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Useless Overheating in Refrigeration Systems upon the Evaporator Type

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***Abstract*— The main objective of this work is a technical and economic analysis of a flooded evaporator in a vapour compression refrigerant cycle using R134a as working fluid. To achieve this goal, it was used a simulation software, the Pack Calculation Pro 4.2. A comparison of the annual energy consumption of the refrigeration system with a flooded evaporator was carried out having as reference the same system with a dry evaporator. In this study are analysed the advantages and disadvantages of using the two types of evaporators, the flooded and dry one, in situations of presence of overheating for the dry evaporator and the presence of the pump in the flooded evaporator. It was concluded that the advantage in the implementation of flooded evaporator is directly proportional to the degree of overheating at the exit of the dry evaporator.**

***Keywords*— dry evaporators, energy use, flooded evaporators, thermodynamics, refrigeration systems**

I. Introduction

Currently, the use of refrigeration systems is indispensable for our day lives [1]. In fact, it is uncommon a house without a refrigeration systems installed, whether an air conditioner or a refrigerator. They play a fundamental role in areas ranging from the preservation of perishable products, the pharmaceutical industry or air conditioning. The scale of applications increases significantly when, instead of considering only domestic applications, it is taken in account industrial, commercial, transportation, among others.

In recent years, with the principle of sustainable development [2], it became clear that changes would have to be made to conventional refrigeration systems trying to maximize their efficiency, and so, reducing the energy consumed without compromising the cooling effect.

The energy consumption of a refrigeration system is mainly due to power of the compressor(s), which is responsible for forcing the fluid flowing through the system. Components such as the evaporator also influence the energy consumption, since the more efficient they are in the absorption of heat, the greater will be the cooling capacity of the entire system, or else, for the same cooling capacity the lower will be the energy consumption [3].

A comparison of the annual energy consumption of the refrigeration system with a flooded evaporator was carried out having as reference the same system with a dry evaporator and working in different situations. In the case of the dry evaporator, if it presents an unnecessary overheating, the system shows a lower COP. In this situation, it is advantageous the inclusion of a flooded evaporator when the medium / long-term system is envisaged, which will lead to a lower annual energy utilization.

From the simulations, made with Pack Calculation Pro 4.2 [4], it was possible to conclude that the relevance of the flooded evaporator implementation is directly proportional to the degree of overheating at the outlet of the dry evaporator.

II. Systems And Methodology

Figure 1 shows a diagram of both refrigeration systems, one with a dry evaporator and the other with a flooded evaporator. The main difference between them lies in the state of refrigerant at their outlet. In the first one, the working fluid leaving the evaporator is saturated or superheated vapor (just one phase), while in second one, the working fluid at the outlet is wet vapor (saturated liquid and saturated vapor). It is also need a drum, in parallel to the evaporator, where the two phases are separated. In it, the saturated vapor arriving from the expansion valve and the one coming from the evaporator flows to the internal heat exchanger and then to the compressors, while the saturated liquid is recirculated to the evaporator. In the second situation, the liquid from the drum can flow by gravity to the evaporator or, if the pressure losses are significant, it is necessary to use a circulating pump. So it was also simulated the possibility of using a circulation pump to feed the evaporator. In both systems, it was used two compressors and an internal heat exchanger.

The methodology used for the simulations it was as follow:

- equal cooling capacity and the temperatures of evaporation and condensation fixed;
- addition of a pump to carry out forced circulation of the flooded evaporator;

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- regarding the first point, it was also considered unnecessary overheating in the evaporator.

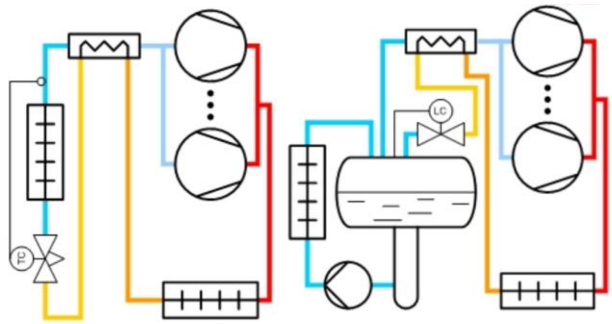

Fig. 1 Refrigeration system with a dry evaporator (left) and with a flooded evaporator (right).

Table 1 displays the common characteristics of both systems: condensation and evaporation temperatures of the systems, cooling effect, the pump power of the flooded evaporator, as well as, the chosen compressors.

