Sustainable Energy in Food Production

NTNU Norwegian University of Science and Technology

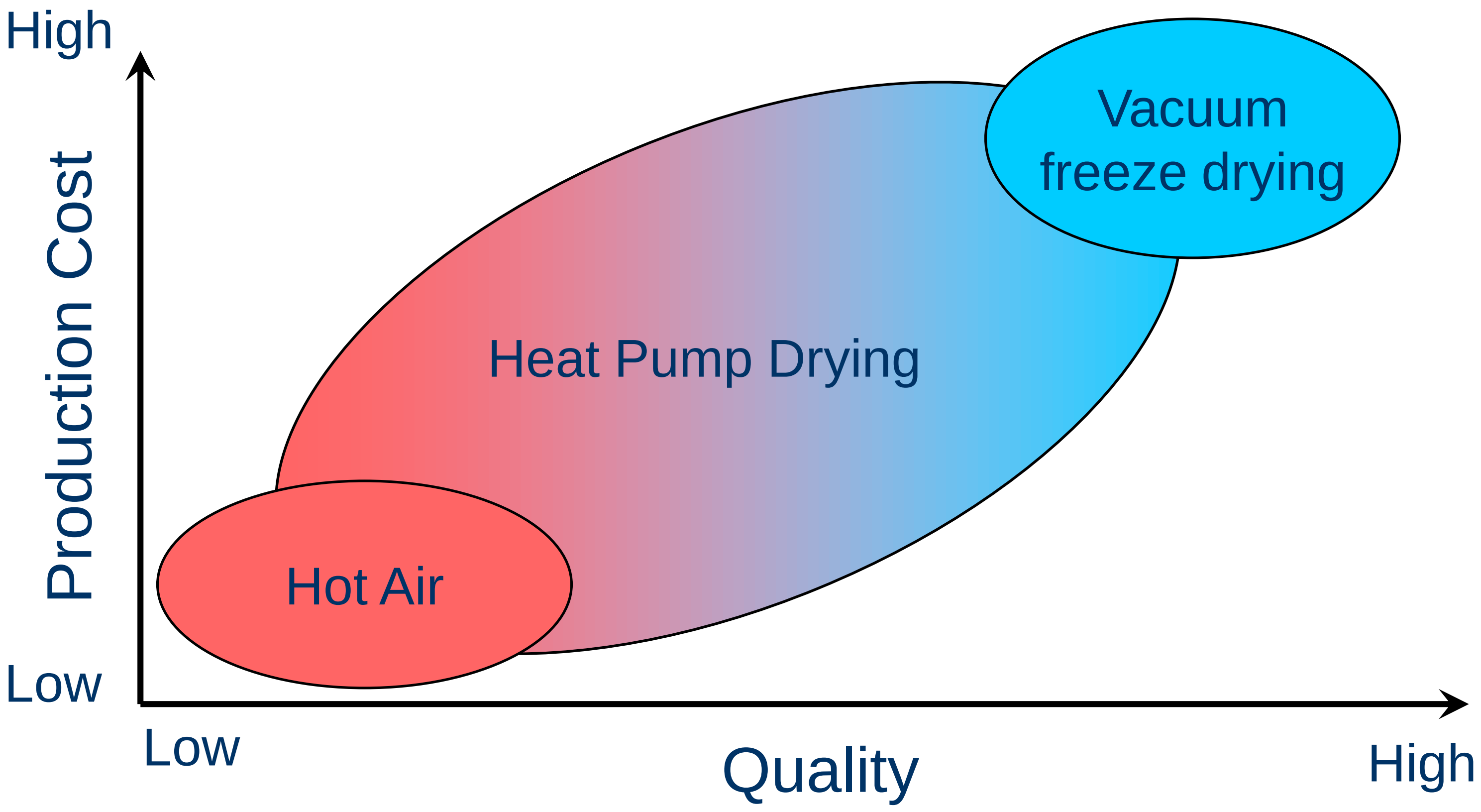
Heat Pump Assisted Drying - Freeze Drying Technology

Trygve M. Eikevik
Professor

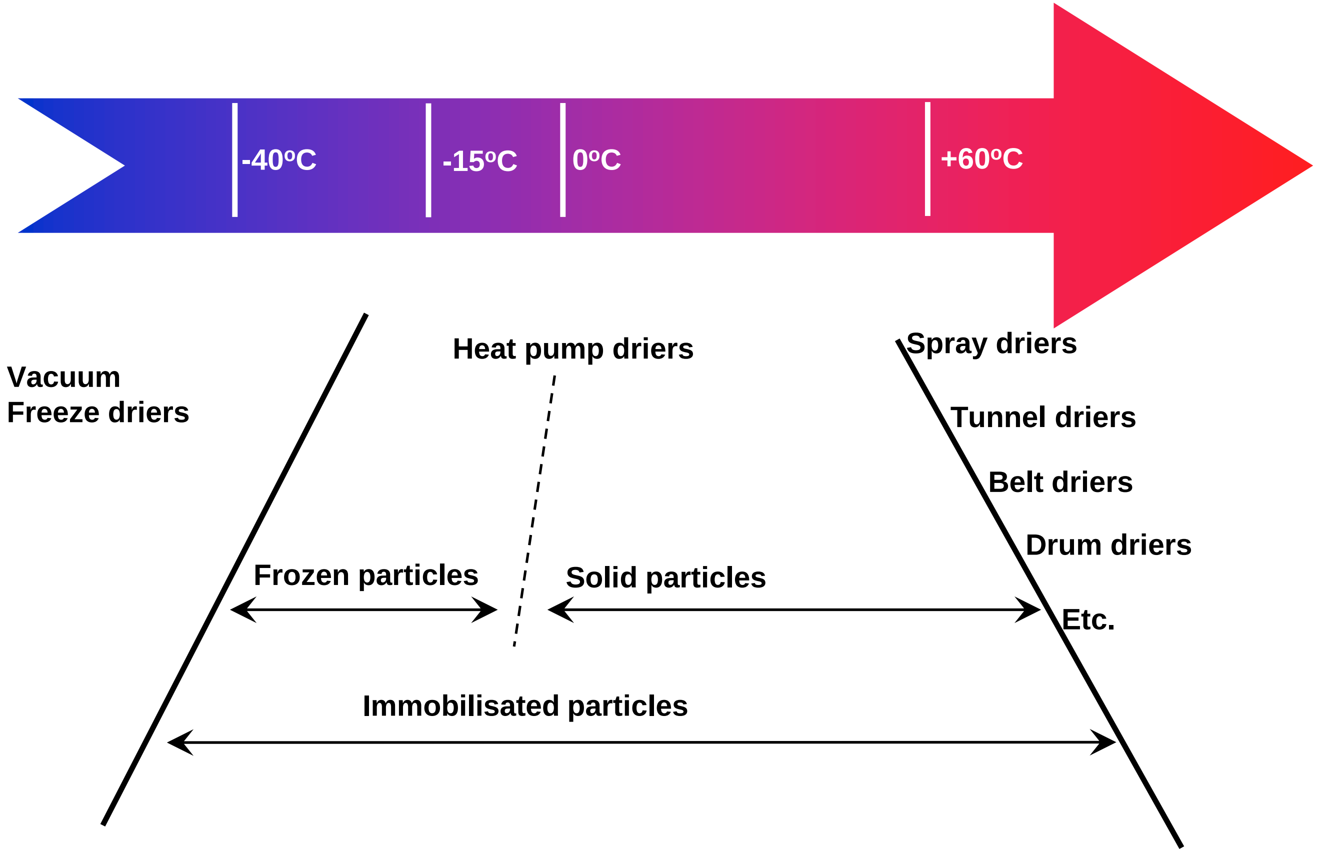
Norwegian University of Science and Technology (NTNU)
Department of Energy and Process Engineering
E-mail: trygve.m.eikevik@ntnu.no
http://folk.ntnu.no/tme

Content

Quality vs. production costs



Comparing different drying methods



Challenges in drying systems

- Optimal product quality (colour, flavour, texture, density and shrinkage) are influenced by the dryer type and dryer conditions, temperature and relative humidity
- Knowledge of product characteristics such as drying curve, water activity and properties / quality attributes
- To achieve high energy efficiency, high SMER-ratio
- Environmental aspects

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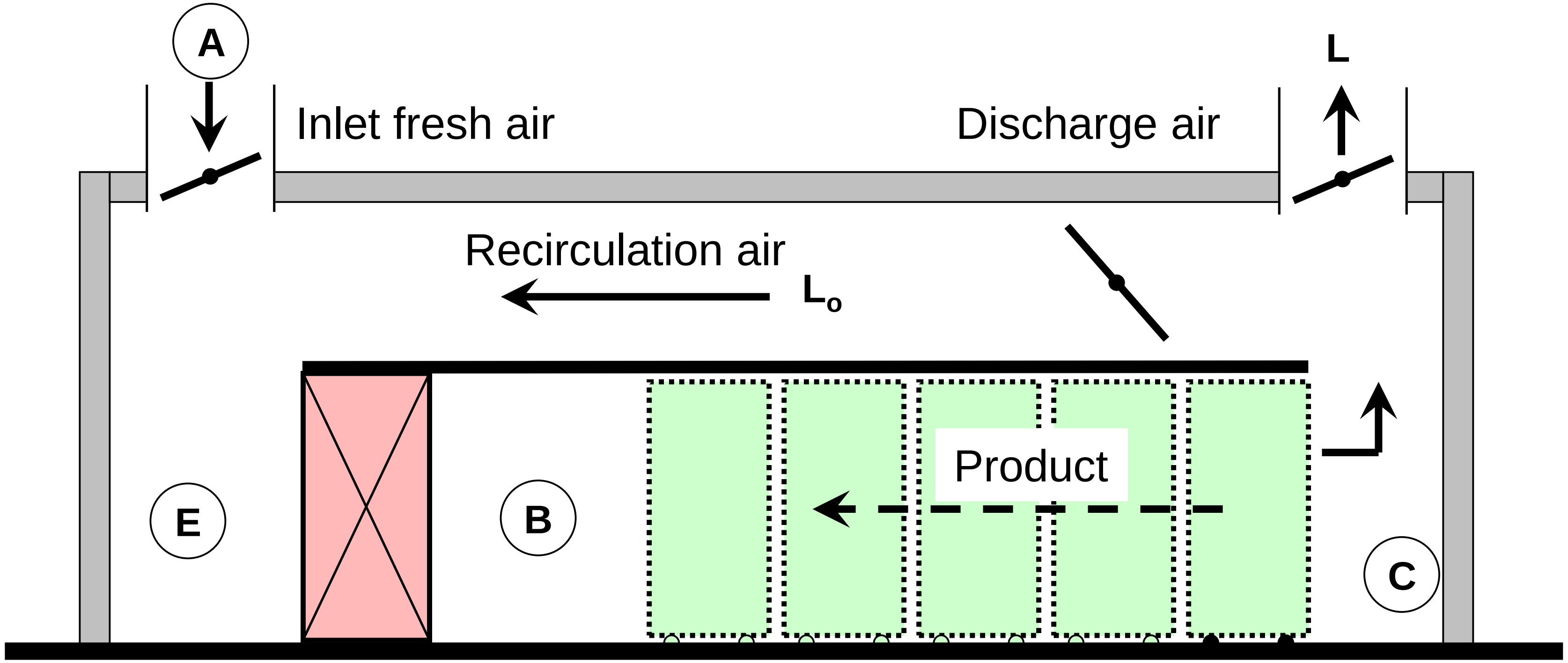
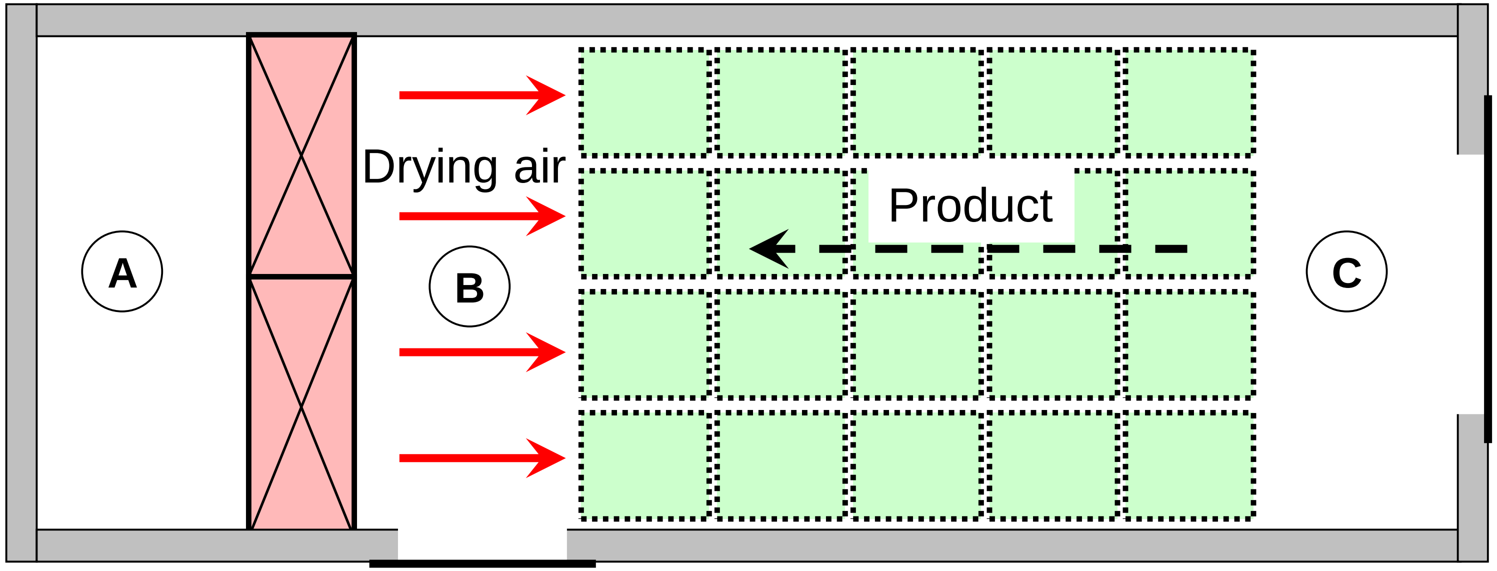
Drying of cod at the clips of west Norway

Traditional tunnel dryers (Hordetørke)



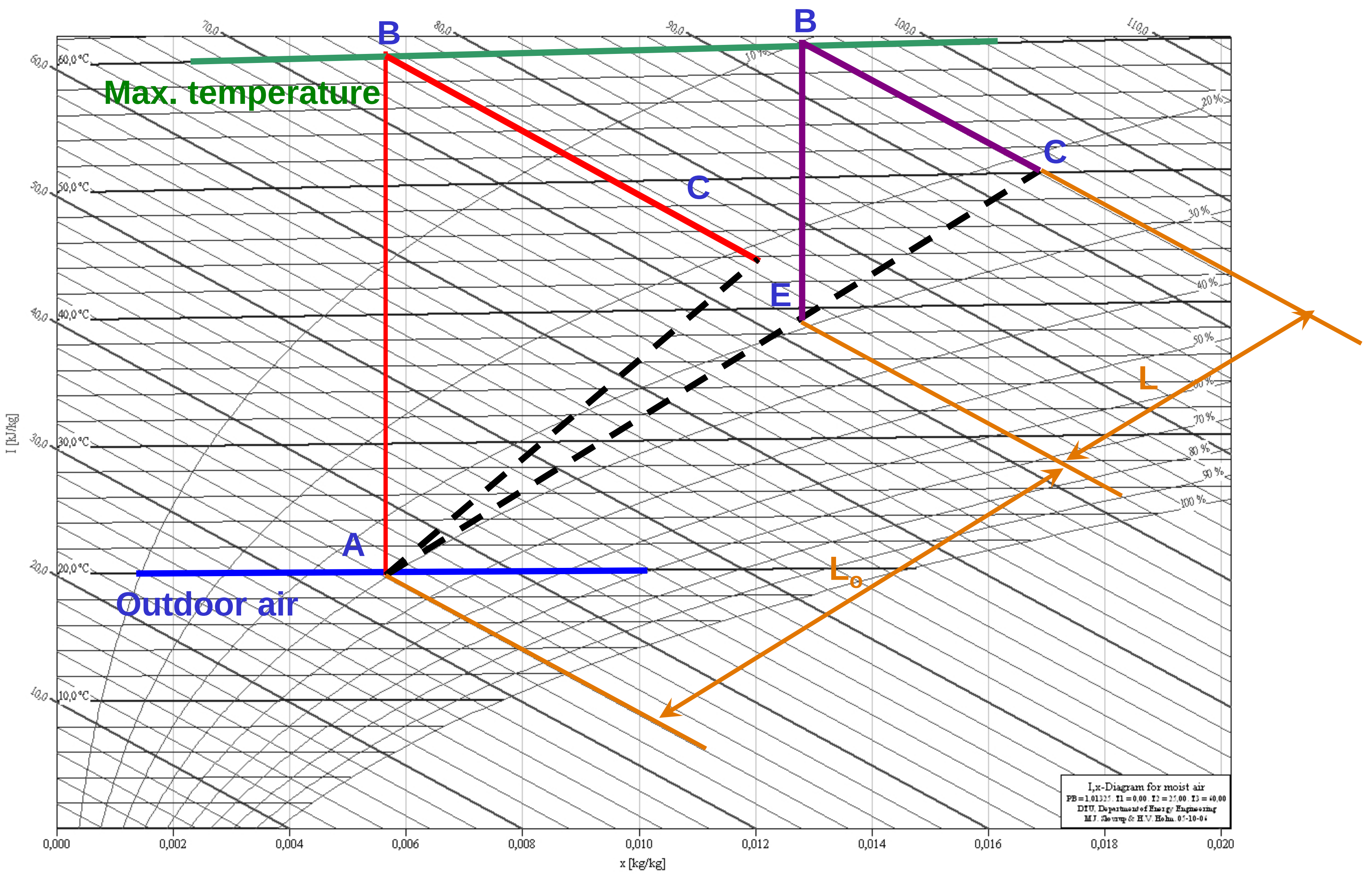
Side view

Traditional tunnel dryers (Hordetørke)

