OPERATIONAL MODES FOR HEAT PUMP DRYING – NEW TECHNOLOGIES AND PRODUCTION OF A NEW GENERATION OF HIGH QUALITY DRIED FISH PRODUCTS

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ABSTRACT

In the production of artificially dried ingredients in different dishes, soups and cereals we find today two dominating technologies, direct heated driers operated at 60°C to 90°C and vacuum freeze drying operated below -30°C. Direct heated dryers have a lower production costs than vacuum freeze dryers but with a much lower quality of the dried product. Vacuum freeze dryer, on the other side, is so expensive that its use is limited. This paper presents a new technology based on heat pump drying with production costs considerably lower than vacuum freeze drying but with similar qualities of the dried product. The focus is on the design, dimensioning and operation of such heat pump dryers using a combined mode with drying temperatures below and above the product freezing point.

By using heat pumps in drying of heat sensitive materials drying temperature and relative humidity can be controlled. The technology saves energy and is more environmentally friend than direct heated dryers. Several materials have been dried in test plants, like fish products, fruits, vegetables and dairy products. These products quality and properties can be controlled as for example color, taste, bulk density and rehydration. By changing the operation mode and time period with atmospheric freeze drying quality parameters will be influenced. Generally, the longer this time period is, the lower the product shrinkage and the higher the rehydration index. This paper has focus on quality parameters in drying of cod pieces dried at combinations of temperatures below and above the freezing point.

The interaction between the air side of the plant and the heat pump is studied and different system solutions with ammonia as the working fluid are scrutinized. Consequences on the dryer thermal efficiency and the heat pump coefficient of performance are presented.

1. ADIABATIC HEAT PUMP DRYERS

Heat pump dryers are attractive for the processing of heat sensitive materials since the drying conditions are easily controlled. Aside from being able to save energy this dryer design is based on an environmentally friendly technology. In Norway it has been applied industrially for the drying of fish and apples. The additional successfully dried products are fish, fish residues, fruits, vegetables, dairy, biological and other active or heat sensitive materials. The drying modes allow controlling implying a high final product quality, which is indicated by hardness, porosity, density, rehydration, colour, aroma and other properties.

A schematic layout of a continuous industrial heat pump dryer is shown in Figure 1.

The advantages of the heat pump dryers are
- low energy consumption due to a high SMER that is expressed by:

$$SMER = COP/(dh/dx) \quad (1)$$

$$COP = Qo / W \quad (2)$$

Typical SMER are in the order of 2 to 5 depending on the drying temperature.

- Drying conditions can be regulated with drying temperatures from –20°C to 110°C. Quality parameters of the product can be controlled due to the low temperatures and the possibility for partly freeze drying.
- The technology is environmentally friendly due to the recirculation of the drying air and the high thermal efficiency of the dryer.