TABLE I
COMMON CHARACTERISTICS OF BOTH SYSTEMS

	Dry evaporator	Flooded evaporator
Te	-11 °C	
Tc	48 °C	
Compressors	Bitzer OSK 8561 50 Hz [1] (2x)	
Power of the pump	-	29 W
Cooling effect	200 kW	

The city chosen for the simulations was Oporto, Portugal. For the simulations, the location of the city is mandatory because of the annual variability of the climate during de year, as can be seen in Figures 2 to 6 where the monthly outside temperature is displayed. The energy costs, based on current tariffs, is 0.14 €/kWh. Regarding equipment, the compressors for Bitzer OSK were consider to have a cost of 20 k€ [5] (for safety two equal compressors were chosen working in parallel), the dry evaporator for a cooling capacity of 200 kW was 7 k€ [6] and the flooded evaporator was considered to have a cost 25% higher [3]. It was admitted a lifetime for both systems of 10 years.

III. Results

A. Dry evaporator without overheating vs flooded evaporator by gravity (without pump)

Figure 2 shows the energy consumption per month of both systems regarding the compressors with dry and flooded evaporators and fans. The fans are used in the evaporator and condenser to exchange the heat more efficiently. When the systems stop, the fans are also stopped.

The left axis represents the monthly energy consumption of the components of the systems while the right axis represents the monthly average temperature of Oporto city. The horizontal axis represents the month of a typical year.

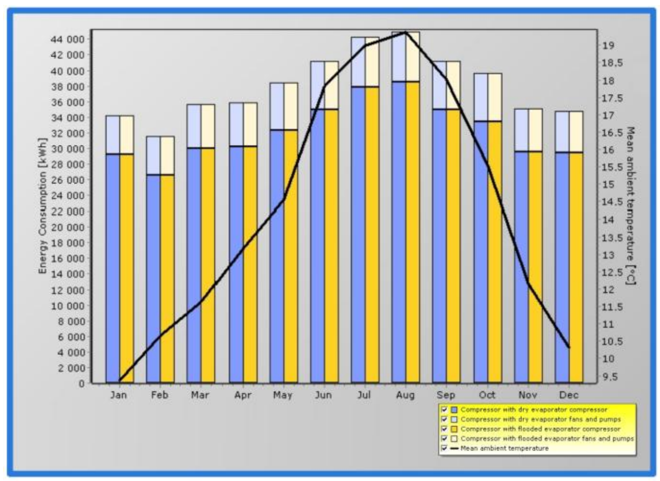

Fig. 2 Monthly energy consumption for the equipment used in both systems.

As can be seen from figure 2, the monthly energy used by each individual component varies along the year as a function of the local weather, accompanying the ambient external temperature. When it increases the electrical energy consumption to run the systems increases and vice-versa. Usually this does not take into account when designing such kind of systems or heat pumps. The energy used by the fans along the year corresponds to the evaporator and condenser.

In the other figures, 3 to 5, only left axis will change according to the electrical energy consumption per month.

Table 2 displays for the same year the global energy used.

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TABLE II
ANNUAL ENERGY CONSUMPTION FOR BOTH SYSTEMS.

	Dry evaporator	Flooded evaporator
COP (average)	3.39	3.39
Energy consumption		
Fans and pumps (kWh)	69 535	69 535
Compressors (kWh)	386 847	386 847
Total (kWh)	456 382	456 382

The COP value displayed in table 2 is the average COP of the systems along the year. They vary from month to month due to fact that for the same cooling effect, the energy used also varies. It can be concluded that in this case there are no advantages from one evaporator over the other.

It was also calculated the lifetime of both systems as shown in Table 3 in which *IRR* is the Internal Rate of Return and *Inf* stands for infinity.

TABLE III
LIFETIME COSTS.

	Dry evaporator	Flooded evaporator
Cost of equipment (€)	47 500	49 365
IRR (%)	-	100
Total annual costs (€)	64 259	64 259
Payback period (years)	-	Inf
Energy (kWh)	578 394	578 394
Lifetime costs (€)	625 894	627 759

The difference between the total annual cost of the main equipment (compressors and evaporators) is due to the piping, directional and expansion valves, other accessories needed for the system, as well as, the labor for the installation. As expected, the energy used in both systems is the same, because the pump of the flooded evaporator is not running. However, the lifetime costs of the flooded evaporator are higher.

Based on the results obtained for the refrigeration cycle with dry evaporator without overheating and flooded evaporator by gravity, it is visible that the running costs of the two systems are all identical. This information is shown in table 3. Taking in account that the working fluid enters exactly in the same thermodynamic state in both evaporators, such behavior would be expected.

B. Dry evaporator without overheating vs flooded evaporator with pump

Considering the use of a circulation pump, it is expected that energy consumption increases compared to the previous condition of the flooded evaporator.

In Fig. 3 it is shown the energy consumption per month of both systems for the equipment used. As can be seen the trend of the graph is similar to the one shown in figure 2, exception for the energy used.

