , Universidade Federal do Espírito Santo.
Av. Fernando Ferrari, 514 - Goiabeiras, Vitória - ES, 29075-073
andrejudah@gmail.com
heber.braga.1990@gmail.com

Abstract. The process of selecting a suitable heat exchanger for a drying process is proposed in this paper. In a drying process the main objective is to remove water in a way that does not cause damage to the material or environment in question. One suitable way to do this is through convection heat transfer where air is directed at a slightly elevated temperature and with low relative humidity. The air leaves at a lower temperature and with a higher relative humidity of the air. After this, this condensing water is withdrawn from the air and from the system and the dry air returns to the process. Using the EES software it was possible to model an ideal drying system. After the modeling of the process in the software, the relationship between the water condensing flow to be withdrawn in the drying system and the heat load of the heat exchangers was found. This was possible by entering different flow values and taking the thermal load values in the EES software. It was possible to note that this relationship is linear and that for a higher condensing water from the system there must be a higher thermal load on the heat exchangers. This information is of great importance in the design and selection of condensers and evaporators.

Keywords: Heat pump, Heat Exchange, Air-cooled Heat Exchanger.

1. INTRODUCTION

Currently there is a global concern regarding the use of energy, both from its original source and the efficiency of its use, avoiding unnecessary losses. Minea (2016) indicates that in the year 2008, 143.850 TWh was supplied worldwide in energy, where 60% corresponded to energy from coal-fired power plants, and 32% of this supply was lost in generation and transportation processes. From the point of view of CO_2 emissions, 40% had electric power generation, 17% industrial consumption, 14% commercial and residential buildings and 21% transportation.

According to Kemp (2011), 10% to 20% of all energy used in the industrial sector of developed countries is consumed in drying processes. Fayose and Huan (2011) argue that the increase in the prices of fossil fuels, electricity and due to the emission of noxious gases to the ozone layer in the use of traditional drying processes have made drying processes sustainable and heat recovery have become important. Alves-Filho (2015) states that conventional drying processes have a high contribution to the emission of greenhouse gases in the atmosphere.

Dinçer and Rosen (2015) argue that heat pump dryers are quite energetically attractive because of their ability to recover heat and remove moisture from the air. Minea (2016) points out that heat pump drying is a sustainable technology because it requires low energy consumption and its operation does not directly emit gases and fumes harmful to the atmosphere.

The heat pump competes with traditional heating systems such as ovens, fireplaces and resistance heaters, presenting lower environmental impacts compared to furnaces and fireplaces and lower energy consumption in relation to electric resistance heaters

The heat pump benefits from the application in the drying process the possibility of drying at low temperatures, low operation cost and high energy efficiency.

In this context, involving an increase in the demand for energy consumption, a high share of fossil fuels in the world energy matrix, emissions of greenhouse gases, classification of the drying process as a process with high energy consumption, it is necessary to propose alternative sustainable technologies in relation to traditional drying processes. The heat pump technology applied to drying has been proposed due to its high energy efficiency associated with a better control of the drying conditions, however it is necessary to propose methodologies that allow to evaluate this technology in terms of energetic/exergetic efficiency, economic and environmental, in order to justify its application.

For this work, we present the specification of heat exchangers in an application directed to the use in condensers and evaporators of a heat pump of industrial use for the purpose of drying.

2. HEAT PUMP

Heat Pump is an equipment that presents the same components of a refrigeration unit operating with the function of extracting heat from a source and rejecting the air or water at a higher temperature than this source (Wang, 2000). Çengel & Boles (2015) argue that the purpose of a heat pump is to maintain a certain medium heated from the absorption of heat from a source at low temperature and to supply this heat to a warmer medium.

Most current heat pumps operate on the steam compression cycle, which consists basically of four devices: compressor, condenser, expansion device and evaporator, as shown in Fig. 1.
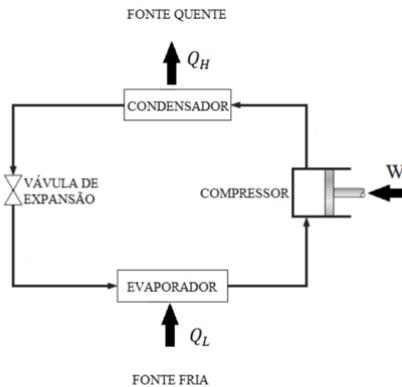

Figure 1. Schematic of the heat pump cycle by steam compression

From the functions of the components of a heat pump, the compressor has the function of compressing the refrigerant, raising its pressure, and performing the movement of this fluid through the process steps.

