Efficiency enhancement in evaporators

Why do evaporators today form a layer of frost more easily than in the past?

Since the first time ventilated evaporators were used, different technical development have entailed efficiency enhancements. As yet, these enhancements have not been taken into account when selecting an evaporator, a problem which can bring about undesired effects during operation.

The following examples will show the innovative developments in evaporator technology and their effects on component selection. The red curve in fig. 1 symbolises the temperature pattern between heat-transferring inner and outer surface of an evaporator tube.The so-called heat transfer coefficient α plays the decisive role here.The steeper the curve, the worse the heat transfer coefficient; the flatter the curve, the better it is.

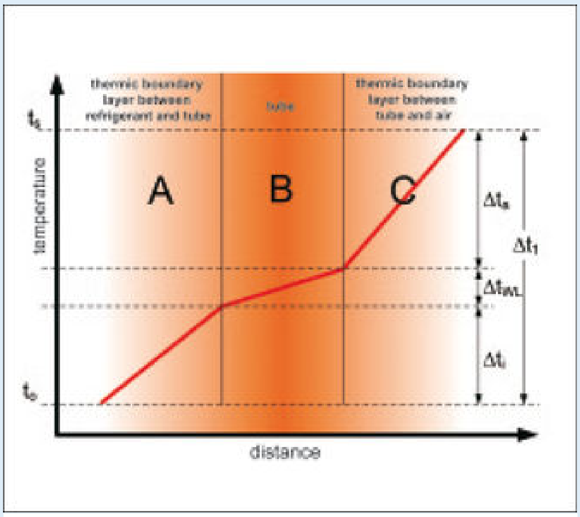

Fig. 1: Temperature pattern through the wall of a refrigerant-carrying tube

Area A in the figure depicts the so-called thermic boundary layer between refrigerant and tube; area C depicts the thermic boundary layer between tube and the air in the refrigerating room. Area B depicts the heat conduction through the tube material itself. In the past, enhancements of the heat transfer characteristics of evaporators were mainly facilitated through an enhancement of α_{intern} and α_{extern}.

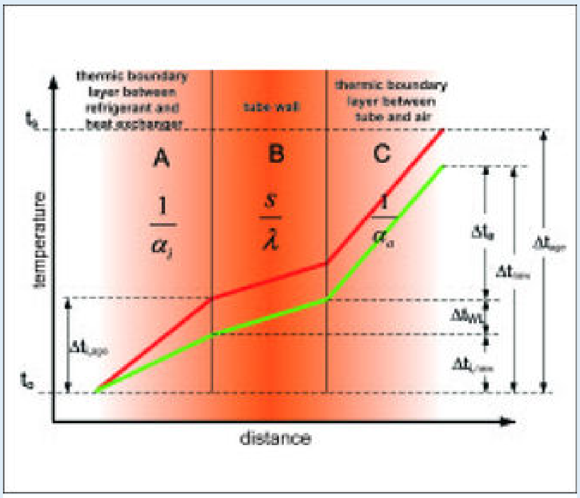

Fig. 2: Temperature pattern through a refrigerant carrying tube with increased internal heat transfer

Use of internally grooved tubes

By using internally grooved evaporator tubes, the turbulence inside the tube during the evaporation of the refrigerant is increased. This entails improved heat transfer characteristics and therefore an elevated evaporating capacity. At the same time, the internal grooves increase the heat transfer surface and improve α_i significantly (see green temperature curve). However, the increase of α_i exclusively affects the temperature difference Δt_i which decreases while the U value (thermal transmittance) increases .The green temperature curve in the areas B and C runs parallel to the red temperature curve; both temperature differences are the same in this area.

Improved evaporator construction due to staggered tubes

In the past, evaporators were constructed exclusively with aligned tube patterns, but the α_a value was considerably improved with the development of staggered tube patterns. With a staggered tube pattern, there are relatively more refrigerant-carrying tubes in a defined space than with an aligned pattern. Stronger turbulence at the outside of the tube additionally benefit the heat transfer and improve the U value.