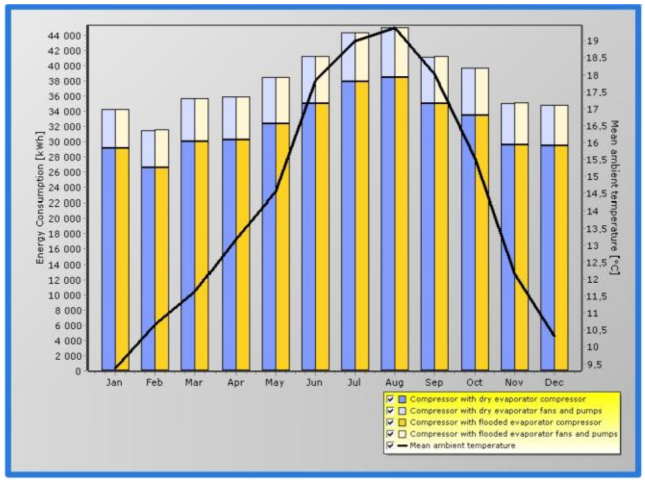

Fig. 3 Monthly energy consumption for the equipment used in both systems.

Table 4 displays, for the same year, the global energy used.

TABLE IV
ANNUAL ENERGY CONSUMPTION FOR BOTH SYSTEMS.

	Dry evaporator	Flooded evaporator
COP (average)	3.39	3.4
Energy consumption		
Fans and pumps (kWh)	69 535	69 759
Compressors (kWh)	386 847	386 847
Total (kWh)	456 382	456 606
Savings		
Annual savings (kWh)	224	-
Annual savings (%)	-	-

The COP values of both systems are very similar because the energy used by the pump is very small. The compressors also use the same amount of energy because they are working in the same conditions.

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However, the total energy used by the flooded evaporator is higher, due the pump, which corresponds to an increase of 224 kWh in energy consumed annually when compared to the system with dry evaporator.

It was also calculated the lifetime of both systems as shown in Table 5.

TABLE V
LIFETIME COSTS

	Dry evaporator	Flooded evaporator
Cost of equipment (€)	47 500	49 365
IRR (%)	-	100
Total annual costs (€)	64 259	64 259 (+31)
Payback period (years)	-	59
Energy (kWh)	578 394	578 678
Lifetime costs (€)	625 894	628 043 (+2 149)

The inclusion of a circulating pump in the flooded evaporator, if necessary, implies a higher lifetime costs of 2129 €.

C. Dry evaporator with useless overheating (3 and 6K) vs flooded evaporator by gravity (without pump)

The presence of unnecessary overheating is very common in cycles with dry evaporators, since from the exit of the evaporator to the inlet of the compressor, due to the piping length (which may be long), absorbs heat from the environment, which results in an increase in the compression work for the same refrigeration power.

Considering the presence of unnecessary overheating of 3K at the inlet of the compressor, the monthly energy consumption results are shown in Fig.4.

Table 6 displays, for the same year, the global energy used.

As can be seen, the flooded evaporator can save 1.7% of the energy in the whole system when compared to the dry evaporator. It was also calculated the lifetime of both systems as shown in Table 7.

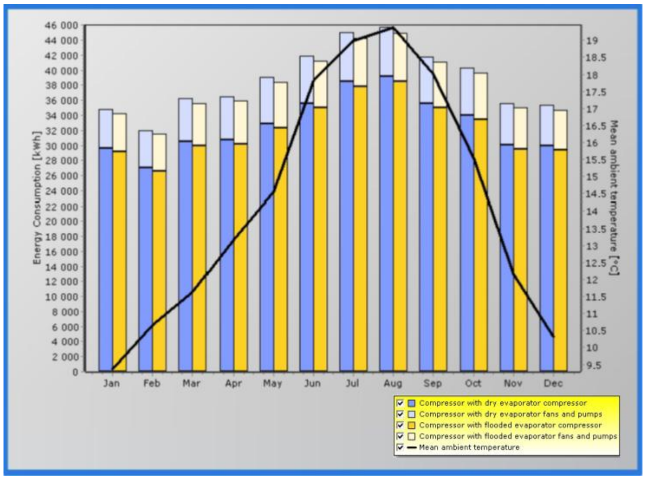

Fig. 4 Monthly energy consumption for the equipment used in both systems (3K useless overheating).

TABLE VI
GLOBAL ENERGY COSTS

	Dry evaporator	Flooded evaporator
COP (average)	3.33	3.39
Energy consumption		
Fans and pumps (kWh)	70 521	69 535
Compressors (kWh)	393 680	386 847
Total (kWh)	464 201	456 382
Savings		
Annual savings (kWh)	-	7 819
Annual savings (%)	-	1.7

TABLE VII
LIFETIME COSTS

	Dry evaporator	Flooded evaporator
Cost of equipment (€)	47 500	49 365
IRR (%)	-	117.58
Total annual costs (€)	65 360	64 259 (-2 194)
Payback period (years)	-	1,7
Energy (kWh)	588 304	578 394
Lifetime costs (€)	635 804	627 759 (-17 882)

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As displayed, the payback period when using the flooded evaporator is 1.7 years if the dry evaporator has 3K of overheating.

