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OPERATIONAL CONDITIONS AFFECTING LOW-TEMPERATURE DRYING ASSISTED BY POWER ULTRASOUND

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UIA ultrasonic industry association
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43rd Annual UIA Symposium
23 – 25 April 2014

CSIC
Madrid, Spain

Introduction

WHY EXPLORING THE USE OF LOW-TEMPERATURE DRYING ***in Solids and Pastes***

HOT AIR DRYING:

PROS:

+ Low cost

+ Simple unit operation

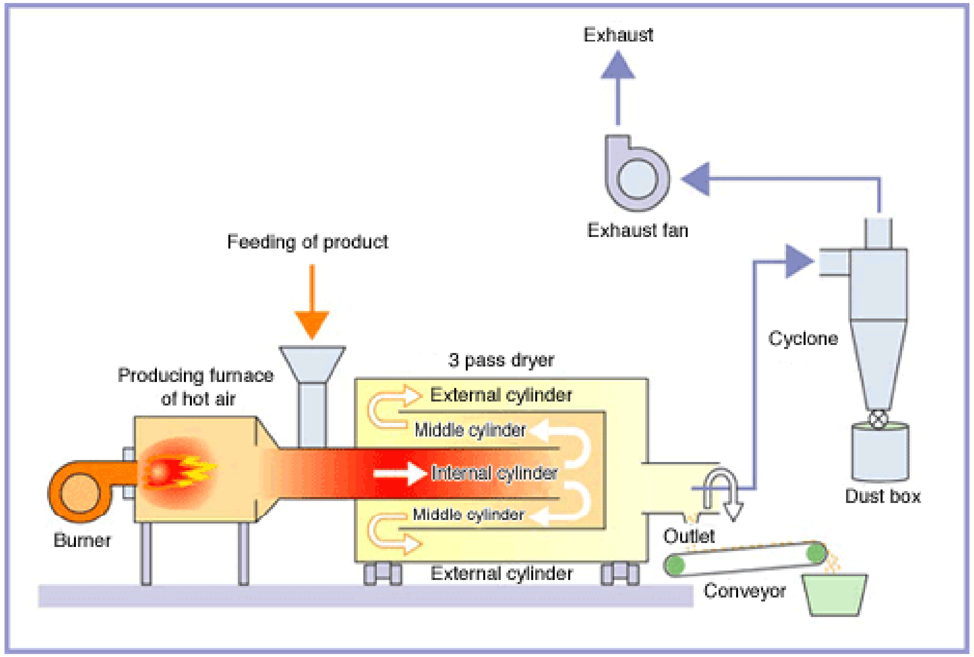
CONS:

- High energy consuming

- Quality loss in biomaterials (high stress)

Structural damage

Nutritional damage (vitamins, etc…)



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FREEZE DRYING OR LYOPHILIZATION

Introduction

WHY EXPLORING THE USE OF LOW-TEMPERATURE DRYING *in Liquids*

SPRAY DRYING (ATOMIZATION):

PROS:

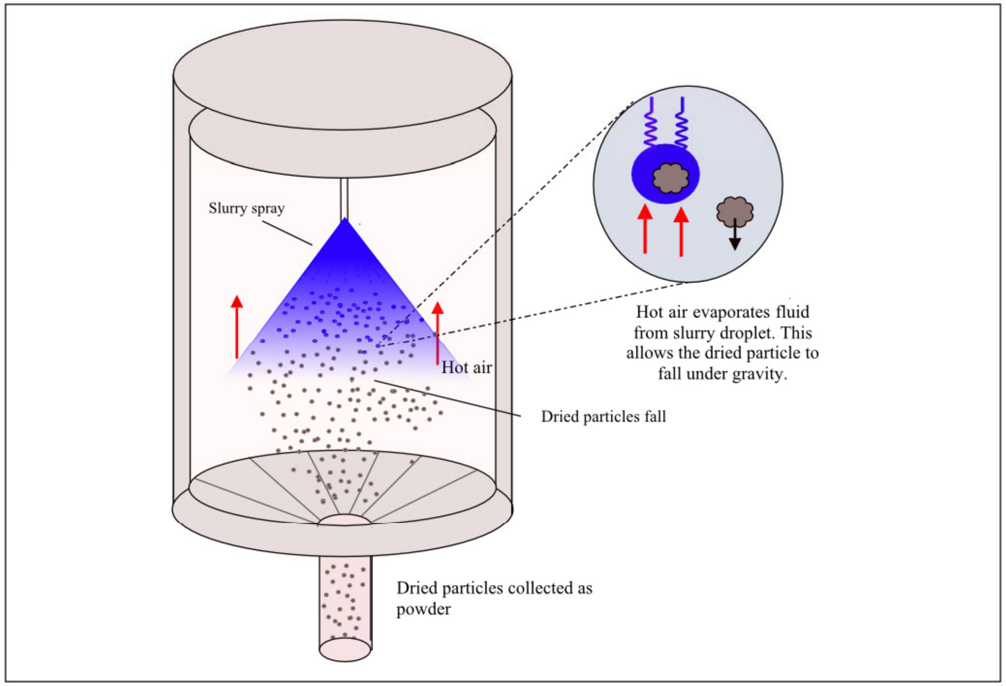
+ Good quality

+ High productivity (Simple operation)

CONS:

- Nozzles

- High viscosity liquids



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FREEZE DRYING OR LYOPHILIZATION

