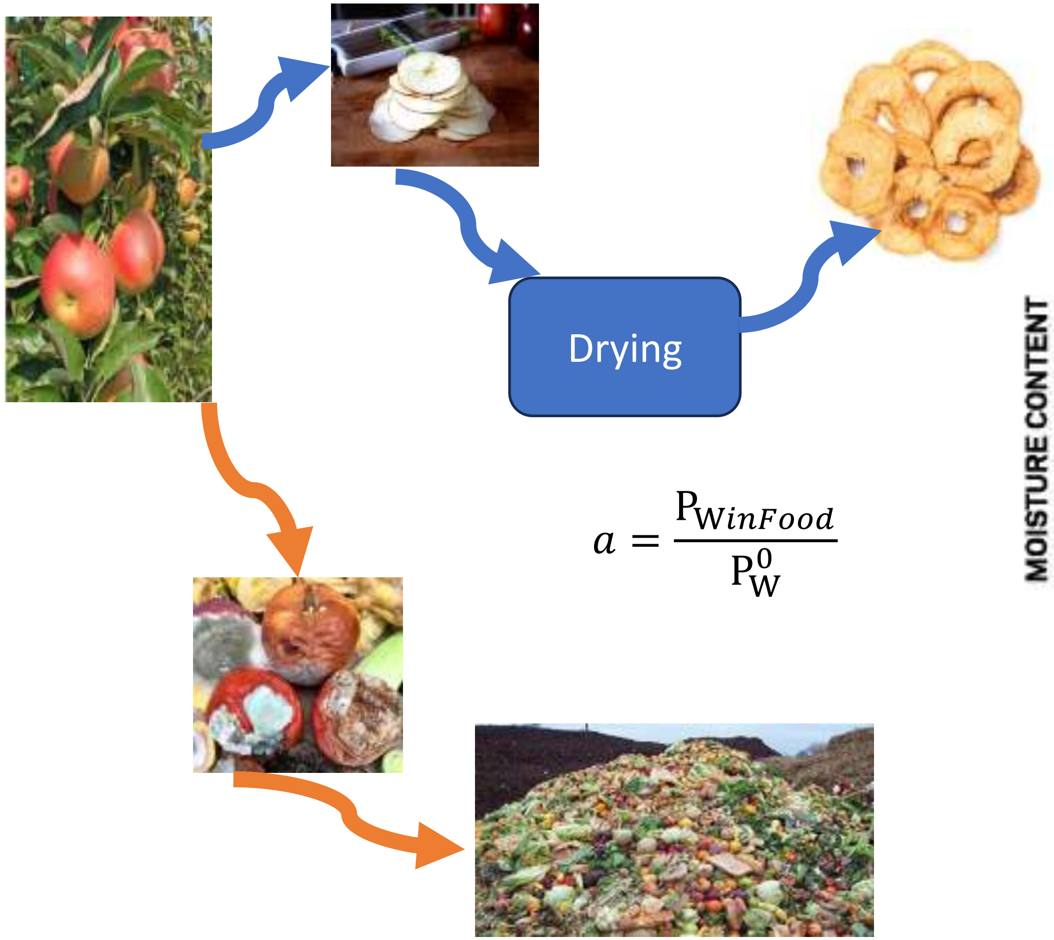
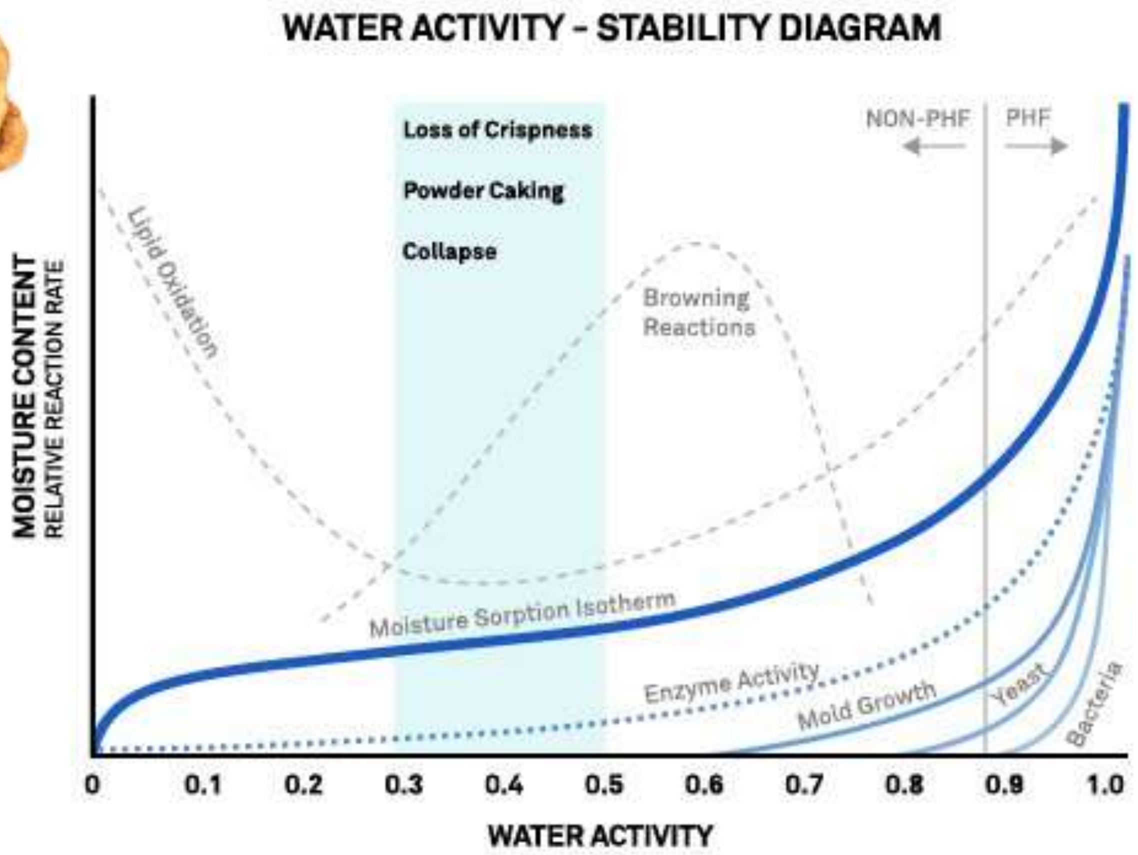
Food drying: Effect of process conditions and use of renewable energy sources

Juma Haydary, Department of Chemical and Biochemical Engineering, Slovak University of Technology in Bratislava

