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Heat and Mass Transfer in Convective Drying Processes

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CONTENT

- Introduction
- Mathematical modelling of drying processes
- Modelling Results
- Conclusions

INTRODUCTION

- AIM: describe the modelling and simulation of the dehydration of fruits and vegetables (grapes) in a complex drying system processes, using COMSOL Multiphysics Program
  - simulation of unsteady convective drying of grapes in static bed conditions
- USE of a dynamic mathematical model, based on
  - physical and transport properties
  - mass and energy balances.

Mathematical modelling
Equation types

The simulation of various product drying systems involves solving a set of heat and mass transfer equations which describe:

- heat and moisture exchange between product and air,
- adsorption and desorption rates of heat and moisture transfer,
- equilibrium relations between product and air,
- psychometrics properties of moist air.

Mathematical modelling
General Ideas - 1

- The most rigorous methods of describing the drying process are derived from the concepts of irreversible thermodynamics in which the various fluxes are taken to be directly proportional to the appropriate “potential”, (Ghiaus, 1997).

Mathematical modelling General Ideas - 2

- For most engineering heat transfer calculations performed in commercial food dehydration, accuracy greater than 2-5 % is seldom needed.
- This is because errors due to varying or inaccurately measured boundary conditions such as air temperature and velocity, would overshadow errors caused by inaccurate thermal properties.

Mathematical modelling
General Ideas - 3

- Most thermal property models are empirical rather than theoretical
  - they are based on statistical curve fitting rather than theoretical derivations involving heat transfer analysis
- The water is treated as a single, uniform component of the food product. It could be argued that the thermal properties of water in the food depend on how it is configured or “bound” within the product.

Mathematical modelling Equations

The mass balance inside the product can be written as:

$$\frac{\partial(\rho_b \cdot X)}{\partial t} = \mathrm{div}\left(\rho_b \cdot D_{eff} \cdot \frac{\partial X}{\partial z}\right)$$

and the heat-energy balance can be set down as

$$\rho_b \cdot c \cdot \frac{\partial T}{\partial t} = \mathrm{div}\left(\lambda \cdot \frac{\partial T}{\partial z}\right)$$

Where

X - grape moisture content;

T - the air temperature;

ρ_b - bulk bed density;

c - specific heat capacity;

λ - thermal conductivity;

D_{eff} - effective mass diffusivity.

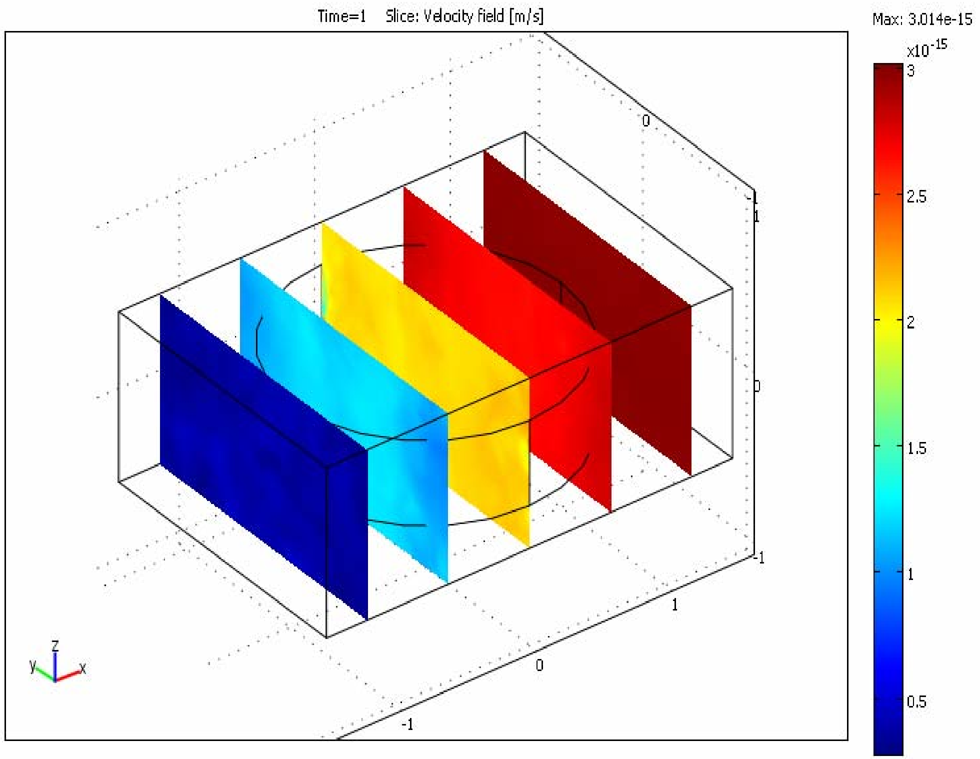
Mathematical modelling
Parameters for Corinthian grapes

