Escola Superior de Biotecnologia
Universidade Católica Portuguesa

Microstructural changes during fruit drying - correlation between fundamental studies, with air drying and solar drying applications.

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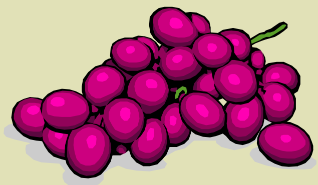
Introduction

Solar Drying

Solar dryer.



Introduction

Diversified products

- Breakfast cereals
- Dairy products
- Bakery
- Confectionery

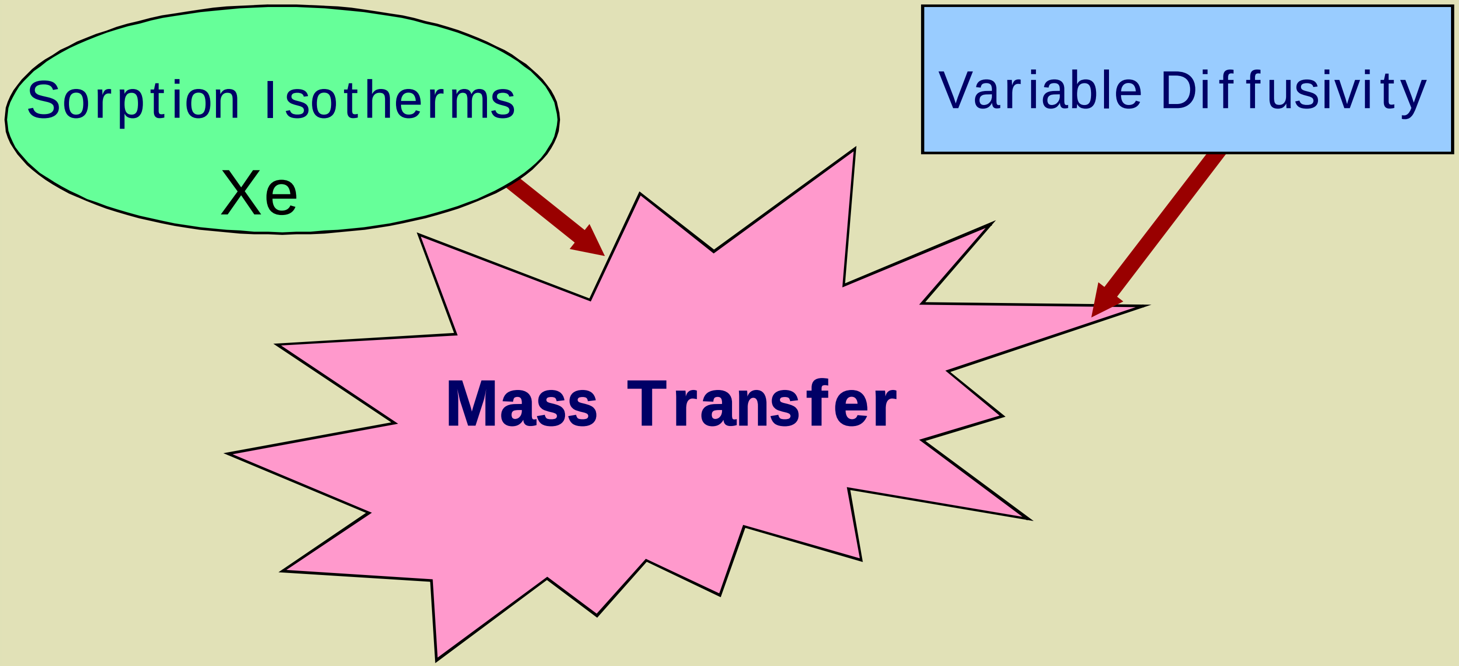
Introduction

Integrated model