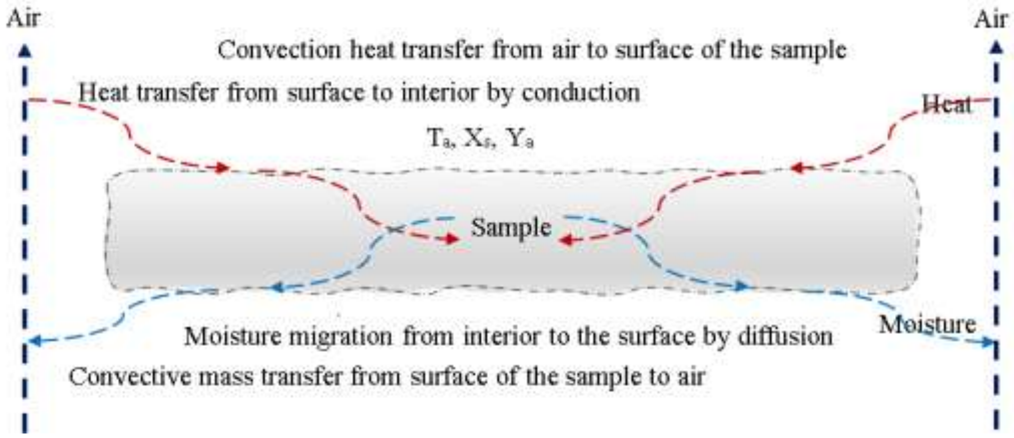
Drying as a method of food preservation

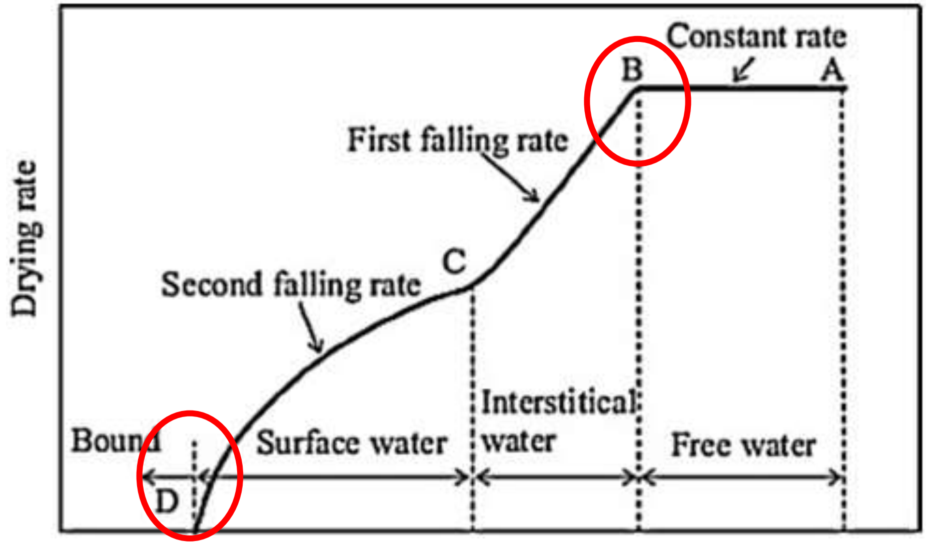


$$a = \frac{P_{WinFood}}{P_W^0}$$

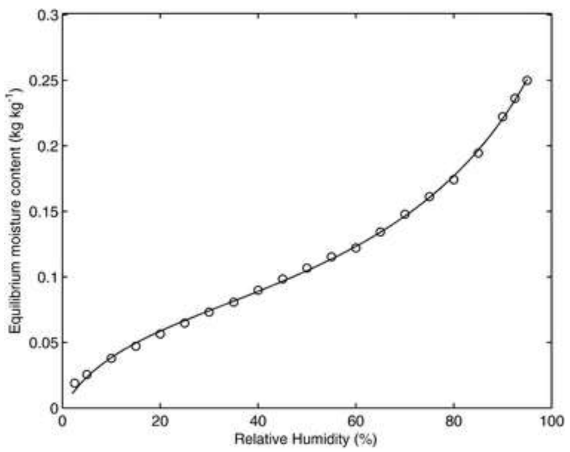


Drying mechanism, drying equilibrium





Moisture content



Energy requirement of drying process

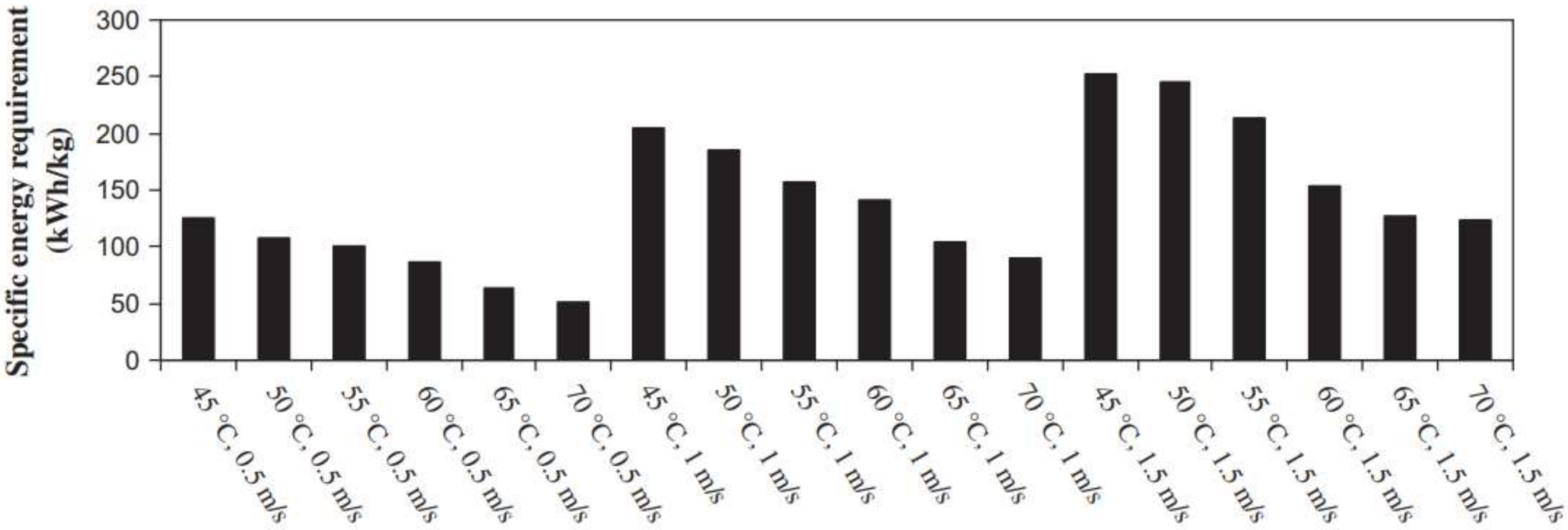
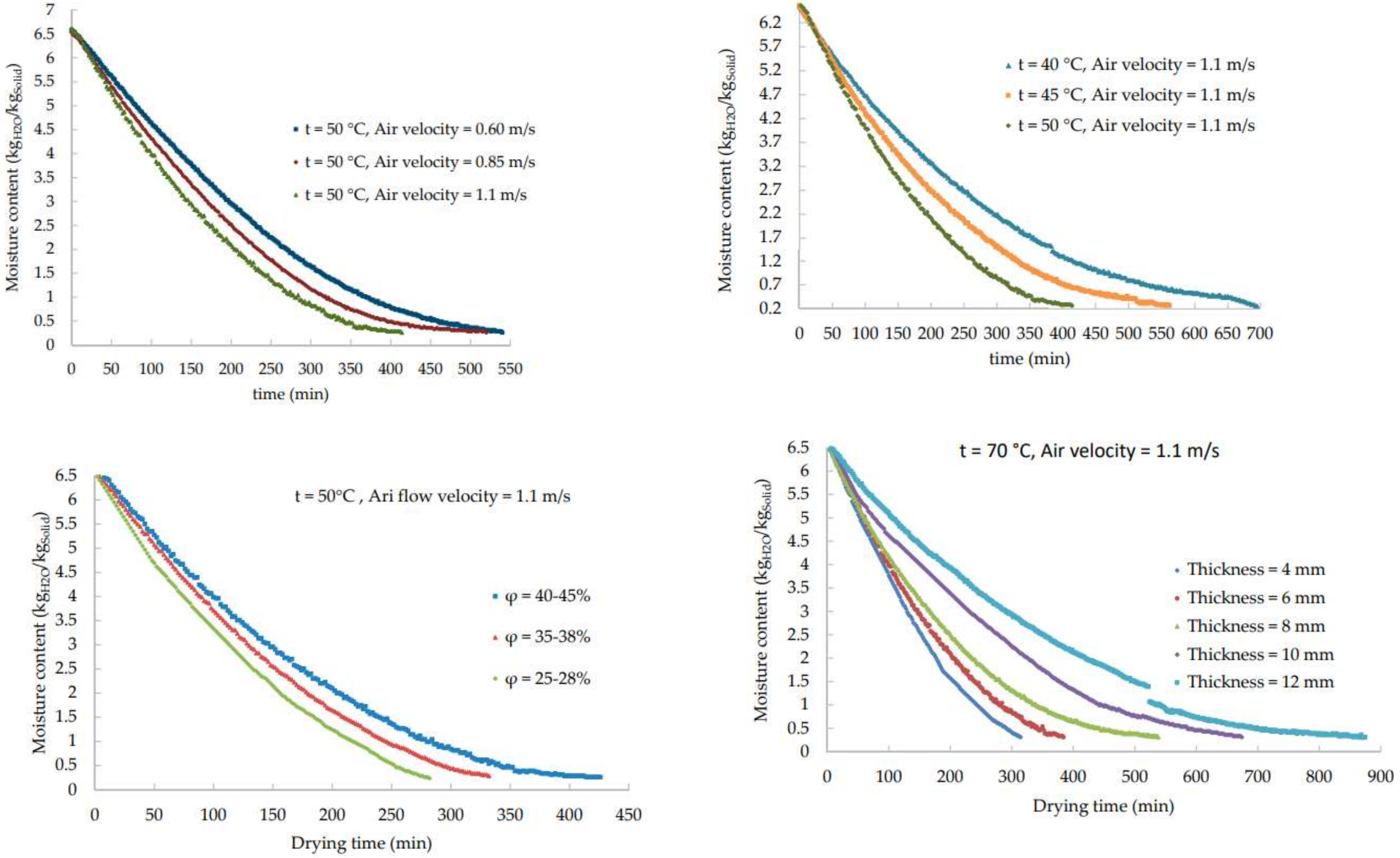