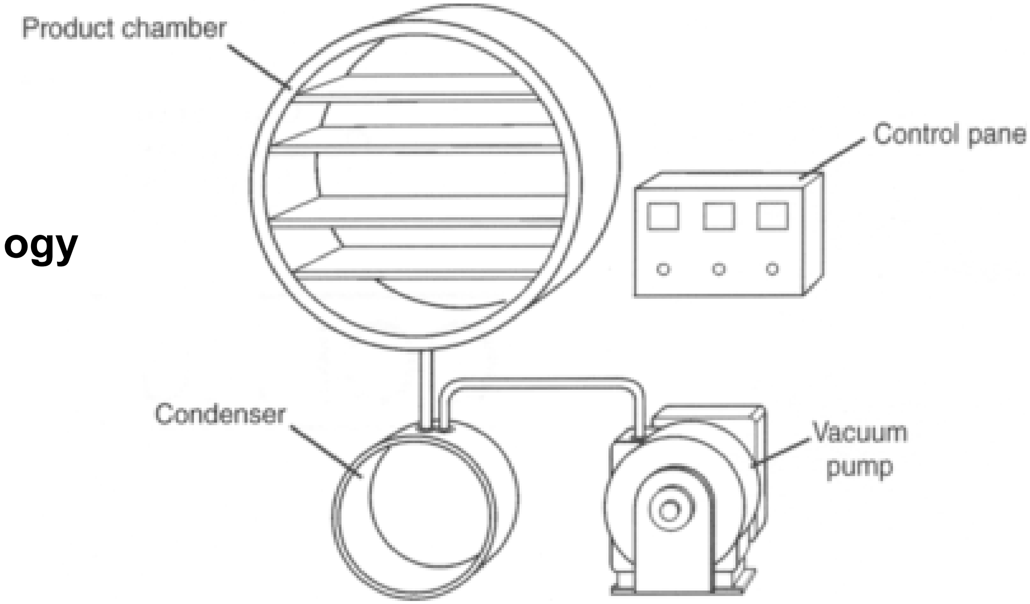
FREEZE-DRYING OR LYOPHILIZATION

PROS:

+ Excellent quality

+ Liquids, solids and pastes

+ Market: Pharmaceutics and Biotechnology



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CONS:

-Vacuum

-Batch operation

-High investment

-High operational costs

-Food industry: High added value products

CONVECTIVE LOW-TEMPERATURE DRYING

Introduction

LOW-TEMPERATURE CONVECTIVE DRYING

Use of air temperatures below standard room conditions (T<15-20 ºC):

$T>T_{freezing}$ (Evaporation)

$T<T_{freezing}$ (Sublimation, Atmospheric Freeze drying)

PROS:

- **No Vacuum (Continuous processing)**
- **Low investment**
- **Liquids, solids and pastes**
- **Similar quality than freeze-drying**
- **Chemical, pharmaceutical,…..**

CONS: VERY SLOW!!!!

INDUSTRIAL APPLICATIONS:

KINETIC INTENSIFICATION

Introduction

ALTERNATIVES FOR LOW-TEMPERATURE DRYING INTENSIFICATION:

Thermal energy:

Direct increase of drying air temperature

Thermal technologies: Microwave

Infrared radiation

High risk of product overheating

Mechanical energy:

Power ultrasound (US)

Higher cost

Not developed technology

(12) SOLICITUD INTERNACIONAL PUBLICADA EN VIRTUD DEL TRATADO DE COOPERACIÓN EN MATERIA DE PATENTES (PCT)

(19) Organización Mundial de la Propiedad Intelectual
Oficina internacional

(43) Fecha de publicación internacional
28 de marzo de 2013 (28.03.2013)

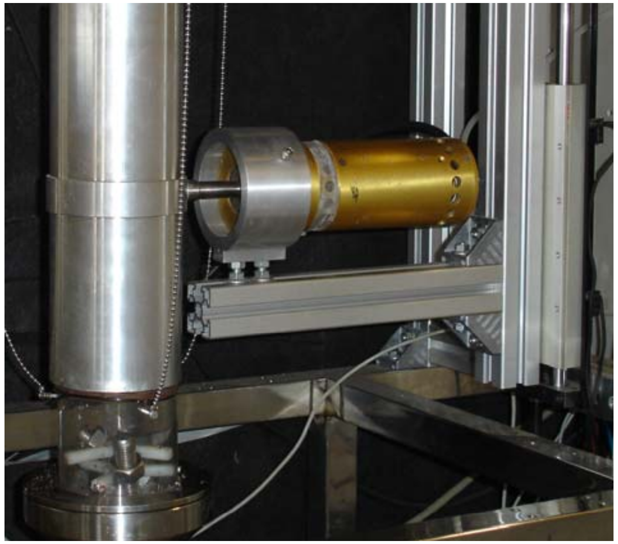
WIPO | PCT

(10) Número de Publicación Internacional
WO 2013/041750 A1

(54) Title: METHOD AND DEVICE FOR IMPROVING MATERIAL TRANSFER IN LOW-TEMPERATURE PROCESSES USING HIGH-INTENSITY ULTRASOUND

Introduction

Recent advances in the design of efficient air-borne ultrasonic devices have been carried by the Power Ultrasonics Group (CSIC, Spain and PUSONICS) and their feasibility for hot air drying intensification has been tested in collaboration with the ASPA Group (Universitat Politecnica de València, UPV, Spain).



CYLINDRICAL RADIATOR (CR)

STEPPED PLATE RADIATOR (SPR)

Introduction

Table. Compendium of previous works carried out by UPV and CSIC groups addressing the application of power ultrasound on convective drying.

REFERENCE	PROCESS VARIABLE UNDER STUDY	MATERIAL BEING TESTED	ULTRASONIC DEVICE*
Gallego-Juarez et al., 1999	Air temperature and ultrasonic power	Carrot	SPR
Gallego-Juarez et al., 2007	Air temperature and velocity and ultrasonic power	Carrot and apple	SPR
Mulet et al., 2003	Ultrasonic power	Carrot	SPR
Garcia-Perez et al., 2011	Ultrasonic power	Eggplant	CR
Ozuna et al., 2011a	Ultrasonic power	Potato	CR
Garcia-Perez et al., 2012a	Product structure and ultrasonic power	Orange peel	CR
Garcia-Perez et al., 2009	Product structure and ultrasonic power	Lemon peel and carrot	CR
Puig et al., 2012	Product structure and ultrasonic power	Eggplant	CR
Carcel et al., 2010	Mass load density	Carrot	CR
Garcia-Perez et al., 2006b	Air velocity, mass load and ultrasonic power	Carrot	CR
Garcia-Perez et al., 2007	Air velocity	Lemon peel, persimmon and carrot	CR
Carcel et al., 2007	Air velocity	Persimmon	CR
Garcia-Perez et al., 2012b	Air temperature	Eggplant, carrot and apple	CR
Garcia-Perez et al., 2006a	Air temperature	Carrot	CR

* CYLINDRICAL RADIATOR (CR), STEPPED PLATE RADIATOR (SPR)

Objective

"Thereby, this work aims to show the influence of air velocity and temperature, two of the most important operational parameters, on Low-Temperature Drying assisted by power ultrasound."