Considering the unnecessary overheating of 6K at the inlet of the compressor, the following results were obtained.

In Fig. 5 it is show the energy consumption per month of both systems for the equipment used. Table 8 displays, for the same year, the global energy used.

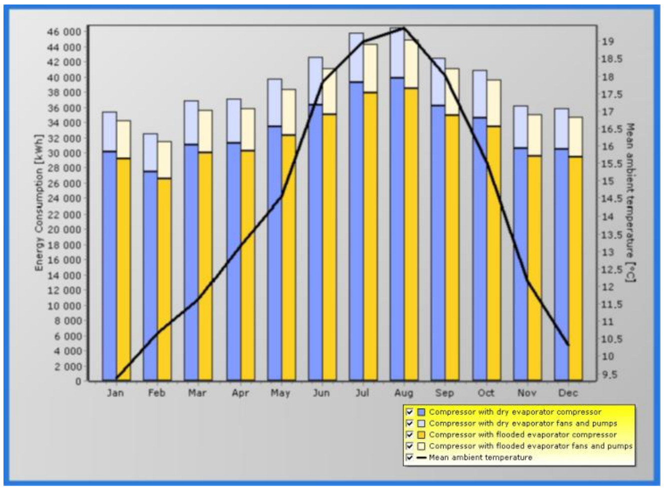

Fig. 5 Monthly energy consumption for the equipment used in both systems.

TABLE VIII
GLOBAL ENERGY COSTS

	Dry evaporator	**Flooded evaporator**
COP (average)	3.28	3.39
Energy consumption		
Fans and pumps (kWh)	71 494	69 535
Compressors (kWh)	400 469	386 847
Total (kWh)	471 963	456 382
Savings		
Annual savings (kWh)	-	15 581
Annual savings (%)	-	3.3

As a consequence, of the increase in the useless overheating of 6K in the dry evaporator, the annual energy savings are now 3.3% when compared with the dry evaporator.

It was also calculated the lifetime of both systems as shown in Table IX.

TABLE IX
LIFETIME COSTS

	Dry evaporator	**Flooded evaporator**
Cost of equipment (€)	47 500	49 365
IRR (%)	-	117.58
Total annual costs (€)	66 452	64 259 (-2 194)
Payback period (years)	-	0.9
Energy (kWh)	598 141	578 394
Lifetime costs (€)	645 641	627 759 (-17 882)

As can be seen now, the payback period is only of 0.9 years.

IV. CONCLUSIONS

In this work it was done a comparison between refrigeration systems based on vapour compression cycle using dry and flooded evaporators. An energy and economic analysis was carried out in order to evaluate when to use one or another. The main conclusions that can be withdraw are:

- During the design phase of refrigeration systems, care must be taken in account with the monthly average temperature of the local where the systems are to be installed. The local affects the ambient external temperature, and thus the energy used. When the environment temperature increases, the electrical energy consumption to run the system increases and vice-versa.
- Dry evaporator without overheating *vs* flooded evaporator by gravity (without pump) - it can be concluded that in this case there are no energetic advantages installing one over the other evaporator. However, the lifetime costs of the flooded evaporator is higher due to the higher initial cost of the flooded evaporator.
- Dry evaporator without overheating *vs* flooded evaporator with pump - the COP values of both systems are very similar because the energy used by the pump is very small. The compressors also use the same amount of energy because they are working in the same conditions. However, the total energy used by the flooded evaporator is higher, due the pump, which corresponds to an excess of used energy of 224 kWh when compared to the system with dry evaporator. The inclusion of a circulating pump in the flooded evaporator, if necessary, implies a higher lifetime costs of 2129 €.

- Dry evaporator with useless overheating of 3K *vs* flooded evaporator by gravity (without pump) - in this situation the flooded evaporator can save 1.7% of the annual energy in the whole system when compared to the dry evaporator and the payback period is 1.7 years. The lifetime costs are also benefited.
- Dry evaporator with useless overheating of 6K vs flooded evaporator by gravity (without pump): in this situation, the flooded evaporator can save 3.3% of the annual energy in the whole system when compared to the dry evaporator and the payback period is 0.9 years. The lifetime costs are also benefited.
- This analysis was done only for one system. In the world there are millions of systems similar to the ones simulated. As can be easily seen, just with a multiplication, how many MWh can be saved contributing in this way for a sustainable development of the world.

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