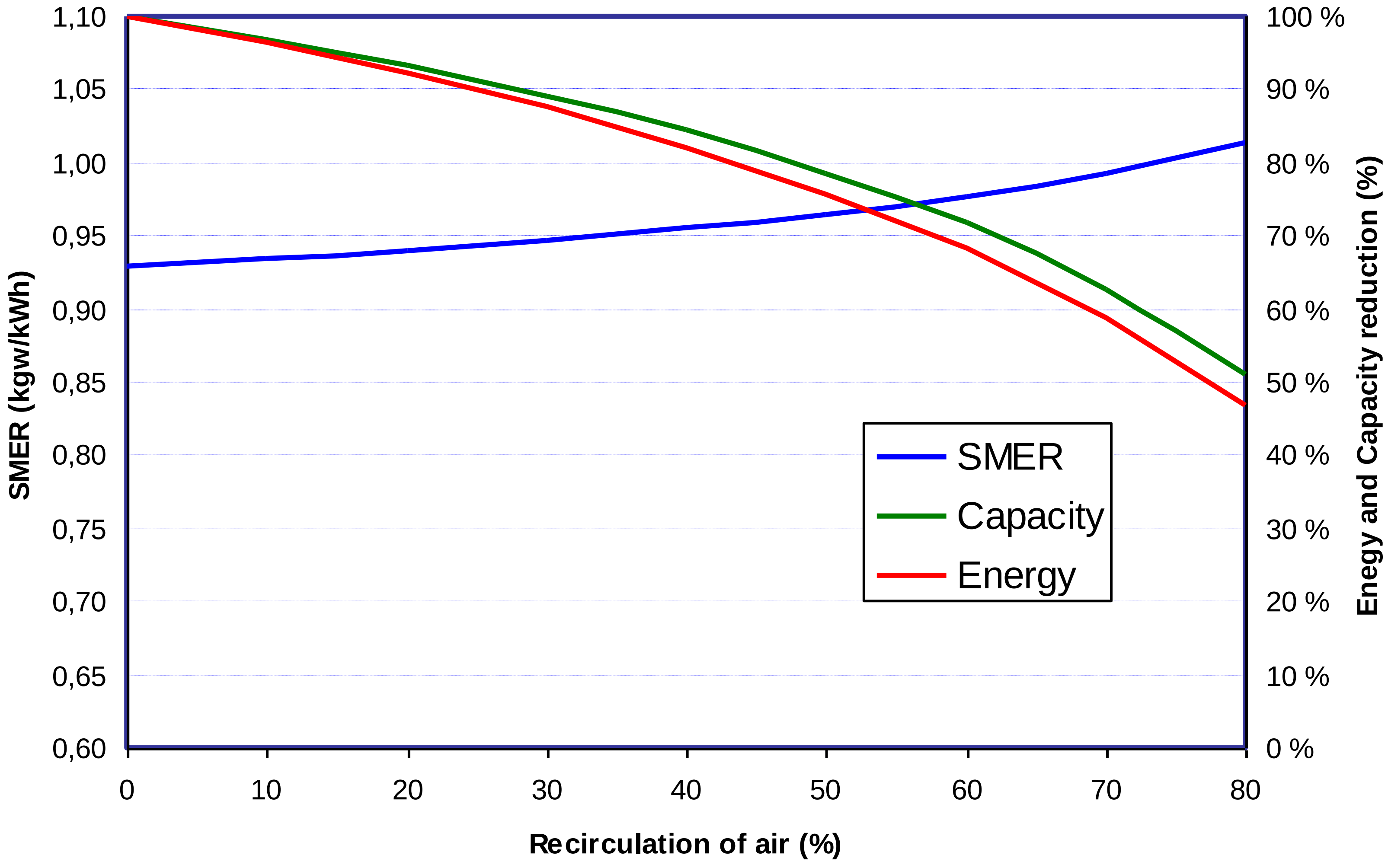


Top view

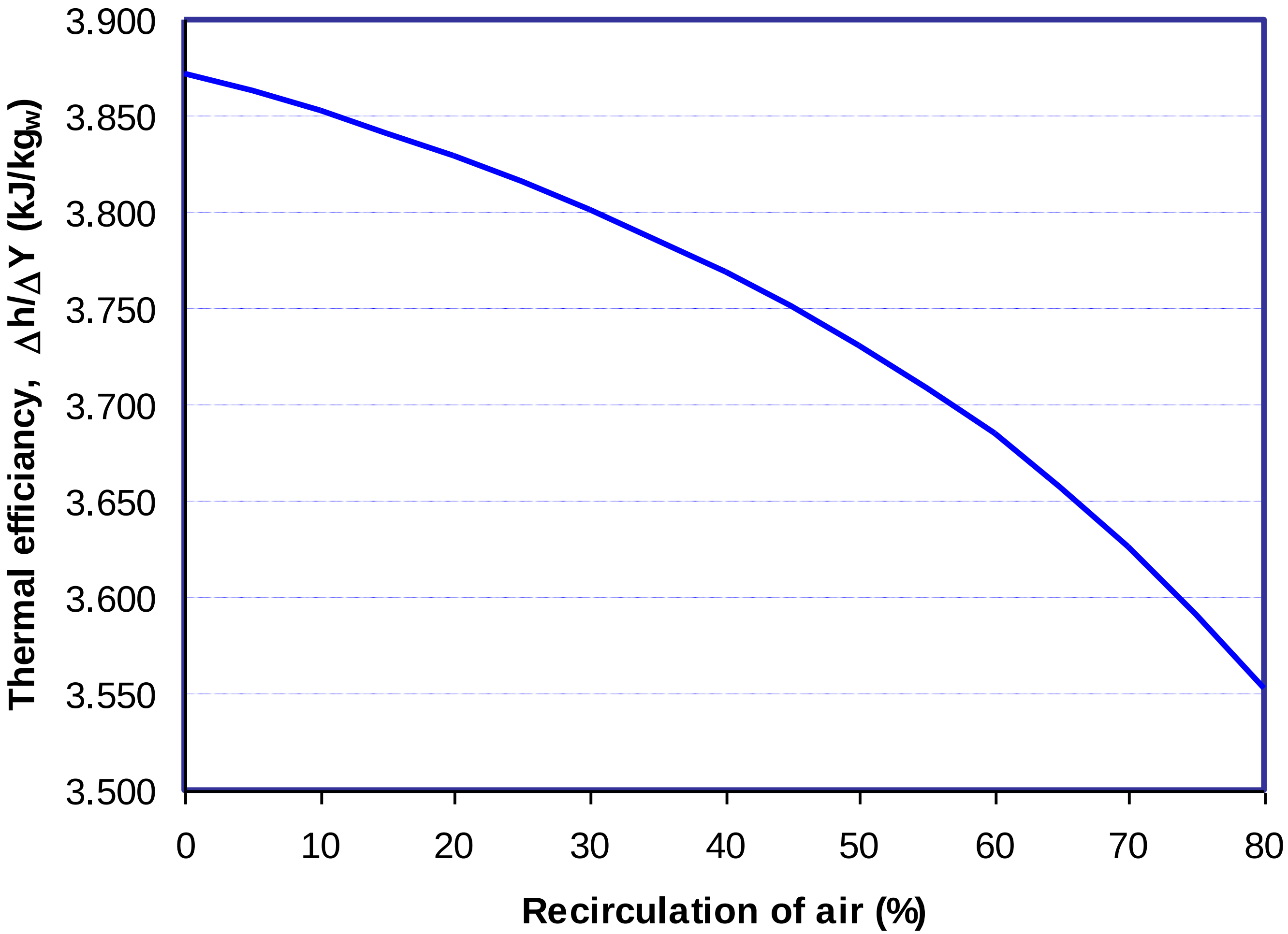
Hot air dryers



Influence of recirculation of air



Reduction in thermal efficiency



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Heat pump drying - Status

- **HP tunnel dryers**

  Have successfully been designed, dimensioned and installed in Norway for drying of fish products (70 industrial plants in Norway)

- **HP fluidized bed dryers**

  By using drying temperatures below and above the freezing point, the rehydration, colour, taste and bulk density of food products can be regulated. Medicine, pharmaceutical and biotechnological products can be dried without loss in biological activity (5 units in Norway, 1 very large HPD plant constructed in Hungary)

- **Non-adiabatic HP fluidizes bed dryers**

  HP condenser is put in the fluidized bed to increase the drying capacity (1 unit in Norway)

Advantages with heat pumps in combination with driers

- **Product quality**

  Drying temperatures from -20ºC to +100ºC secure high quality for heat sensitive products

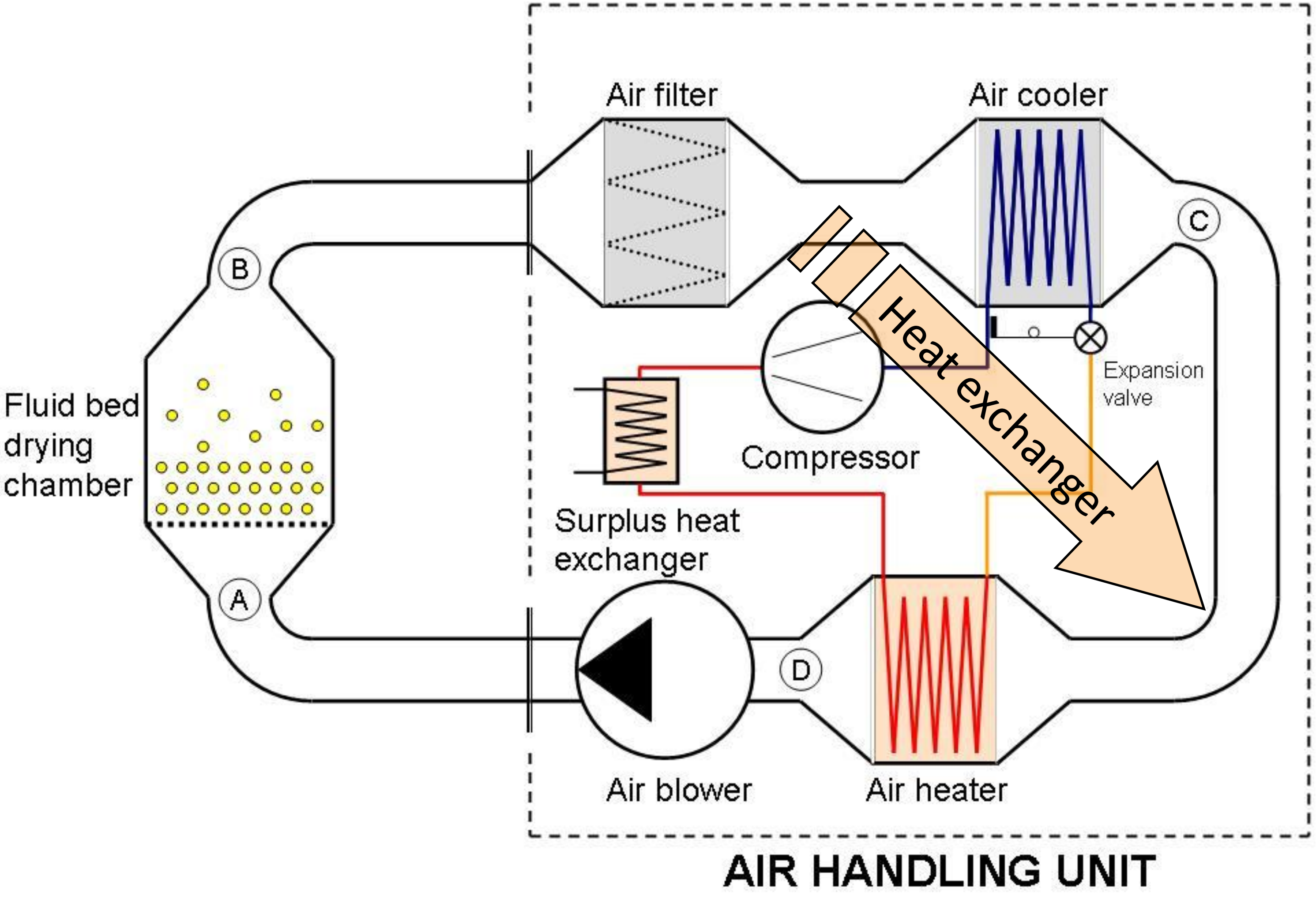
- **Environmental aspects**

  Recirculation of drying gas (air or inert gas) eliminates waste gas from the dryer. Electric driven machinery have not emissions of CO_2, SO_2 or NO_x

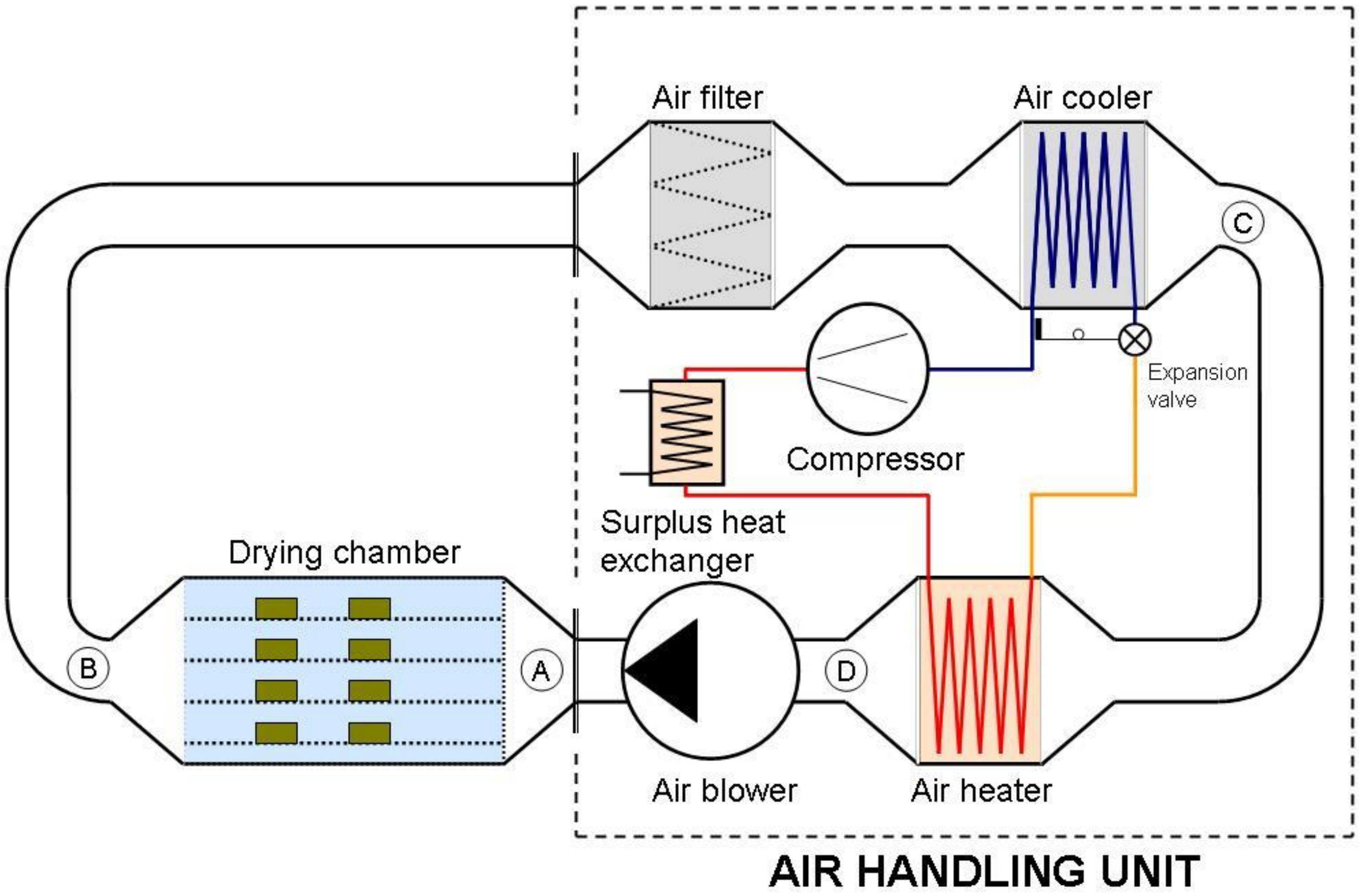
- **Energy aspects**

  Energy consumptions for a heat pump dryer are typical 20% to 35% compared to conventional dryers