Materials and Methods

RAW MATERIAL:

- **Materials with very different internal structure have been used.**
- **Structure has been characterized by macroscopic and microscopic analysis :**

  Density and porosity measurements

  SEM and Cryo-SEM observations

  Instrumental texture tests have been performed.

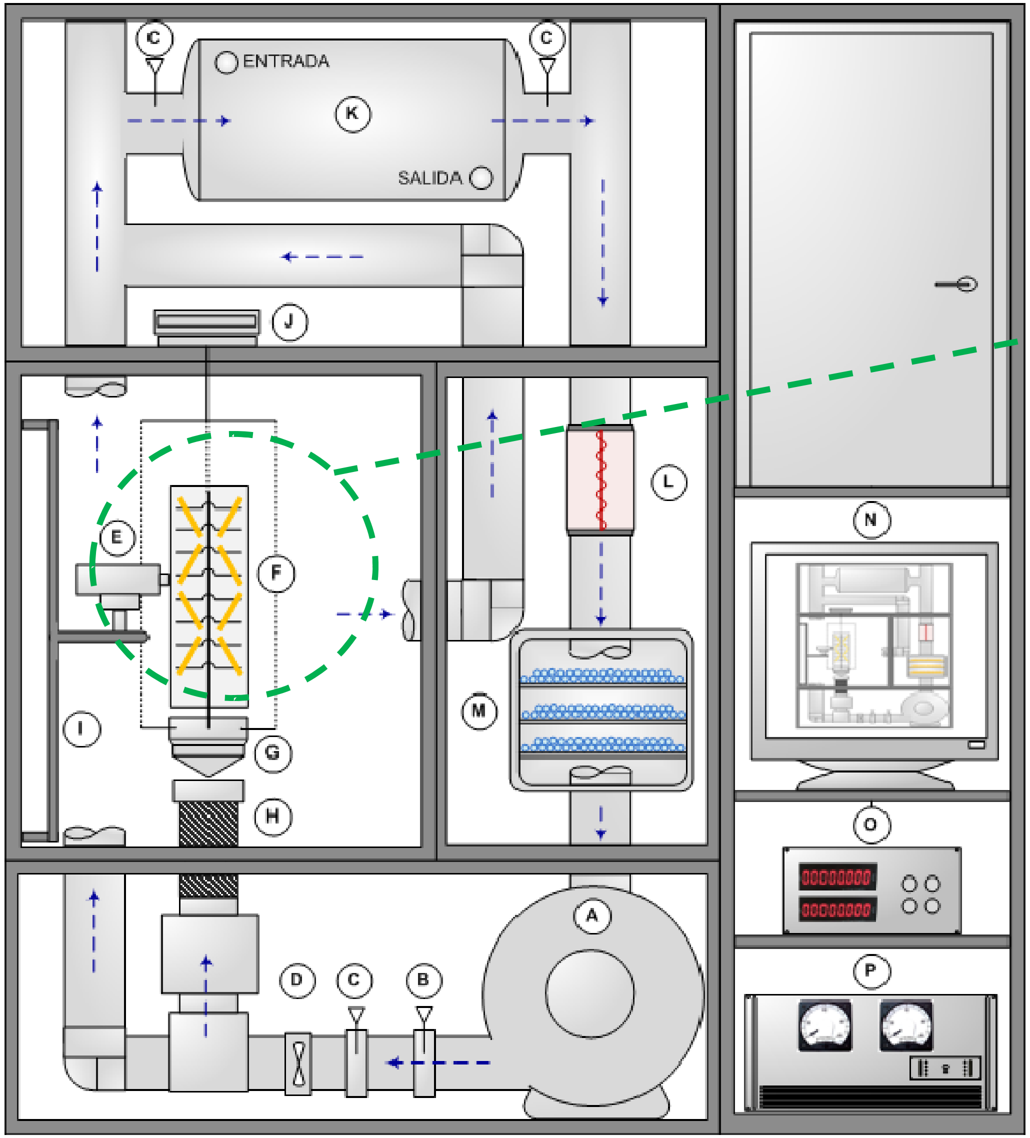
EGGPLANT

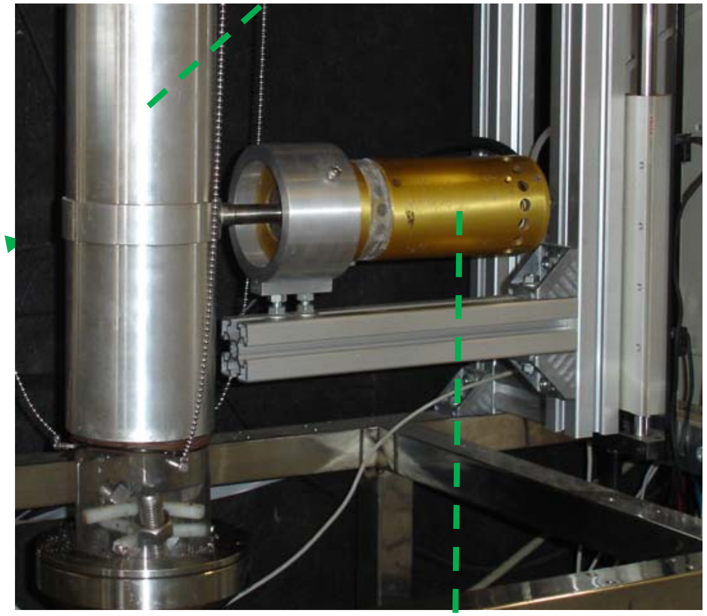
APPLE

CARROT

Materials and Methods

Scheme of the convective drier with the cylindrical radiator:





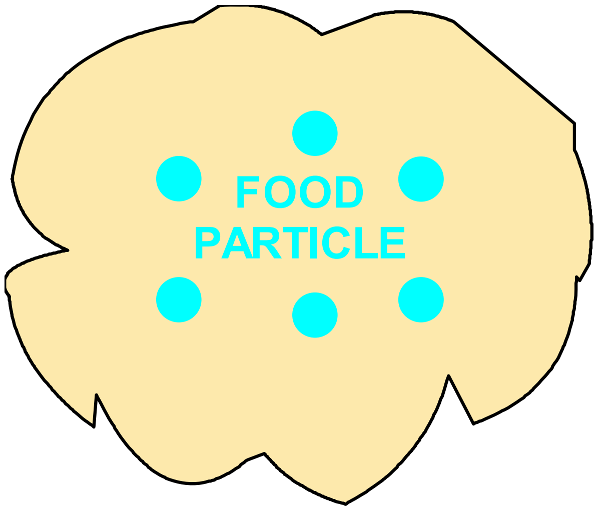
Materials and Methods

DRYING TESTS :

PROCESS VARIABLES:

- **Air velocity (from 1 to 6 m/s)**
- **Air temperature (from -14 to 10 ºC)**

DIFFUSION MODELS were used to describe the water transport mechanisms during drying, as well as to quantify the influence of power ultrasound on kinetic parameters.



EFFECTIVE DIFFUSIVITY, D_e

EXTERNAL COEFFICIENT, K

Results and Discussion

Influence of raw material:

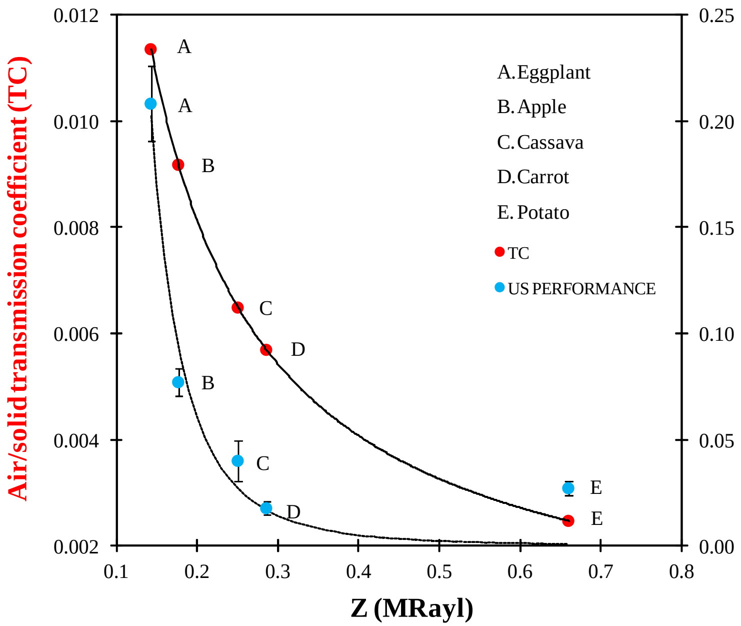


Figure. Influence of acoustic impedance on TC and ultrasonic performance for hot air drying operations (Ozuna et al., 2014a).

Ultrasonics Sonochemistry 21 (2014) 1235–1243
Contents lists available at ScienceDirect
Ultrasonics Sonochemistry
journal homepage: www.elsevier.com/locate/ultson

Influence of material structure on air-borne ultrasonic application in drying

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Drying Technology, 30: 1199–1208, 2012
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ISSN: 0737-3937 print/1532-2300 online
DOI: 10.1080/07373937.2012.675533
Taylor & Francis

Intensification of Low-Temperature Drying by Using Ultrasound

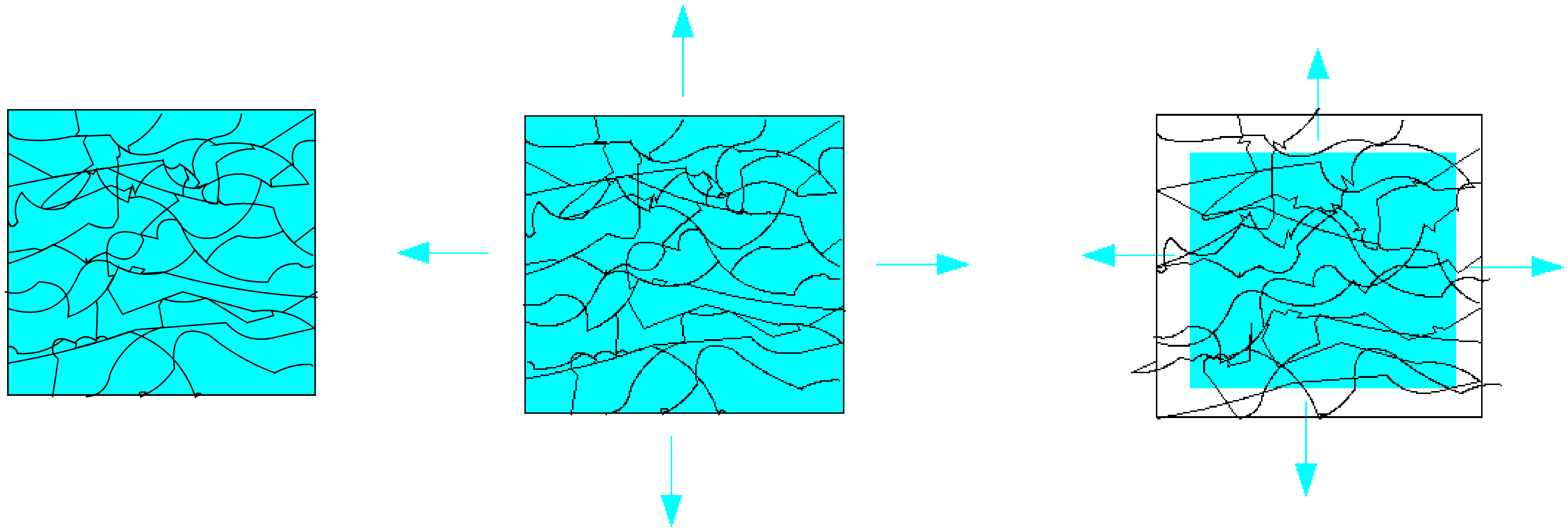
Jose V. Garcia-Perez,[1] Juan A. Carcel,[1] Enrique Riera,[2] Carmen Rosselló,[3] and Antonio Mulet[1]

		D_e (10^{-11} m^2/s)	VAR (%)
Carrot	AIR	1.1±0.1	99.3
	AIR+US	3.1±0.3	91.8
	Increment (%)	182	
Apple	AIR	1.6±0.4	98.0
	AIR+US	5.5±1.1	93.3
	Increment (%)	244	
Eggplant	AIR	4.8±1.3	93.4
	AIR+US	15.8±3.3	92.3
	Increment (%)	229	

Table. Influence of ultrasonic application on effective moisture diffusivity for low-temperature drying (-14 ºC) (Garcia-Perez et al., 2012).