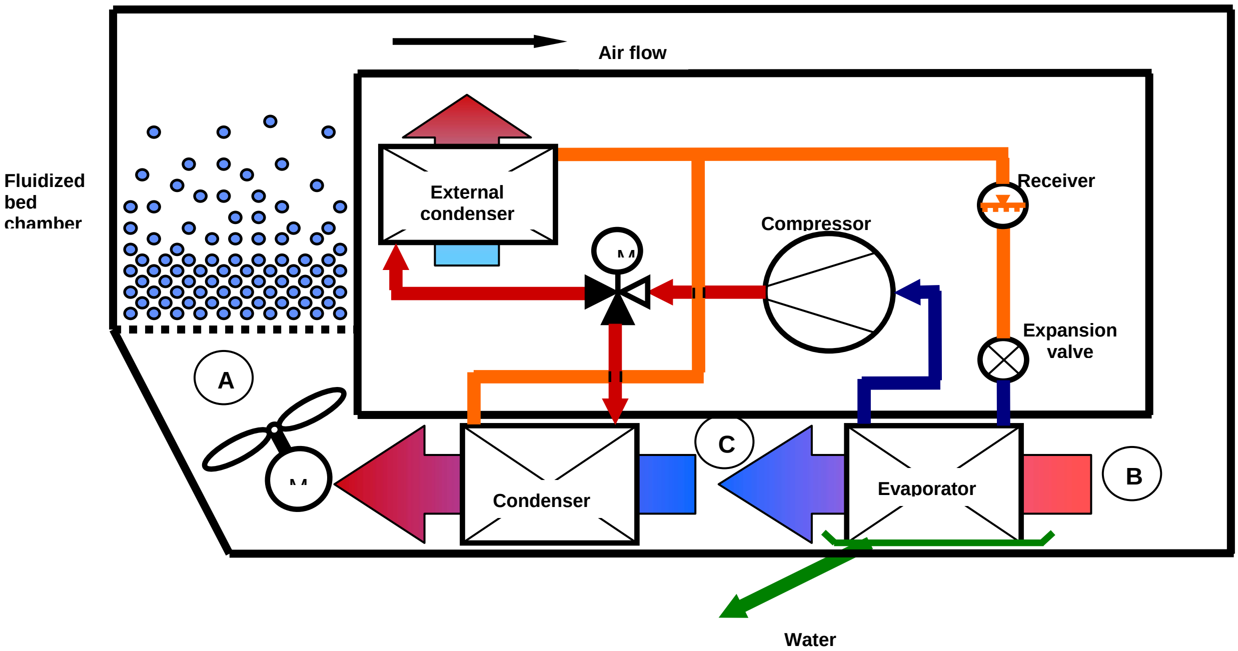

Figure 1. Schematic layout of a heat pump fluidised bed dryer

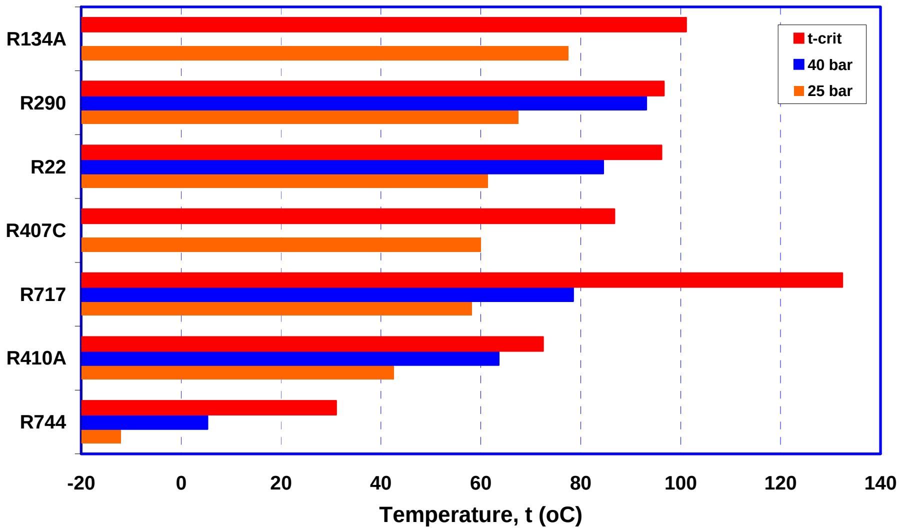

Figure 2. Critical and condensing temperatures for different heat pump working fluids at pressure of 25 and 40 bar

Actual working fluids and their corresponding SMER numbers are shown in Figures 2 and 3 (Eikevik 2000).