The purpose of the condenser is to exchange heat with the environment that will receive this energy, where the temperature of the refrigerant must be higher than the environment that would receive the heat in order to have the heat transfer process, for this the equipment receives the superheated steam which exits the compressor and cools it to initially remove the superheat and then the latent heat until the refrigerant returns to the state of the cooled liquid.

The function of the expansion device is to control the flow of refrigerant from the high pressure side to the low pressure side. The expansion valve causes the pressure and temperature of the fluid to drop dramatically due to the throttling effect, thus allowing the absorption of heat in the evaporator.

The evaporator absorbs heat from the environment that will be cooled by transferring the heat to the refrigerant fluid, the thermal exchange in this equipment must occur with the refrigerant having a lower temperature than the cold environment for the heat transfer to take place.

3. HEAT TRANSFER

The transfer of thermal energy between fluids is one of the most important and frequently used processes in engineering. Heat transfer is usually accomplished by means of a device known as heat exchanger, or heat exchangers. Heat exchangers are devices that are used to transfer heat energy from one fluid to another without mixing the two fluids (Lienhard, 2008). Common applications of heat exchangers in the nuclear field include boilers, fan coolers, cooling water heat exchangers and condensers.

The basic design of a heat exchanger normally has two fluids of different temperatures separated by some conductive medium. The most common design has a fluid flowing through metal tubes and the other fluid flowing around these tubes. From each side of the tube, the heat is transferred by convection. Heat is transferred through the pipe wall by conduction. This type of equipment can be specified by type of service or type of construction (Pope, 1996).

Table 1 shows examples of types of heat exchangers. One of the most common types found in the industry is the hull-and-tube type, and this type of heat exchanger is typically designed and manufactured by TEMA (Tubular Exchange Manufacturers Association) standards. Another type of heat exchanger is air-cooled, this type of heat exchanger, usually fined to increase the area of thermal exchange, is mounted together with one or more fans, and may also be in a cluster of heat exchangers. They are more economical in cases where the cost of cooling water is high. One kind of exchanger used is the double tube, where one tube passes inside the other, and the inner tube can be finned or not, usually used for small units.

Table 1. Examples of types of heat exchangers. Material adapted from Pope, 1996.

TYPE	MAIN CHARACTERISTICS	APPLICATION
Hull and tubes	Package of tubes embedded in a cylindrical hull.	Always the first type of exchanger to consider
Air-cooled heat exchangers	Pipe packages mounted on a rectangular frame, with air being used as a cooling medium.	Economical where the cost of cooling water is high
Double tube	Tube inside a tube. The inner tube may be finned or flat.	For small units
Extended surface	Tube with external fins.	Services where the thermal resistance of the outer tube is appreciably greater than the internal resistance. Also used to increase performance on existing drives
Spiral Exchanger	Coiled coil serpentine inside a helmet.	Cryogenic services: fluids must be clean
Bayonet tube	The tube element consists of an outer and inner tube.	Useful for high temperature difference between case and tube fluids
Film coolers	Vertical units using a thin film of water through the tubes	Special cooling applications
Barometric condensator	Direct contact with water and steam	Where mutual solubilities of water and process fluid are allowed
Cascade coolers	Cooling water flows over a series of pipes	Special cooling applications for highly corrosive process fluids
Impermable graphite	Built in graphite for corrosion protection	Used in highly corrosive heat exchange services

For the dimensioning of a heat exchanger, it is necessary to define basic parameters such as which fluid I want to cool or heat, what parameters the desired inlet and outlet temperatures are and whether the second fluid used for thermal exchange is a utility with low cost to obtain.

In the literature (Cheremisinoff, 2000), the governing expressions for the heat exchanger design are as follows:

$$Q = UA\Delta T_m \tag{1}$$

Where A = total heat exchange area (m^2), q = total heat transfer (W) and U = global heat transfer coefficient, assumed to be constant throughout the exchanger (W/m^{2}K). The parameter is the mean logarithmic temperature difference, defined by the following expression:

$$\Delta T_m = \frac{(T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in})}{ln(T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in})} \tag{2}$$

And the global coefficient of heat transfer is given by:

$$U = \frac{1}{\frac{1}{h_1} + \frac{\Delta r}{k} + \frac{1}{h_2}} \tag{3}$$

Where k is the thermal conductivity of the pipe (W/m^{2}K), h$_1$ is the convective heat transfer coefficient on the inner side of the pipe (W / m^{2}K), h$_2$ is the convective heat transfer coefficient on the outside of the pipe (W/m^{2}K) and is the wall thickness of the pipe (m).