Results and Discussion

Influence of raw material



Raw Product

(Homogeneous frozen product)

Beginning of drying

(water removal by sublimation)

Partially dried product

1. Internal: Frozen core

2. External: Dry outer layer

- **Uniform Retreating Ice Front (URIF) models for freeze drying ($T \leq T_{freezing}$)**
- **FROZEN CORE + EXTERNAL POROUS LAYER → Low acoustic impedance (Z)**
- **It is being reduced the influence of internal structure → Similar behavior**

Results and Discussion

Influence of air temperature

10 ºC

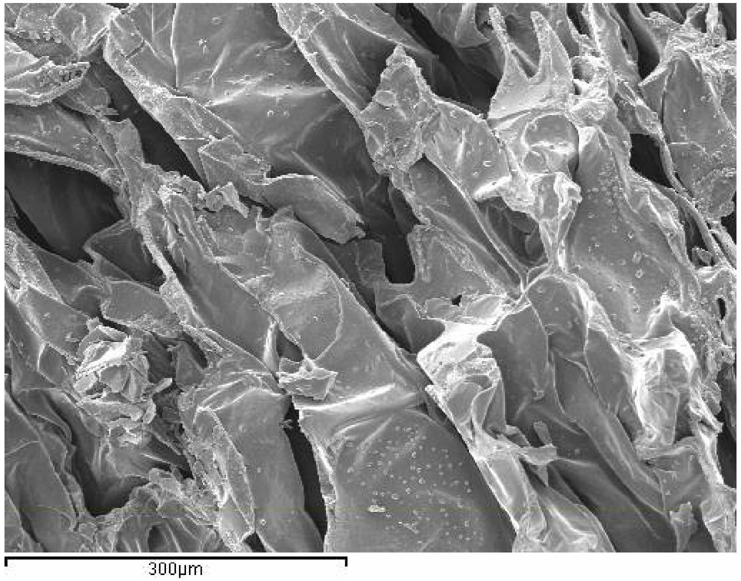


Figure. Cryo-SEM image of apple cubes AIR dried at 10 ºC.

-10 ºC

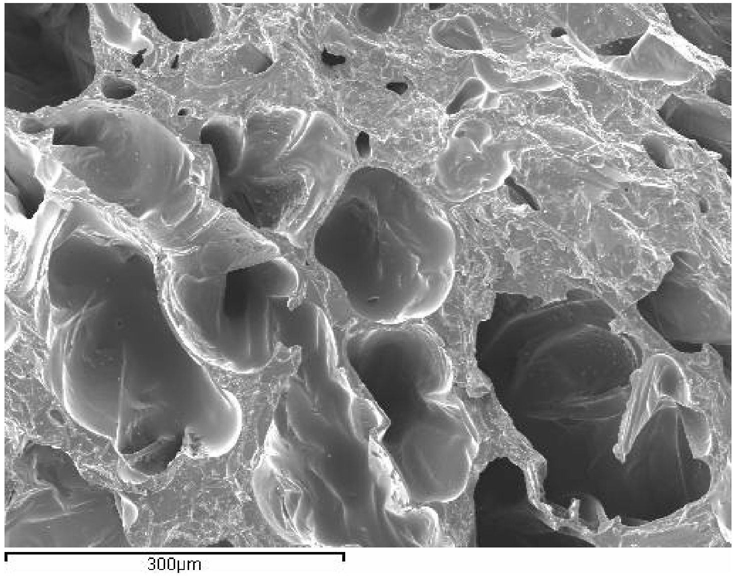


Figure. Cryo-SEM image of apple cubes AIR dried at -10 ºC.

- **Drying at -10 ºC involves a more porous structure.**
- **Any remarkable effect of US was observed on product structure.**

Results and Discussion

Influence of air temperature

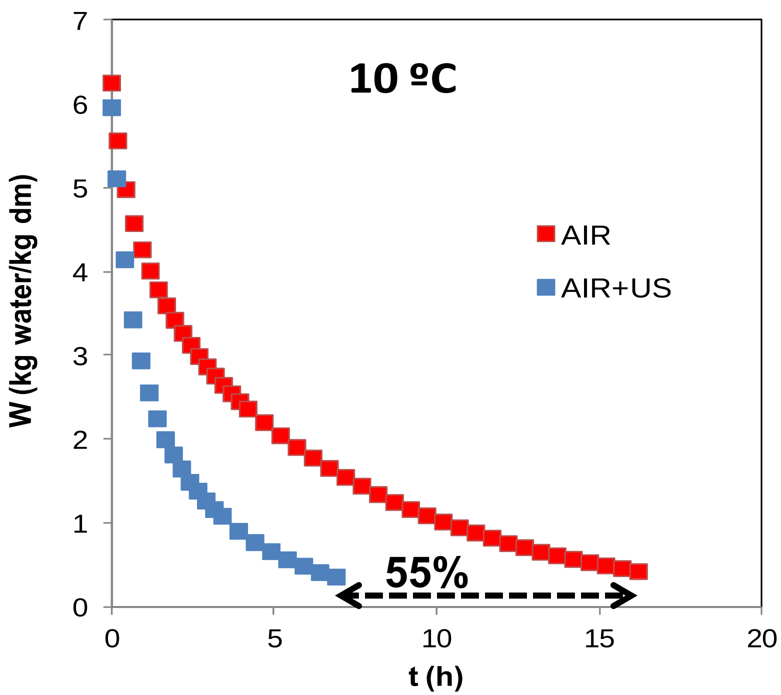


Figure. Drying kinetics of apple cubes at 10 ºC (Santacatalina et al., 2014).