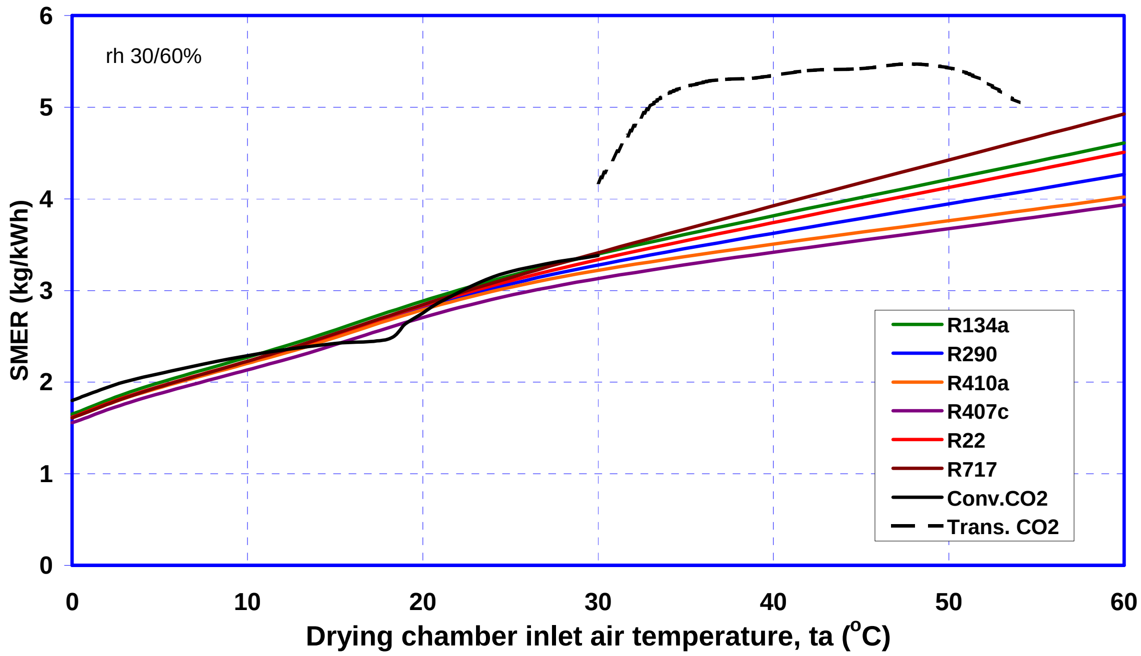

Figure 3. SMER as function of air temperature for different fluids at subcritical and transcritical cycles (CO_2)

Subcritical refrigeration cycles are used except for one case that was a transcritical CO_2 cycle, in which a higher COP is achieved due to gliding temperatures on the high temperature side.

2 Non adiabatic Heat Pump Dryers

Limitations with the adiabatic heat pump dryers are reduction in dryer capacity due to the cooling of drying air. At the Norwegian University of Science and Technology and SINTEF a non adiabatic, plug-flow fluidised bed heat pump drier with two stages using ammonia as refrigerant was constructed (Jonassen 1994, Strømmen 2000). The dryer is shown in Figure 4.