Fig. 4. Specific energy requirement for convection drying of arils (control treatment).

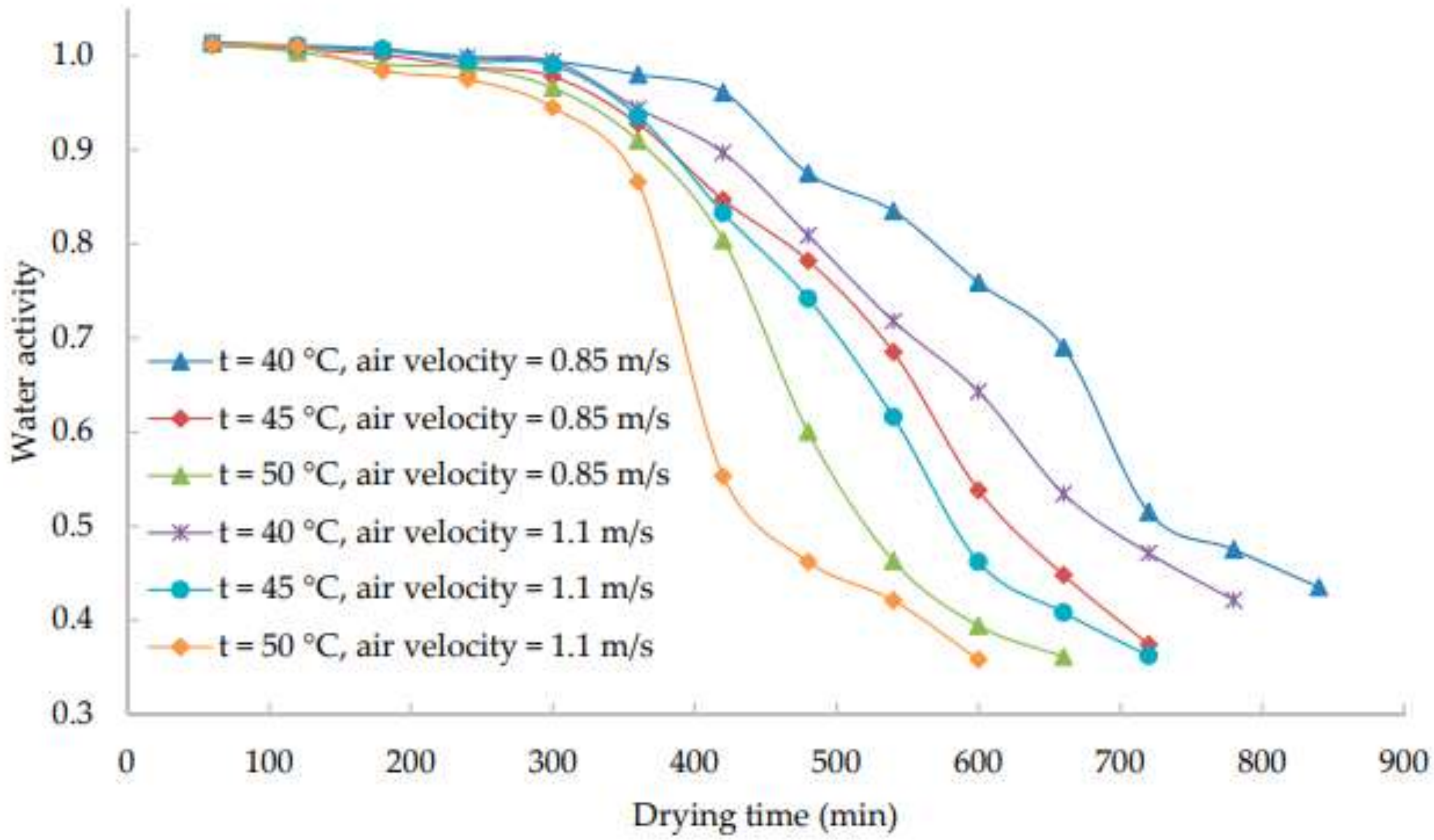
Motevali, A., Minaei, S., & Khoshtagaza, M. H. (2011). Evaluation of energy consumption in different drying methods. *Energy conversion and management*, *52*(2), 1192-1199.

