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

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Heat pump dryers are applied for heat sensitive materials due its controllable drying conditions. It saves energy and is more environmentally friendly than conventional direct or indirect heated dryers. In Norway, R&D on this technology has been conduted over a period of more than 20 years that resulted in industrial applications. Materials like fish products, fruits, vegetables, dairy, biological active and heat sensitive materials have been dried in test plants. Typical quality controlled parameters are color, taste, density and rehydration properties. This paper covers design, energy consumption, operation modes and criteria and influence of product quality of heat pump dryers as well as the interaction between drying chamber and dryer operation. Heat pump systems with different natural working fluids are simulated at different drying conditions and evaporating temperatures. Consequences on the dryer thermal efficiency and the heat pump coefficient of performance are studied at different operational modes. Quality and energy use at different drying modes for several food products and chemical pulp are studied.

Keywords: Heat pump, drying, heat sensitive materials.

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Adiabatic 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. In these days a large industrial dryer are under constructions in Hungary. This dryer will produce atmospheric freeze dried peas and sweet corn.

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.

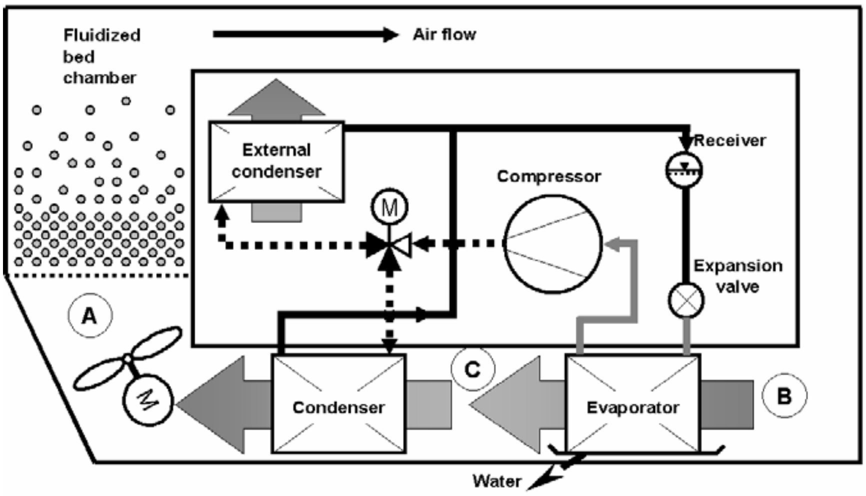

Figure 1 Schematic layout of a fluid bed dryer with heat pump

The most important components in the heat pump dryer is the size of the compressor and the air cooler (evaporator). To large compressor gives low relative humidity in the inlet of the drying chamber, but it will increase the power consumption of the plant. The air cooler shall remove the moisture from the air. The design of this heat exchanger depends totally of the temperature level in the drying chamber.

The advantages of the heat pump dryers are:

- low energy consumption due to a high SMER that is expressed by:

$$SMER = \frac{COP}{\frac{dh}{dx}} \quad (1)$$

$$COP = \frac{Q_o}{W} \quad (2)$$

- Drying conditions can be regulated with drying temperatures from -20°C to +100°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.

Non-adiabatic 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 2.

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.

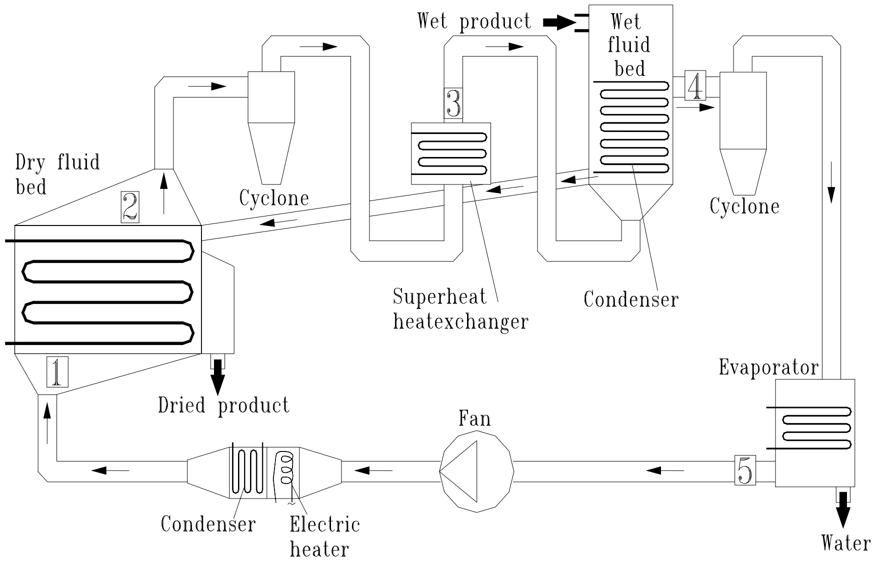

Figure 2. Nonadiabatic, two-stage, plug-flow NH_3 heat pump fluid bed dryer

Quality of dryed products

Drying of cod pieces with initial atmospheric freeze drying

Quality of the dried products is influenced to a large extent by the drying temperature. Figure 3 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 4, 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.