Item	Value
Water content, W, [%]	75
Thermal conductivity, λ, [W/m K]	0.5721
Specific heat, c, [J/kg K]	3600
Effective diffusion, D_{eff}, [m^2/s]	$3.6 \cdot 10^{-9}$
Bulk bed density, ρ_b [kg/m^3]	691

Results and Discussion

- COMSOL Mutiphysics program is used to simulate the dehydration of grapes in a complex drying system processes which correspond to the numerical solution of these model equations.
- The above system of non-linear Partial Differential Equations, together with the already described set of initial and boundary conditions, has been solved by Finite Elements Method implemented by Comsol Multiphysics 3.4.

Results and Discussion



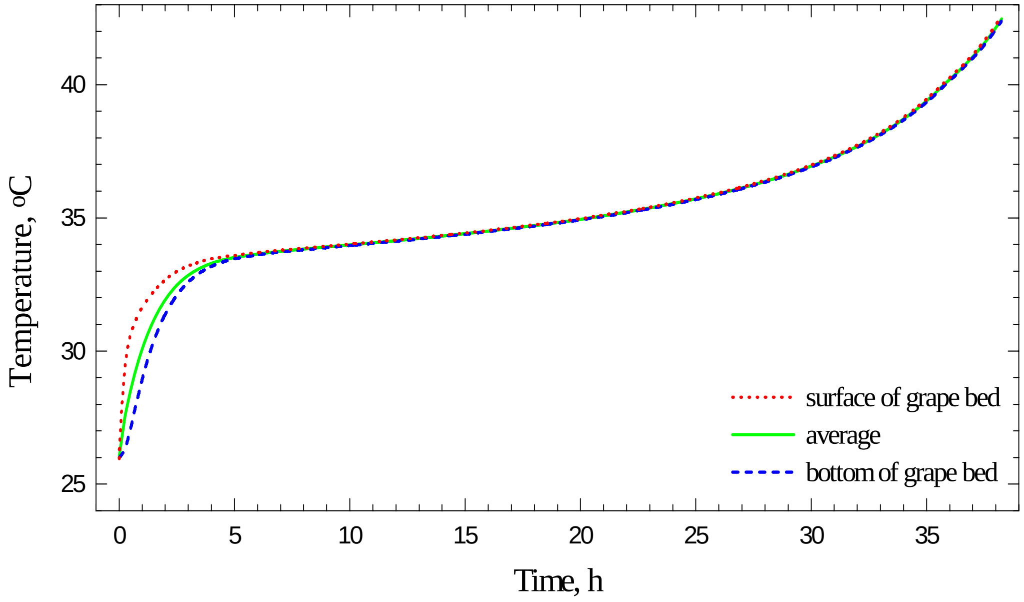
Results from the compute solution in COMSOL Multiphysics

- **Steps:**

  - Build the geometry of the model,
  - Fix the boundary settings, the mesh parameters
  - Fix the Parameters for Corinthian grapes
  - Compute the final solution.