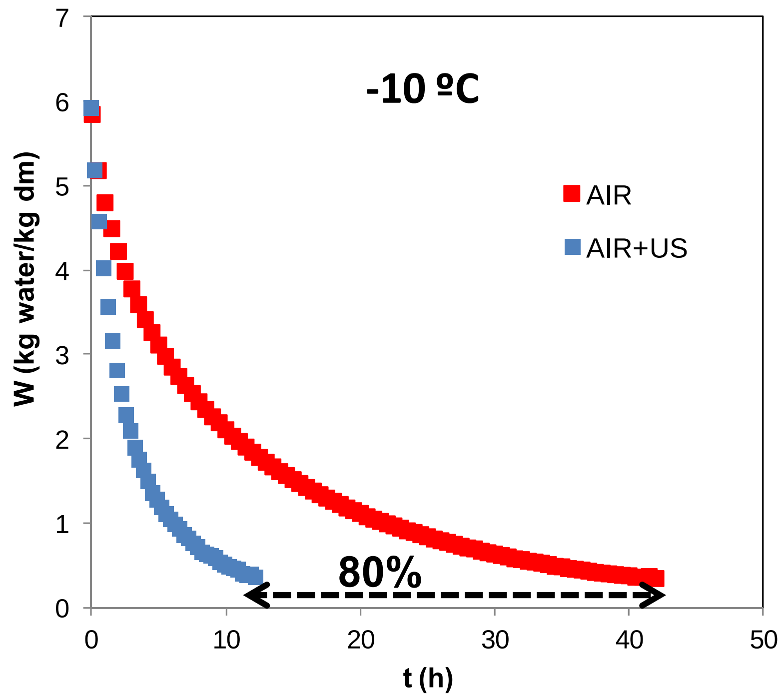


Figure. Drying kinetics of apple cubes at -10 ºC (Santacatalina et al., 2014).

- **Larger effects of US at temperatures below freezing point (-10 ºC, more porous structure)**

Results and Discussion

Influence of air temperature

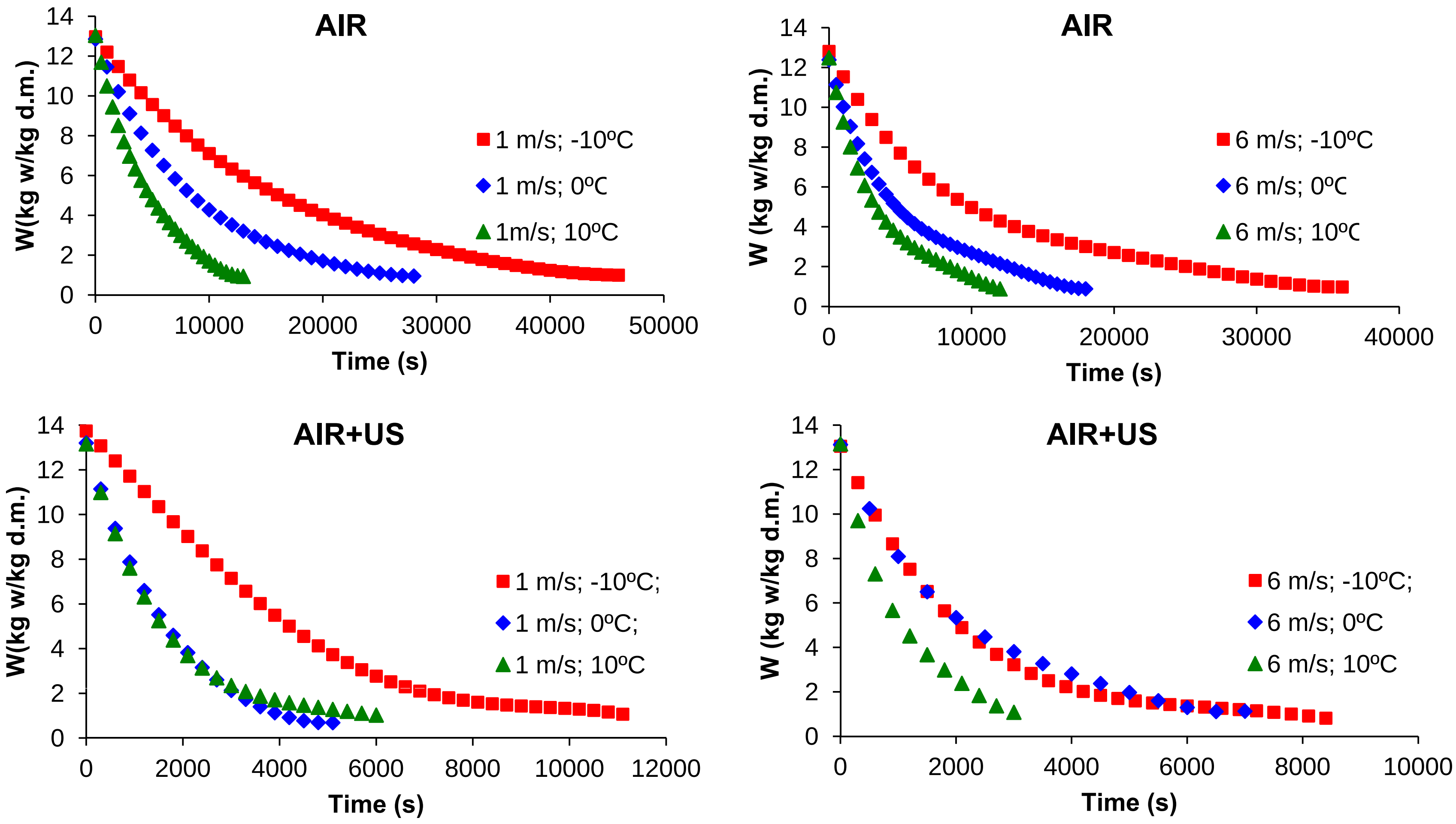


Figure. Drying kinetics of eggplant cubes (8.5 mm) at different air velocities and temperatures.

