Use of Unit Coolers & Air Cooled Condensers with Less-than-claimed Nominal Performance

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Introduction

Using equipment (unit cooler or air cooled condenser) with output lower than declared in its catalogue will alter the functional conditions of the refrigeration plant in which it is installed.

In such cases, the refrigeration plant reaches a state of balance on the evaporation and condensation temperatures, respectively lower and higher.

In this anomalous condition, the compressor has to operate for longer and with lower COP in order to guarantee the designed temperature of the room (cold reservoir).

Two operational cases are analysed in this article: one is a room at low temperature, the other at high temperature. Operating costs are calculated in both cases for certified equipment and 'non-certified' equipment having less than the performance claimed in the catalogue.

Logical Procedure

A model for the calculation of functional conditions of a refrigeration cycle during operational transients – the result of numerous experimental tests – has been developed in the R&D Laboratory of LU-VE SpA, Uboldo (Varese) in Italy. In addition to the thermodynamic parameters of the evaporator (power, air flow, frost thickness, useful refrigeration energy, COP, defrosting times, yield, etc.), running costs are calculated under three fundamental headings: compressor, fans (air cooled condensers and unit coolers) and, where appropriate, defrosting.

The main hypotheses adopted in the calculation model are as follows:

- Constant temperature of the cold reservoir (cold room).
- Constant temperature of the heat reservoir (ambient temperature outside the cold room).
- Power absorbed by the fans remains constant over time.

The errors between the experimental values and the simulation values are as follows:

- Refrigeration power at the end of the frosting cycle: ± 3.3%
- Air flow at the end of the frosting period: ± 6.1%
- Relationship between refrigeration power at the end of

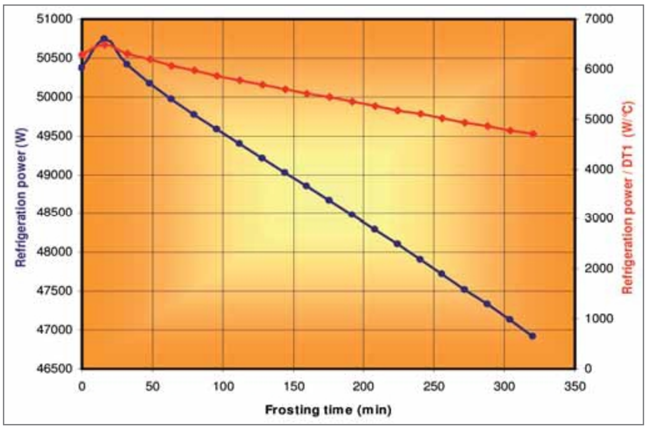

Figure 1: Refrigeration power as a function of frosting time

About the Author

Umberto Merlo is also a mechanical engineer from Milan, with 22 years experience. He has been the laboratory manager at LU-VE Contardo for 15 years.

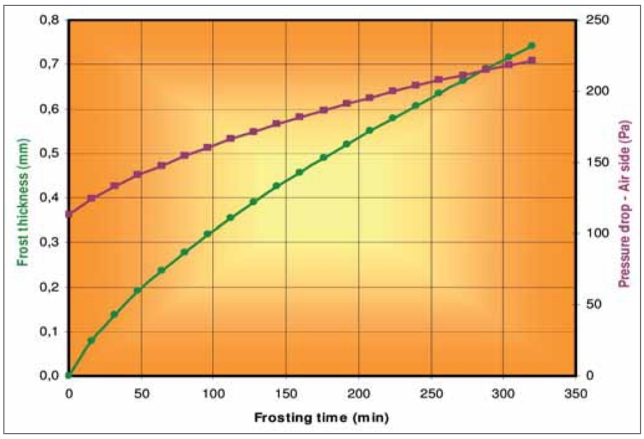

Figure 2: Frost thickness vs. frosting time

frosting and refrigeration power at the beginning of frosting: ± 1.7%

- Final frost mass: ± 5.0%.

The graph in *Figure 1* shows the trend of the refrigeration power and compares it to DT1 (i.e. the difference between the temperature of the cold room and the evaporation temperature) as a function of the frosting time. The graph in *Figure 2* represents the trend of frost thickness accumulated on the fins and the pressure drop of the fin pack (air side – crossing the characteristic curve of its fan) as a function of the frosting time.