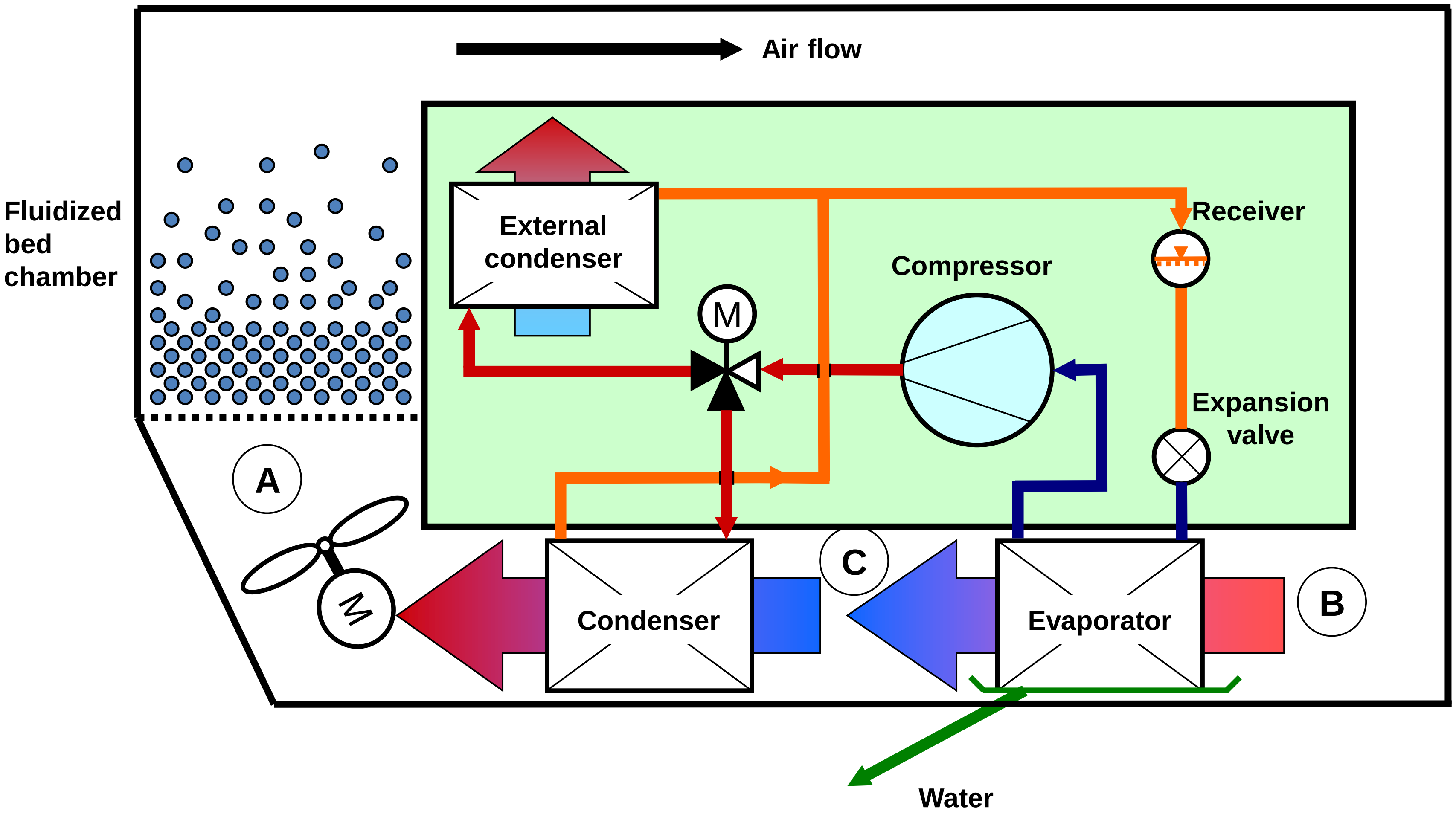
Fluidized bed heat pump dryer



Tunnel dryer with heat pump

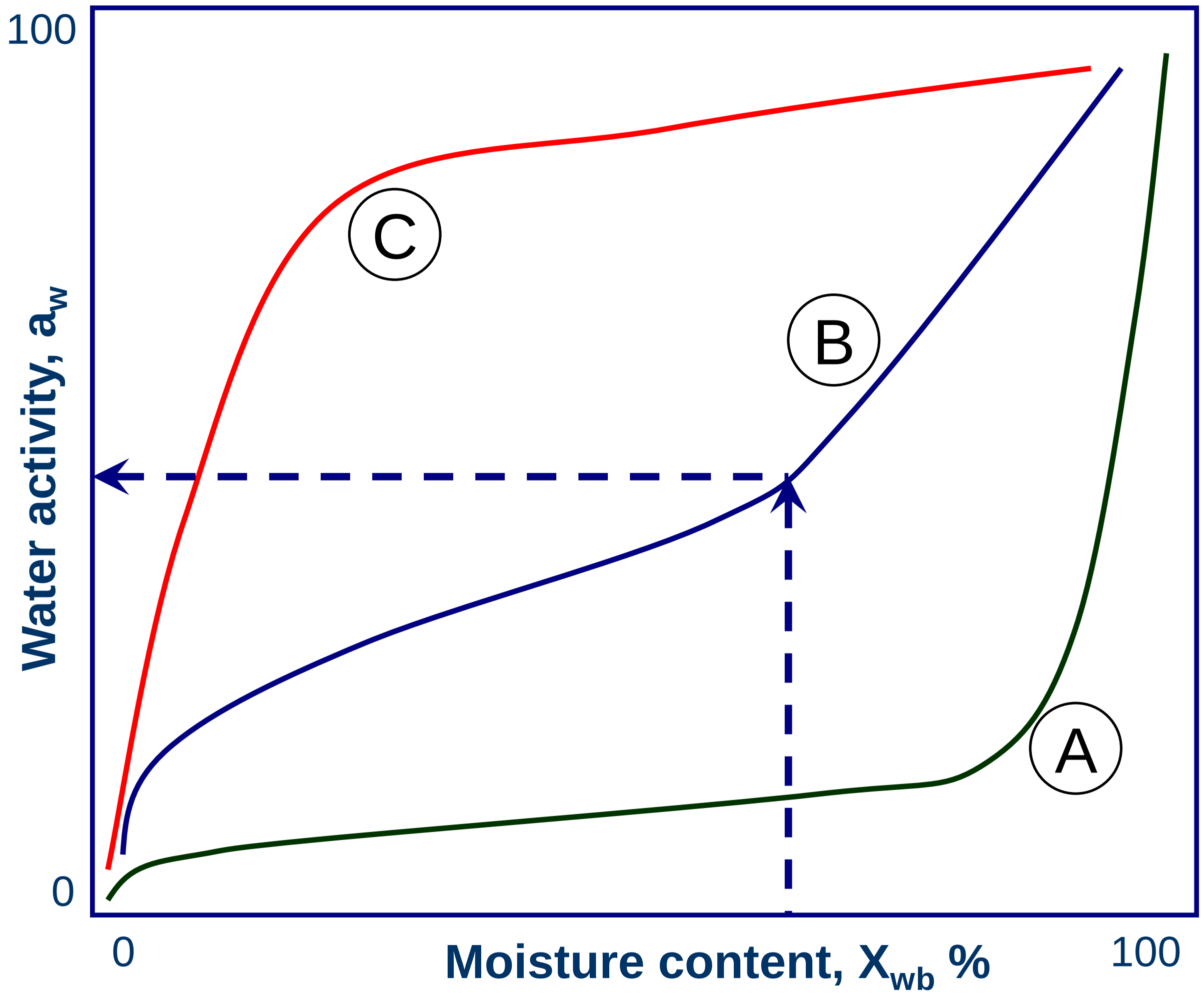


Schematic layout of a heat pump fluidised bed dryer



Water activity, a_w

(product in equilibrium with the ambient air)



$$a_w = \frac{p}{p_{w'}}$$

A), B) and C) shows different types of materials/products

Water activity vs. relative humidity

Water activity $a_w = \frac{p_p}{p_{w'}}$

Relativ humidity $\phi = \frac{p_a}{p_{w'}}$

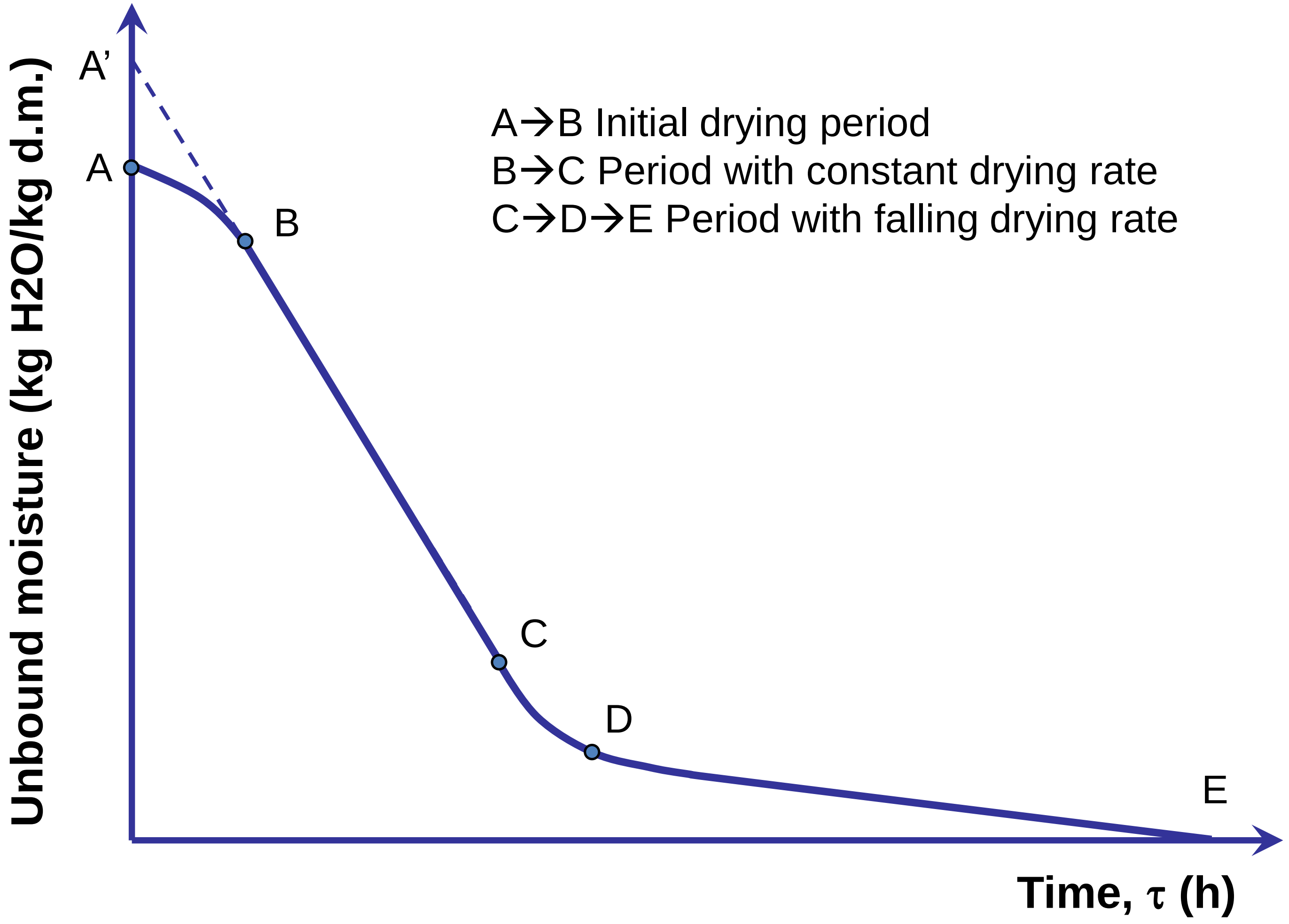
p_p: vapor pressure close to product surface

p_a: vapor pressure in free air

$p_{w'}$: saturated vapor pressure for water at t

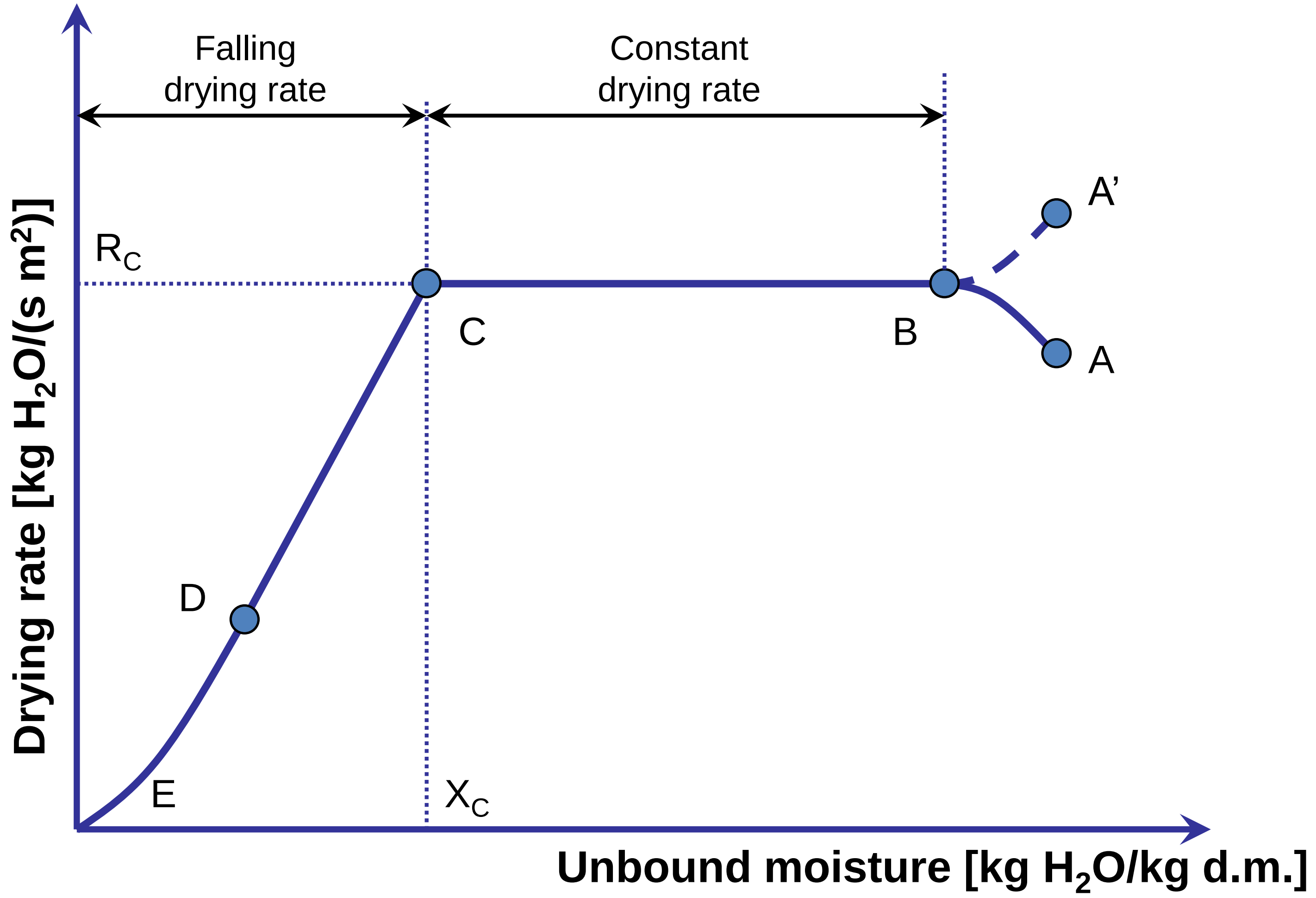
$a_w > \phi$ Product will dry (loosing moisture/weight)
$a_w = \phi$ Product is in equilibrium (is not loosing or gaining weight - stable)
$a_w < \phi$ Product will gain water/moisture from air (weight is increasing)