4. MODEL OF INDUSTRIAL DRYING SYSTEM

From a simplified heat pump drying model, Fig. 2, we identify the system components, the refrigerant and air flows and the location of the points where the thermodynamic properties are identified.
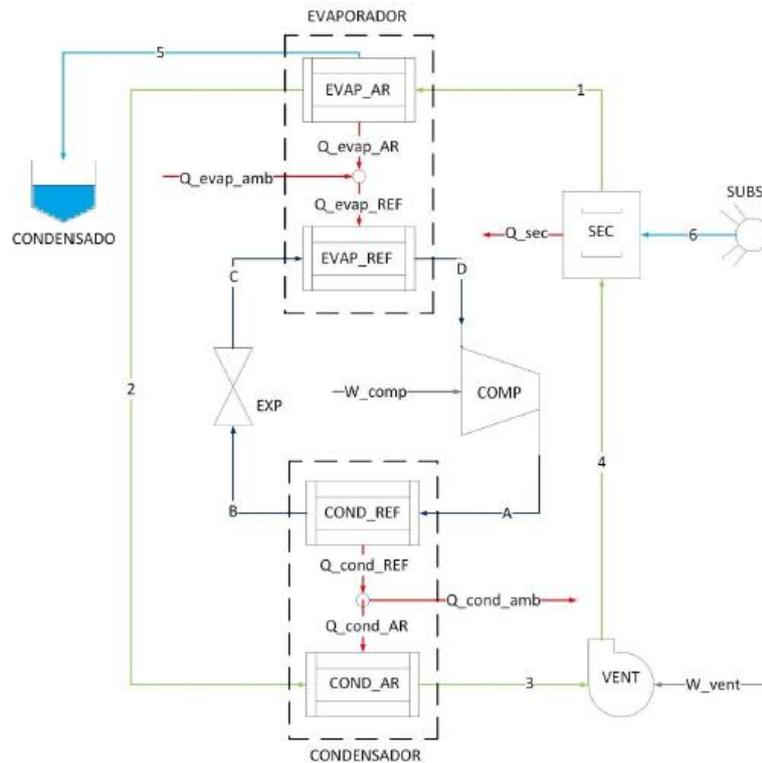
Figure 2. Schematic of the thermodynamic model.

The physical structure of the thermodynamic model is represented. The control volumes EVAPORADOR, COMP, CONDENSER, EXP, SEC, VENT represent respectively the evaporator, compressor, condenser, expansion valve, the dryer and the fan.

In the physical structure, there is further shown the condensate tray to which the moisture withdrawn from the air in the evaporator is drained and the SUBS component represents the substance or matter being dewatered in this dryer. The numbers are used to represent the air and water flows and the letters are used to represent the coolant flows. The condensate and moisture absorbed by the air in the dryer were considered water.

The thermodynamic model was implemented in the EES program based on the works from Fortes (2017), where the various thermodynamic parameters of the model are calculated and including the thermal load of the evaporator and condenser. These values are the inputs for the dimensioning of the heat exchangers.

For the accomplishment of the thermodynamic analysis all the processes were considered operating in permanent regime. The refrigerant used within the EES routine was R-22. Dry air and moisture present in the air were treated as ideal gas. For the dead state definitions, the ambient temperature (303,15 K), the pressure of 101,315 kPa and the ambient relative humidity of 74% were considered. Kinetic and potential energy variations were considered negligible.

These results were used as input for the specification of heat exchangers.

5. RESULTS

Several simulations were performed where we attempted to clarify the relation of condensed water flow with the thermal load of both the evaporator and the condenser.

For this to be possible it was necessary to transcribe in the code used in the EES that the input data will be the condensate flow. And the values to be obtained will be the thermal loads on the evaporator and condenser.

After the construction of the code and verification its validation, the simulation process was started. Some flow values were chosen. For each flow value, it was possible to obtain a thermal load value for the evaporator and for the condenser. The results of these simulations are shown in Fig. 3.
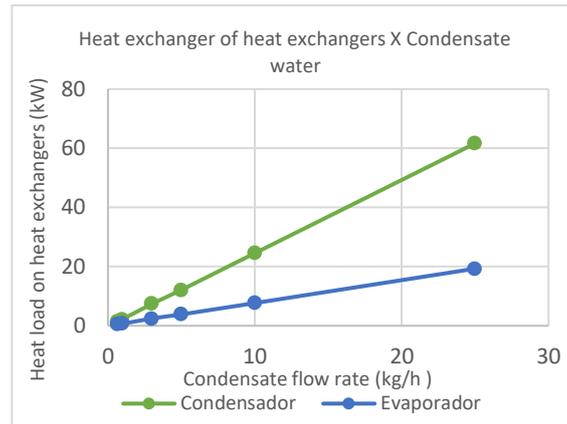
Figure 3. Thermal load of heat exchangers X Condensate water

The graph indicates that the value of the condensed water varies proportionally with the thermal load involved in the condenser and the evaporator. That is, as we seek to increase the flow of condensed water and thus increase the withdrawal of water in the industrial process we must increase the thermal load in both the evaporator and the condenser.