Key factors influencing drying kinetics and energy consumption

- Drying method and technology
- Air relative humidity
- Air temperature
- Air velocity
- Sample characteristics
- Pressure


Moisture content (kgH2O/kgSolid)
time (min)
t = 50 °C, Air velocity = 0.60 m/s
t = 50 °C, Air velocity = 0.85 m/s
t = 50 °C, Air velocity = 1.1 m/s
t = 40 °C, Air velocity = 1.1 m/s
t = 45 °C, Air velocity = 1.1 m/s
t = 50 °C, Air velocity = 1.1 m/s
Drying time (min)
t = 50°C , Ari flow velocity = 1.1 m/s
φ = 40-45%
φ = 35-38%
φ = 25-28%
t = 70 °C, Air velocity = 1.1 m/s
Thickness = 4 mm
Thickness = 6 mm
Thickness = 8 mm
Thickness = 10 mm
Thickness = 12 mm

Effect of process conditions on water activity



Prediction of drying kinetics by mathematical modelling

Two approaches:

1. **Drying models employing the analysis of physical phenomena, such as mass diffusion, heat transfer, and surface tension**

Macroscale Models

Heat transport equations

1 $\frac{\partial T}{\partial t} = \nabla \cdot (\alpha \nabla T)$

2 $\frac{\partial T}{\partial t} = \alpha \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right)$

3 $\frac{\partial T}{\partial t} = \alpha \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right)$

4 $\frac{\partial T(\varsigma,\tau)}{\partial \tau} = Le \frac{\partial^2 T(\varsigma,\tau)}{\partial \varsigma^2}$

Mass transport equations

5 $\frac{\partial X}{\partial t} = \nabla \cdot (D_{eff} \nabla X)$

6 $\frac{\partial X}{\partial t} = D_{eff} \left(\frac{\partial^2 X}{\partial x^2} + \frac{\partial^2 X}{\partial y^2} \right)$

7 $\frac{\partial X}{\partial t} = D_{eff} \left(\frac{\partial^2 X}{\partial x^2} + \frac{\partial^2 X}{\partial y^2} + \frac{\partial^2 X}{\partial z^2} \right)$

8 $\frac{\partial}{\partial \tau} \left(\frac{X}{J} \right) = \frac{\partial}{\partial \xi} \left(a_{11} JD \frac{\partial X}{\partial \xi} + a_{12} JD \frac{\partial X}{\partial \gamma} \right) + \frac{\partial}{\partial \gamma} \left(a_{21} JD \frac{\partial X}{\partial \xi} + a_{22} JD \frac{\partial X}{\partial \gamma} \right)$

9 $\frac{\partial X}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} \left(r Deff \frac{\partial X}{\partial r} \right) + \frac{\partial}{\partial y} \left(Deff \frac{\partial X}{\partial y} \right)$

10 $C_m \frac{\partial \psi}{\partial t} + \nabla .(-K_m \nabla \psi) = 0$

11 $\frac{\partial X}{\partial t} + u \frac{\partial X}{\partial x} = D_{eff} \frac{\partial^2 X}{\partial x^2}$

12 $(1 - \varphi) \rho_{sol} \frac{\partial X_{pol}}{\partial t} = \dot{m} pol$

Momentum equations

13 $\rho \frac{\partial u}{\partial t} - \nabla \left(\eta + \rho \frac{C_\mu k^2}{\sigma_{s} \varepsilon} \right) \cdot (\nabla u + (\nabla u)^T) + \rho u \cdot \nabla u + \nabla P = 0 \lim_{x \to \infty}$

14 $\rho_a C_{pa} \left(\frac{\partial T_\infty}{\partial t} \right) + \nabla(-\lambda_a \nabla T_\infty) + \rho_a C_{pa} u \nabla T_\infty = 0$

2. **Empirical models based on experimental measurements**

Table 1. Selected thin-layer mathematical models.

Model name	Model
Page	$MR = \exp(-kt^n)$
Modified Page	$MR = \exp[-(kt)]^n$
Henderson and Pabis	$MR = a \exp(-kt)$
Two-term	$MR = a \exp(-k_0 t) + b \exp(-k_1 t)$
Two-term exponential	$MR = a \exp(-kt) + (1 - a) \exp(-kat)$
Midilli	$MR = a \exp(-kt)^n + bt$
Approximation of diffusion	$MR = a \exp(-kt) + (1 - a) \exp(-kbt)$
Verma	$MR = a \exp(-kt) + (1 - a) \exp(-gt)$

Development of a new Process Conditions Sensitive (PCS) thin-layer mathematical model of hot air convective drying

Taylor & Francis

Chemical Engineering Communications

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/gcec20

Process conditions sensitive (PCS) thin-layer mathematical model of hot air convective drying

Juma Haydary, Mohammad Jafar Royen & Abdul Wasim Noori

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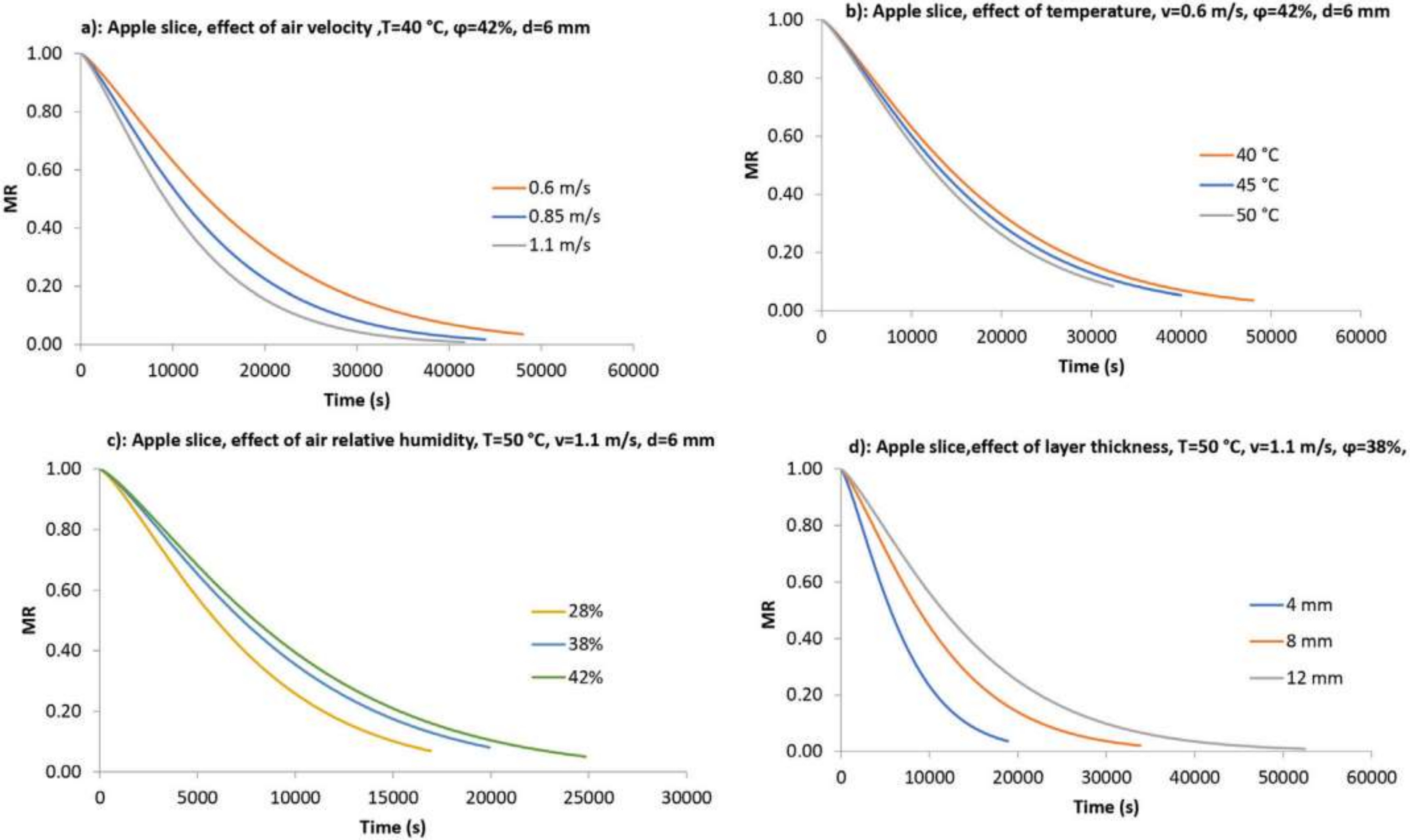
$$MR = \mathrm{EXP}\left[-kF_k t^{nF_t}\right]$$