Results and Discussion

Influence of air velocity

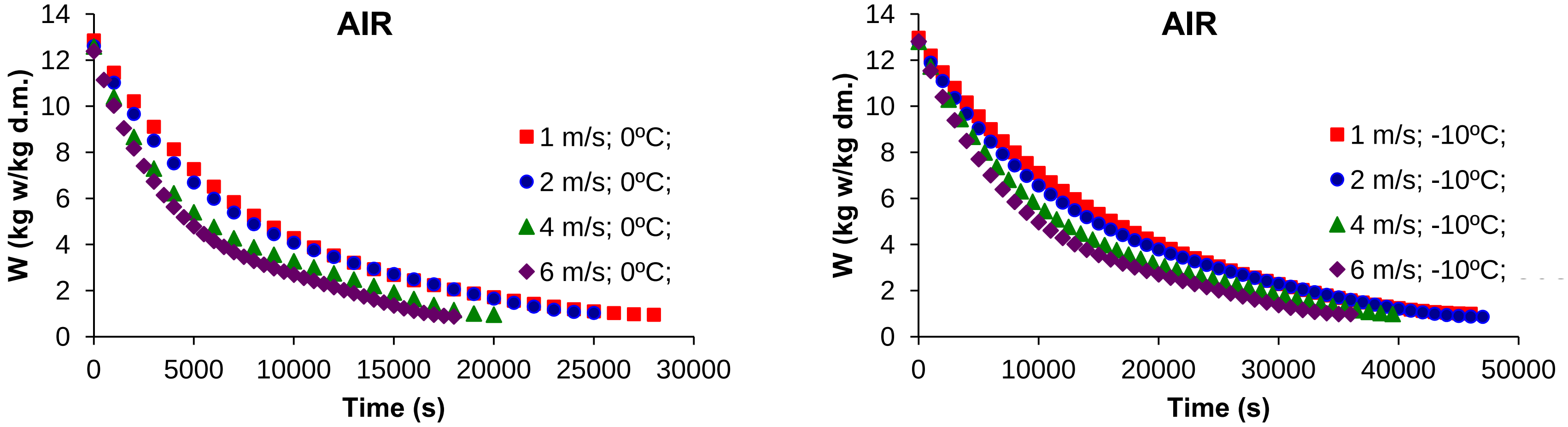
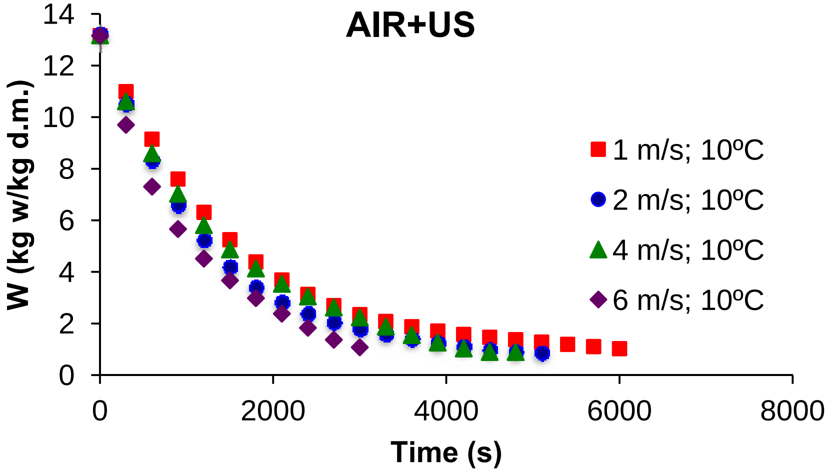


Figure. Drying kinetics of eggplant cubes (8.5 mm) at different air velocities and temperatures.

- **The higher the air velocity, the faster the drying.**
- **The same effect is observed at the different temperatures.**
- **The increase of air velocity reduces the external resistance to mass transfer (greater turbulence in the air/product interface)**

Results and Discussion

Influence of air velocity



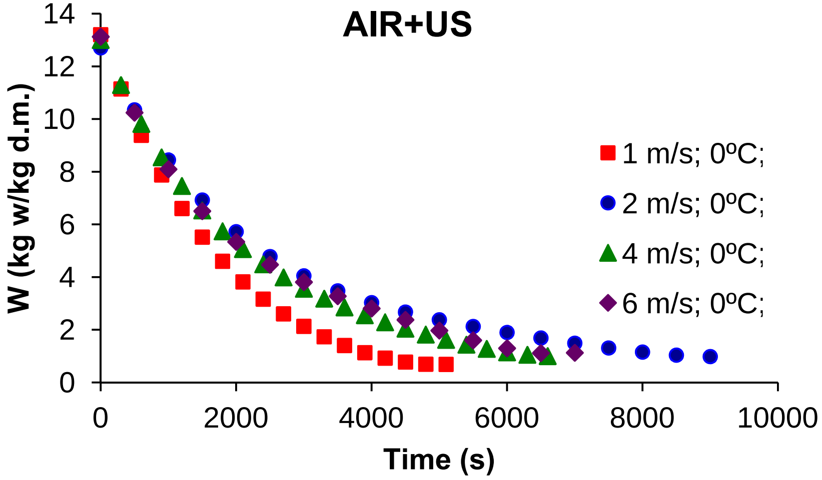


Figure. Drying kinetics of eggplant cubes (8.5 mm) at different air velocities and temperatures.