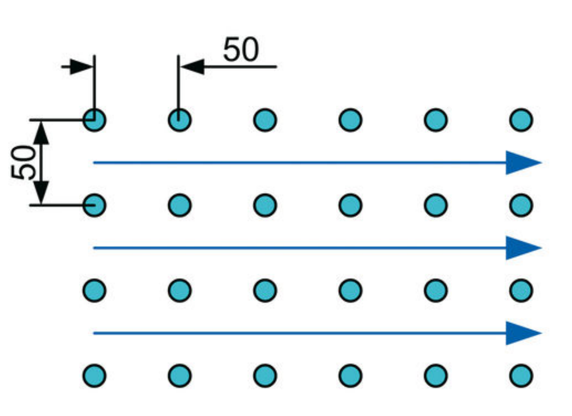

Fig. 3: Aligned tube pattern with tube clearance and routing of air flow along the fins

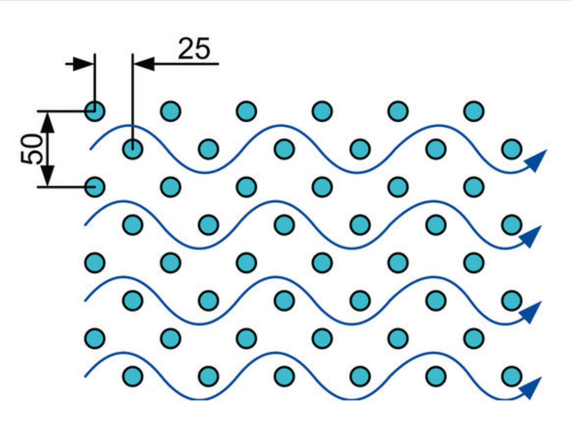

Fig. 4: Staggered tube pattern with horizontal and vertical tube clearance

Structured fins

The introduction of structured fins was a fundamental contribution to enhance the capacity of evaporators. This change also affected exclusively the external heat transfer coefficient α_a substantially increasing the U value of evaporators in general.

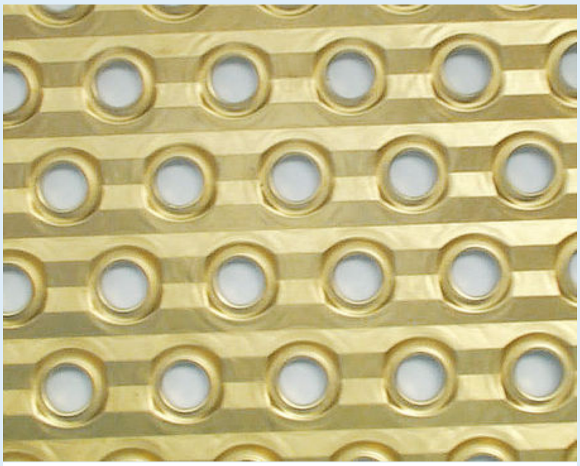

Fig. 5: Structured fin

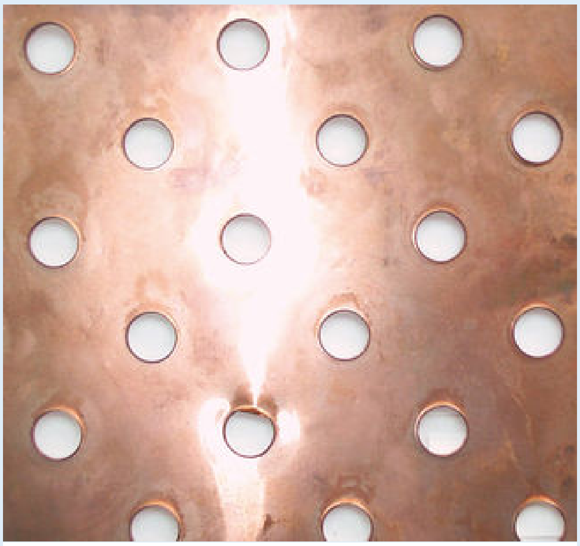

Fig. 6: Smooth fin

Impact of evaporator surface on dehumidification and formation of frost

Fig. 7 shows two possibilities of reaching the same refrigerating capacity with different evaporator surfaces.