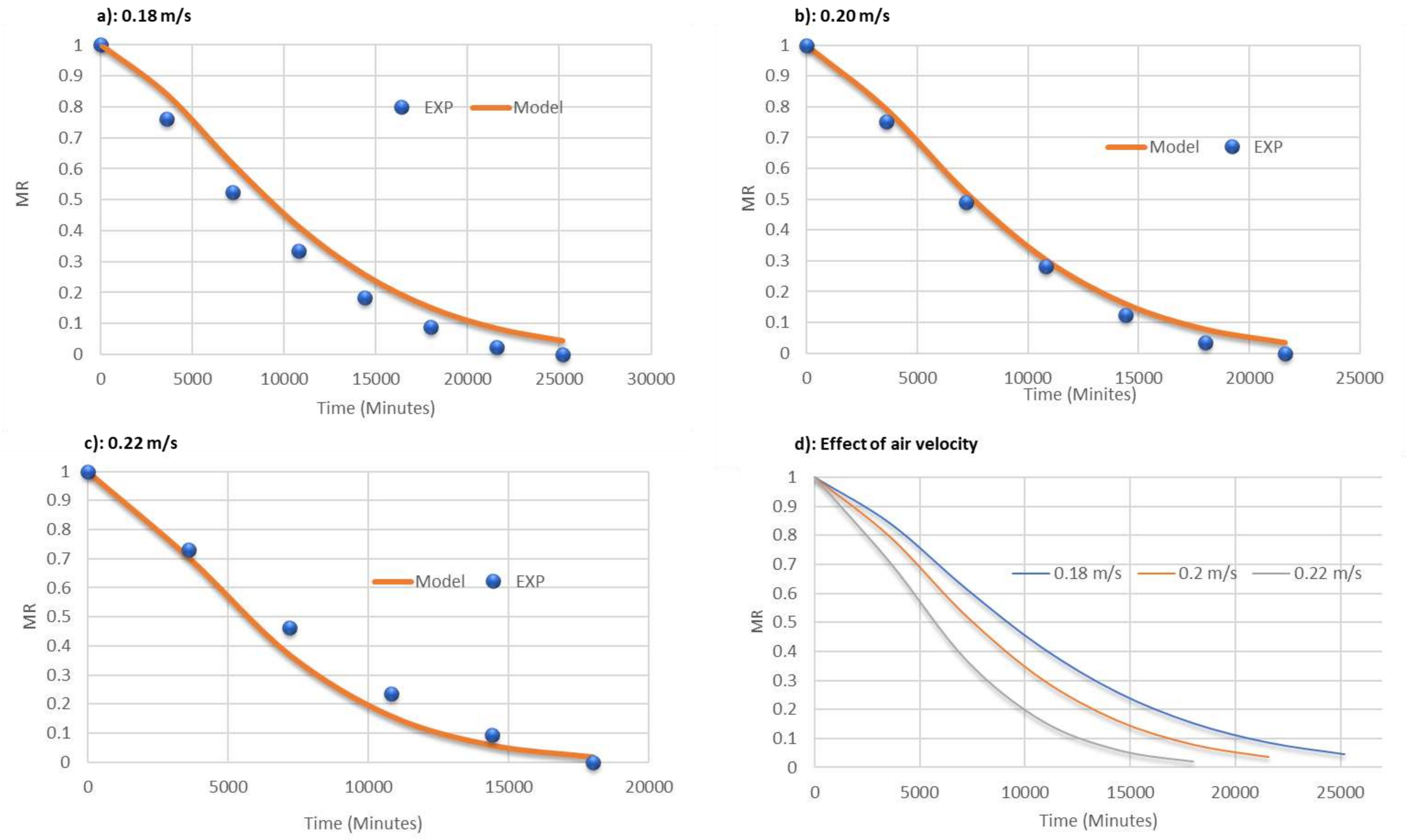
$$F_k = \left(\frac{T/T_{\min} \quad v/v_{\min}}{d/d_{\min} \quad \varphi/\varphi_{\min}}\right)^p$$

$$F_t = \left(\frac{T/T_{\min} \quad v/v_{\min}}{d/d_{\min} \quad \varphi/\varphi_{\min}}\right)^r$$

$$MR = \frac{M - M_e}{M_0 - M_e}$$

$$OF = \sum_T \left(\sum_i \left(MR_{Exp,i} - MR_{Pred,i}\right)^2\right)_{min} + \sum_v \left(\sum_i \left(MR_{Exp,i} - MR_{Pred,i}\right)^2\right)_{min} + \sum_\varphi \left(\sum_i \left(MR_{Exp,i} - MR_{Pred,i}\right)^2\right)_{min} + \sum_d \left(\sum_i \left(MR_{Exp,i} - MR_{Pred,i}\right)^2\right)_{min} = min$$


a): Apple slice, effect of air velocity ,T=40 °C, φ=42%, d=6 mm
MR
Time (s)
0.6 m/s
0.85 m/s
1.1 m/s
b): Apple slice, effect of temperature, v=0.6 m/s, φ=42%, d=6 mm
MR
Time (s)
40 °C
45 °C
50 °C
c): Apple slice, effect of air relative humidity, T=50 °C, v=1.1 m/s, d=6 mm
MR
Time (s)
28%
38%
42%
d): Apple slice,effect of layer thickness, T=50 °C, v=1.1 m/s, φ=38%,
MR
Time (s)
4 mm
8 mm
12 mm