Mass Transfer

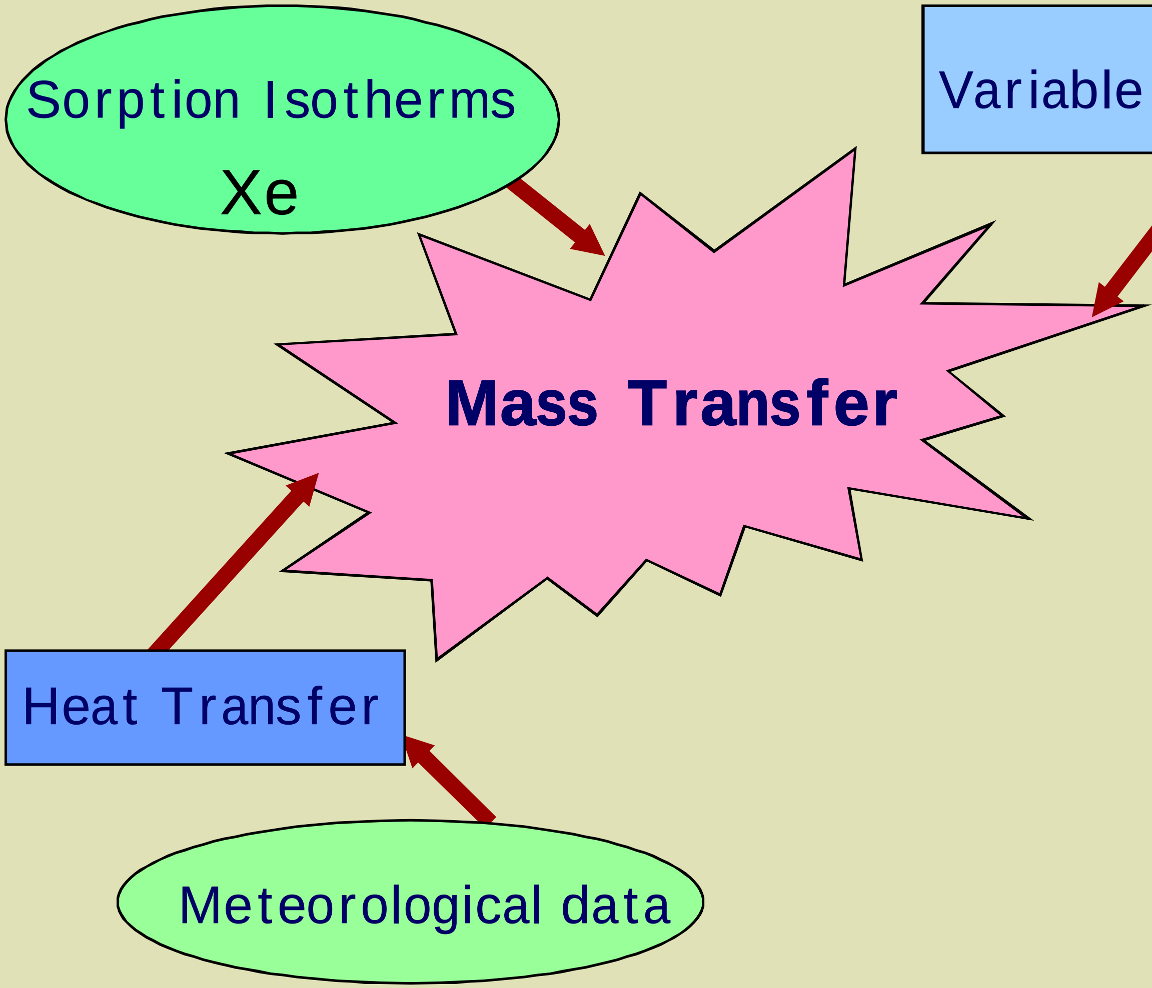
Introduction

Integrated model



Introduction

Integrated model



Introduction

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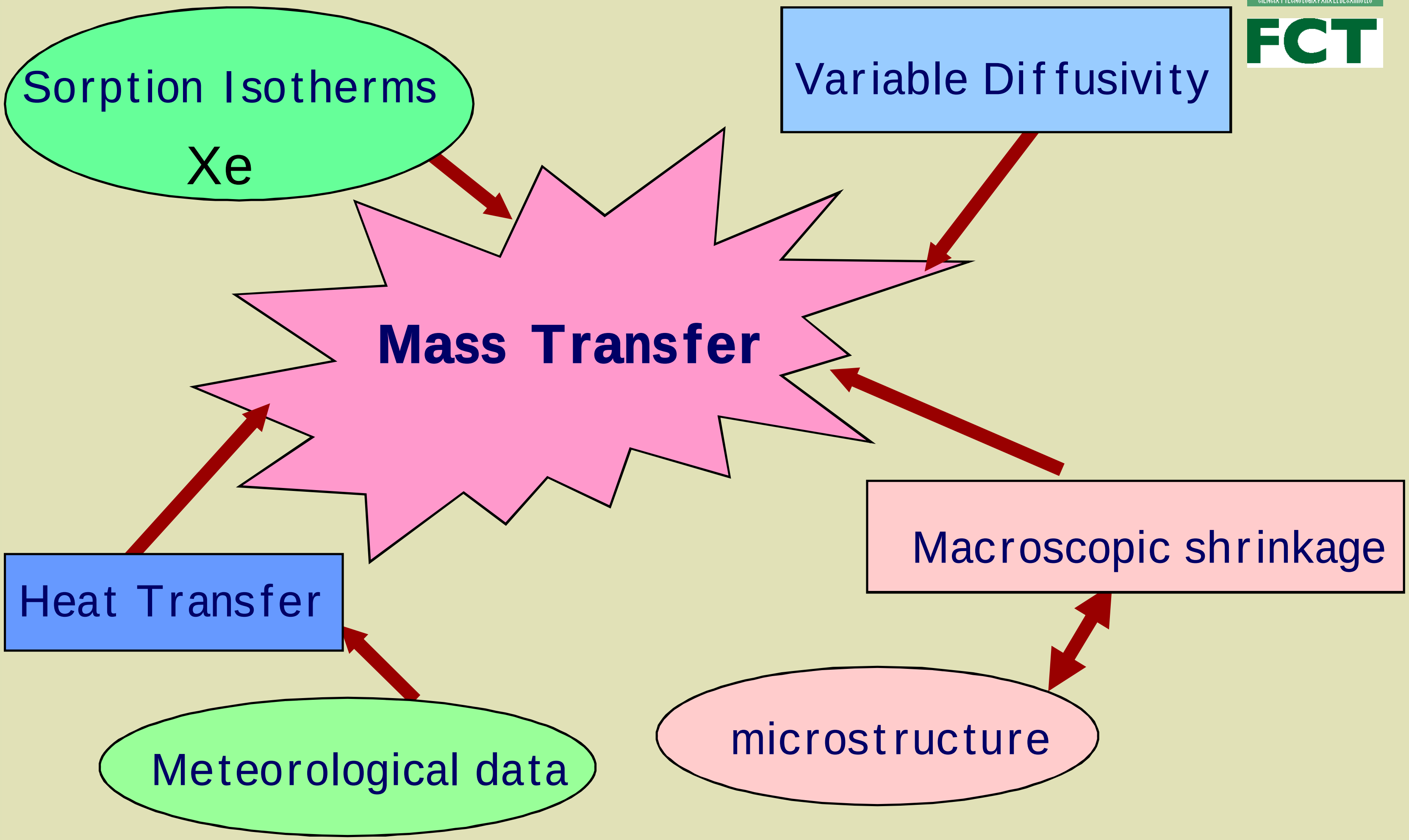

Introduction

Predict and simulate the drying behaviour:

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- Mechanistic models are more complex, but allow accurate predictions (Mulet, 1994).
- Empirical models are much simple, but appropriate to practical uses (e.g. dryers design).