Results and Discussion

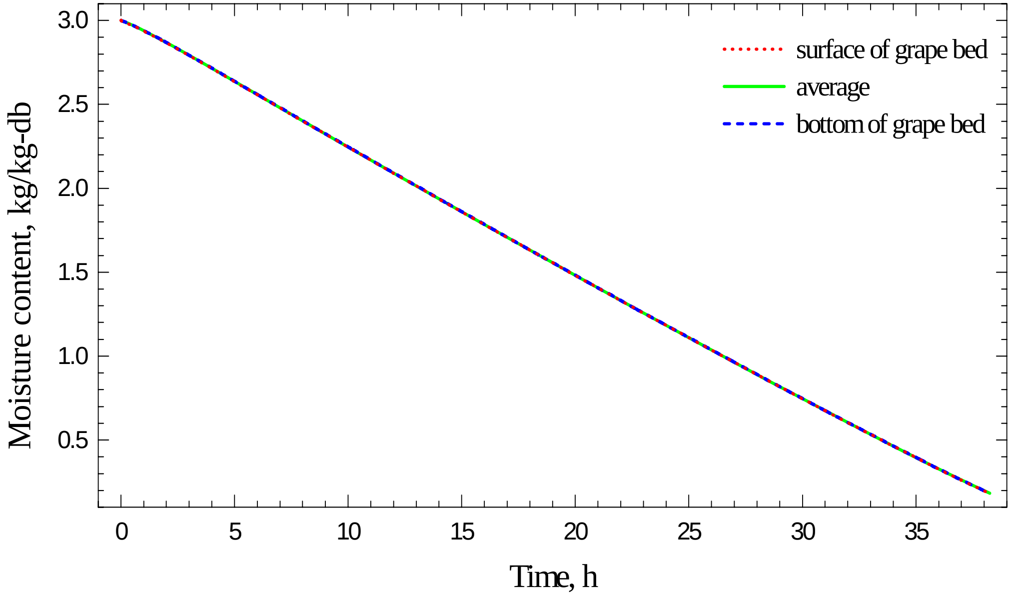
Temperature



Evolution of grape temperature during the drying process.

- **Evolution of grape temperature during the drying process, at the surface and bottom of the bed and as an average.**
- **Differences of temperature between the base and surface of the bed appear only during the first period of drying, approx. the first 5 hours. After this the bed temperature remains uniform**

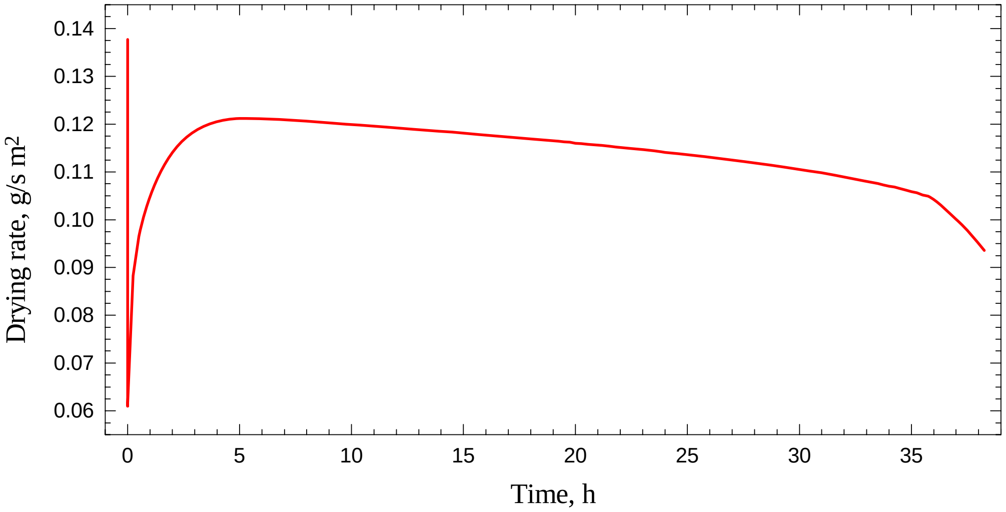
Results and Discussion
Moisture



Evolution of grape moisture content during the drying process.

- Evolution of grape moisture content at the surface and bottom of the bed and as an average value.
- During the whole process the moisture content of the grapes is uniform within the bed thickness. This is due also to the small thickness of the grape bed.