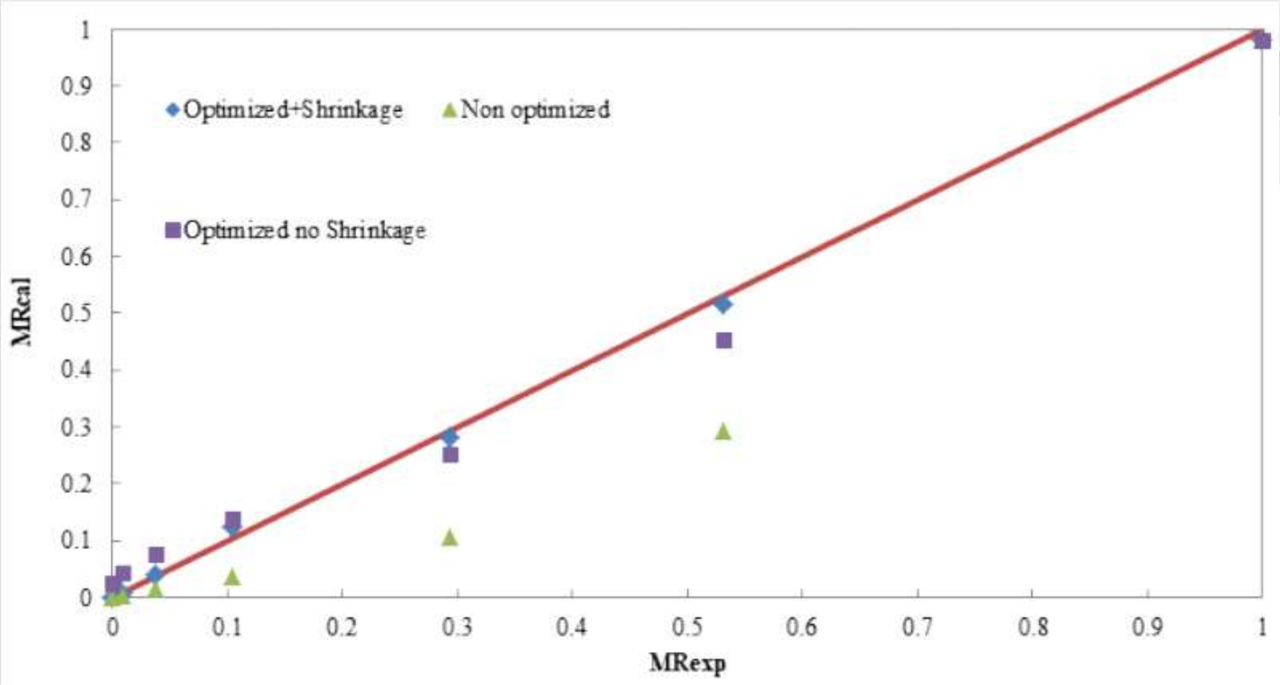
a): 0.18 m/s
MR
Time (Minutes)
EXP
Model
b): 0.20 m/s
MR
Time (Minites)
Model
EXP
c): 0.22 m/s
MR
Time (Minutes)
Model
EXP
d): Effect of air velocity
MR
Time (Minutes)
0.18 m/s
0.2 m/s
0.22 m/s

Effect of shrinkage

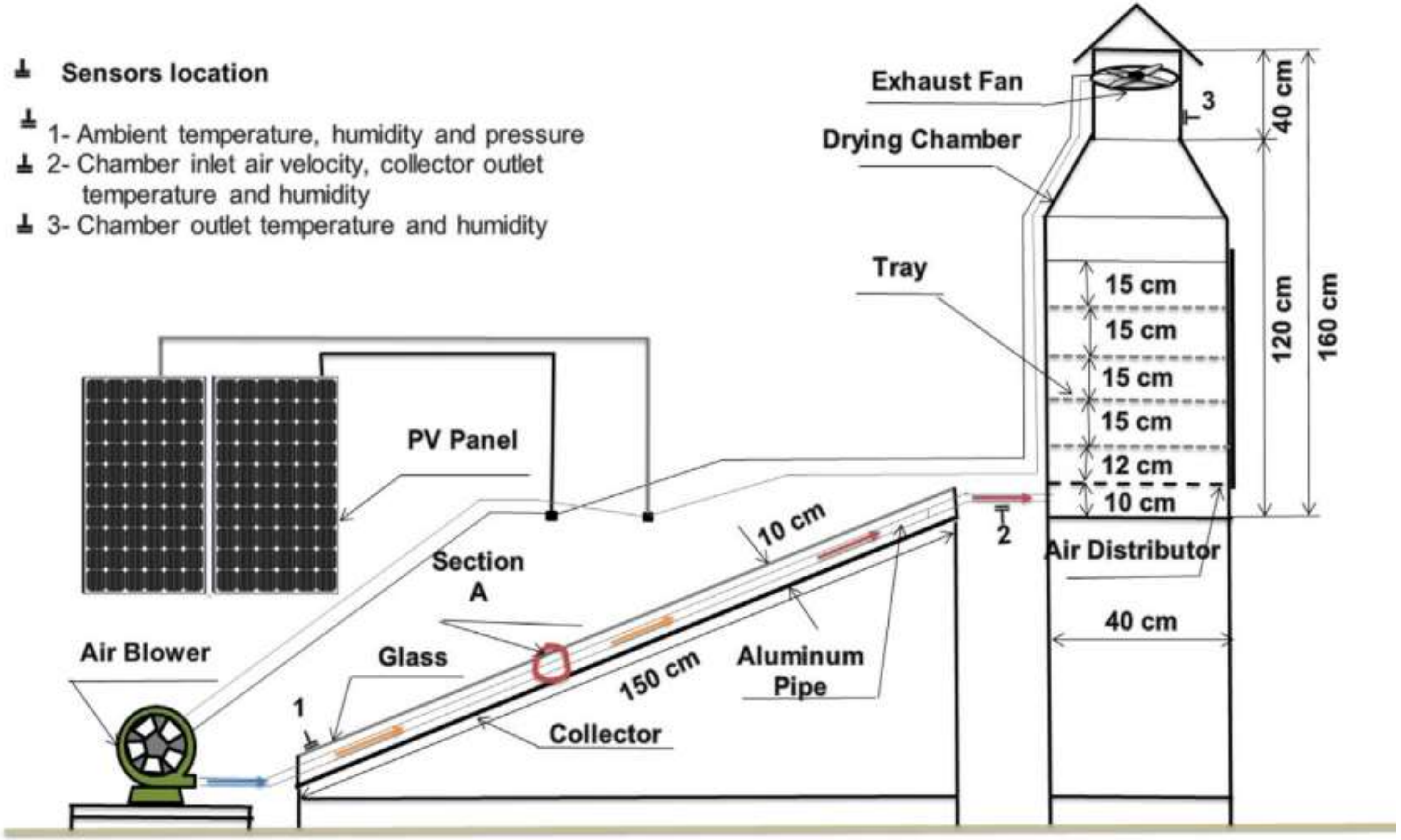
$$MR = \sum_{n=0}^{\infty} \frac{8}{(2n+1)^2\pi^2} Exp\left(-\frac{(2n+1)^2\pi^2 D_{eff} t}{4\, l^2}\right)$$

Effective diffusion coefficient

D_{eff} ($m^2\,s^{-1}$)	Non-optimized	Optimized shrinkage not considered	Optimized shrinkage considered
Day 1	$6.10\ 10^{-10}$	$3.30\ 10^{-10}$	$2.33\ 10^{-10}$
Day 2			
Day 3			
Lab. Ba			