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Balance of the advantages and disadvantages, depending on the final purpose.

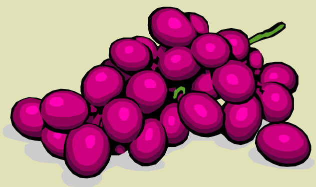
Introduction

Physical properties ⇄ **Microstructure**

Drying mechanisms

Quality changes

e.g. **Texture**



Mass Transfer

Short constant-rate period

Long falling-rate period

Fick's 2nd law

Mass Transfer

Fick's 2nd law

- Water concentration at the surface constant
- Sphere:

$$\frac{X - Xe}{Xo - Xe} = \frac{6}{\pi^2} \sum_{1}^{\infty} \frac{1}{n^2} \exp\left(-n^2 \pi^2 \frac{D_{eff}\, t}{r^2}\right)$$

Mass Transfer

- Consider uniform temperature inside the food

non-isotropic characteristics of the medium

porosity → D_{eff}

(effective diffusivity)

variable

Effective diffusivity

D_{eff} **varies:**

- considerably with **water content** (Karathanos, Villalobos and Saravacos, 1990)

- with **temperature**

Arrhenius law:

$$D = D_{ref}\ \exp\left[-\frac{Ea}{R}\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)\right]$$

Effective diffusivity

- Dependence on water content is usually neglected
- Proposed models:

exponential, power-law, gamma function

Exponetial are the most used models

Effective diffusivity

$$D_{eff} = \exp\left(a + bX + cX^2\right)$$

(Vásquez, Chenlo, Moreira & Costoyas, 2000)

$$D_{eff} = \exp\left(d + e/T + fX\right)$$

(Mulet et al., 1989)

$$D_{eff} = D_o \exp\left(-D_T/T\right) \exp\left(-D_x/X\right)$$

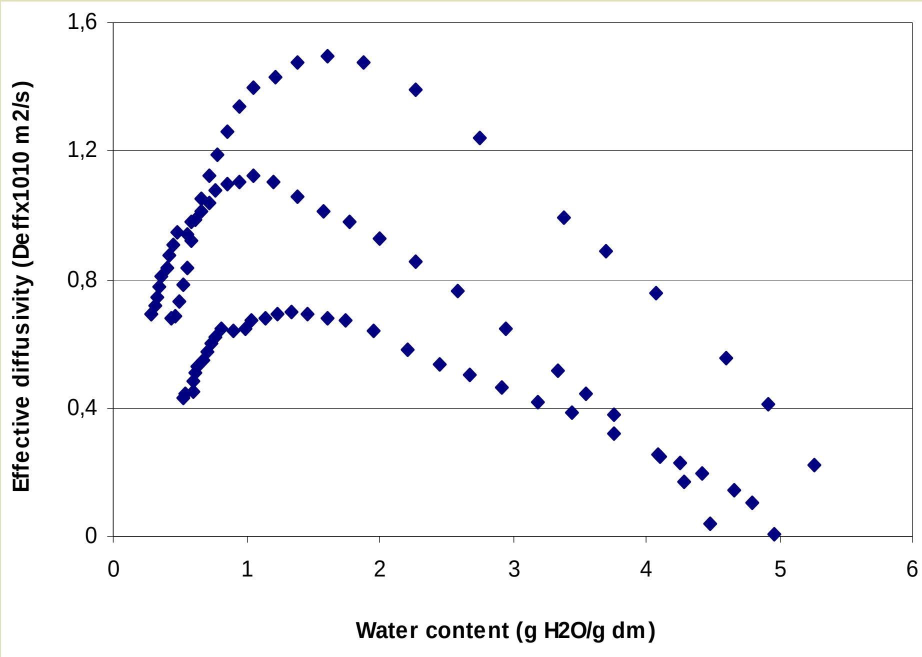
(Maroulis, Kiranoudis & Marinos-Kouris, 1995)

Effective diffusivity

Experiments performed in a convective dryer.

Pilot plant convective tray drier (Armfield UOP8).

Effective diffusivity



Data similar to Raghavan et al., 1995

Equilibrium value

Sorption isotherms

The G.A.B. model is recently widely applied:

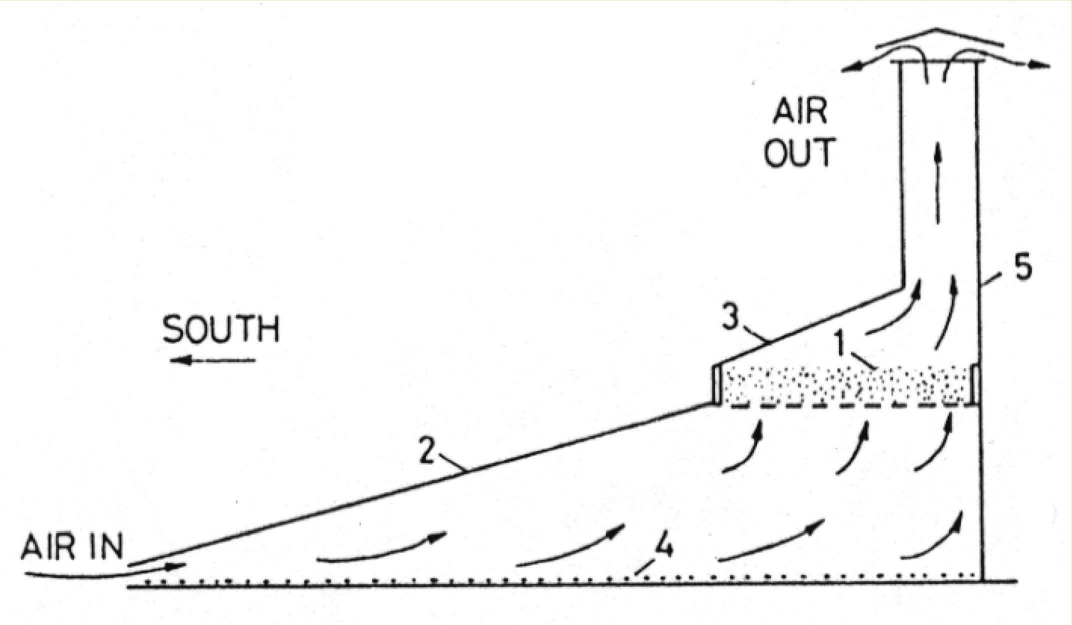
$$\frac{X_e}{X_m} = \frac{C\,k\,a_w}{(1-k\,a_w)\,(1-k\,a_w + C\,k\,a_w)}$$

$$C = C_0 \exp\left(\frac{\Delta H_c}{RT}\right) \qquad k = k_0 \exp\left(\frac{\Delta H_k}{RT}\right)$$

Temperature dependent

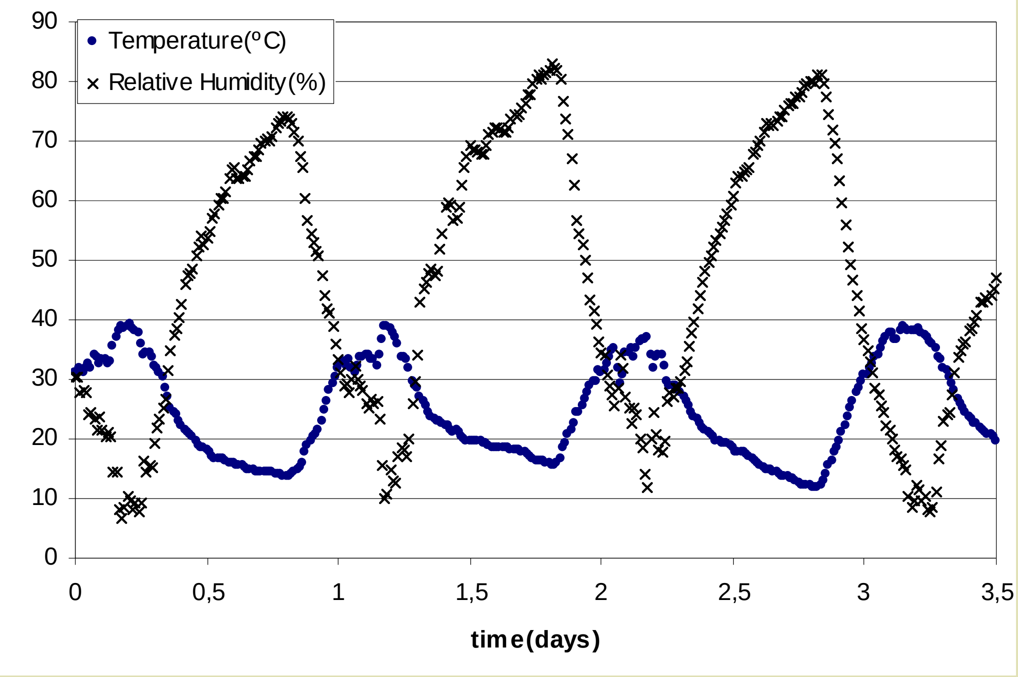
Heat Transfer

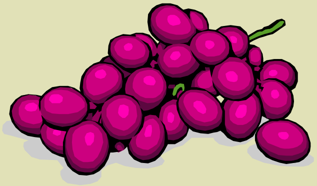
Solar **radiation** originates a ‘**greenhouse’** effect



Heat Transfer

Air conditions inside a solar drier :





Heat Transfer

Global energy balance :

$$\frac{d\,(m\,Cp\,T)}{dt} = \alpha\,Q_s - hA(T - Ta) - \frac{d(\lambda\,m)}{dt} - A\,\varepsilon\,\sigma\,(T^4 - Ta^4)$$

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obtained from **meteorological data**