General drying curve with different drying phases



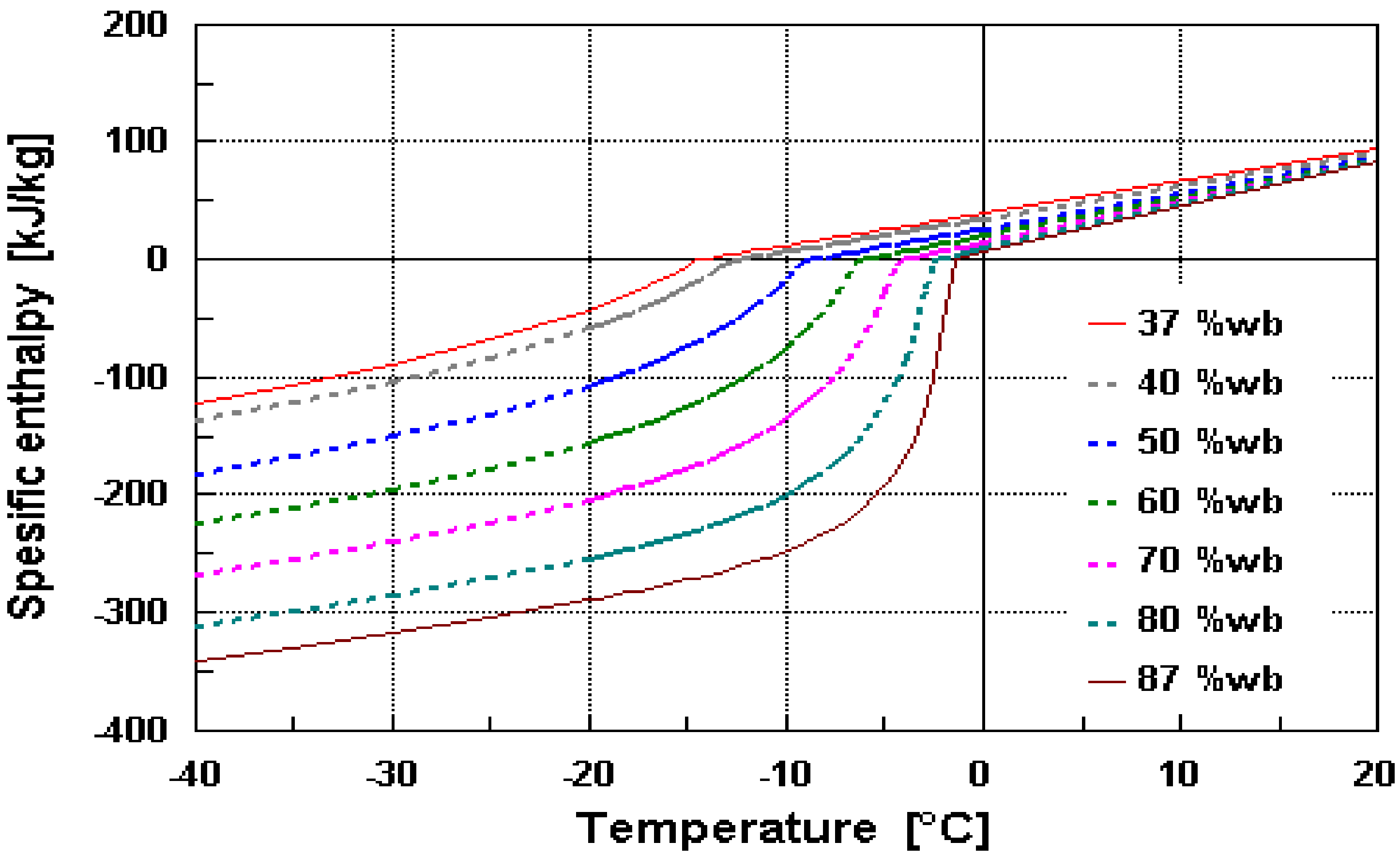
A→B Initial drying period
B→C Period with constant drying rate
C→D→E Period with falling drying rate

General drying rate curves



Change in initial freezing point with reduction of water content

Apple’s enthalpy family curves



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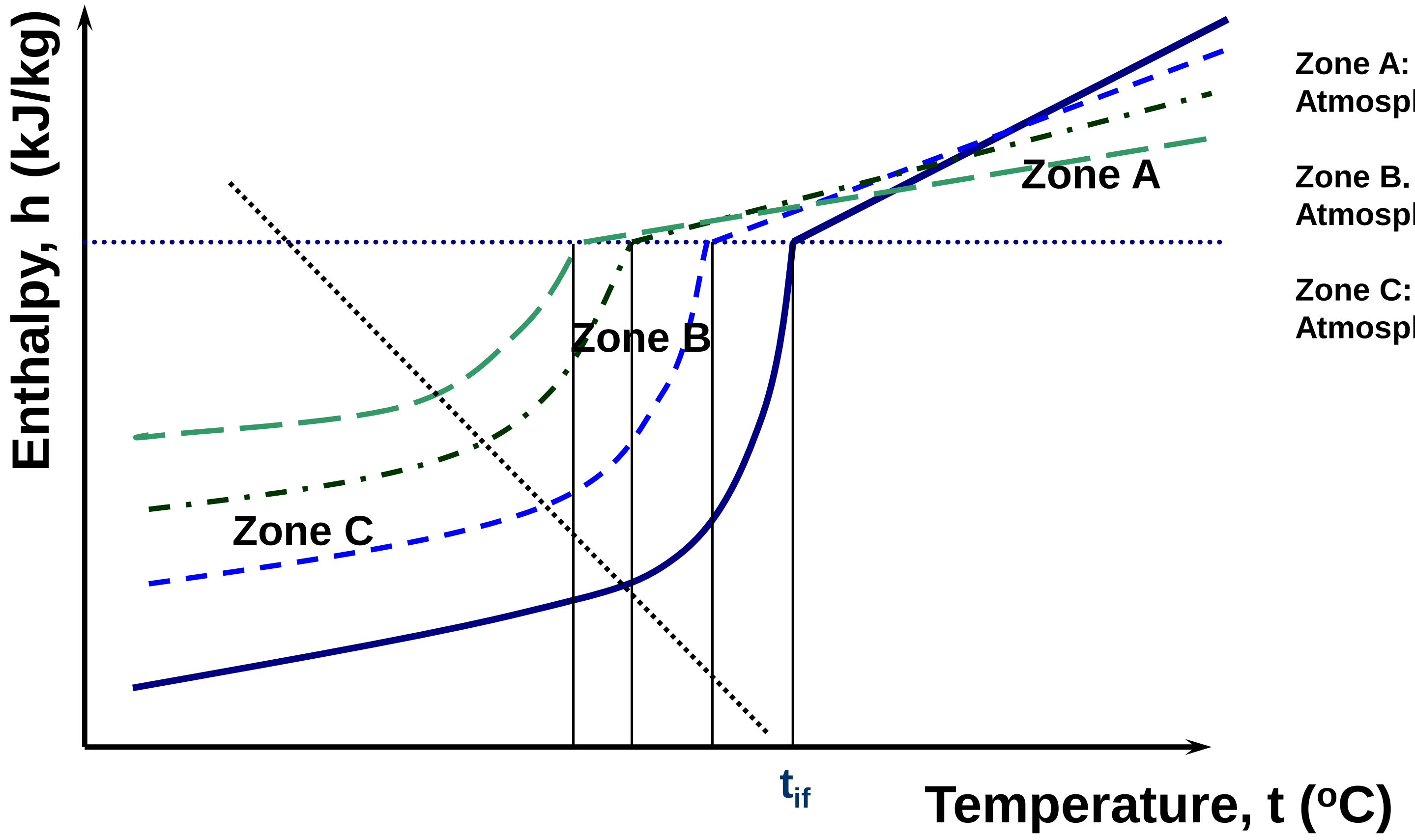
Enthalpy as a function of temperature and water content



Zone A:
Atmospheric drying – unfrozen

Zone B.
Atmospheric drying – partly frozen

Zone C:
Atmospheric drying - frozen

Design rules for heat pump dryers

- Continuous operation
- Countercurrent operation (air – product)
- Inlet air temperature to the drying chamber as high as possible
- Avoid over dimensioning the refrigeration capacity
- Provide for the air flows over product without possibility to by-pass
- Optimal SMER

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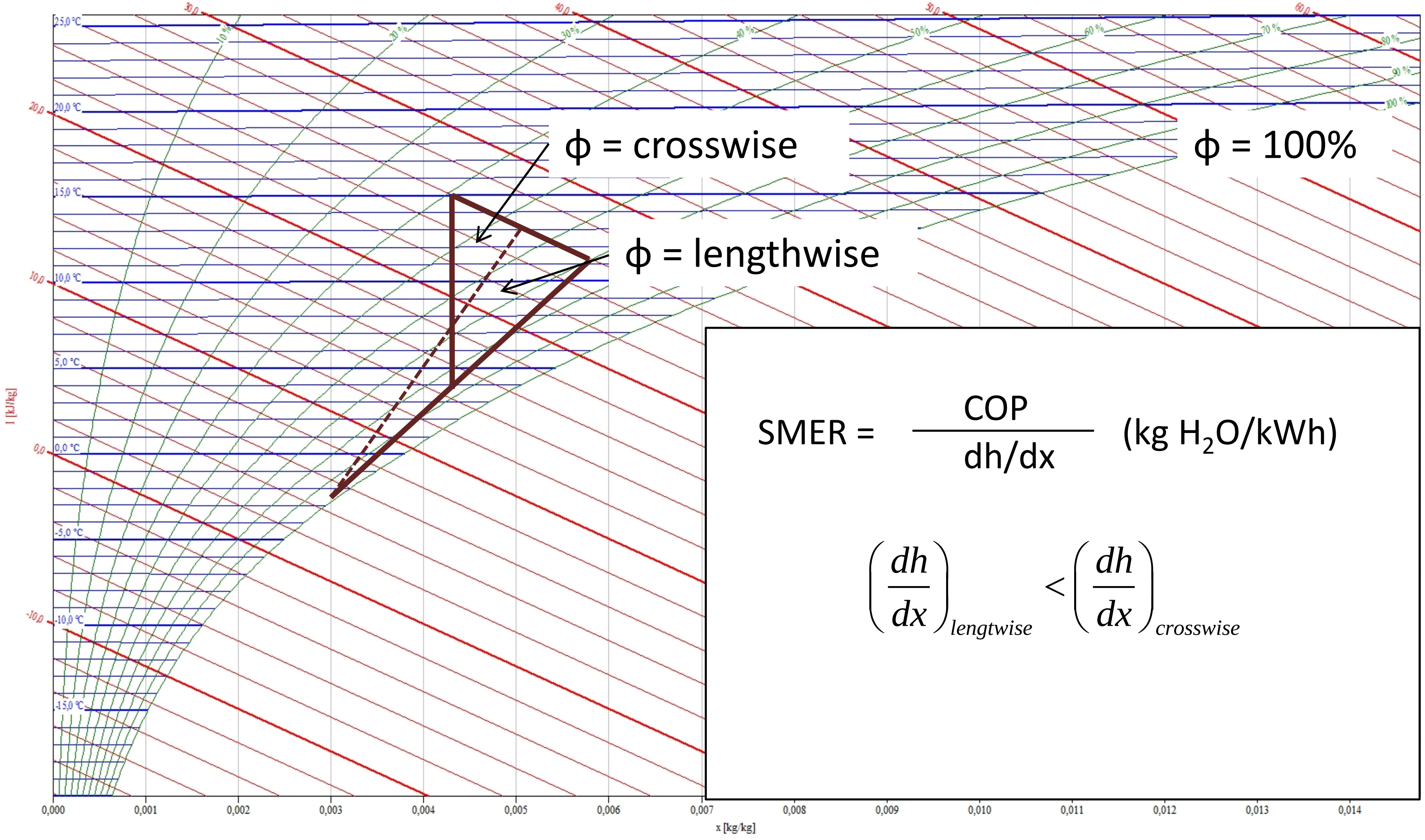
Design of heat pump dryers

Lengthwise countercurrent drying

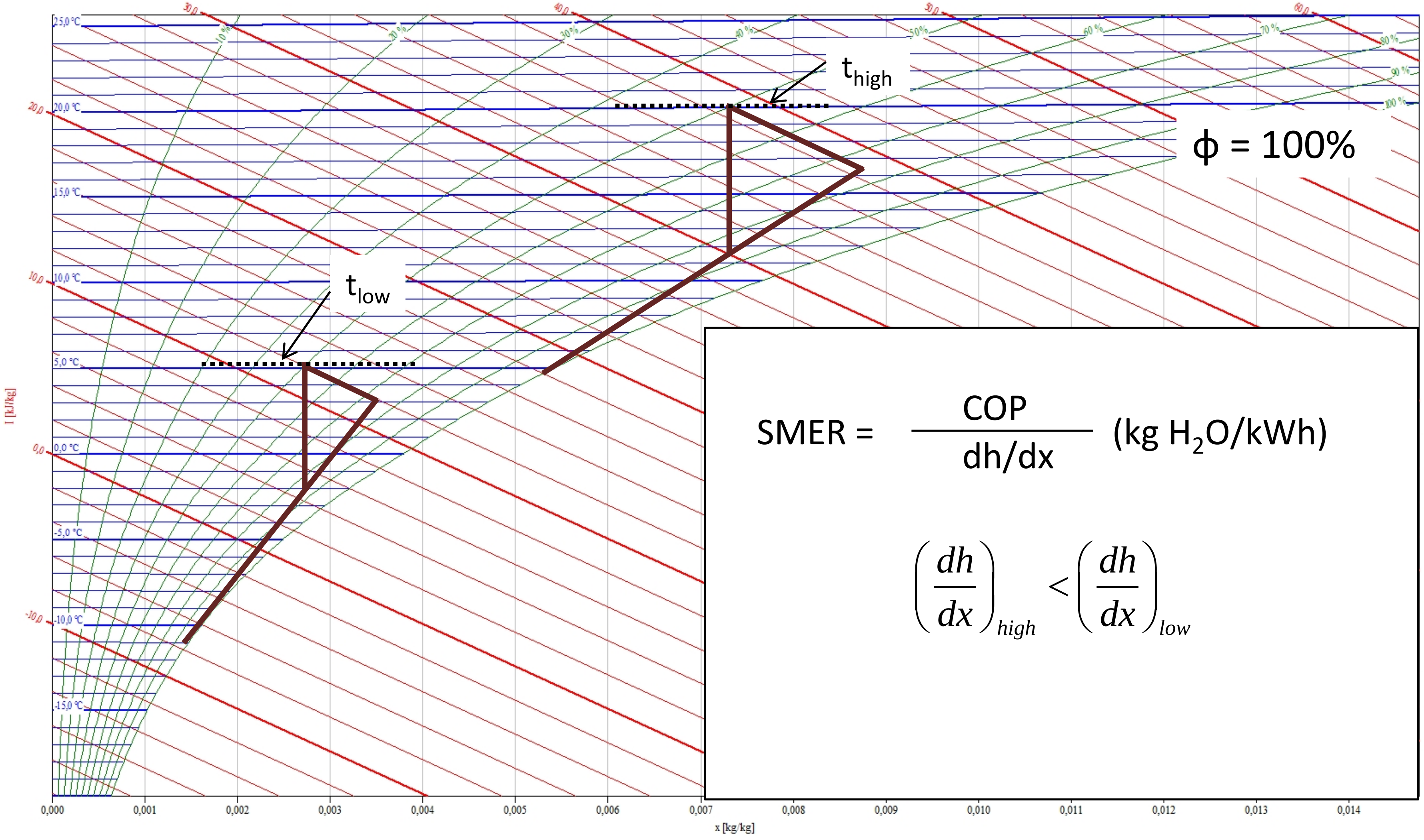


$$\text{SMER} = \frac{\text{COP}}{dh/dx} \quad (\text{kg } H_2O/\text{kWh})$$

$$\left(\frac{dh}{dx}\right)_{lengtwise} < \left(\frac{dh}{dx}\right)_{crosswise}$$