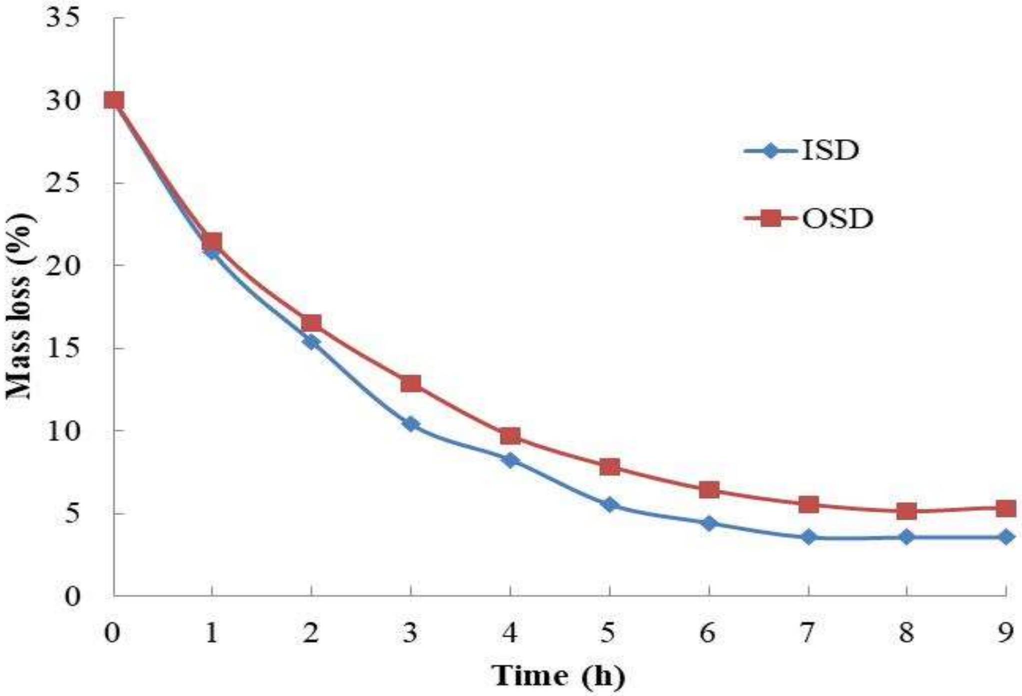


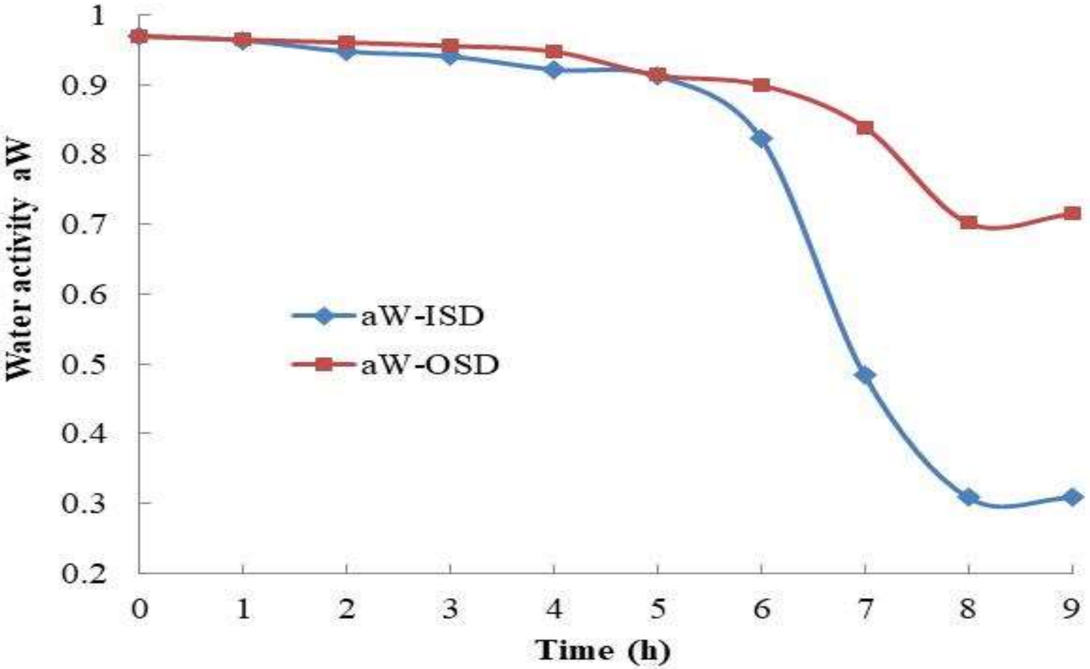
Use of renewable energy in food drying, solar drying

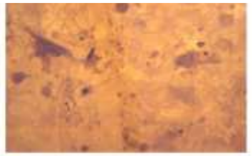


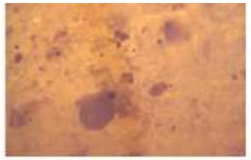
Indirect forced solar drying system

Why indirect solar drying?