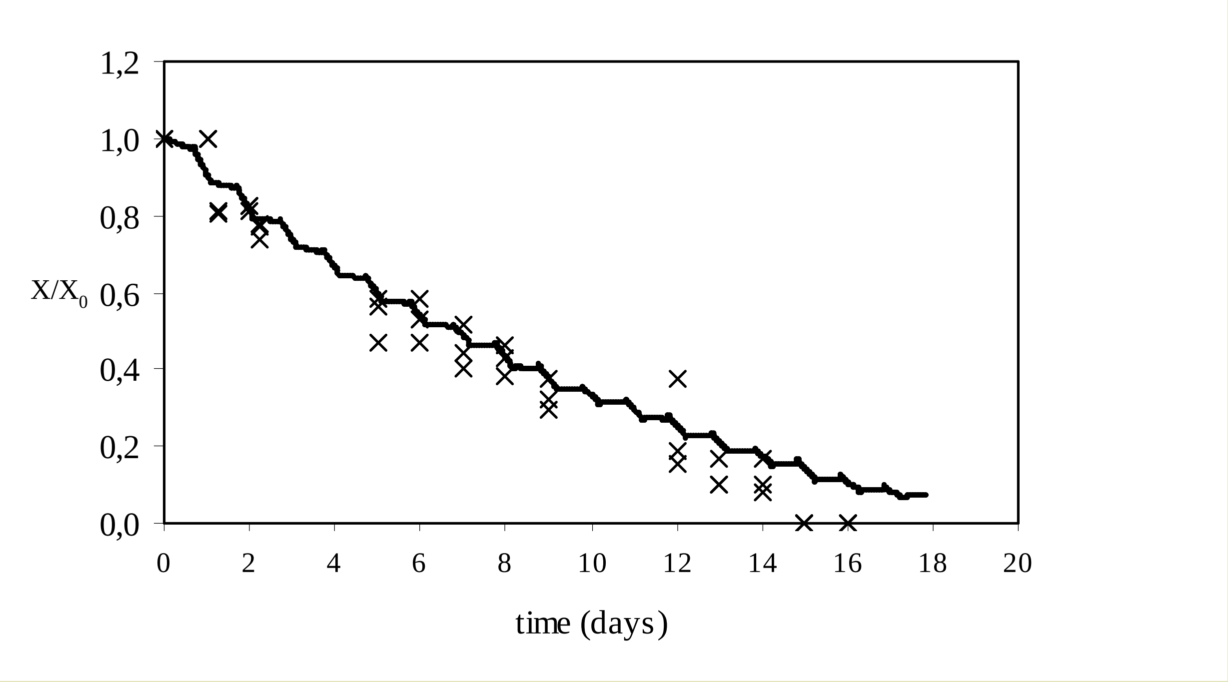
Heat Transfer

- **Lack of data on radiation properties of foods**

Heat Transfer

- Lack of data on radiation properties of foods
- Cp is strongly dependent on water content
  - compilation on Sweat (1986)
  - most of the research on freezing and refrigeration !!!

Simulation under dynamic conditions on a pilot scale and **Data of solar dryer**



Shrinkage

Loss of water → shrinkage

reduction in cellular dimensions

Macroscopic Shrinkage

Commonly defined: $\dfrac{V}{Vo}$

Macroscopic Shrinkage

Measurement :

- direct with a calliper
- picnometry with organic solutions
- photography and image analysis:

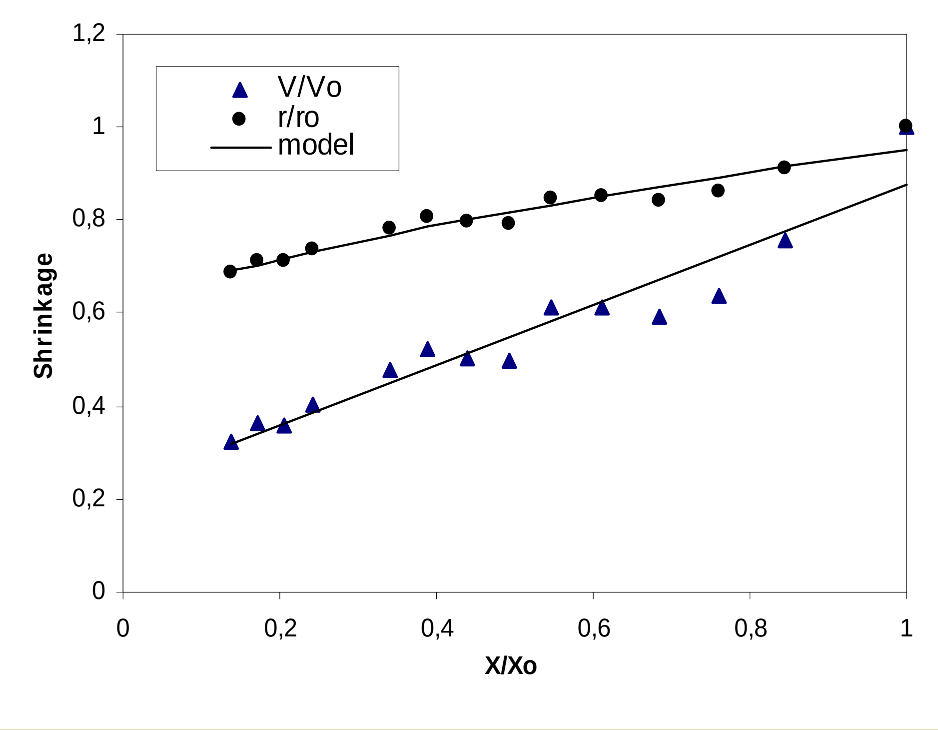
Grape shrinkage under dynamic conditions.