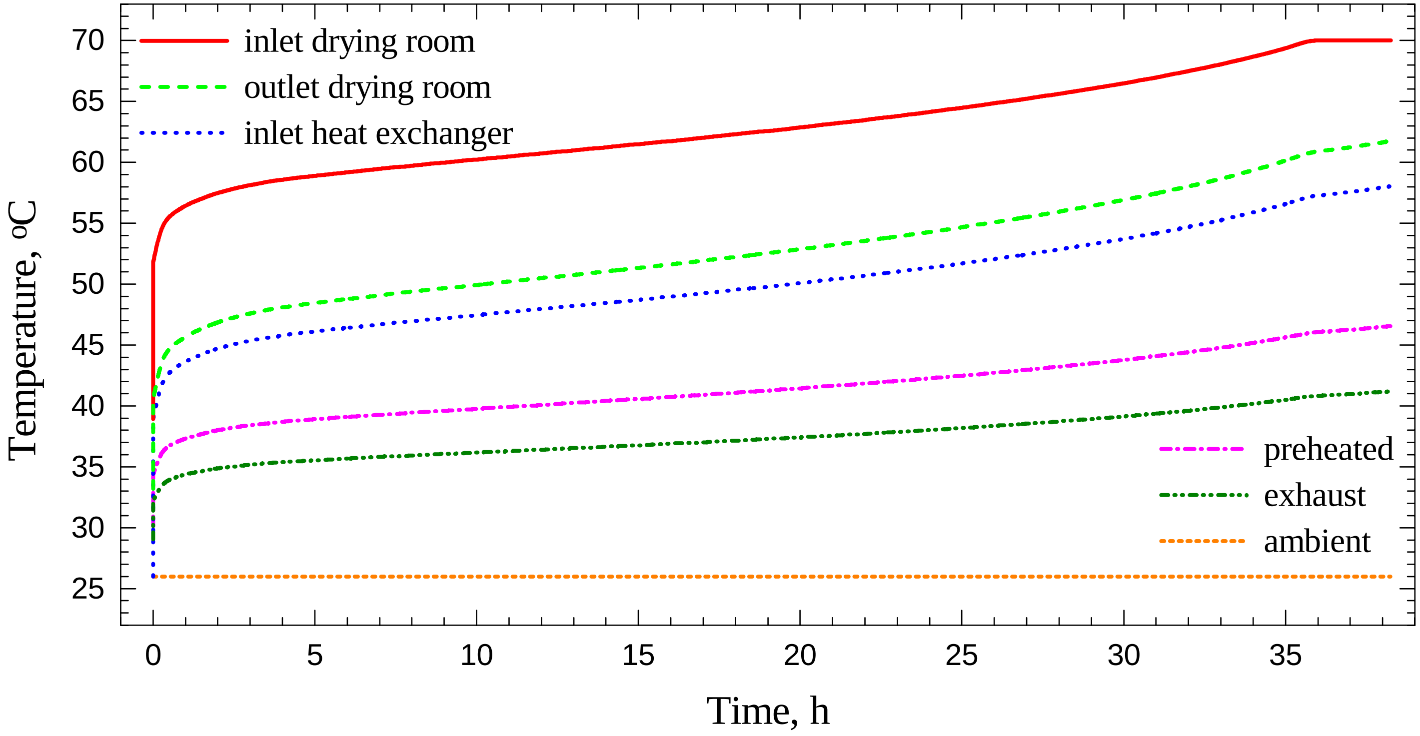
Results and Discussion Drying Rate



Drying rate vs. drying time for grape dehydration.