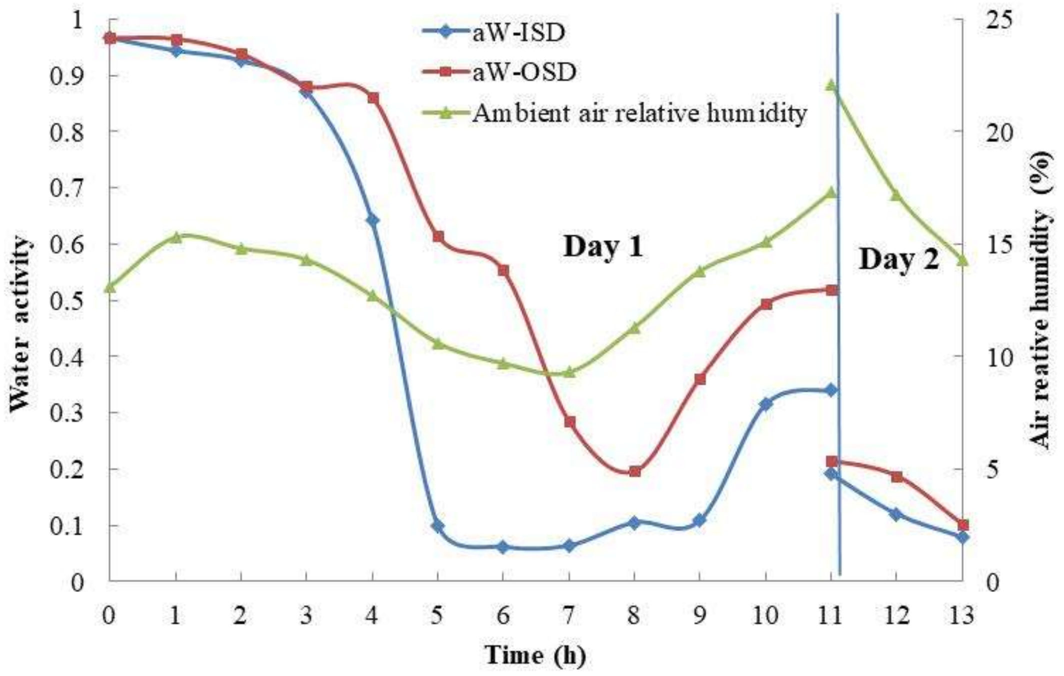


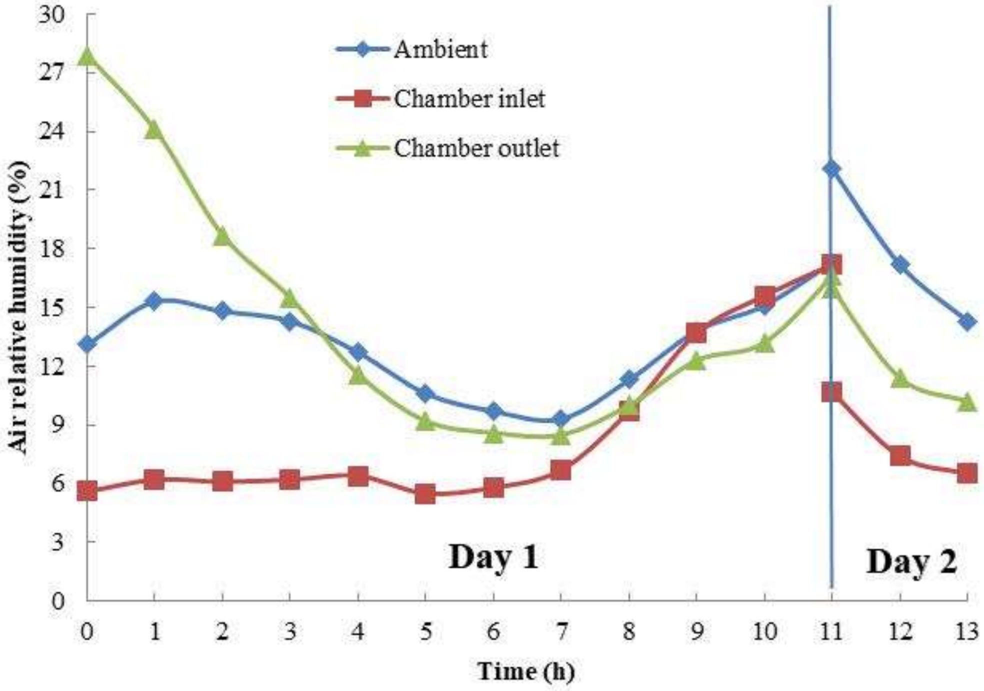




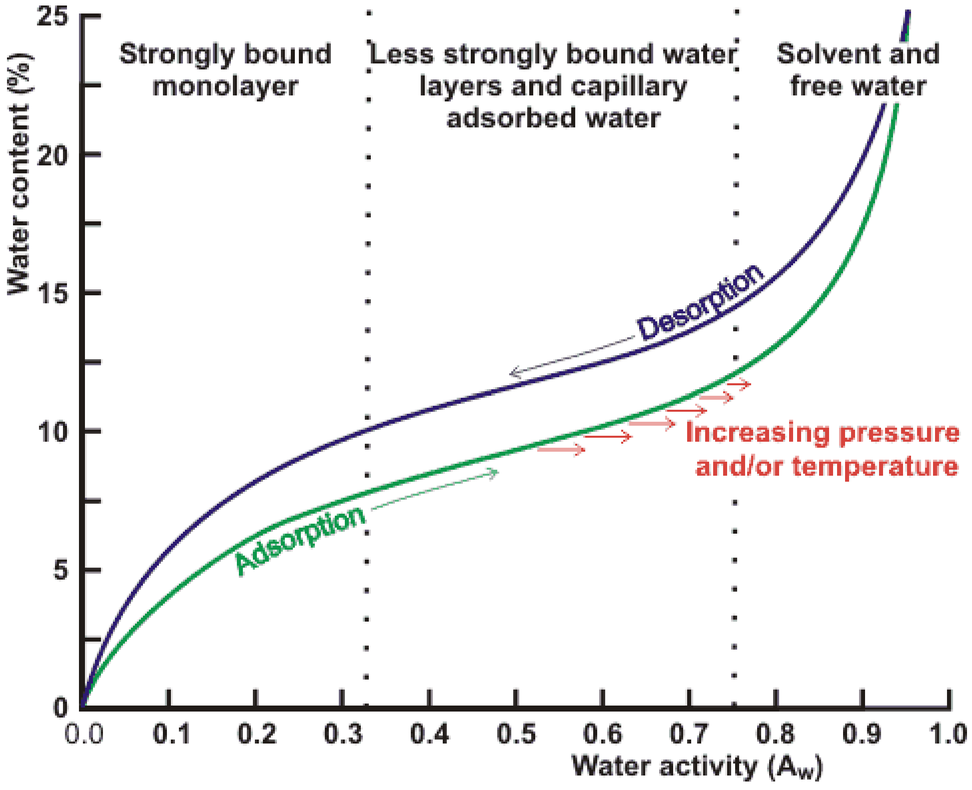


Effect of ambient air relative humidity

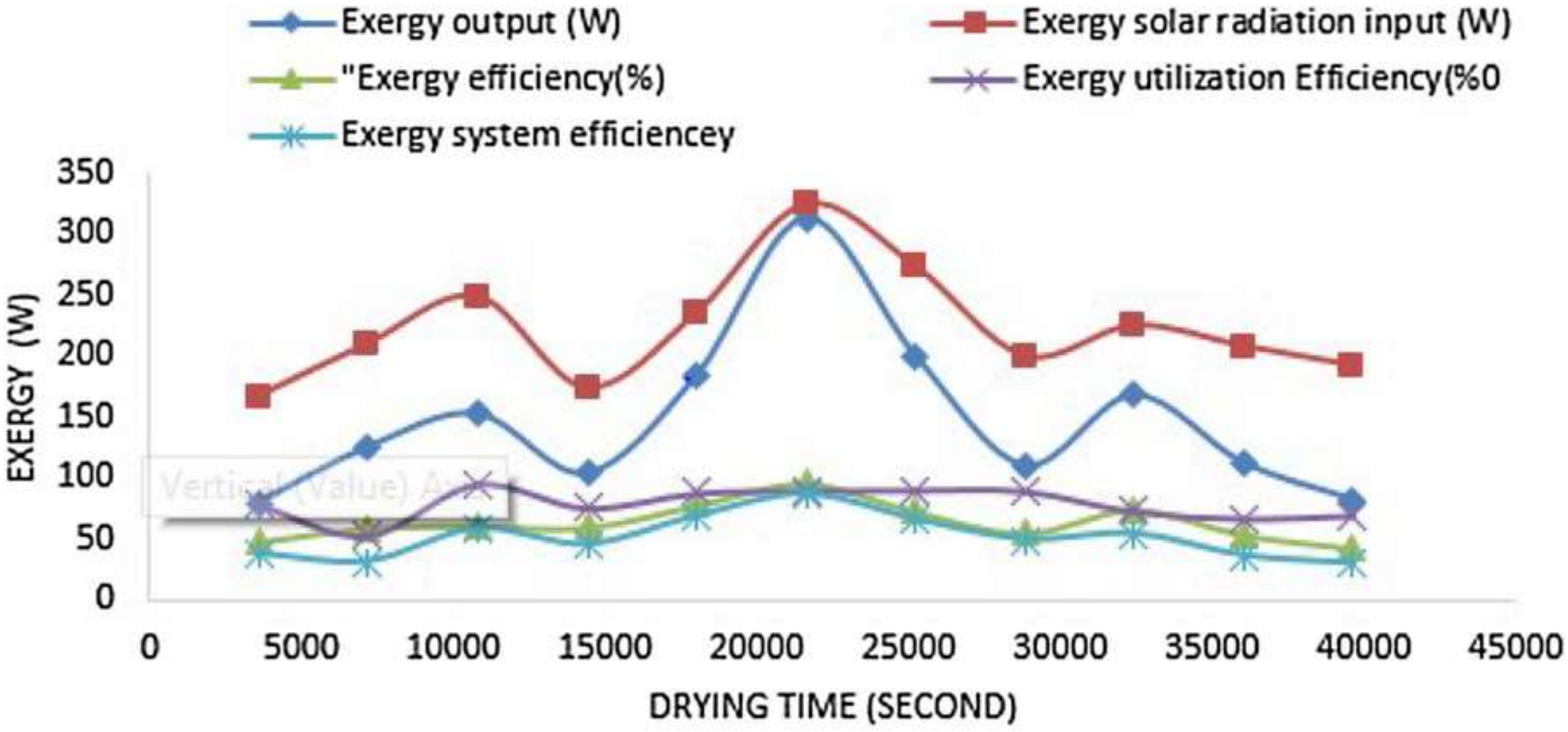




Rehydration of dried products



Energy efficiency of solar drying



Sintie, Y. T., & Aduye, G. T. (2020). Potential assessment and experimental analysis of solar vegetable dryer: in case of northern Ethiopia. *Renewables: Wind, Water, and Solar*, *7*(1), 1-28.

Thank you for your attention