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PII: S0260-8774(18)30392-3

DOI: [10.1016/j.jfoodeng.2018.09.004](https://doi.org/10.1016/j.jfoodeng.2018.09.004)

Reference: JFOE 9391

To appear in: *Journal of Food Engineering*

Received Date: 8 March 2018

Revised Date: 4 September 2018

Accepted Date: 6 September 2018

Please cite this article as: R.O. Aguirre-Alonso, C.A. Huescas-Osorio, M.A. Salgado-Cervantes, J.M. Tejero-Andrade, G.C. Rodríguez-Jimenes, M.A. García-Alvarado, State-space thermodynamic modeling of vanilla ethanolic extract spray drying with heat pump and N<sub>2</sub>, *Journal of Food Engineering* (2018), doi: 10.1016/j.jfoodeng.2018.09.004

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# State-space thermodynamic modeling of vanilla ethanolic extract spray drying with heat pump and $N_2$

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## Abstract

State-space thermodynamic modeling of vanilla ethanolic extracts spray drying with heat pump and  $N_2$  was developed. Thermodynamic modeling considers activity coefficients for Raoult law deviations of ethanol vapor pressure, water vapor pressure, ethanol evaporation latent heat and water evaporation latent heat in a  $N_2$ -ethanol-water-vanilla solids system. State space considers 12 ordinary differential equations (ODEs) for ethanol and water concentrations in solid,  $N_2$  and condensed liquid; temperatures and condensed liquid rate. The model was validated with 32 treatments of vanilla ethanolic extract experimentally spray dried with heat pump and  $N_2$ . The mathematical model reproduced the experimental gas outlet temperature with 4% of averaged error. An additional two parameters fit reached 11.4% of averaged error with respect to product outlet moisture and gas outlet temperature simultaneously. Proposed model demonstrated that heat pump spray drying can reach a 58% of thermal efficiency and a conventional spray drying can reach only 30%.

**Key words:** Ethanolic vanilla extracts; spray drying; heat pump; mathematical modeling; thermal analysis.

## Nomenclature

$a$	Specific surface	$m^2 \cdot m^{-3}$
$a$	Thermodynamic activity	...
$A$	Surface area	$m^2$
$C_p$	Constant pressure specific heat	$J \cdot kg^{-1} \cdot K^{-1}$
$D$	Jacobian matrix	...
$E$	Total energy requirement	$J \cdot kg^{-1}$
$F_{1-\alpha(1,n-3)}$	$F$ cdf with 1 and $n-3$ degrees of freedom	...

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