Macroscopic Shrinkage

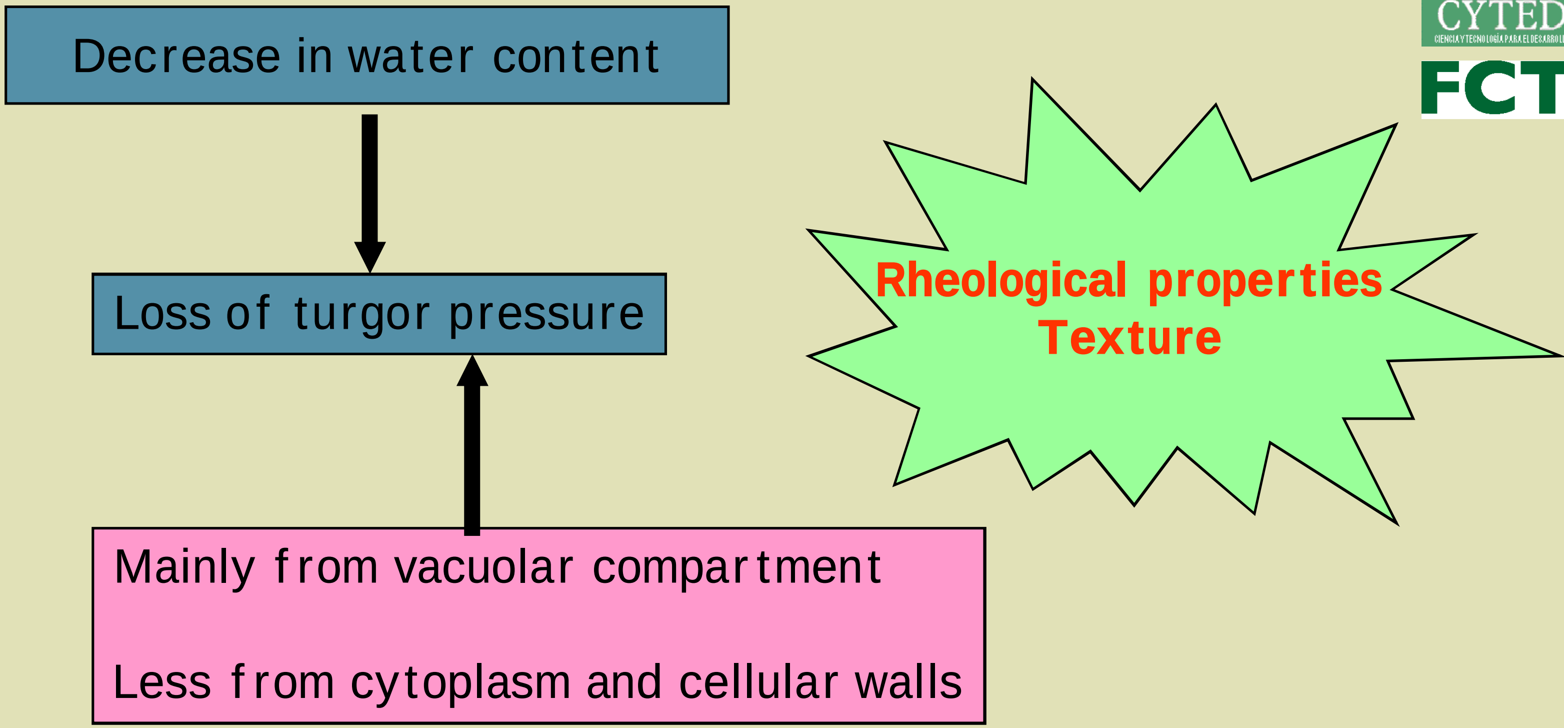
Dependence of shrinkage on water content