Design of heat pump dryers

As high inlet temperature as possible

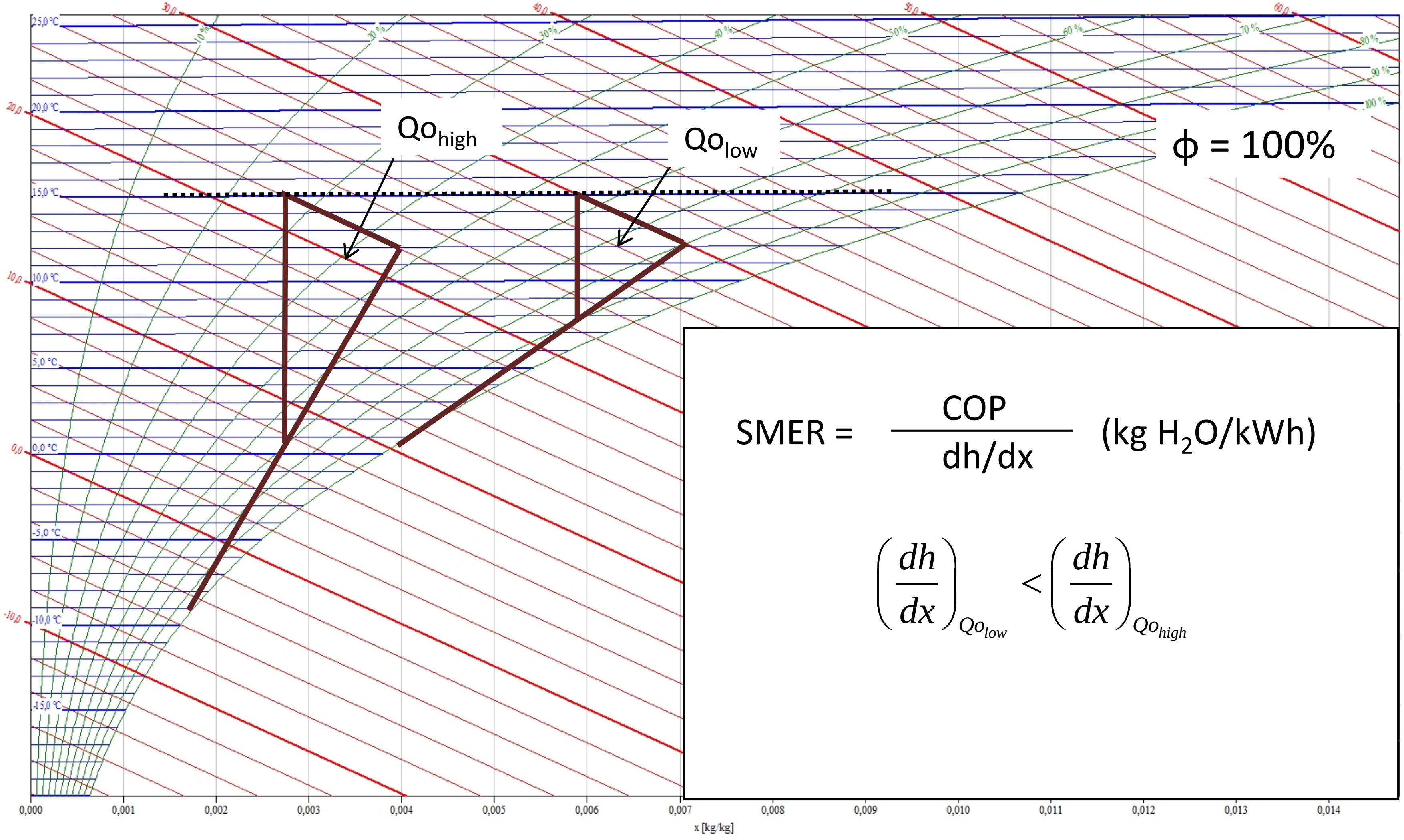


$$\text{SMER} = \frac{\text{COP}}{dh/dx} \quad (\text{kg } H_2O/\text{kWh})$$

$$\left(\frac{dh}{dx}\right)_{high} < \left(\frac{dh}{dx}\right)_{low}$$

Design of heat pump dryers

Heat pump capacity: Q_o

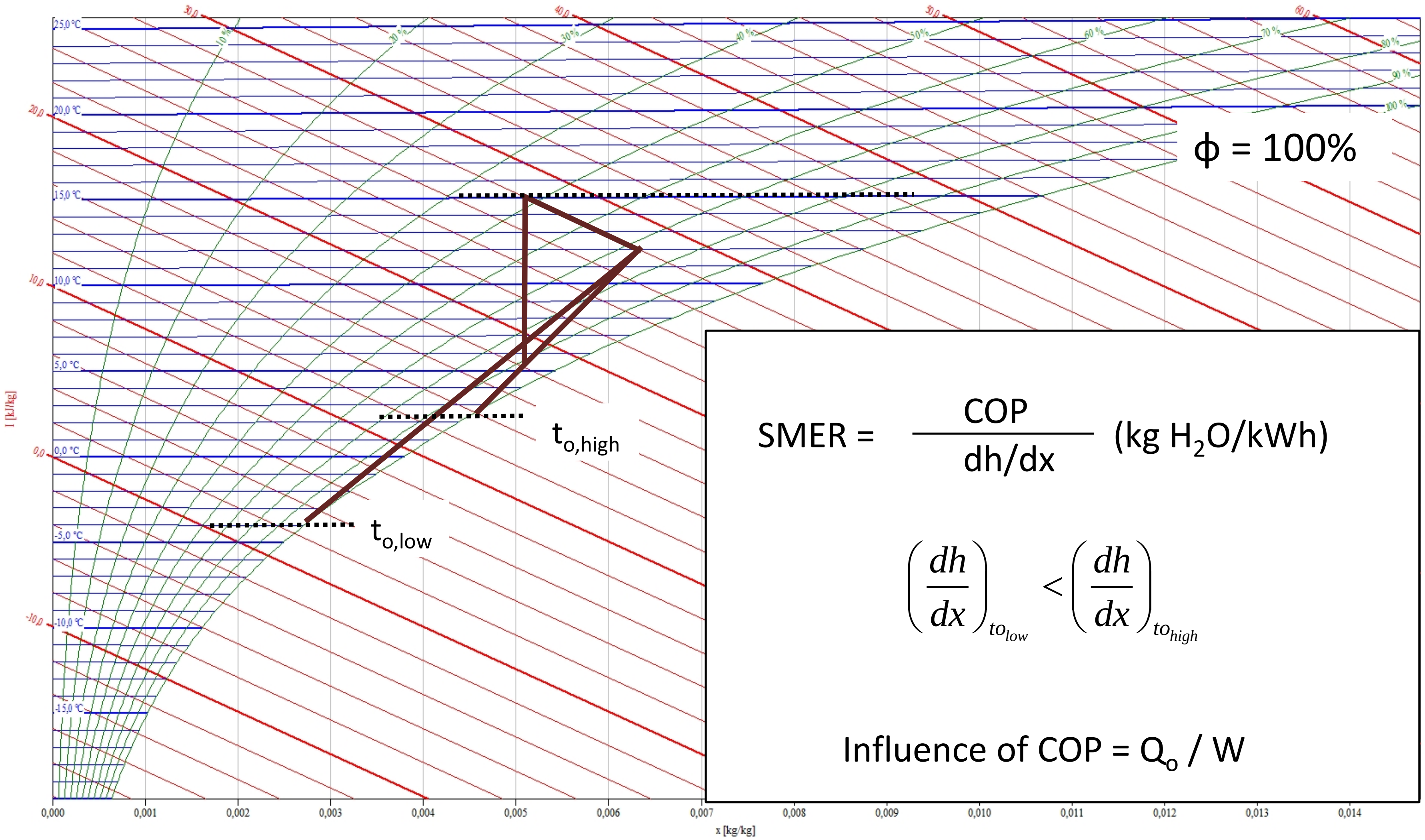


$$SMER = \frac{COP}{dh/dx} \quad (kg\ H_2O/kWh)$$

$$\left(\frac{dh}{dx}\right)_{Qo_{low}} < \left(\frac{dh}{dx}\right)_{Qo_{high}}$$

Design of heat pump dryers

The choice of t_o, t_c

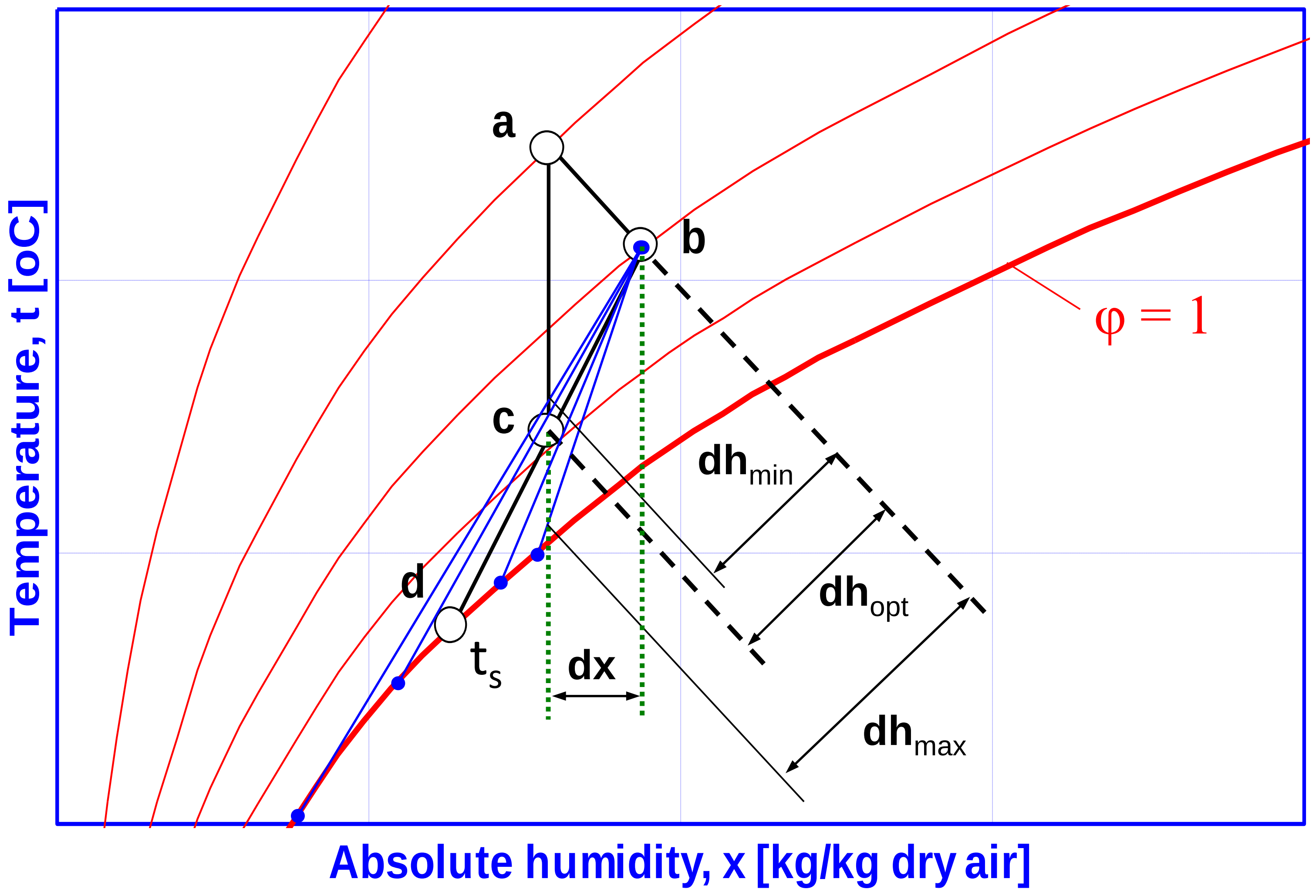


$$\text{SMER} = \frac{\text{COP}}{dh/dx} \quad (\text{kg } H_2O/\text{kWh})$$

$$\left(\frac{dh}{dx}\right)_{to_{low}} < \left(\frac{dh}{dx}\right)_{to_{high}}$$

Influence of COP = Q_o / W

Mollier diagram



Equations

Specific **M**oisture **E**xtraction **R**ate

$$SMER = COP / (dh/dx)$$ [kg water/kWh]

Coefficient **O**f **P**erformance

$$COP = Q_o / (W_{compr} + W_{fan})$$ [-]

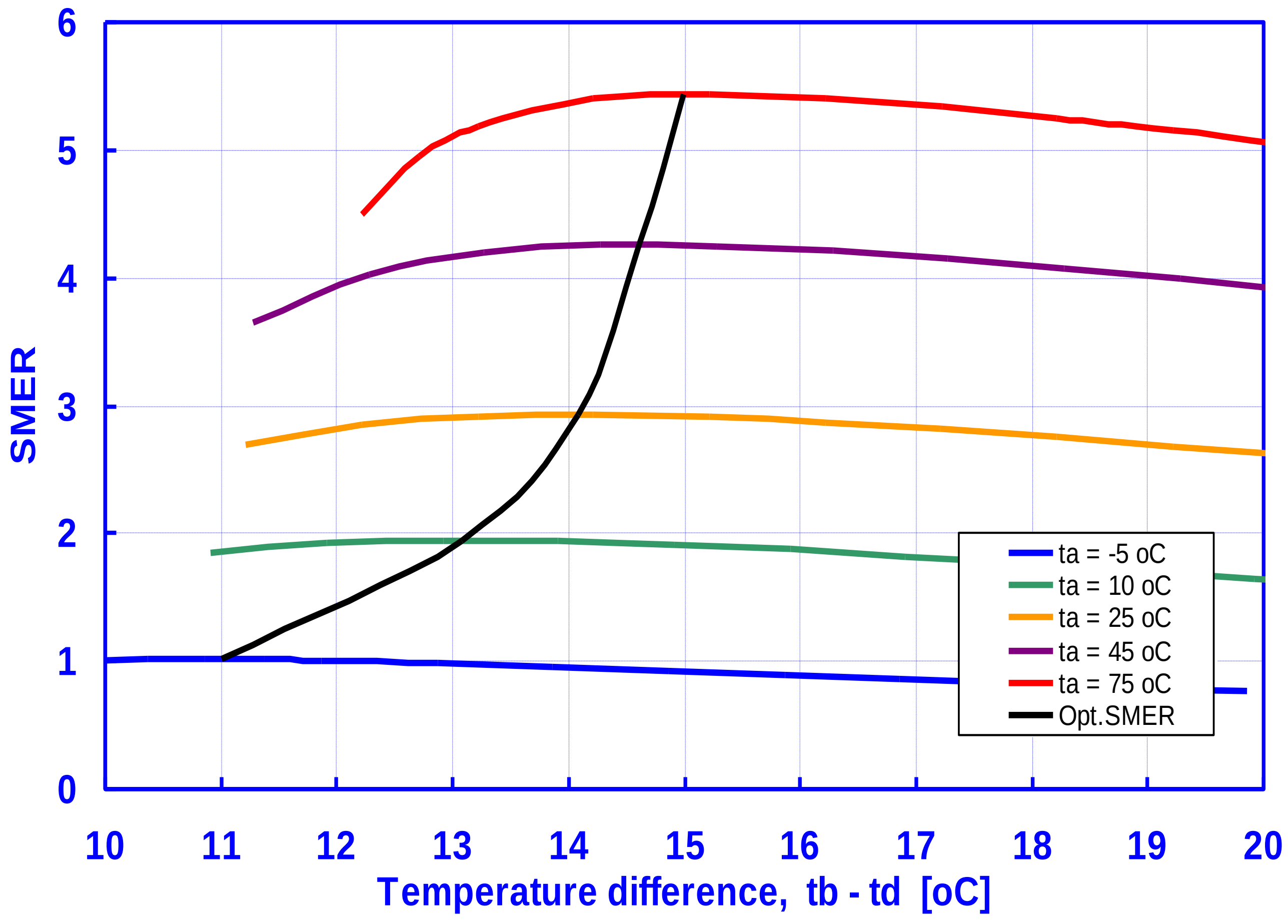
Evaporator capacity

$$Q_o = m_a * (h_b - h_c)$$ [kW]

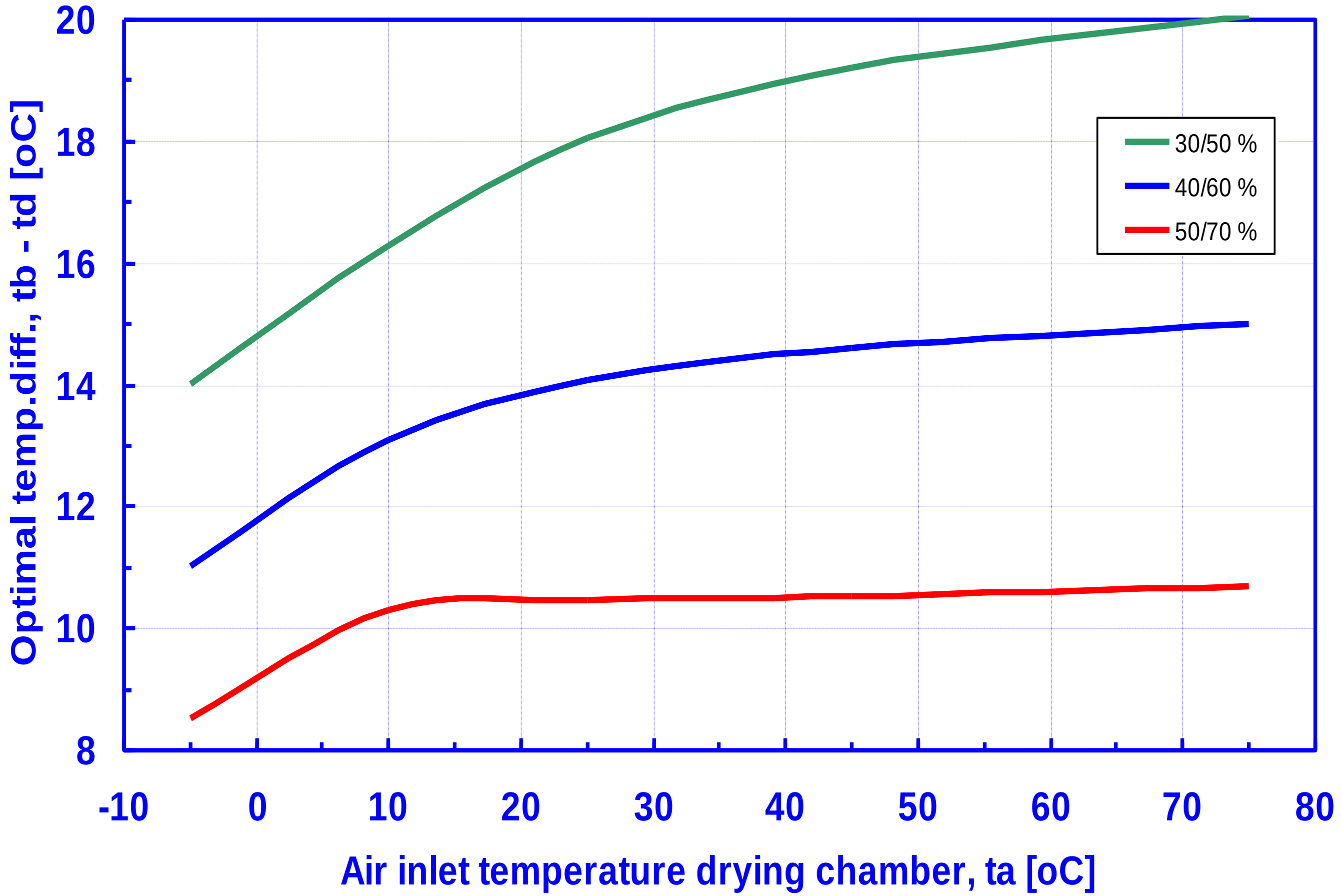
Compressor power

$$W_{compr} = (Q_o / dh_{re}) * (dh_{is}/\eta_{is})$$ [kW]