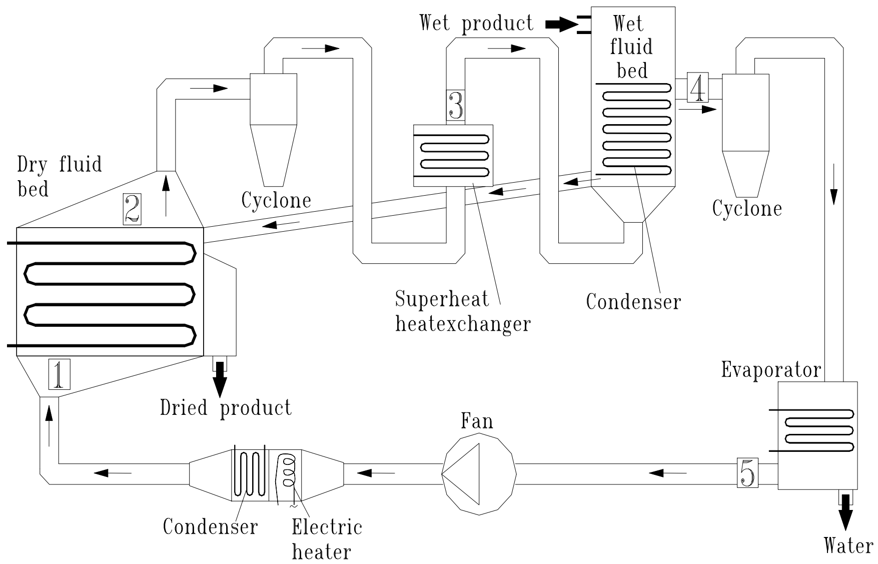

Figure 4. Nonadiabatic, two-stage, plug-flow NH_3 heat pump fluid bed dryer

A capacity increase of 380% compared to an adiabatic design is achieved in this dryer and the measured maximum SMER was 4.7 kg H_2O/kWh. The inlet air temperature in the drying chamber was above 100°C in these experiments and measurements where done with herring meal under continuos operation of the dryer.

3 Physical properties and quality of dried products

Quality of the dried products is influenced to a large extent by the drying temperature. Figure 5 shows the influence on bulk density for 5 mm cubes of cod-fish dried at different temperature from –10° C to 30°C. The final water content was in all cases below 10% and initial water content about 80% wet basis. In some of the drying tests a temperature program was used with varying time period at drying temperatures below the freezing point of the product. As can be seen from Figure 6, the lower the drying temperature and the longer time period with freeze drying temperatures the lower the bulk density of the cod pieces. This again will influence the rehydration ability of the product.