The logical procedure used to analyse the variations in the functioning of the system is based on the hypothesis of a reference refrigeration plant and examines the following points:

A. Variations in the temperature of evaporation and condensation
B. Reduction of real refrigeration power supplied by the compressor
C. Increase of the use factor (number of real operating hours/24 hours), i.e. the number of operating hours of the compressor per 24 hour day
D. Increase in energy consumption
   - ventilation: evaporator and condenser
   - compressor
   - inefficiency due to any frost formation
E. Increase in running costs
   - fans
   - compressor
   - possible frost formation.

The comparisons in all the different operating situations are carried out considering as constant the useful/net energy exported from the hypothetical cold room, calculated by subtracting from the refrigeration power the energy emitted from the fans and the energy emitted during defrosting (equal to the energy used during defrost, multiplied by $(1-\eta_{defrost})$).

Logical Procedure Analyses

A. ***Variations in the Temperature of Evaporation and Condensation***

It can be stated that, for a ventilated exchanger, the relationship between power and the DT is on average constant: P/DT= constant.

This entails, for example in a unit cooler functioning inefficiently, an increase in DT1 and therefore a reduction in the temperature of evaporation. The increase in DT1 improves the heat exchange recovering in part the inefficiency of the unit.

In an air cooled condenser functioning inefficiently, DT increases as a consequence, raising the temperature of condensation.

B. ***Decrease in Refrigeration Power***

As a consequence of the increase in DT, the volumetric compressor registers a decrease in intake pressure and a decrease in the density of the refrigerant fluid at the intake.

As the refrigeration power supplied by the compressor is directly proportional to the mass that passes through it, the reduction of density – at equal flow rate – reduces the available refrigeration power.

The variation of the refrigeration power decreases the evaporation temperature (increases for the evaporator and decreases for the compressor). This brings about a new operational balance with lower power than the designed nominal value.

C. ***Increase in the Number of Functioning Hours of the Compressor***

The refrigeration energy supplied by a volumetric compressor is directly proportional to the refrigeration power and the time in operation. With the reduction of the evaporation temperature, the compressor has to work for a longer time in order to provide the same amount of refrigeration energy to the cold room.

D. ***Increase in Energy Consumption***

The increase in energy consumption is essentially due to two factors:

- Greater consumption by the fan groups (unit coolers and air cooled condensers) due to the increased time of operation
- Greater consumption by the compressor because of increased running time: this effect prevails compared to the modest reduction of absorbed electric power which it has in the new functioning point.

E. ***Increase in Annual Added Costs***

Putting a value on the increase in energy consumption and comparing it with the market value of unit coolers, a different trend is recorded as a function of the relationship between effective power/nominal power. The greater the refrigeration power, the greater is the size of the increase in annual costs – as much in terms of absolute value as in comparison with the market value of the unit.

Results of the Analyses

The graphs in *Figure 3* and *5* show the increase in running costs – separately for a unit cooler and a air cooled condenser – as a function of the variation in their effective power compared to their nominal power (catalogue data). In the case where there is a lack of power in both exchangers, the principle of superimposition of the effects applies i.e. the sum of the two differences of cost. The graphs in *Figure 4* and *6* show the percentage increases in running costs, by individual topic, as a function of the variation of the effective power of a unit cooler alone.

Case A indicated in *Figure 3* and *4* refers to the operation of a refrigeration cycle in frost condition:

- Cold room temperature: –18°C
- Nominal evaporation temperature: –25°C
- External ambient temperature: 25°C
- Nominal condensation temperature: 40°C
- Nominal refrigeration power: 50 kW
- Number of defrosts per day: 3
- Cost of electricity: 0.12 €/kWh