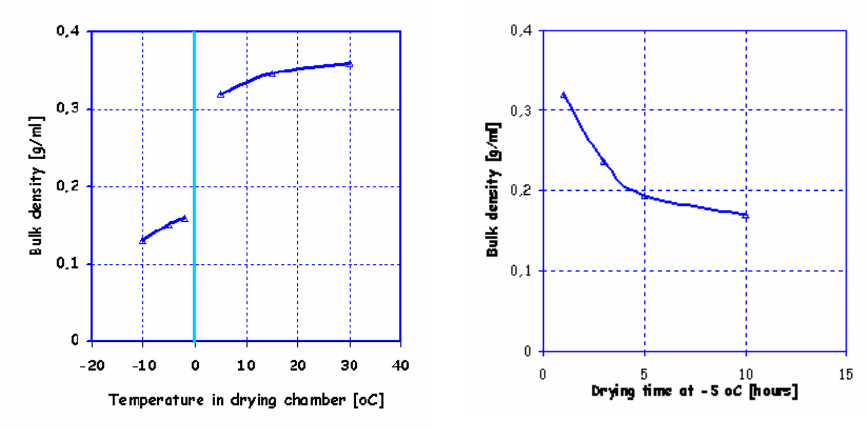

Figure 3. Bulk density of cod pieces dried at temperatures from –10^{o}C to 30^{o}C

In Figure 4 we see that the longer time period at freeze drying conditions and the lower the drying temperature the higher the rehydration ability. Figure 5 shows the colour measurements of cod pieces dried at -5^{o}C and 30^{o}C. Drying at temperatures below freezing point gives a product with a much higher white component and lower yellow component than drying at 30^{o}C (Strømmen 1994).

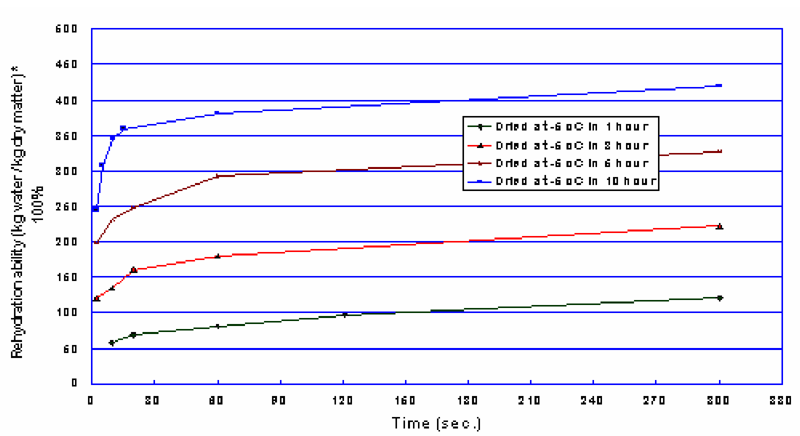

Figure 4. Rehydration ability of cod pieces dried with different time periods at freeze drying conditions