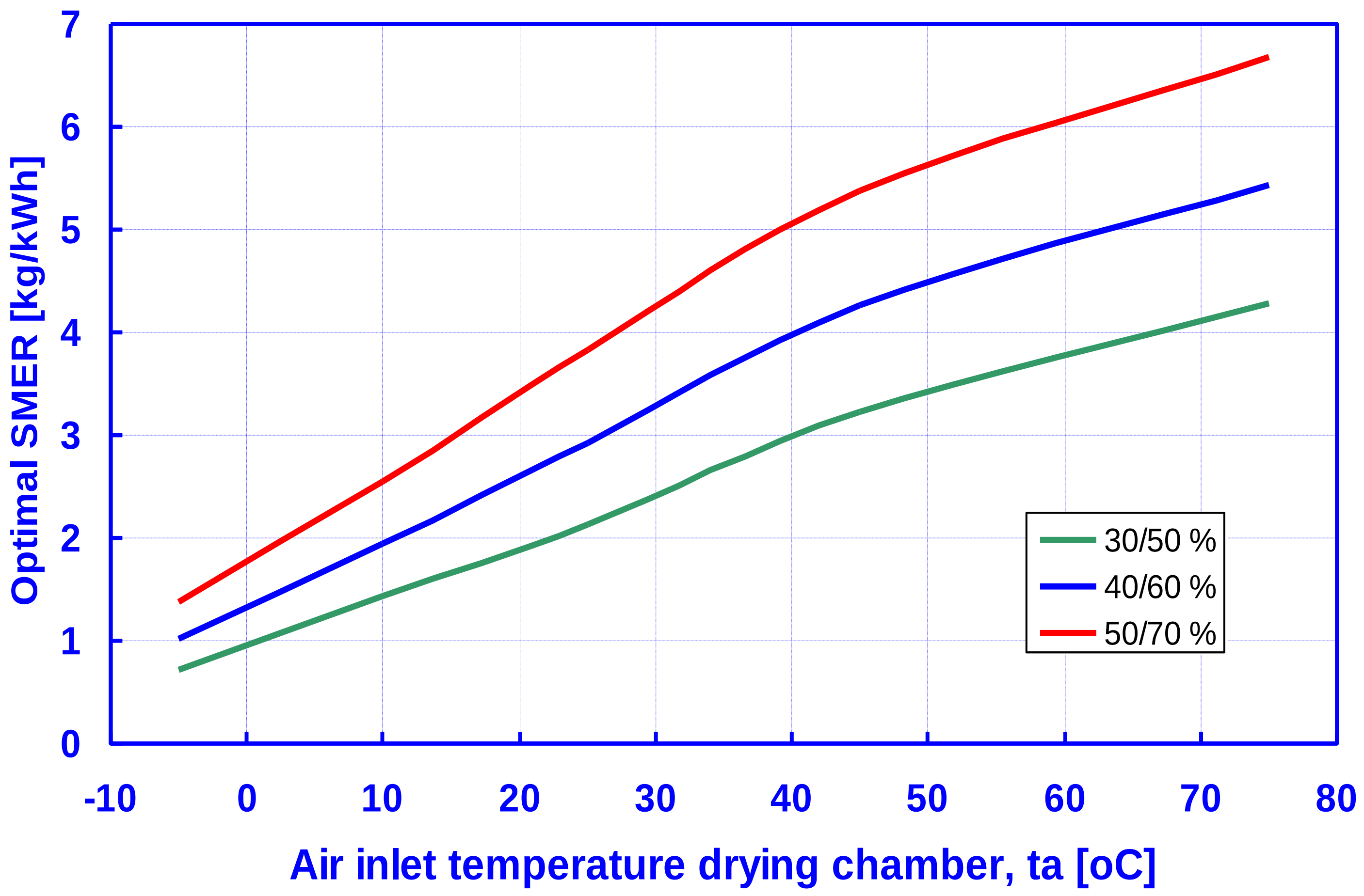
SMER (40/60%, R717)



Optimal temperature difference (R717)



Optimal SMER (R717)



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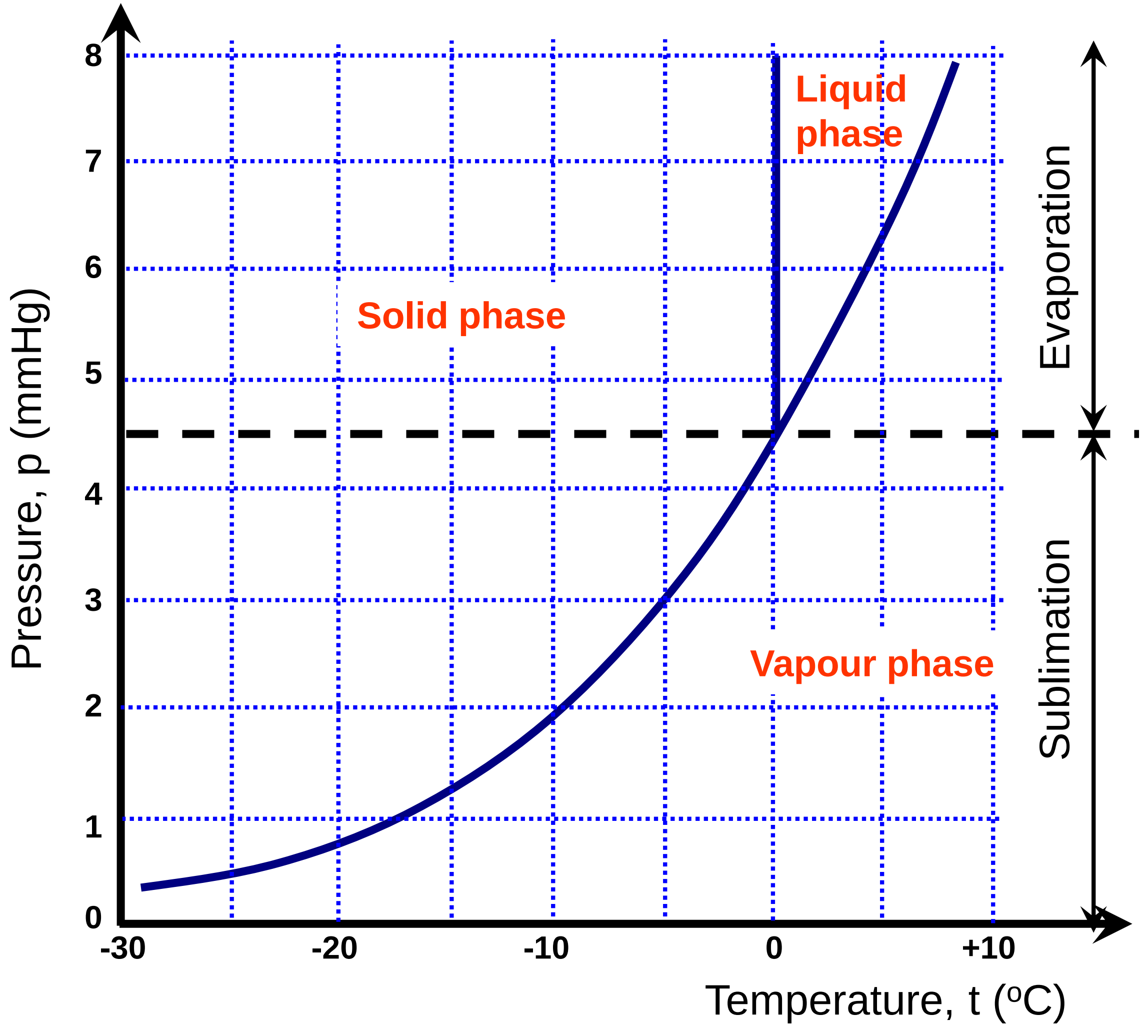
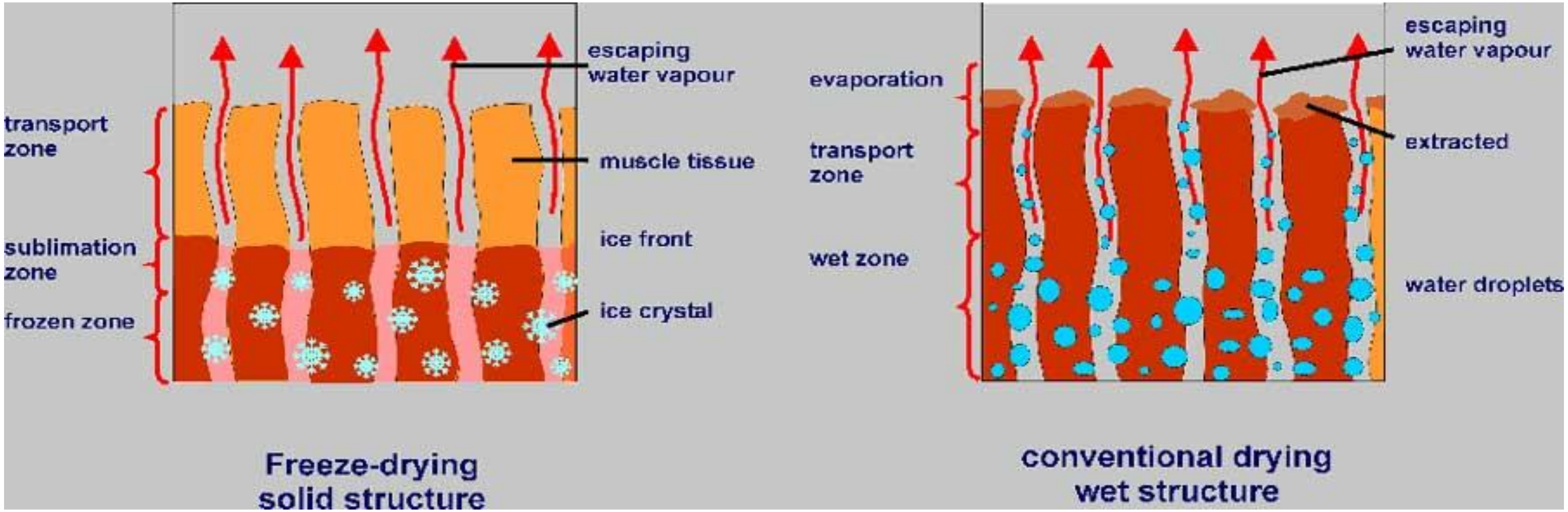
Phase diagram for water



Freeze drying, solid structure



- Vacuum freeze drying are carried out by first freeze the product to achieve a solid structure and than dry at pressure lower than the triple point. The drying will occur by sublimation – ice crystals evaporates directly without melting
- Only water vapor will be transported in the product and cause no internal transport of dissolved components like sugar, salt etc.

- Conventional convective drying at air temperatures above 0^{o}C will a larger part of the water removal be done by evaporation from the surface of the product. Liquid will be transported from internal out to the outer layers of the product. This will cause a internal transport of dissolved components.

Benefits with vacuum freeze drying

- Tastes as fresh
  - Will retain taste and nutrition's. Only water will be removed. (some light volatiles will be lost)
- Look fresh
  - Will retain shape and color
- Lower weight than fresh product
  - Freeze drying will normally remove up to 98% of the water. That means the weight of the product will be reduced with 90%
- Can be stored like fresh
  - Can be stored at room temperatures

Benefits and drawbacks compared with traditionally conservation methods

- Retention of morphologic, biochemical and immunological properties
- High viability / activity of biological components
- Lower temperatures, oxygen level and operational conditions than other comparable methods
- High recovery of volatile components
- Retention of structure, surface area
- High yield
- Long shelf life
- Reduced weight at storage, transport and handling

Drawbacks

- Higher investment costs
- Higher energy consumption
- Higher maintenance costs

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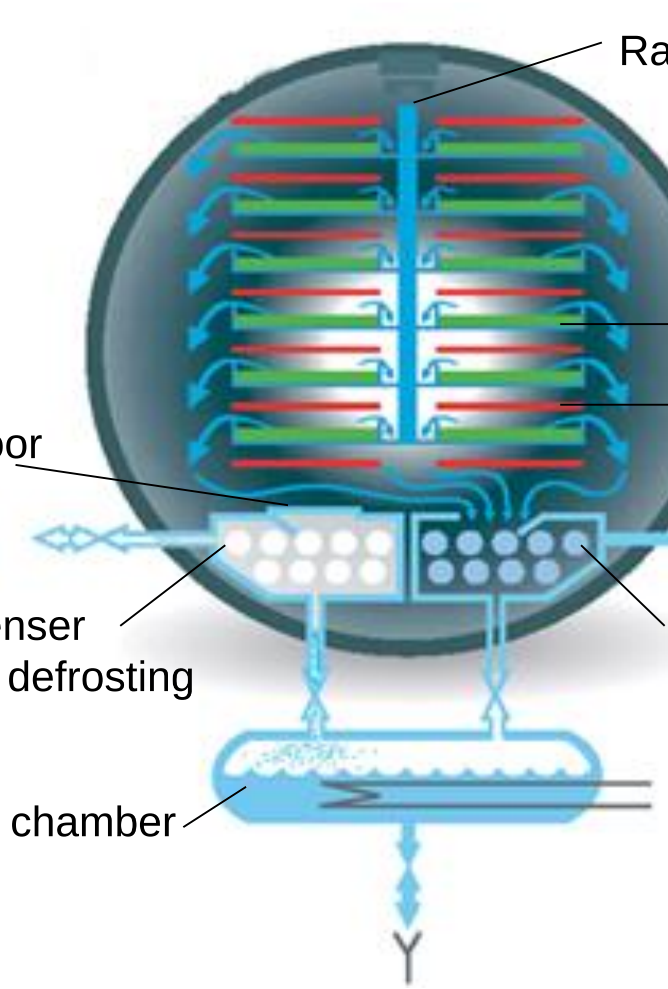
Vacuum freeze drying system based on heat radiation



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Advantages with Atmospheric Freeze Drying

- **Constant or step vice temperature program**
  - -15ºC to +30ºC
- **Product quality control of**
  - Shrinkage
  - Rehydration ability
  - Color
  - Taste
  - Aroma
- **Close to vacuum freeze drying qualities**
  - Peas (Industrialized)
  - Corn (Industrialized)
  - Vegetables, fruits, berries, herbs (Tested)
  - Biological active components (Tested)

Actual products

- **Fish/meat** (snacks, fast food etc.)
  Rehydration, colour, taste, aroma
- **Peas, corn** (bag food, quick preparation)
  Rehydration, formation of cracks, colour, taste
- **Herbs** (ethereal oils, spice)
  Extraction level, taste, aroma, appearance, biological effect
- **Berry, fruits** (breakfast cereals ingredients, ”topping”)
  Rehydration, colour, taste, aroma
- **Dairy** (bioactive products, aroma products)
  Biological activity, rancidity, taste

