PE3.09 Analysis, optimization and testing of spiral freezer utilizing CO2 432.00

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Abstract - In the past years, the use of CO2 has gained widespread acceptance as a natural refrigerant used in industrial freezing systems. Optimization of industrial freezing equipment using CO2 has been performed and tested. The higher capacity indicated by the specially developed simulation programmes was confirmed. The work on the spiral freezer is covered by this paper. The airflow pattern and cooling rate was analysed and optimized using measurements and simulation (CFD). The tests were performed on full-sized equipment using a purpose built 100 kW CO2 cascade system including hot gas defrost with the use of only one compressor.

Index Terms CO2, spiral freezer, refrigerant, flow optimisation, food quality.

I. INTRODUCTION

CO2 as refrigerant in industrial freezing applications has been accepted as a natural, environmentally friendly, cheap and very efficient alternative and has been utilized in large scale for more than 8 years. As the market for equipment is still small compared with other refrigerants, the equipment optimized for CO2 is not substantial, especially when the utilization of the CO2 benefits is in question. Compared to refrigerants traditionally utilized in industrial freezing, CO2 makes it possible to reach lower evaporation temperatures with a smaller drop in COP. Furthermore, it has the benefit of smaller compressors as well as smaller suction lines, better heat transfer and efficient brine. In order to investigate the possibility to obtain an improved quality of frozen food by using CO2 as refrigerant the project 'COMPFREEZE' under the EU CRAFT program has been succeeded /1,2,3/. The freezing equipment covered by the project comprises: Cascade freezing plant including hot gas defrost, plate freezer, spiral freezer with horizontal air flow and ice-cream freezer.

II. SPIRAL FREEZER

The spiral freezer has horizontal airflow across the product. Figure 1 shows the airflow indicated with arrows. The air is cooled in the evaporator and distributed to the different layers of the belt tower. The products are cooled with an average air velocity of up to 10 m/s. The air returns to the fan beneath the spiral belt. The limiting parameter for speeding up the freezing process (especially at the beginning where the product is warm compared to the air) is the heat transfer coefficient between the product and the air. The heat transfer coefficient will increase with the local air speed across the product.

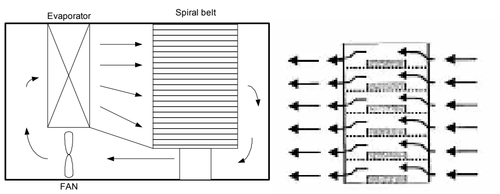

Figure 1: Spiral freezer with horizontal flow and airflow above the product. The local heat transfer coefficient was measured in full band width (three blocks: A (out most), B and C) at 5 positions, as shown in figure 2 and 3 using a lumped model /4/.

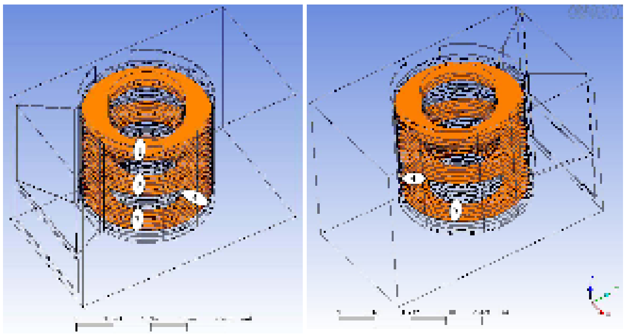

Table 1: Measured local heat transfer coefficients at two fan speeds with and without sealed internal leaks. The results are shown in table 1.