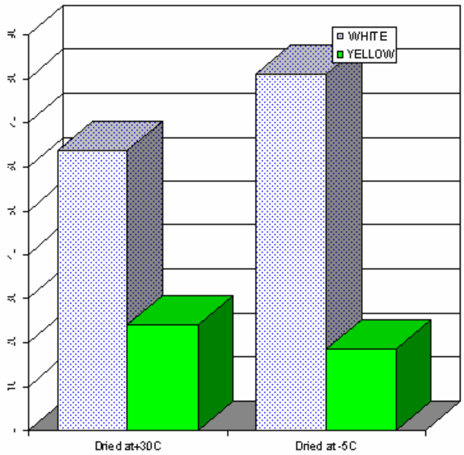

Figure 5. Colour test of cod pieces dried at different temperatures

Drying of chemical pulp at low temperatures

Heat pump drying has also been tried for drying of chemical pulp. The concept is based on drying in combinations with heat pump. This makes it possible to dry at low and moderate temperatures and ability to optimize product quality. Initial drying experiments have shown that better quality is obtained by this drying method. The drying temperature was chosen to be –15^{o}C (below freezing point for the pulp) and +20^{o}C. Examples of such quality parameters are swelling, which can be assessed by water retention value (WRV) and tensile index respectively. Water retention value (WRV) is a measure of the fibres ability to swell. It is an empirical measure of a sample of pulp fibres ability to retain water. The WRV value increases with increased beating due to internal and external fibrillation and delamination of the fibre wall. The WRV (g/g) gives the amount of water that is present in the pulp after centrifugation with a certain centrifugal force (3000 ± 50 g) a definite period of time (15 minutes). The swelling is often assessed by plot of a beating curve, where WRV is measured as a function of the degree of beating, given as evolutions in a PFI mill (A PFI mill is a standardized laboratory mill, used to assess effects of milling by the pulp and paper industry world wide). Tensile strength is the maximum tensile force per unit width that paper and board will withstand before breaking under the conditions defined in the standard test method. Tensile index is tensile strength divided by grammage (which is g/m^2). A test piece of given dimensions (width 15 mm ± 0.1mm, test length 180 ± 1 mm) is stretched to rupture at a constant rate of elongation using a tensile-testing apparatus that measure the tensile force. The tensile index is used to quantify the strength of a paper. The weak link in paper is not the fibre itself, but the bonds between the fibres. Thus, the tensile index is a measure of the joint strength of fibre – fibre bonding.

Figure 6 and 7 shows the water retention value and the tensile index as a function of revolutions in a PFI-mill. The undried pulp have the highest value in all cases, and represent the reference quality. The mill dried pulp has the lowest values. The differences between those two represent the quality loss with the present drying technology. The curves in between represents the new drying technology dried at two different temperatures (not optimized). Both water retention value and tensile index is increased substantially compared to drying with the present technology. Water retention value is improved by 20-30 % and tensile index with 7-10 %.

A potential for large energy savings is revealed. In the traditional drying process the SMER is 1,3 (kg water removed per kWh). The new drying concept with drying at +20°C will increase the SMER to 3,2. For a chemical pulp mill with annually pulp production of 400.000 ton this gives the following figures:

Current drying process:	310 GWh/year
New drying process:	130 GWh/year
Energy savings:	180 GWh/year

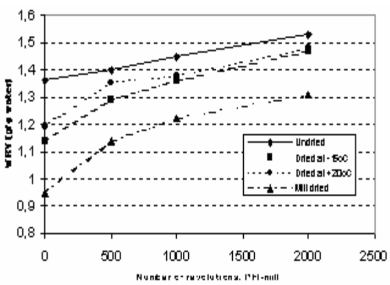

Figure 6 - Water retention value as a function of revolutions in a PFI mill. The heat pump dried pulps are compared to mill

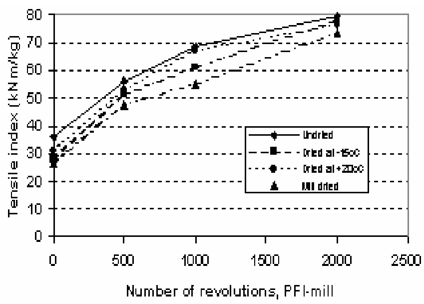

Figure 7 - Tensile index as a function of revolutions in a PFI mill. The heat pump dried pulps are compared to mill dried

In this case the highest WRV and Tensile index are achieved at 20°C drying temperature and not a combined mode drying. However the process is not optimized. Further research will study the mechanisms of the improved water retention value and tensile index when the chemical pulp is dried at low temperatures. [Lauritzen, 2003]

Energy consumption and SMER in combined drying mode

The energy consumption in an a continuous heat pump drying operated in a combined drying mode at temperatures at –5^{o}C in the first stages and at 30^{o}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 ^{o}C	30 ^{o}C
Air inlet relative humidity	40%	40%
Air outlet relative humidity	80%	80%
Surface temperature of air cooler	t_{dp} - 5^{o}C	t_{dp} - 5^{o}C
Heat pump evaporating temperature	air cooler surface temperature – 2^{o}C	air cooler surface temperature – 2^{o}C
Heat pump condensing temperature	air inlet drying temperature + 5^{o}C	air inlet drying temperature + 5^{o}C
Heat pump refrigerant	NH_3	NH_3

The results of the calculations are shown in the Figures 8 and 9. Drying at –5^{o}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^{o}C only. The SMER for the combined drying at 10 hours at –5^{o}C will be reduced with 67% of the SMER at +30^{o}C.