Scrimps dried at low and high temperature

Pieces of Cod dried at –5ºC and +30ºC

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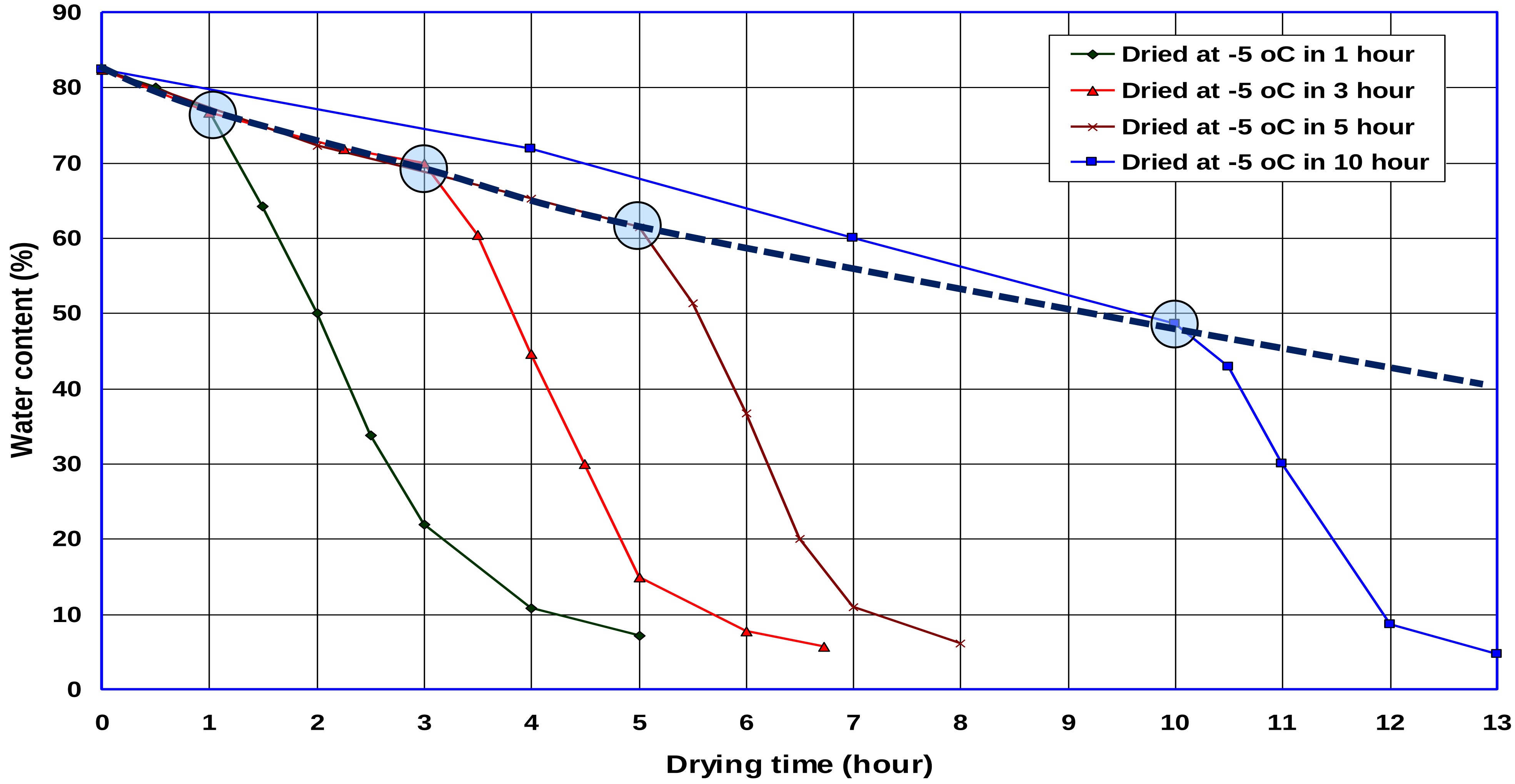
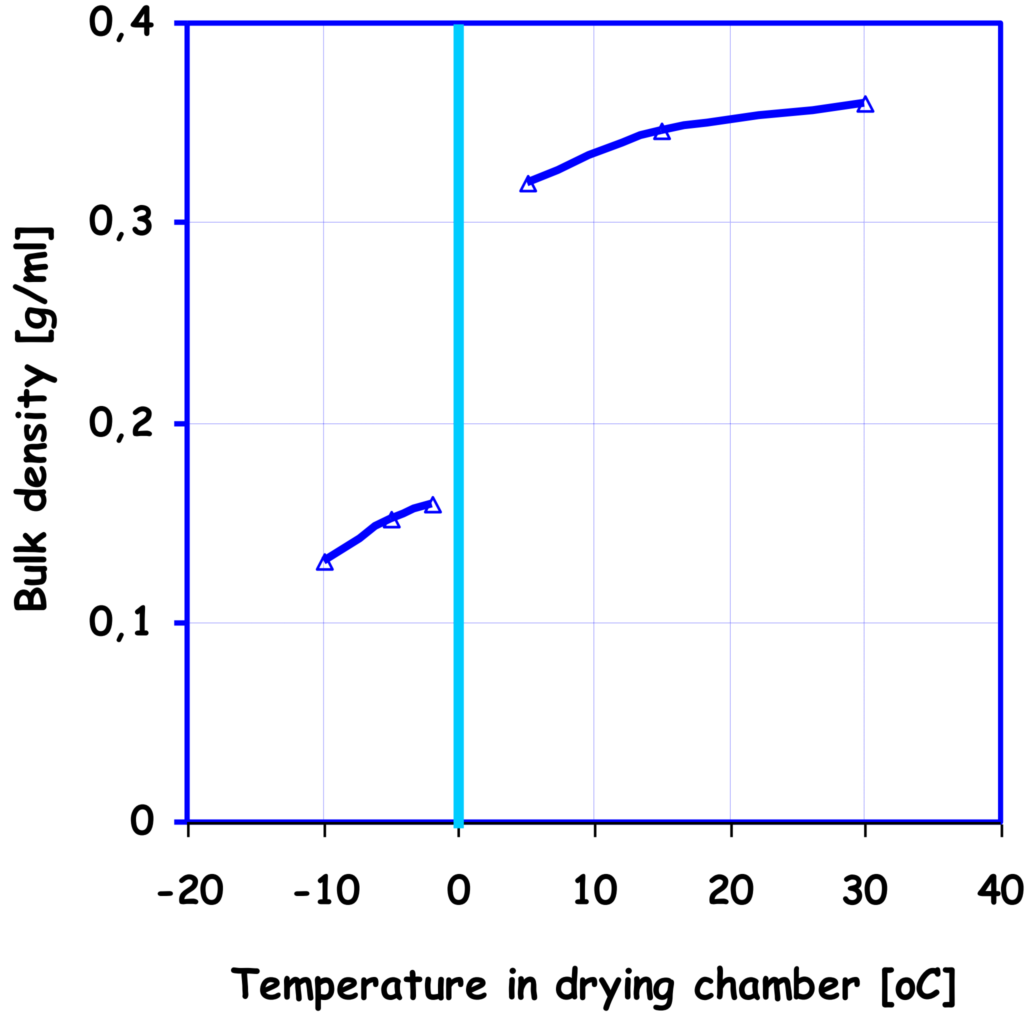
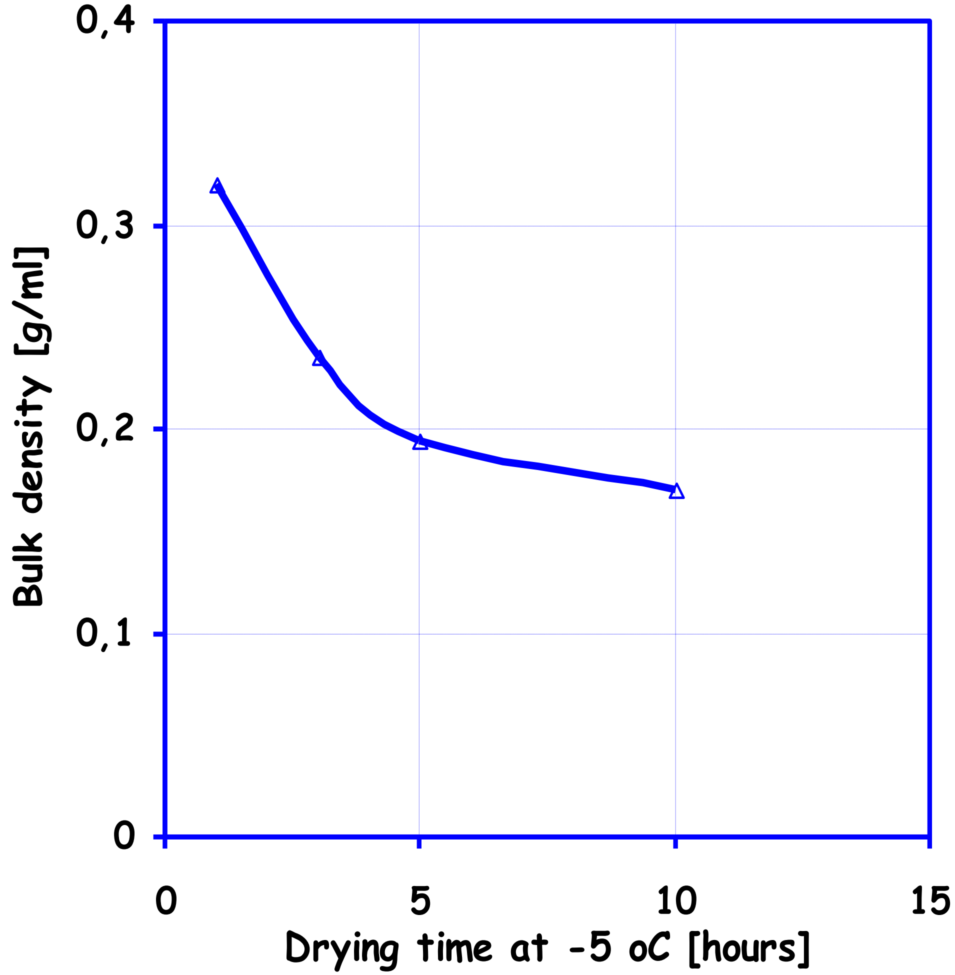
Drying curves - temperature program

Pieces of Cod (5*5*5 mm)



Bulk density of cod after drying





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Energy consumption in a heat pump dryer operated at a continued mode drying

Assumptions:

	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

$$SMER = \left(\frac{COP_{LT}}{(dh/dx)_{LT}}\right) * \left(\frac{\tau_{LT}}{\tau_{tot}}\right) + \left(\frac{COP_{HT}}{(dh/dx)_{HT}}\right) * \left(\frac{\tau_{HT}}{\tau_{tot}}\right)$$

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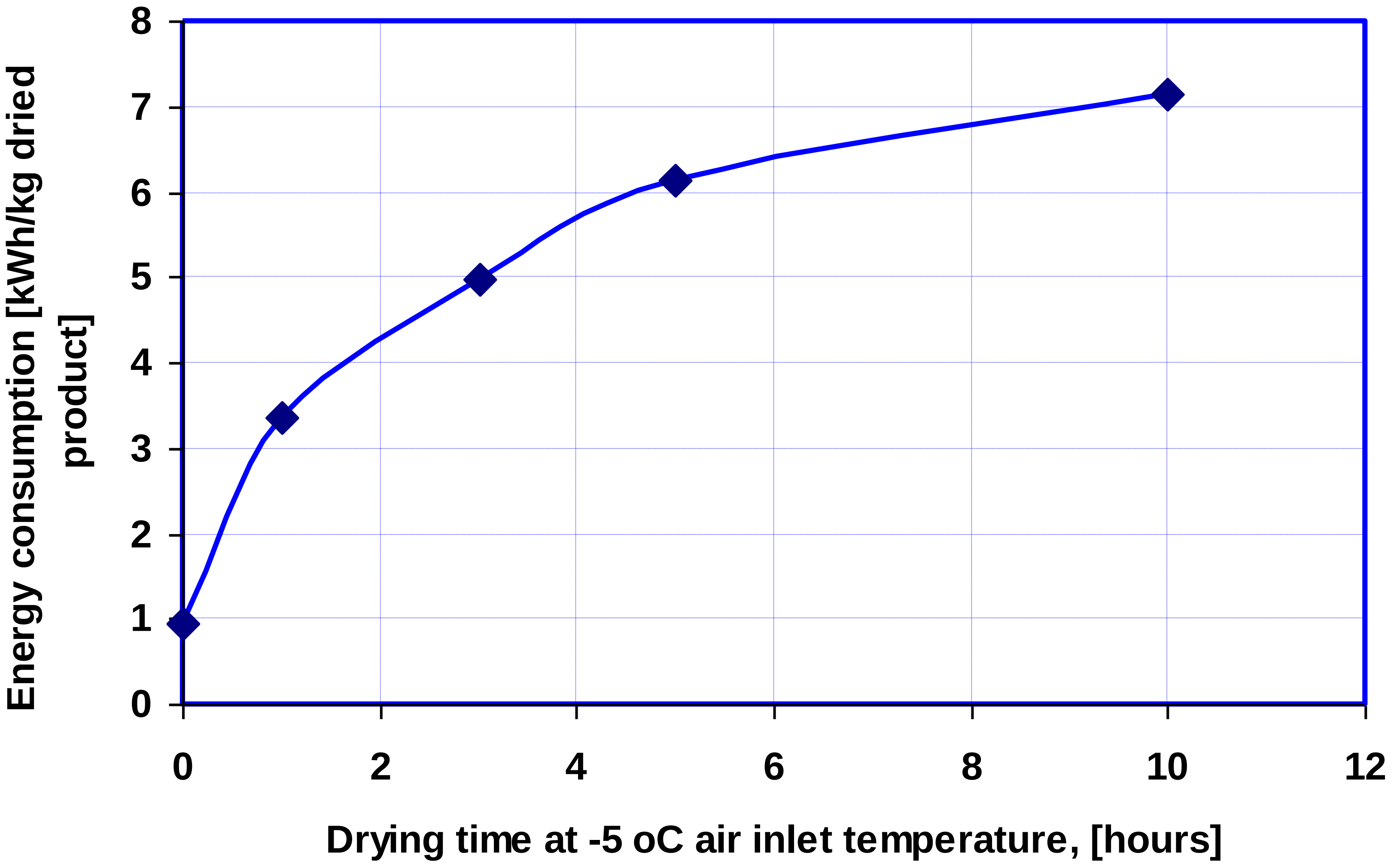
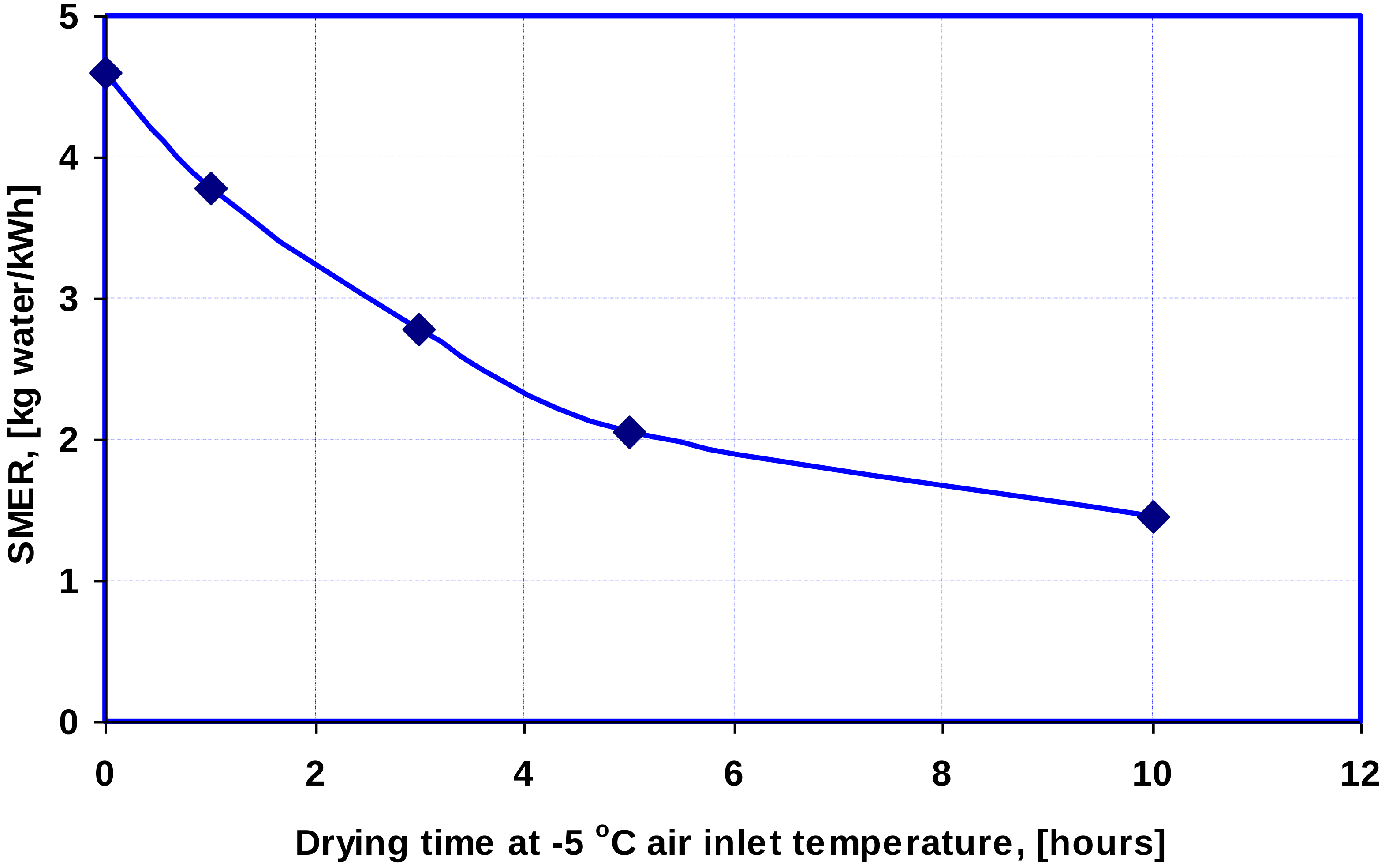
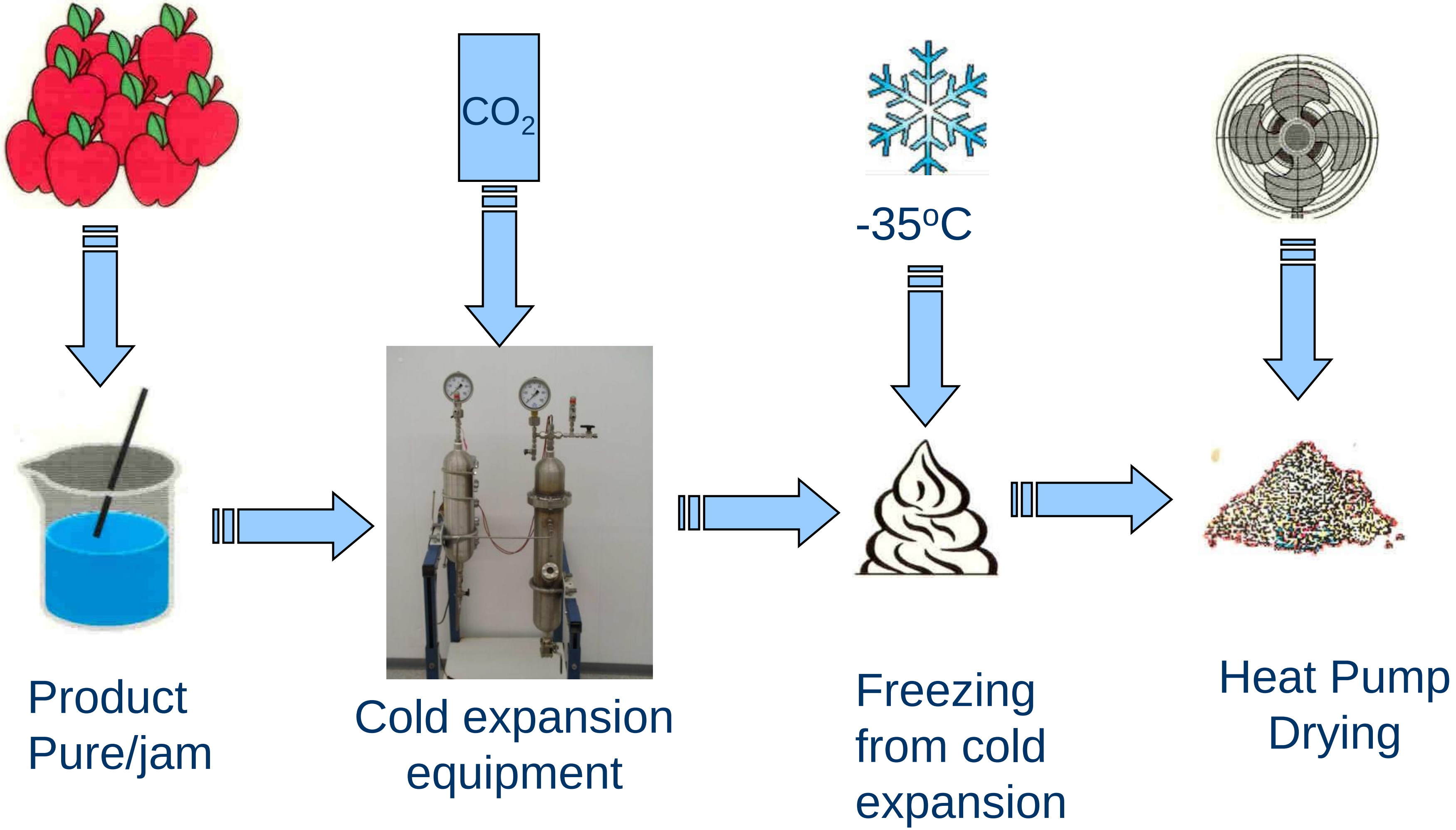
Energy consumption in a heat pump dryer 0perated at a continued mode drying