Some considerable internal leaks was identified and sealed in test III. The cooling of products in the spiral freezer was investigated utilizing a commercial CFD (Computerized Fluid Dynamics) code. Two CFD models of the spiral freezer were established: A simplified model of the whole height of the band stack incl. in- and outlet and a detailed model including product but considering only two tiers of the spiral freezer in order to reduce the calculation time. The first CFD model was verified against the airflow field at the in- and outlet of the band stack using LDV (Laser Doppler Velocimetry) /1/. Validation of the second CFD model against the measured local heat transfer data showed a deviation of -3 to + 7% The validated model has been used to carry out a study of: ' the influence of product size on the product cooling ' the influence of inlet design on the product cooling Four different product heights were considered: 20 mm, 30 mm, 50 mm and 60 mm (max. height 65 mm). In figure 4 the overall heat transfer coefficient and heat flux are plotted for the given product sizes. Figure 4: Left: Overall heat transfer coefficients; Right: Mean heat flux for product sizes 20, 30, 50 and 60 mm. From figure 4 it can be seen that a product size increase has a great impact on the overall heat transfer coefficient. The convection coefficient increases by 40% for the products placed on the outside edge of the conveyer belt. The products placed on the centre of the conveyer belt experience the smallest change with an increase of 16%. The increase of the convection coefficient is a result of only a small reduction of the airflow through the spiral freezer: The flow has been reduced by only 6% due to a flat fan characteristic. The larger products create a more turbulent and chaotic flow which together with the small reduction of the total airflow results in an increase in the heat transfer coefficient. When considering the cooling rate of the product, the temperature difference between the product and the cooling air must be taken into consideration. In figure 4 it appears that the changing air temperature along the products results in a heat flux which is different compared to the heat transfer coefficient: The cooling rate depends on the product size. The temperature and air velocity plots for 20 and 60 mm block height can be seen in figure 5 and figure 6. Figure 5: Temperature plot in between the products. Left: Product size 20 mm; Right: Product size 60 mm. Figure 6: Velocity plot in between the products. Left: Product size 20 mm; Right: Product size 60 mm. Two different inlet designs (one as shown in figure 3 and one fully open) have been analyzed for the smallest and biggest product sizes in order to investigate the impact on the performance. Figure 7: Mean heat flux 60 mm product height to the left; 20 mm product height to the right. For the product size of 60 mm a narrower inlet design is preferred. With a narrow inlet, the airflow creates a high stagnation pressure and forces the flow to penetrate between the products to the inner edge of the conveyer belt, cooling the inner products efficiently, see figure 7. With a larger inlet and high products the cooling air tends to flow by the products located at the outer edge of the conveyer belt and those creating poor cooling conditions for the inner products. When considering smaller products, the narrow inlet design forces the air to flow close to the drum and therefore creates poor cooling conditions for the products located at the outer edge of the conveyer belt, see figure 7 (right). With a larger inlet design the airflow pattern has changed, creating better cooling of products located at the outer edge. The results indicate that the negative effects of the changing product height can be compensated for by changing the design of the inlet manifold. The simulations have also been carried out at -10°C product temperature giving the same result except for the heat flux, which as expected was lower due to the lower temperature difference.

III.CONCLUSION

A spiral freezer was redesigned especially for low temperature operation using CO2 and tested on a full scale industrial cascade refrigeration system. Based on CFD calculations and air velocity and local heat transfer coefficient measurements on the spiral freezer it can be concluded that the product size as well as the design of the inlet manifold affect the cooling condition in the spiral freezer in addition to the internal air leaks in and around the band stack. The flow pattern changes with product height, changing the cooling conditions. Preliminary investigations show that the effects of the changed product height can be discouraged by changing the design of the inlet manifold. Flat products require larger inlet; high products smaller inlet. Optimum inlet design could presumably give benefits with respect to final product quality (even product temperature distribution) and reduction of the product residence time in the spiral freezer. In order to obtain a more realistic picture of product cooling, a time dependent study must be carried out. It is estimated that a lot of spiral and blast freezers will benefit from an analysis and optimization of the presented type.