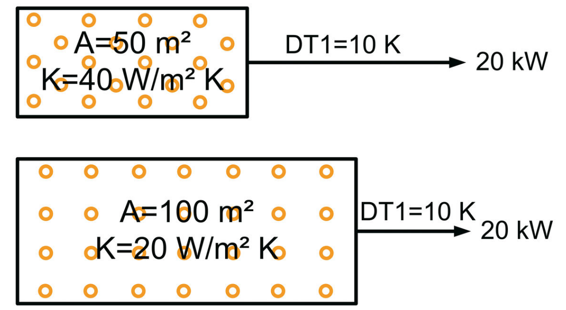

Fig. 7: Aligned and staggered tube pattern with same nominal capacity in comparison

The following holds for both cases:

refrigerating capacity $\dot{Q}_0 = A \times k \times \Delta t$

$\dot{Q}_0$ = refrigerating capacity

A = evaporator surface

k = thermal transmittance

Δt_m = medium logarithmic temperature difference

DT1= air inlet temperature difference

In the upper example, a total of 20 kW nominal capacity are reached with a staggered tube pattern and the resulting good U value of 40 W/m2K. The aligned tube pattern, on the other hand, results in a U value of only 20 W/m2K due to the inferior heat transfer at the outer tube wall, needing twice the evaporator surface in order to reach the same nominal capacity at the same DT1.

Using the same DT1 (temperature difference between evaporating temperature and air inlet temperature) of 10 Kelvin, the evaporator with bigger tube surface and aligned pattern shows slightly less formation of frost than the evaporator with staggered pattern due to the inferior U value and the resulting higher surface temperature.

In order to ensure that the dehumidification of the air and therefore of the refrigerated produce is kept as slight as possible, evaporators today are selected according to the results of the latest research, with a large U value, but with a DT1 that is as small as possible (see example fig. 8, DT1 = 5 K).

Designing an evaporator with a DT1 of only 5 Kelvin shows considerable advantages not only regarding dehumidification, but also regarding the compressor design.

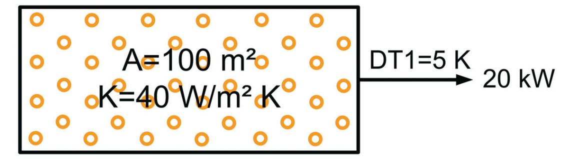

Fig. 8: Highly efficient evaporator with larger surface

Compressor selection

Smaller compressor

When selecting the compressor, you will find that it is possible to use a smaller compressor in order to generate the re-calculated, lower refrigerating capacity.

example 1: t_0 = –10°C, t_c = 40°C, Δt_1 = 10 K
$\dot{Q}_0$ = 20 kW
➪ Bitzer compressor 4VCS-6.2Y-40P: 3.711 €

example 2: t_0 = –5°C, t_c = 40°C, Δt_1 = 5 K
$\dot{Q}_0$ = 20 kW
➪ Bitzer compressor 4DCS-5.2Y-40S: 2.585 €

Lower current consumption of the compressor

By elevating the evaporating temperature from -10 °C to -5 °C, the Carnot process efficiency of the compressor is increased (see calculation), leading to a decrease in current consumption by 13 %.

$$COP_{-10°C} = \frac{T_0}{T_c - T_o} \cdot \eta_{ise} = \frac{(273 - 10)}{(273 + 40) - (273 - 10)} \cdot 0{,}5 = 2{,}63$$

$$COP_{-5°C} = \frac{T_0}{T_c - T_o} \cdot \eta_{ise} = \frac{(273 - 5)}{(273 + 40) - (273 - 5)} \cdot 0{,}5 = 2{,}98$$

Less dehumidification -> less defrosting

By elevating the evaporating temperature, the amount of condensation at the evaporator decreases; thus, there is less frost to be removed when operating at negative evaporating temperatures. The defrosting periods are shorter, defrosting intervals can be reduced. This saves energy and therefore money.

Less dehumidification of air -> small weight loss of unpackaged produce

When operating at low evaporating temperatures, dehumidification of storage air and therefore dehumidification of unpackaged produce in the refrigerating room increases. Unpackaged produce like for example meat, fruit, vegetables and cheese are dehumidified in the same way as the air in the refrigerating room, so that not only their natural appearance suffers, but also their sellable weight.

Summary

Therefore, the operator of the refrigerating room must not only compensate for increased energy costs for compressor operation and defrost energy, but also for mass losses and poor appearance of the produce.

The experienced plant contractor will be able to convince the end customer that the potentially higher purchase costs for a generously dimensioned evaporator or a model from our GHFB-Bio series is an absolutely rewarding investment, showing not only his expertise, but also his case and energy awareness.

If you have any questions, our sales team will be happy to help you!