- **The typical effect is observed at 10 and -10 ºC (the higher the air velocity, the faster the drying).**
- **At 0ºC, the opposite behavior was found (the higher the air velocity, the slower the drying)**
- **WHY???**
  - ✓ **Water removal causes the temperature reduction (close to product freezing)**
  - ✓ **Ultrasound could contribute to the product freezing**
  - ✓ **A portion of the energy is employed for nucleation and less amount of energy is assigned for mass transport improvement.**

Results and Discussion

Influence of air velocity

T (ºC)			Air velocity (m/s) 1	2	4	6
-10	AIR	D_e ($10^{-10}m^2/s$)	1.44_a	1.20_a	1.34_a	1.48_a
		K (10^{-3}kg w/m²/s)	0.44_a	0.52_a	0.74_{ab}	0.95_b
		VAR (%)	99.8	99.5	99.6	99.7
		EMR (%)	4.1	6.4	7.6	4.1
	AIR+US	D_e ($10^{-10}m^2/s$)	8.40_b	11.05_b	10.01_b	10.85_b
		K (10^{-3}kg w/m²/s)	1.46_c	2.22_d	3.07_e	3.55_f
		VAR (%)	99.1	99.5	99.9	99.7
		EMR (%)	7.6	4.6	3.8	4.3
		ΔD_e (%)	*485*	*824*	*645*	*631*
		ΔK (%)	*227*	*322*	*313*	*271*

Table. Modeling of drying kinetics of eggplant cubes (8.5 mm) at -10 ºC and different air velocities.

- US improved both internal (D_e) than the external (K) mass transport.
- The increased was more marked on D_e (up to 824%) than K (up to 313%).
- The influence of air velocity on US performance was negligible at -10 ºC (FLUIDIZED BED DRYING OPERATION)

Conclusions

- **The feasibility of power ultrasound to improve low-temperature convective drying of foodstuffs has been confirmed.**

- **Ultrasound was able to speed-up both internal and external water transport, but the effect was more marked in internal transport.**

- **Air velocity and temperature are significant variables affecting the low-temperature drying assisted by power ultrasound.**

- **Although, the effect was different to that found in hot air drying operations.**

- **The scaling-up of ultrasound technology for drying operations is still a challenge ahead.**

Literature

Carcel, J. A., Garcia-Perez, J. V., Riera, E. & Mulet, A. (2007). "Influence of high intensity ultrasound on drying kinetics of persimmon", Drying Technology, 25, 185-193.

Carcel, J. A., Garcia-Perez, J.V., Riera, E. & Mulet, A. (2010). "Improvement of convective drying of carrot by applying power ultrasound. Influence of mass load density". Drying Technology, 29, 174-182.

Gallego-Juarez, J. A., Rodriguez-Corral, G., Galvez-Moraleda, J.C. & Yang, T.S. (1999). "A new high intensity ultrasonic technology for food dehydration", Drying Technology, 17, 597-608.

Gallego-Juarez, J. A., Rodriguez, G., Riera, E., Vazquez, F., Campos, C. & Acosta, V. M., (2002), "Recent development in vibrating-plate macrosonic transducers", Ultrasonics, 40, 889-893

Gallego-Juarez, J. A., Riera, E., De la Fuente; S., Rodriguez, G., Acosta, V. M. & Blanco A., (2007), "Application of high-power ultrasound for dehydration of vegetables: Processes and Devices", Drying Technology, 25, 1893-1901.

Gallego-Juarez, J. A., Rodriguez, G., Acosta, V. & Riera, E., (2010) "Power ultrasonic transducers with extensive radiators for industrial processing", Ultrasonics Sonochemistry, 953-964.

Garcia-Perez, J. V., Carcel, J. A., De la Fuente, S. & Riera, E. (2006a). "Ultrasonic drying of foodstuff in a fluidized bed. Parametric study", Ultrasonics, 44, e539-e543.

Garcia-Perez, J. V., Rossello, C., Carcel, J. A., De la Fuente, S. & Mulet, A. (2006b). "Effect of air temperature on convective drying assisted by high power ultrasound", Defect and Diffusion Forum, 258-260, 563-574.

Garcia-Perez, J. V., Carcel, J. A., Benedito, J. & Mulet, A. (2007). "Power ultrasound mass transfer enhancement in food drying", Food and Bioproducts Proccessing, 85, 247-254.

Garcia-Perez, J.V., Carcel, J.A., Riera, E. & Mulet, A. (2009). "Influence of the applied acoustic energy on the drying of carrots and lemon peel", Drying Technology , 27, 281-287.

Garcia-Perez, J. V., Ozuna, C., Ortuño, C., Carcel, J. A. & Mulet, A. (2011). "Modeling ultrasonically assisted convective drying of eggplant", Drying Technology, 29, 1499-1509.

Garcia-Perez, J. V., Ortuño, C., Puig, A., Carcel, J. A. & Perez-Munuera, I. (2012a). "Enhancement of water transport and microstructural changes induced by high intensity ultrasound application on orange peel drying", Food and Bioprocess Technology, 5, 2256-2265.

Garcia-Perez, J. V., Carcel, J. A., Riera, E., Rossello, C. & Mulet, A. (2012b). "Intensification of Low-Temperature Drying by Using Ultrasound", Drying Technology , 30, 1199-1208.

Mulet., A., Carcel, J. A., Sanjuan, N. & Bon, J. (2003). "New food drying technologies-Use of ultrasound", Food Science and Technology International, 9, 215-221.

Ozuna, C., Cárcel, J. A., Garcia-Perez, J. V. & Mulet, A. (2011a). "Improvement of water transport mechanisms during potato drying by ultrasonic application", Journal of the Science of Food and Agriculture, 91, 2511-2517.

Ozuna, C., Cárcel, J. A., Santacatalina, J. V., Mulet, A. & Garcia-Perez, J. V. (2011a). "Improvement of water transport mechanisms during potato drying by ultrasonic application", Proceedings of 11th International Congress of Food Engineering (ICEF 2011), Athens, Greece, pags. 1997-1998.

Puig, A., Perez-Munuera, I., Carcel, J. A., Hernando, I., Garcia-Perez, J. V. (2012). "Moisture loss kinetics and microstructural changes in eggplant (Solanum melongena L.) during conventional and ultrasonically assisted convective drying", Food and Bioproducts Processing, 90, 624-632

Riera, E.; Garcia-Perez, J.V., Acosta, V.M., Carcel, J.A. & Gallego-Juarez, J.A. (2011). A computational study of ultrasound-assisted drying of food materials In Multiphysics Simulation of Emerging Food Processing Technologies, IFT Press.

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