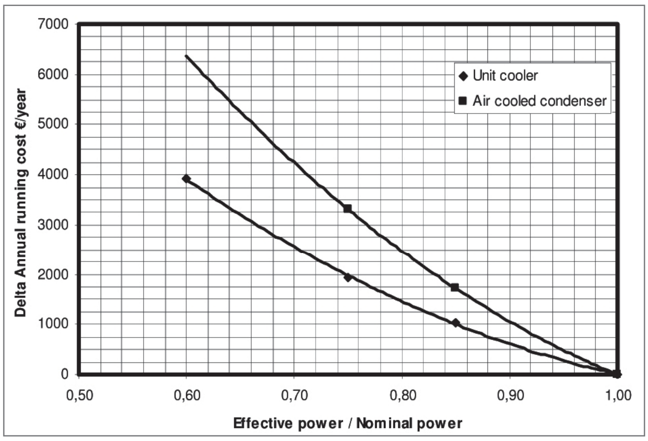

Figure 3: Additional running cost vs. variation in effective power – Case A

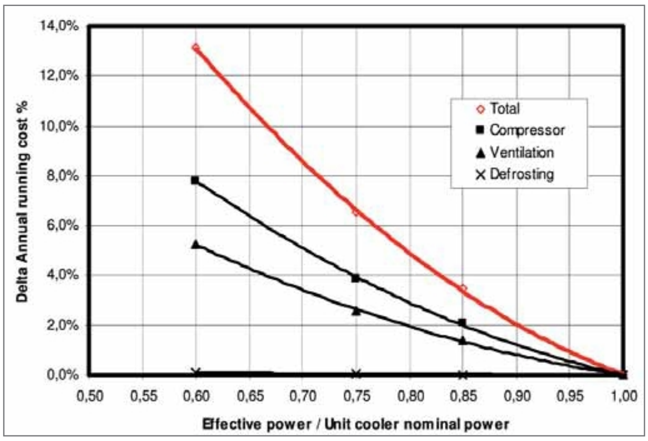

Figure 4: Break-up of additional running cost of a unit cooler – Case A

For example, the graph in *Figure 3* gives the major annual running cost for an air cooled condenser with effective power 25% less than the nominal value; entering the graph on the x-axis with a value of 0.75 leads to the corresponding value of a cost of 3,300 €/year; for an evaporator with a deficit of 25% the increase in annual running cost would be 1,950 €/year. Therefore, in terms of increased running cost, with the same level of underperformance, the air cooled condenser is more heavily affected than the unit cooler.

Analysing instead the graph in *Figure 4*, for a single unit cooler underperforming by 25%, entering the x-axis with a value of 0.75 shows a percentage running cost increase equal to 6.5% compared to a unit cooler which provides the nominal power. The total value of 6.5% is the sum of three contributing factors: the compressor accounts for 3.9%, the fans for 2.5% and defrosting for 0.1% (this last value is negligible in that it is reasoned in comparison to equal useful refrigeration energy removed from the cold room and therefore at equal frost load deposited on the surfaces of the unit cooler.

Case B indicated in *Figure 5* and *6* refers to the function of a refrigeration cycle in dehumidification condition:

- Cold room temperature: 10°C
- Nominal evaporation temperature: 0°C
- External ambient temperature: 30°C
- Nominal condensation temperature: 42°C
- Nominal refrigeration power: 92 kW
- Cost of electricity: 0.12 €/kWh

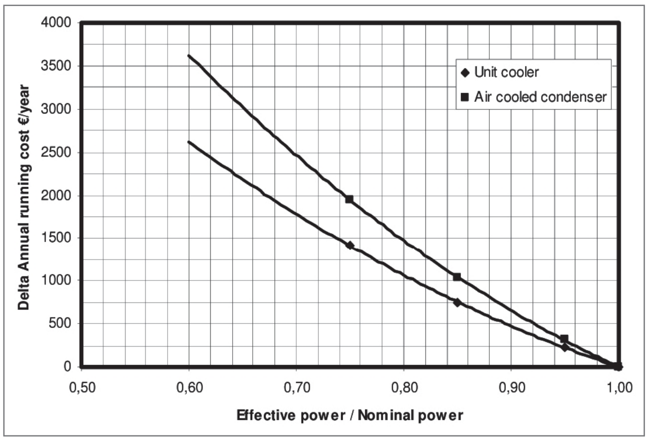

Figure 5: Additional running cost vs. variation in effective power – Case B

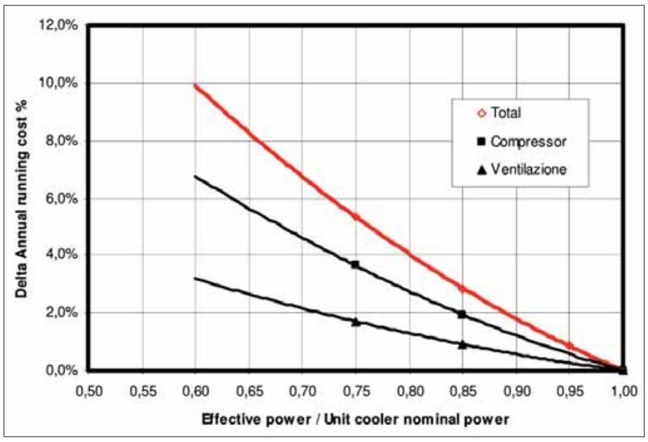

Figure 6: Break-up of additional running cost of a unit cooler – Case B

Conclusions

Efficiency, in terms of the correct conservation of foodstuffs and the economic management of a refrigeration unit, is the outcome of careful design and in particular of the choice of components. This choice is based on the data in the catalogues of the supplier of the specific components.