→ common linear relationship

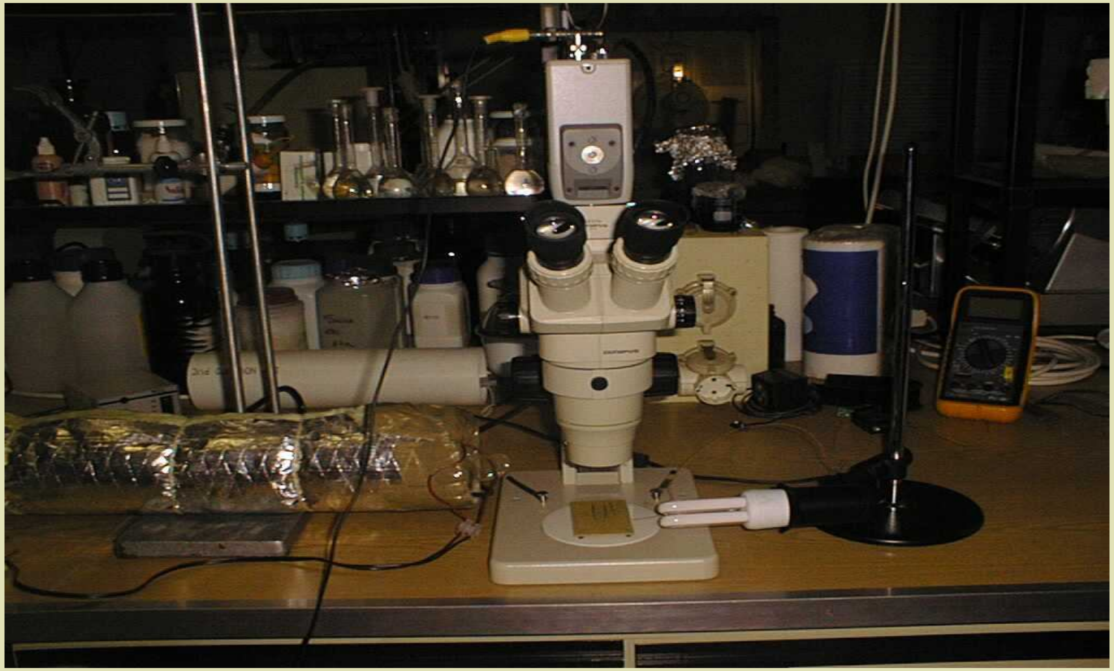
$$\frac{V}{Vo} = a + bX$$



Microscopic Shrinkage



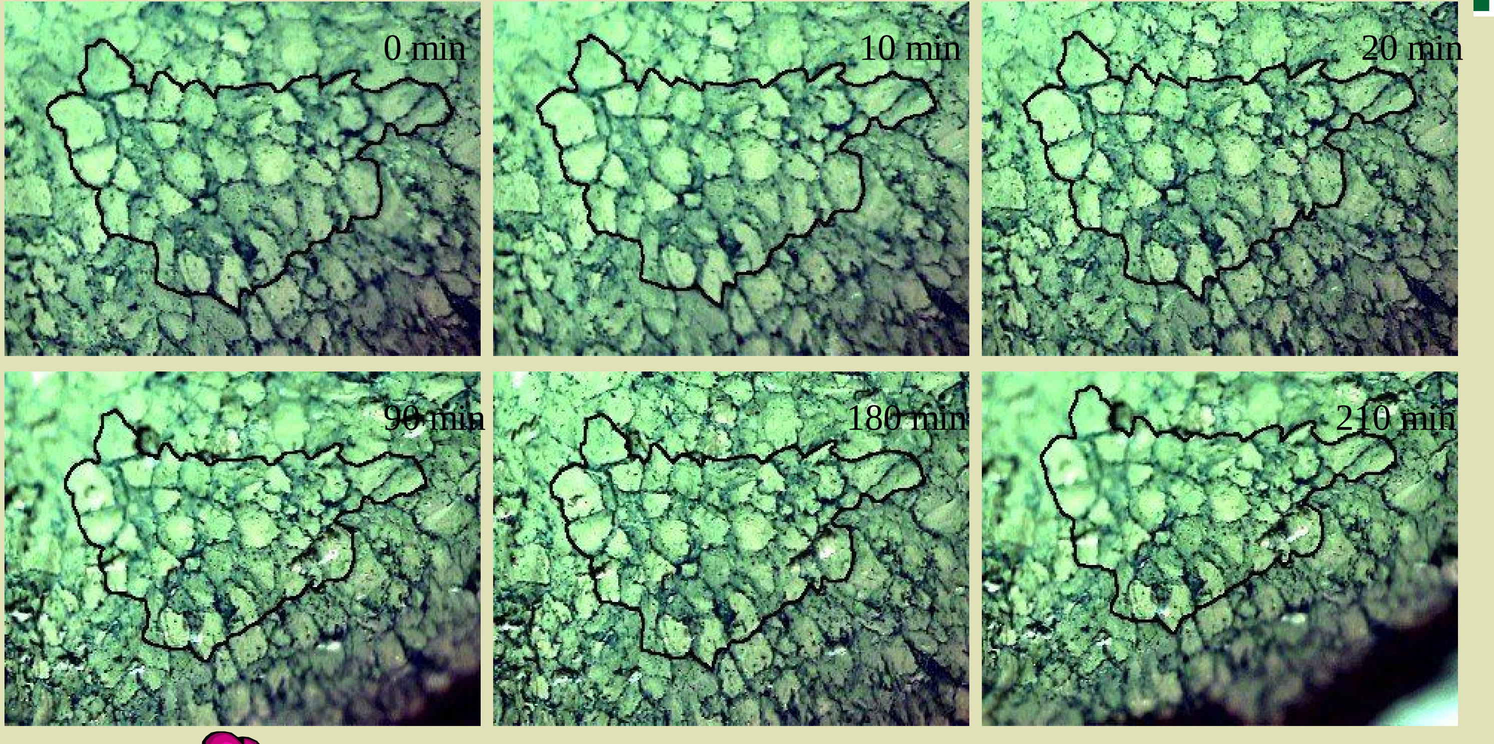
Microscopic Shrinkage

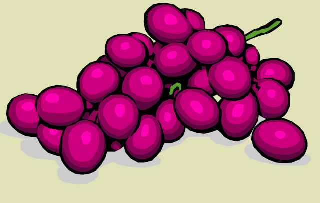


Stero-microscope with video camera and air-drying tube.

Microscopic Shrinkage

Cellular geometric features quantified by **image analysis**





Images of grape cells shrinkage at 40°C as a function of time.

Microscopic Shrinkage

- Parameters:

➢ Dimensional: **area**, **perimeter**,

➢ **major** and **minor axis length**

➢ **Feret diameter** $FD = 2\sqrt{\frac{area}{\pi}}$

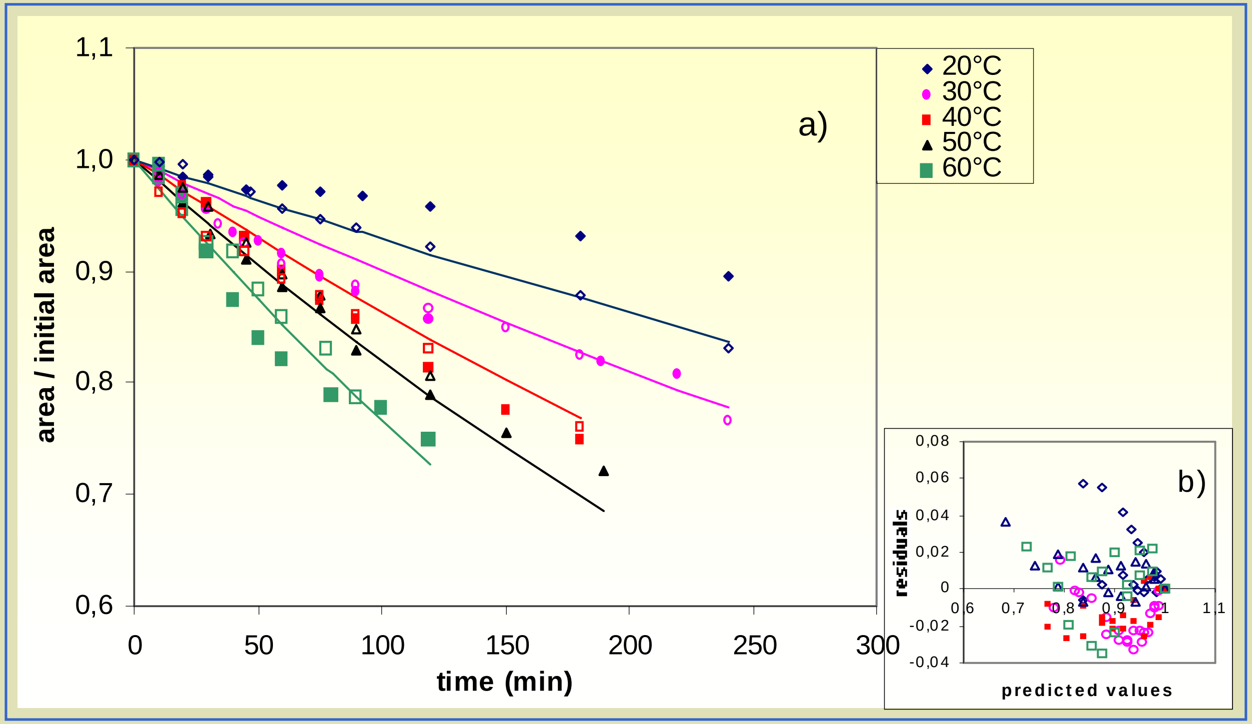
➢ Shape:

$$elongation = \frac{major\ \ axis\ \ length}{minor\ \ axis\ \ length}$$

$$roundness = \frac{4\pi\ \ area}{perimeter^{2}}$$

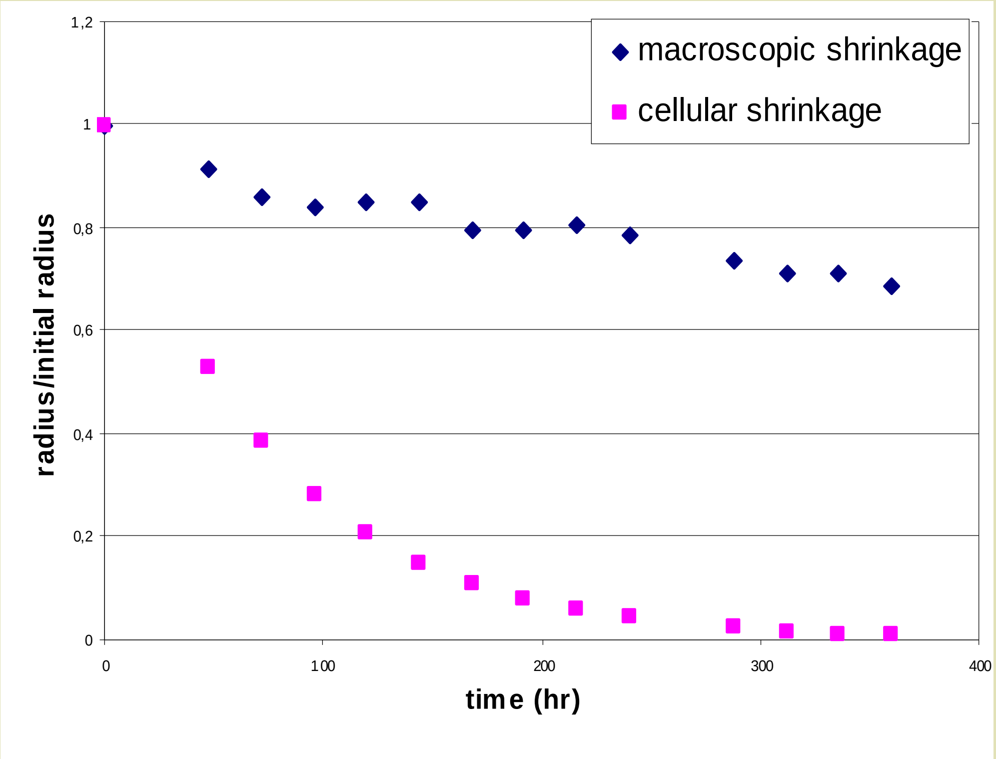
$$compactness = \frac{FD}{major\ \ axis\ \ length}$$

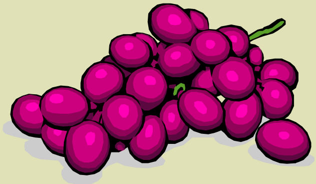
Microscopic Shrinkage



$$\frac{r}{r_0} = \exp\left\{ -K_{ref} \exp\left[-\frac{Ea}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right] t \right\}$$

Relate Macroscopic and Microscopic Shrinkage





Final Remarks

- Develop the mathematical basis and considerations for integrating heat and mass transfer phenomena.

  - include variable diffusivity
  - sorption isotherms
  - shrinkage

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- Microstructure helps understanding drying mechanisms.

Final Remarks

- Developed the mathematical basis and considerations for integrating heat and mass transfer phenomena.

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  - sorption isotherms
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- Lack of data on thermal properties of foods.
- Microstructure helps understanding drying mechanisms.
- Correlating microstructure, texture measurements and sensory analysis is an attractive area.

Acknowledgments

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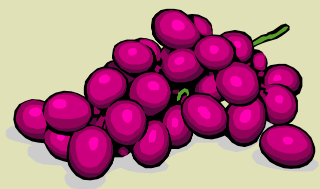
CYTED XI.13 "Relaciones Estructura - Propriedad en la Deshidratacion y Almacenaje de Alimentos Dehidratados"



Thank you