This premise is fundamental for the design of the heat exchangers to be used in the process since the thermal load depends on the design of the heat exchangers. According to Eq. 1, the thermal exchange area and the overall coefficient ions are directly proportional to the thermal load of the process. Thus, the selection for a heat exchanger must provide the appropriate dimensions and specifications for the process.

6. EQUIPMENT SPECIFICATION

From the results of thermal load of the heat exchangers as a function of the condensed water production, the commercial heat exchanger was specified. In this work the specification was performed for the condenser.

Super Radiator Coils software was used for the design of heat exchangers (Fig. 4). The input of the program are the desired fluid inlet and outlet temperature conditions (air and refrigerant R22) and some adjustable parameters such as basic dimensions of the exchanger, height and length, fin fabrics (aluminum) and tubes (copper). And the output parameters are the final dimensions of the exchanger, thermal exchange area, thermal capacity and number of passes.

Figure 4. Example of Air-cooled heat exchanger.

For the load **values** given in Fig. 3 the main parameters of the specified heat exchangers are shown in the table below.

Table 2. Specification of heat exchangers.

Demand (kW)	Specified Model	Capacity (kW)	Length (mm)	Height (mm)	Width (mm)	Finned Surface (m2)
1,47	13x15.748 - 4R - 0.313/96	1,54	400	330	114	4,75
2,27	15x15.748 - 4R - 0.313/96	2,32	400	381	114	5,49
7,48	16x27.559 - 5R - 0.313/96	7,50	700	406	130	11,66
12,16	24x39.37 - 5R - 0.313/96	12,86	1.000	610	130	24,99
24,53	28x55.118 - 5R - 0.313/96	24,60	1.400	711	130	40,82
61,63	31x98.425 - 6R - 0.313/96	62,63	2.500	787	146	90,55

7. CONCLUSIONS

A procedure for selecting heat exchangers to be used in a drying process was established in that article. The relation between the load and the water flow is taken from the system and the heat load on the heat exchangers has been established. The process was modeled from the EES software and values of different flow values were inserted to give the return of the thermal loads from the software. The conclusions reached were as follows:

1. The selection of a heat exchanger for a drying process has as main parameter the flow of water to be withdrawn from the system.
2. The thermal load of the heat exchangers is in a linear relationship with the water flow withdrawn from the system. So, the more water you want to remove the greater the heat load.
3. From the thermal load it was possible to select the heat exchanger (condenser) suitable for the process. The results lead to a procedure for selecting heat exchangers to be used in a drying process.

8. REFERENCES

Alves-Filho, O., 2015. *Heat Pump Dryers - Theory, Design and Industrial Applications.* CRC Press.

Çengel, Y. A. and Boles, M. A., 2015. *Thermodynamics: An Engineering Approach*. 8 ed. New York, EUA: McGraw-Hill.

Cheremisinoff, N. P., 2000. *Handbook of chemical processing equipment.* Butterworth-Heinemann.

Dincer, I. and Rosen, M., 2002. *Thermal energy storage systems and applications*. 2 ed. John Wiley e Sons.

Fortes, A. F. C., 2017. *Análise termoeconômica e ambiental de um secador por bomba de calor.* Dissertação (Mestrado em Engenharia Mecânica). Programa de Pós-Graduaçao em Engenharia Mecânica. Universidade Federal da Paraíba, João Pessoa.

Kemp, I. C., 2011. *Fundamentals Of Energy Analysis Of Dryers.* Modern Drying Technology, v. 4, p. 1-46.

Kreith, F., 1999. *Mechanical engineering handbook.* CRC Press LLC.

Lienhard IV, J. H.; Lienhard, J. H. V., 2008. *DOE fundamentals handbook: thermodynamics, heat transfer, and fluid flow*. Washington, DC: US Department of Energy.

Minea, V., 2016. *Advances in Heat Pump-Assisted Drying Technology*. CRC Press.

Pope, J. E., 1996. *Rules of thumb for mechanical engineers*. Gulf Professional Publishing.

Standard, A. P. I. 661, 1992. *Air-Cooled Heat Exchangers for General Refinery Service*.

Trott, A. R.; Welch, T. C., 1999. *Refrigeration and air conditioning*. Butterworth-Heinemann.

Wang, S. K., 2000. *Handbook of Air Conditioning and Refrigeration*. 2 ed. McGraw-Hill.

9. RESPONSIBILITY NOTICE

The author(s) is (are) the only responsible for the printed material included in this paper.