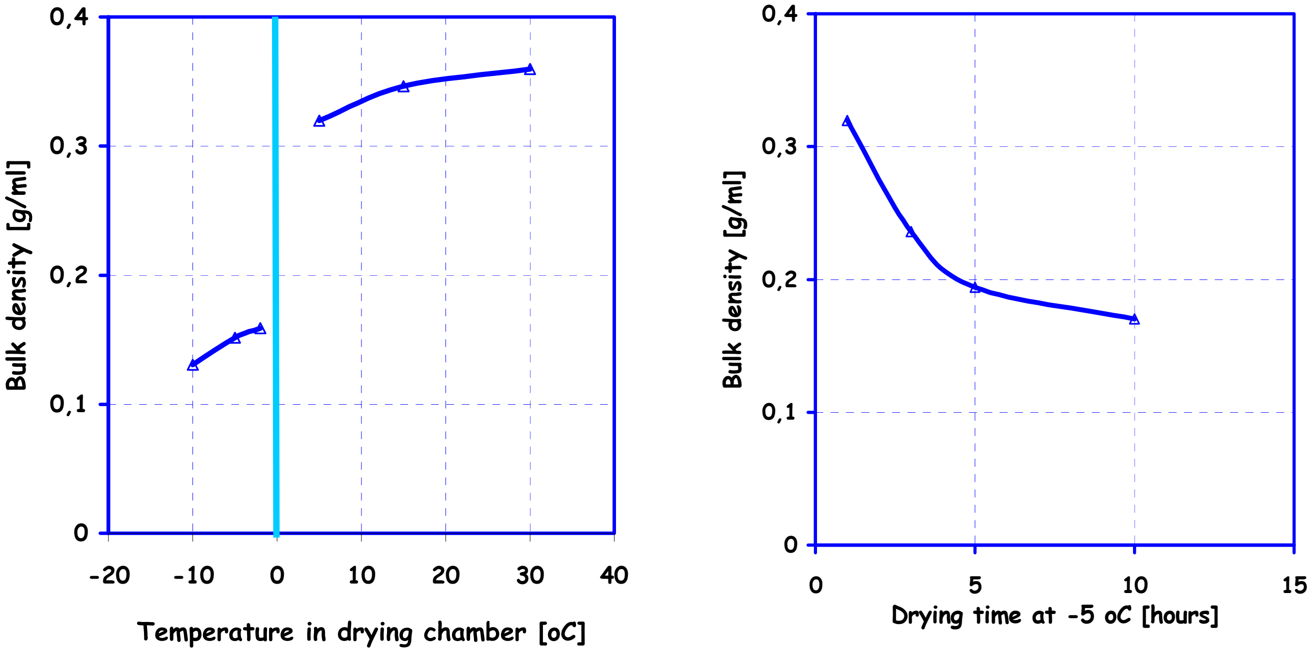

Figure 5. Bulk density of cod pieces dried at temperatures from –10°C to 30°C

In Figure 6 we see that the longer time period at freeze drying conditions and the lower the drying temperature the higher the rehydration ability. Figure 7 shows the colour measurements of cod pieces dried at -5°C and 30°C. Drying at temperatures below freezing point gives a product with a much higher white component and lower yellow component than drying at 30°C (Strømmen 1994).

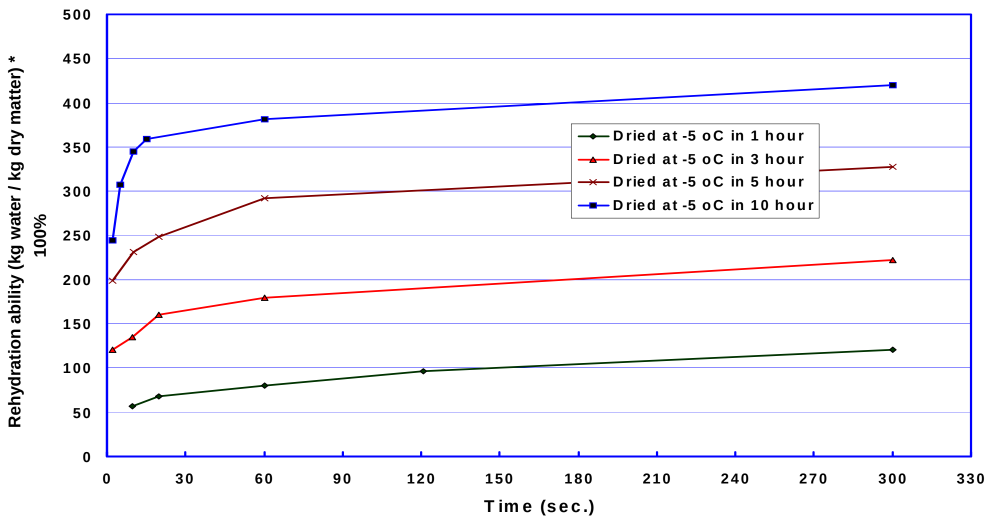

Figure 6. Rehydration ability of cod pieces dried with different time periods at freeze drying conditions

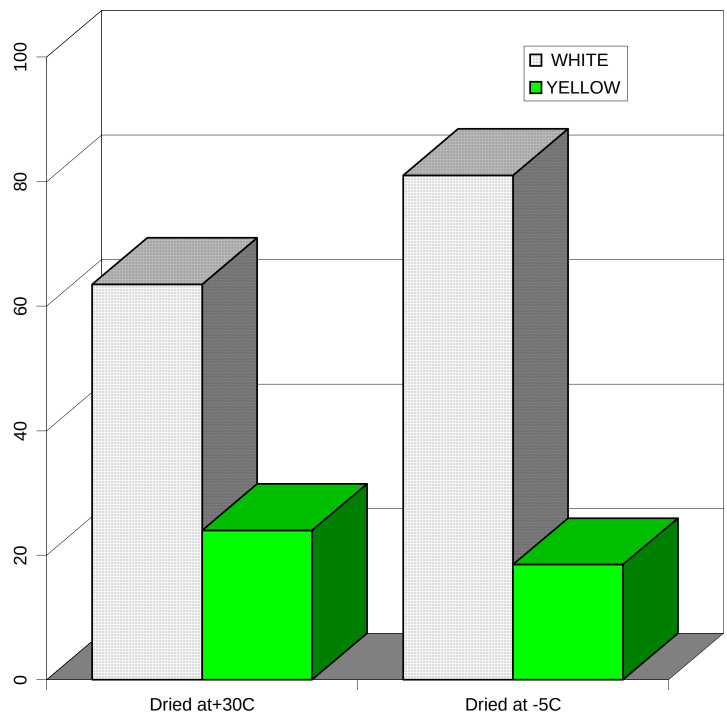

Figure 7. Colour test of cod pieces dried at different temperatures

4 Design of heat pump drying in combined drying mode with drying temperature below and above the freezing point

To achieve as high SMER as possible, industrial fluidised bed heat pump dryers should be designed according to the following “design rules”:

- Drying operation with optimum bed height to attain a higher relative humidity at the dryer outlet
- Stable fluidisation due to the sorption characteristics of the material being dried
- Continuous, not batch operation, due to the lowering of capacity and efficiency during a batch process
- As high inlet temperature in the dryer as possible, due to improved thermal efficiency and capacity
- As low refrigeration capacity as possible, as long as the desired production is achieved (over-sizing will increase dh/dx and reduce SMER)
- The choice of evaporating and condensing temperature of the heat pump should be the combination giving the best combination of COP and dh/dx (an optimum might exist).

The energy consumption in an a continuous heat pump drying operated in a combined drying mode at temperatures at –5°C in the first stages and at 30°C at the second stage can be calculated from the following equation:

$$SMER = (COP_{LT}/(dh/dx)_{LT})*(\tau_{LT}/\ \tau_{tot}) + (COP_{HT}/(dh/dx)_{HT})*(\tau_{HT}/\ \tau_{tot}) \qquad (3)$$

The following reference process in the Mollier humid air diagram:

Table 1: Process conditions for the heat pump drying operated at combined drying mode

	LT	**HT**
Air inlet drying temperature	-5 °C	30 °C
Air inlet relative humidity	40%	40%
Air outlet relative humidity	80%	80%
Surface temperature of air cooler	t_{dp} - 5°C	t_{dp} - 5°C
Heat pump evaporating temperature	air cooler surface temperature – 2°C	air cooler surface temperature – 2°C
Heat pump condensing temperature	air inlet drying temperature + 5°C	air inlet drying temperature + 5°C
Heat pump refrigerant	NH_3	NH_3

The results of the calculations are shown in the Figures 8 and 9. Drying at –5°C for 10 hours will give a lower bulk density, a higher rehydration ability and an energy consumption 7.5 times higher than drying at 30°C only. The SMER for the combined drying at 10 hours at –5°C will be reduced with 67% of the SMER at 30°C.

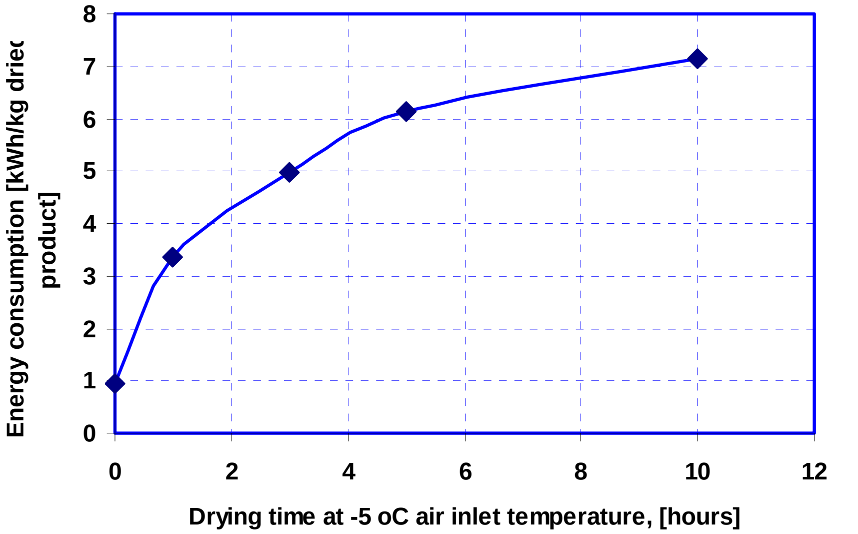

Figure 8: Dryer energy consumption per kg dried cod pieces with increasing time at low temperature