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	I	***II***	***III***					
Position	***30% fan*** ***h*** [W/m^2°C]	***70% fan*** ***h*** [W/m^2°C]	***70% fan no leaks*** ***h*** [W/m^2°C]	***II/I***	***III/II***	***I Relative to 1C (average)***	***II Relative to 1C (average)***	***III Relative to 1C (average)***
1A	46	65	63	141%	97%	105%	100%	100%
1B	42	65	63	155%	97%	95%	100%	100%
1C	44	65	63	148%	97%	100%	100%	100%
2A	43	61	55	142%	90%	98%	94%	87%
2B	47	65	67	138%	103%	107%	100%	106%
2C	53	75	70	142%	93%	120%	115%	111%
3A	43	61	57	142%	93%	98%	94%	90%
3B	45	65	61	144%	94%	102%	100%	97%
3C	43	67	57	156%	85%	98%	103%	90%
4A	35	45	52	129%	116%	80%	69%	83%
4B	30	45	52	150%	116%	68%	69%	83%
4C	23	35	50	152%	143%	52%	54%	79%
5A	20	28	25	140%	89%	45%	43%	40%
5B	16	21	21	131%	100%	36%	32%	33%
5C	13	17	15	131%	88%	30%	26%	24%

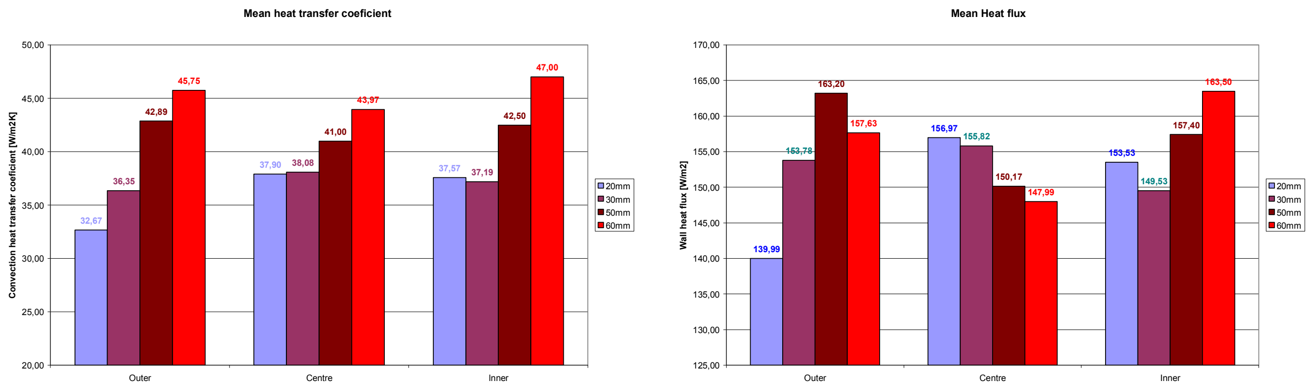

Figure 4: Left: Overall heat transfer coefficients; Right: Mean heat flux for product sizes 20, 30, 50 and 60 mm.

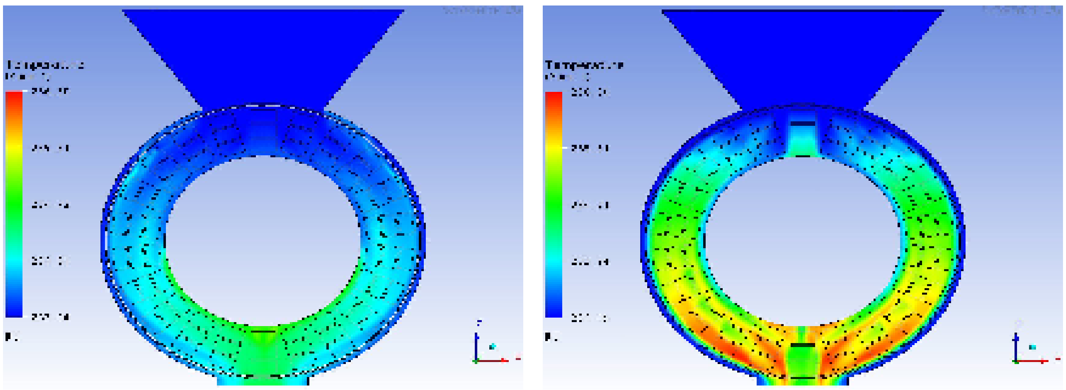

Figure 5: Temperature plot in between the products. Left: Product size 20 mm; Right: Product size 60 mm.