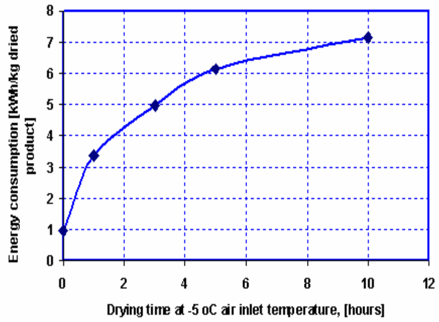

Figure 8: Dryer energy consumption per kg dried cod pieces with increasing time at –5°C

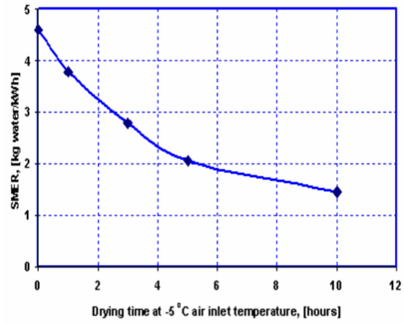

Figure 9: SMER for dried pieces of cod with increasing drying time at –5°C

If the $\varphi_{inlet}/\varphi_{outlet}$ of drying chamber is 40/80% The volume flow needed at –5°C compared to +30°C will be approx 300% higher compared to +30°C due to the much lower Δx at –5°C. The volume flow (m^3/s) will also decide the plant size of the air system if the plant is operated in a combined mode with initial freeze drying.

Conclusions

Adiabatic and non-adiabatic heat pump fluidized bed 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 from 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 achived compared to adiabatic dryers. Drying temperatures from -20°C to 100°C are used. Quality properties can be influenced to a large extent by the drying temperature below and abowe product freezing point. Bulk density, taste, coloure and rehydration ability can be controlled with an initial freeze drying step. Promissing results on chemical pulp will be followed up by further research.

In this paper cod pieces are dried at combined mode (low and medium temperature) showing improved rehydration ability and colour with an initial drying av -5°C. With an initial time periode of 10 hours at -5°C the MER will be reduced with 67% compared to drying av 30°C only. The energy consumption will be 7.5 times higher compared to drying av 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	(^oC)
τ_{LT}	Drying time at low temperature	(hours)
τ_{HT}	Drying time at high temperature	(hours)
τ_{tot}	Total drying time	(hours)

References

1 Jonassen, O., Kramer, K., Strømmen, I., Vagle, E.: *Nonadiabatic two-stage counter-current fluidized bed dryer with heat pump*. International Drying Symposium, Gold Coast, Australia, Aug 1994.

2 Strømmen, I., Kramer, K. New Applications of Heat Pumps in Drying Processes. Drying Technology; vol. 12, No.4, 1994, ISSN 0703-3937, Marcel Dekker Inc., New York, USA.

3 Alves-Filho, O., Strømmen, I.,: Heat Pump Fluidized bed Drying of Fruit Pieces. 19th International Congress of Refrigeration. The Hague, The Netherlands, Aug 1995

4 Strømmen, I., Eikevik, T.M., Alves-Filho, O.: Design and Dimensioning Criteria of Heat Pump Dryers, 20th International Congress of Refrigeration, IIR/IIF, Sydney, Australia. September 1999

5 Strømmen, I., Bredesen, A.M., Eikevik, T.M., Nekså, P., Pettersen, J., Aarlien, R.:Selected review article (English/French) in the Bulletin of the International Institute of Refrigeration: Refrigeration, Air-conditioning and Heat-Pump Systems for the 21st Century. “Pompes à chaleur, applicatins frigorifiques et de conditionnement d`air pour le 21e siècle. Vol. LXXX, Hefte 2, s. 2-18, 2000.

6 Alves-Filho, A., Lystad, T., Eikevik, T., Strømmen, I.: “A new carbon dioxide heat pump dryer – an approach for better product quality, energy use and environmentally friendly technology”. IDS, Amsterdam, Holland. August 28-31, 2000.

7 Eikevik, T., Alves-Filho, O., Strømmen, I.: Dimensioning of heat pump dryer components - an economical operation for quality, energy use and water removal”. IDS, Amsterdam, Holland. August 28-31, 2000.

8 Strømmen, I., Eikevik, T.M., Alves Filho, O., Syverud, K.; *Heat Pump Drying of Sulphate and Sulphite Cellulose*, IDS, Sao Paolo, Brazil, August 2004, ISBN: 85-904573-1-1

9 Strømmen, I.; Eikevik, T.M.; Alves-Filho, O.; Syverud, K., Jonassen, O.; *Low temperature Drying with Heat Pumps – New Generations of High Quality Dried products.* The 2nd Nordic Drying Conference, Copenhagen Denmark, June 25th – 27th 2003 ISBN 82-594-2550-5

10 Strømmen, I., Eikevik, T. M., Alves-Filho, O.; Operational modes of heat pump drying – new technologies and production of a new generation of high quality dried fish products. 21st International Congress of Refrigeration, IIR/IIF, August 2003, Washington, D.C. ISBN 2-913149-32-4