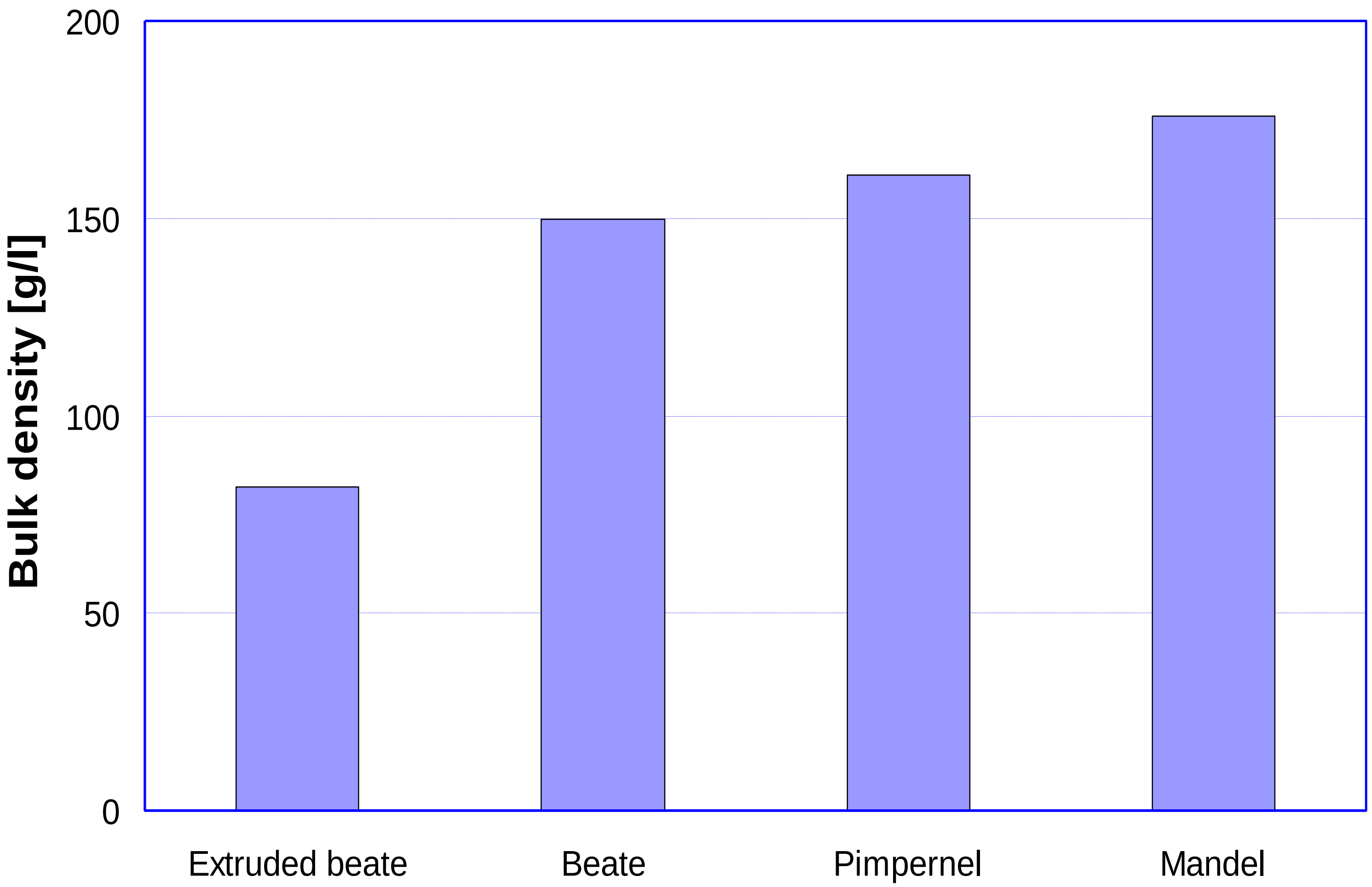
SMER for a heat pump dryer operated at a continued mode drying



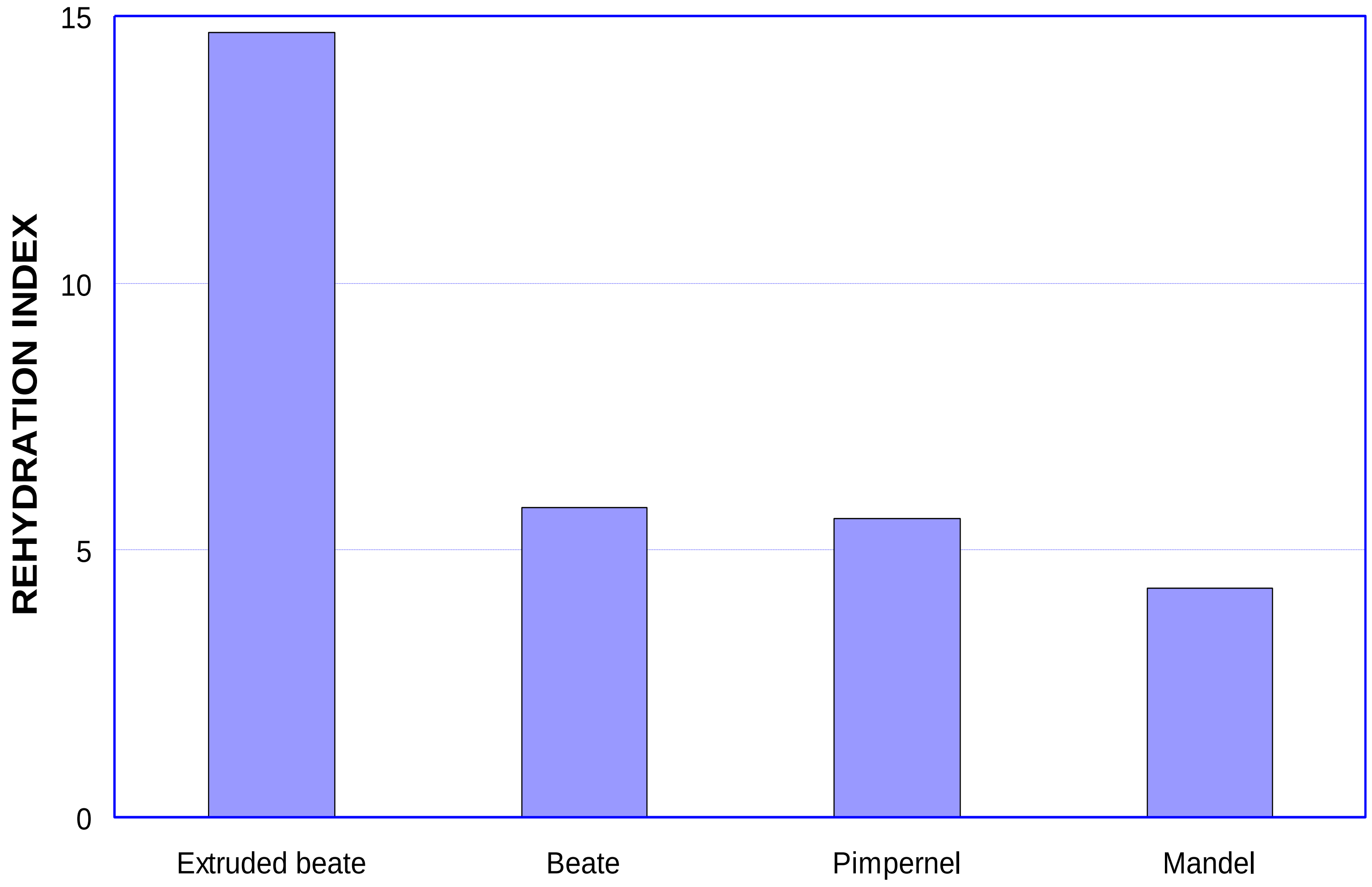
Production line for instant products



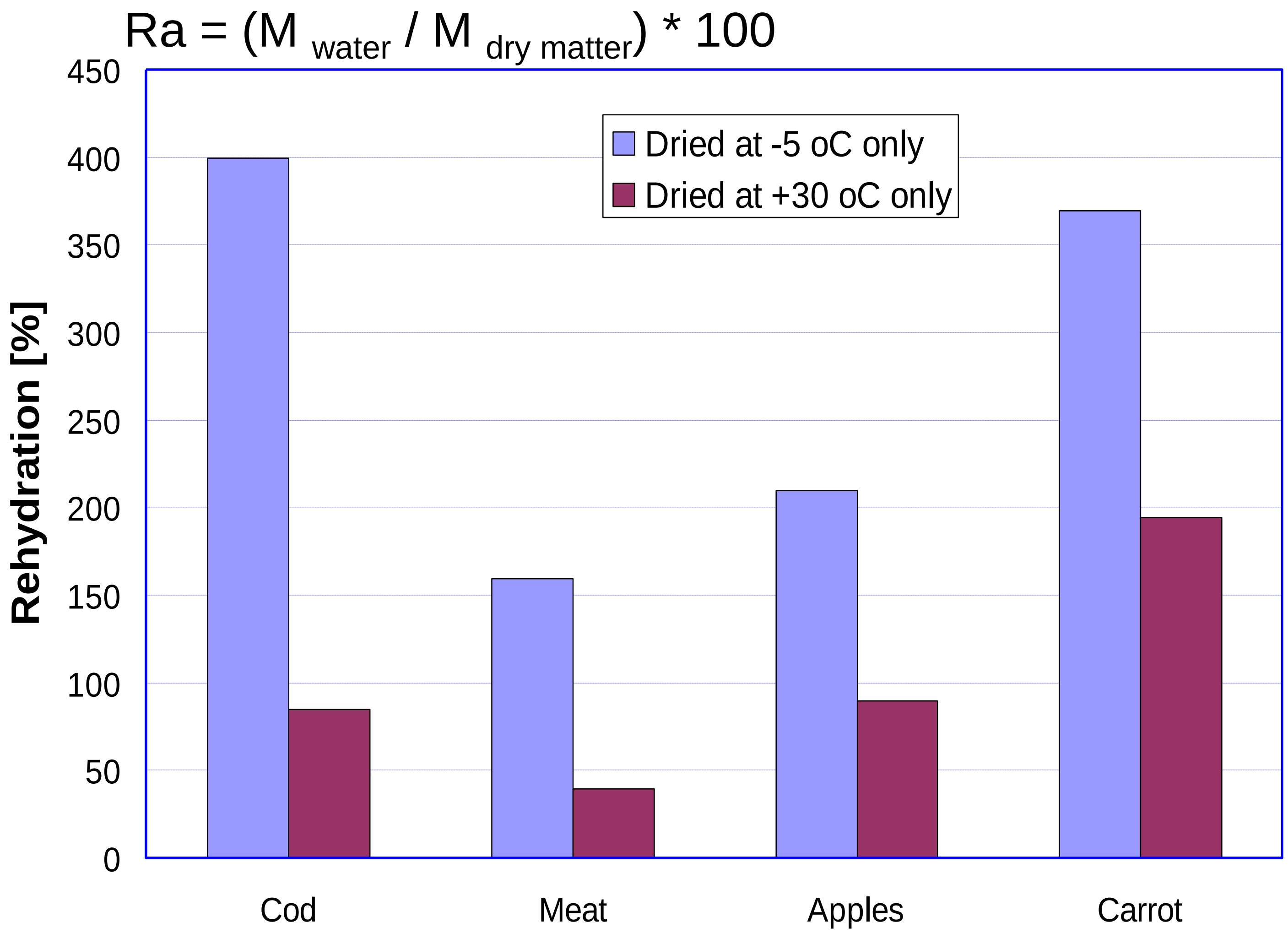
Bulk density for different potatoes and extrusion with CO_2



Standard rehydration (30 sec) for different potatoes and CO_2 extrusion



Rehydration in cold water of dried products (after 2 minutes)



Content

Conclusions

- New generations of high quality low density dried products can be produced by heat pumps operated in a combined drying mode at drying temperatures below/above the freezing point.
- There is an optimal SMER-ratio. This gives an optimal inlet temperature difference for the air cooler
- SMER values for heat pumps operated in combined modes will be in the order of 1,5 to 4,5 kg H_2O/kWh depending on temperature and time at freeze drying conditions.

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Thank you for your attention!

Спасибо за внимание!