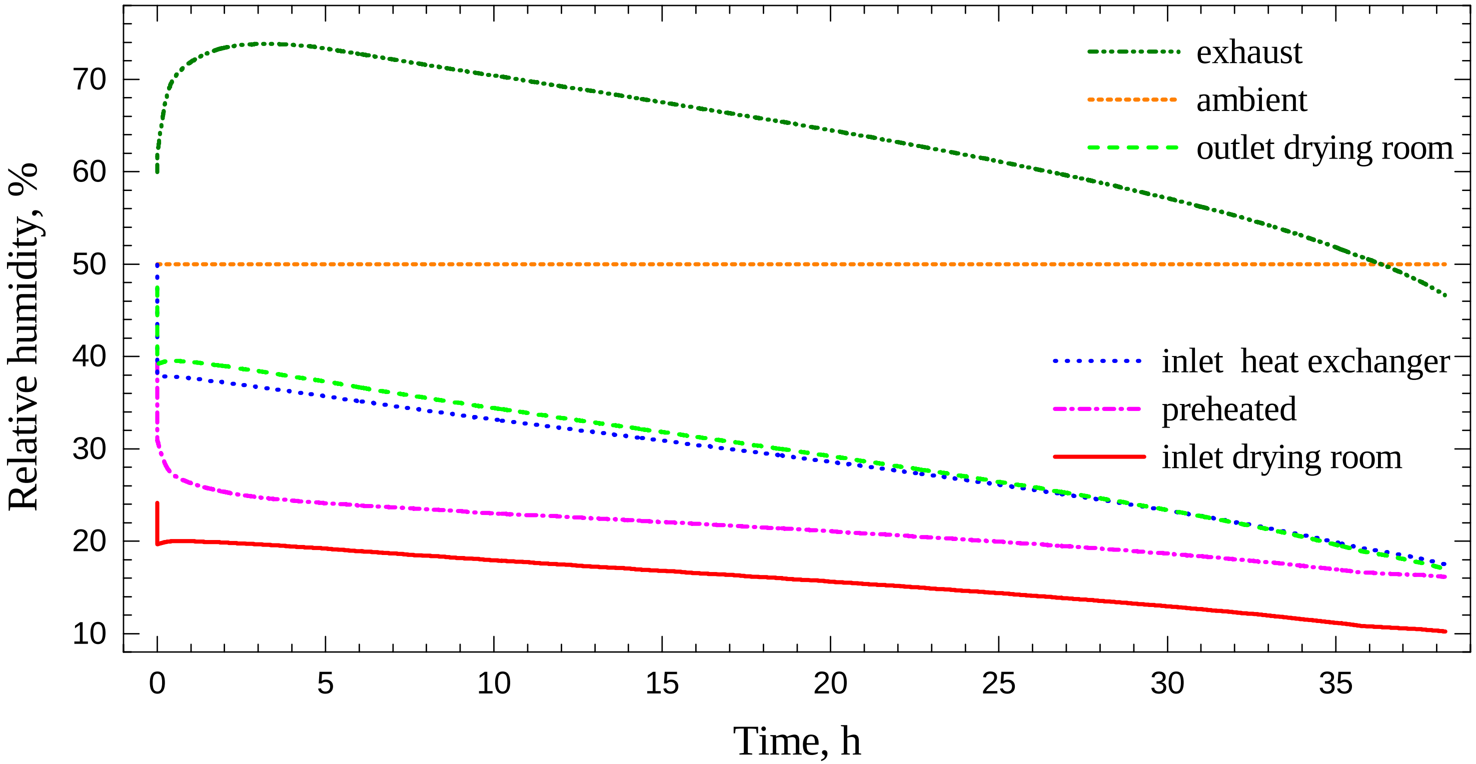
- **Parameter: drying rate**
  - **Represents the rate of evaporated water from one square meter of drying product.**
- **At the beginning of the process it increases from 0.06 g/s m^2 to 0.12 g/s m^2 and then has a very small decreasing slope.**
- **At the end of the process it decreases rapidly.**

Results and Discussion
Drying Air Temperature



Drying air temperature at different locations vs. drying time.

Results and Discussion
Relative Humidity



Relative humidity of drying air at different locations vs. drying time.

CONCLUSIONS

- We have demonstrated the versatility of COMSOL Multiphysics with regard to the modelling and simulation of the dehydration of grapes in a complex drying system processes.

- The model was applied to the full scale experimental data with good results.

Thank You!

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