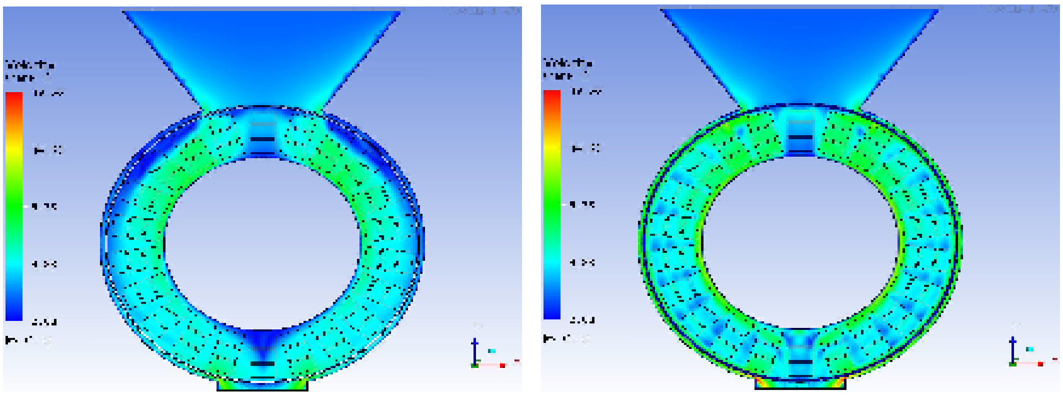

Figure 6: Velocity plot in between the products. Left: Product size 20 mm; Right: Product size 60 mm.

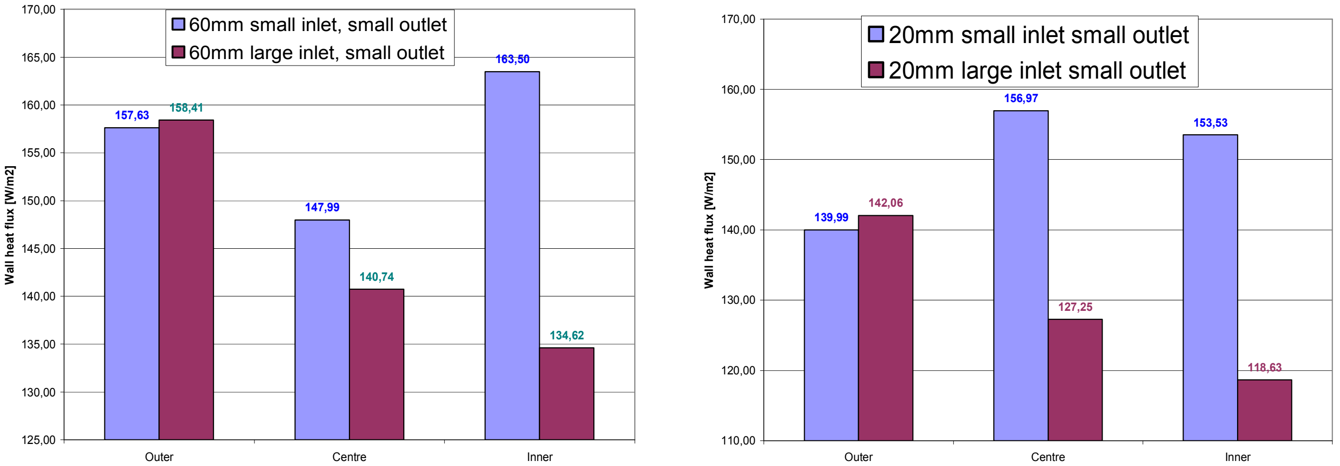

Figure 7: Mean heat flux 60 mm product height to the left; 20 mm product height to the right.