The standard procedure in the industry, common throughout the world for suppliers of exchanger equipment (unit coolers and condensers) was to supply 'generous' performance data with 20% – in some cases up to 40% – in excess of the real data.

The 'morality' has been greatly improved by the introduction of certification.

Manufacturers can, through performance tests carried out by specialised independent laboratories (for example TUV), certify their product with the obligation to keep the gap between catalogue data and effective data to a maximum tolerance of 8% by project, production and test.

This article shows the situation when the choice is based on inflated catalogue information.

Table 1: Additional running cost of non-certified equipment

		Case A	Case B
		Frost	Dehumidification
Cold room /external ambient temperature	°C	-18/+25	+10/+30
Nominal evaporation/ condensation temperature	°C	-25/+40	0/+42
Nominal refrigeration power	kW	50	92
Power yielded by the condenser	kW	81	123
Running cost of certified equipment	€/year	29,818	26,417
Running cost of 'non certified' equipment (with 25% less thermal power)	€/year	34,882	29,739
Delta running cost	€/year	**€5,064** (+17.0%)	**€3,322** (+12.6%)

Hypothesising the purchase price of a non-certified unit at 25% less than a certified one, after 10 years of operation the comparison of costs is given in *Table 2*.

Table 2: Life cycle cost comparison over 10 years

Estimated cost of acquisition of certified equipment	€	15,000	14,300
Estimated cost of acquisition of non-certified equipment	€	12,000	11,500
Estimated saving (between certified and non-certified equipment)	€	3,000	2,800
Delta running cost in 10 years of operation	€	€50,640	€33,220
Added outlay for greater electricity consumption as the number of times the supposed initial saving		**17 times** (50,640/3,000)	**12 times** (33,220/2,800)

As can be seen in *Case A*, the supposed saving at acquisition of €3,000 has 'cost' €50,640 in the course of using the equipment (equivalent to 17 times the supposed saving on the purchase price of the unit).

In *Case B*, the supposed saving at acquisition of €2,800 has 'cost' €33,220 in the course of using the equipment (equivalent to 12 times the supposed saving on the purchase price of the unit).

Moreover, in *Case A*, operating with non-certified products leads to an increased cost of €50,640 – equal to 4.2 times the purchase price of the products.

In *Case B*, on the other hand, operating with non-certified products leads to an increased cost of €33,220 – equal to 2.9 times the purchase price of the products.

Using products with less than their claimed performance not only leads to an enormously increased outlay during the life cycle of the unit but is also damaging from the ecological point of view (higher energy consumption and more CO_2 in the environment: 15.2 t_{CO_2}/year (*Case A*) and 10.0 t_{CO_2}/year (*Case B*), aggravating the commercial bala nce of the country through the costs of importing energy.

It is evident that an intelligent, prudent, optimised acquisition favours not simply the purchase price of the equipment, but also takes into consideration the total life cycle costs.

Furthermore, the use of certified products guarantees the designer, the installer and the final user the creation of an approved plant for the optimum conservation of refrigerated foodstuffs. ❖

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Refrigeration for Breweries

Nowadays, water chilling also takes place through Vapour Absorption Machines using waste heat available in the brewery.

There is a fourth refrigeration process that saves almost 17% power, where the refrigerant directly cools water as well as removes heat during brewing and fermentation. IDMC have set up a Fully Automated Refrigeration Plant for a Green Field Brewery with this system for United Breweries in Andhra Pradesh. The water is chilled and stored at 3°C in large storage tanks. Water chilling is not continuous but batch type. Depending upon the brew length and the number of brews per day, the water is chilled and kept ready.

Distribution

The product is transported to dealers in standard vans at ambient temperature and stored in boxes. Some bottles are stored in bottle coolers for immediate consumption. When the consumer buys beer and takes it home, it is stored in the cooling chamber of the domestic refrigerator at 16 to 18°C till it is consumed. Here, too, refrigeration is necessary for the beer to taste its best.

Conclusion

Beer, perhaps the most popular alcoholic beverage consumed just like water around the globe, needs refrigeration at all stages of its life cycle from manufacturing to storage and consumption. Therefore it becomes imperative to ensure robustness of the refrigeration system and the associated cold chain in order to give the consumer a delightful taste and consumption experience. ❖