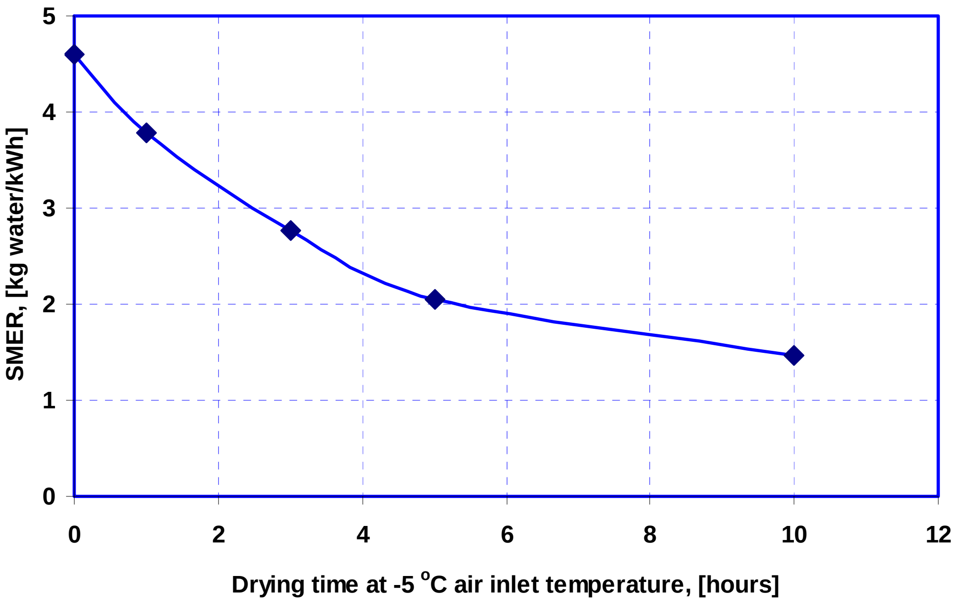

Figure 9: SMER for dried pieces of cod with increasing drying time at low temperature

5 CONCLUSIONS

Adiabatic and non-adiabatic heat pump fluidised bed or tunnel dryers are built in Norway for the drying of different type of food products. The energy consumption in heat pump dryers are 60-80% lower than other dryers operating at the same temperature. Typical SMER is in the range of 2 to 5 in such dryers. By drying in a non-adiabatic mode with part of the heat pump condenser put into the drying chamber a 400 % capacity increase is achieved compared to adiabatic dryers. Drying temperatures from –20°C to 110°C are used. Quality properties can be influenced to a large extent by the drying temperature. Bulk density, colour, taste and rehydration ability can be controlled with an initial freeze drying step.

In this paper cod pieces are dried at combined drying mode (low and high temperatures) showing improved rehydration ability and colour with an initial drying at –5°C. With an initial drying time period of 10 hours at –5°C the SMER will be reduced with 67 % compared to drying at 30°C only. The energy consumption will be 7.5 times higher compared to drying at 30°C only.

NOMENCLATURE

SMER	Specific Moisture Extraction Ratio	(kg water/kWh)
LT	Low temperature drying	
HT	High temperature drying	
dh	Enthalpy difference for the air	(kJ/kg dry air)
dx	Difference in humidity for the drying air	(kg water/kg dry air)
Q_o	Refrigeration Capacity	(kW)
W	Energy consumption	(kW)
COP_{LT}	Coefficient of performance for the low temperature drying heat pump	(-)
COP_{HT}	Coefficient of performance for the high temperature drying heat pump	(-)
t_{dp}	dewpoint temperature	(°C)
τ_{LT}	Drying time at low temperature	(hours)

τ_{HT}	Drying time at high temperature	(hours)
τ_{tot}	Total drying time	(hours)

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