

## Drying of sugarcane bagasse in a partially filled horizontal drum

Tada, É. F. R.<sup>a\*</sup>; Bück, A.<sup>b</sup>; Casciatori, F. P.<sup>c</sup>; Thoméo, J. C.<sup>a</sup>

<sup>a</sup> Department of Food Engineering and Technology. Institute of Biosciences, Humanities and Exact Sciences. São Paulo State University, São José do Rio Preto, Brazil

<sup>b</sup> Institute of Particle Technology. Friedrich-Alexander University Erlangen-Nuremberg, Erlangen, Germany.

<sup>c</sup> Chemical Engineering Department, Center of Exact Sciences and Technology. São Carlos Federal University, São Carlos, Brazil.

\*E-mail of the corresponding author: erikartada@gmail.com

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### **Abstract**

*One-phase model have been reported to describing the simultaneous heat and mass transfer in a horizontal drum partially filled by sugarcane bagasse with attention to the loss of water promoted by the increase of temperature. Mass and energy balances were written in MatLab language and solved by finite difference method. Predicted temporal and spatial profiles of moisture content and temperature are shown. Experimental tests were carried out in a horizontal drum and the temporal profiles were obtained. Great adjustments between experimental and predicted data were observed, indicating that the model is able to describe the transport phenomena in this system.*

**Keywords:** *horizontal drum; heat and mass balances; sugarcane bagasse; solid-state fermentation process.*

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## **1. Introduction**

Rotary drums are widely employed in several industrial processes involving particulate systems. Specifically in solid-state fermentation processes, the use of rotary drum bioreactors have been investigated because these equipments offer more mechanisms to control of operational conditions during the fermentation process [1].

Solid-state fermentation (SSF) is a prodigious technology that it enables the obtention of high-value compounds from solid cultivate of microorganisms in wet agro-industrial residues [2], as such the fibers of sugarcane bagasse [3]. Promissors results have been reported by literature in laboratorial scale on the yield of compounds through FES [4]. However, the industrial scale yet is not available to use due to difficulties related to scale-up of bioreactors for FES, such as the undesirable increases of temperature during the process. Considering the use of rotation in intermittent regime as a mechanism of heat removal, the particles bed keeps static during long periods and then are periodically moved. This allows tha analysis of this process from a static bed in a horizontal drum.

The increase in the temperature observed during SSF process can promote other phenomena that deserve attention, such as the loss of water in heated regions of the bed. The recent literature has reported that the moisture content of the organic particles is directly related to bed properties as porosity and efficient thermal conductivity [5,6]. Fundamental studies have been reported about the no-reactional particulate systems in geometries similar to bioreactors and are important to understand some aspects about transport phenomena in these systems [7,8]. In this context, this work aims the proposition of heat and mass balances to describe the temperature and water profiles in a partially filled horizontal drum by a sugarcane bagasse bed, in attention to possible water remotion due to increases on the temperature.

## **2. Materials and Methods**

### **2.1. Physical situation**

The physical situation in this case study is presented in Fig. 1. The horizontal drum was built in stainless stell and has 10 cm of inner dimeater and 20 cm of length. The inner wall of the drum was kept at constant temperature (45 °C or 65 °C) and the bed was initially at 25 °C. The bed was continually heated by heat penetration through of the wall and the water removal occurrred simultaneously as a response to increases in the temperature. The fibers of sugarcane bagasse were employed at 3 kg-water/kg-dried solid, which is corresponding to the operational condition for a solid-state fermentation process [3,9].



$$r = R, \quad \left. \begin{array}{l} T = T_w \\ D_{\text{eff}} \frac{\partial X}{\partial r} = 0 \end{array} \right| \quad \begin{array}{l} (7) \\ (8) \end{array}$$

in which  $r = r_{i(0)}$  is the superficial position and  $r = R$  represents the wall of the drum.

For the solution, the spatial variation were discretized by finite difference method. The resultant equations were written in MatLab® language and solved by *ode15s* for a geometry of a partially filled circumference, as described by [8].

### 2.2.1. Parameters of the model

The effective diffusivity of the water through the bed have been experimentally determined by [10] as a function of the temperature. The effective thermal conductivity of sugarcane bagasse bed as a function of moisture content of the fibers was extracted from [5].

The coefficients  $\alpha$  and  $\beta$  were teorically estimed using correlations available in the literature for the parallel flow of a fluid above the surface of a rugous flat plate. The velocity  $V_r$  was estimed using correlations for free convection through a packed-bed constituted by spherical particles.

### 2.2.2. Simulations and verification of the model

Simulations were carried considering the temperature of the wall ( $T_w$ ) at 45 or 65 °C and the temporal predicted profiles were compared with experimental profiles. The experimental tests were carried out in a jacketed horizontal drum (inner diameter: 10 cm, length: 20 cm). The inner wall of the drum was kept at 45 or 65 °C and the fibers of sugarcane bagasse were insered in the drum at 25 °C and about 3 kg-water/kg-dried solid in filling degree 0.5. Samples of the bed were collected to determination of moisture content in a drying oven at 105 °C until constant weight. The quality of adjustment was evaluated thorough statistical indicators such as the coefficient of determination ( $R^2$ ) and the root mean square error (RMSE).

## 3. Results and Discussion

The temporal mean temperature profiles for  $T_w$  at 45 and 65 °C are shown in Fig. 2.

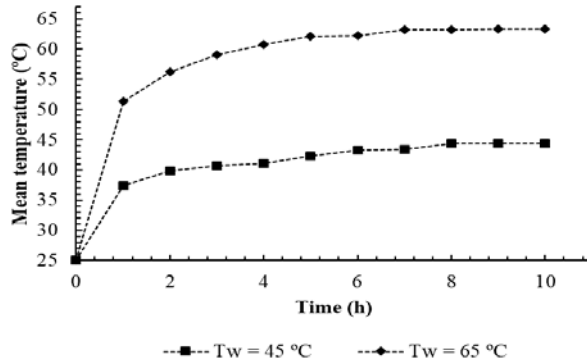


Fig. 2. Temporal mean temperature profiles of a sugarcane bagasse bed in a horizontal drum with temperature of the wall drum at 45 and 65 °C.

The temperature increases subtly in the first hour as reported by [11] for a bed composed by dried fibers of sugarcane bagasse in this same horizontal drum. Discrete increase on the temperature were observed for the interval from 1 to 4 hours and the thermal equilibrium was obtained around  $t = 4$  h of process for all conditions. It indicates that the initial non-isothermal problem becomes an isothermal problem along the time and it could be approximated and solved just through a mass balance for the equilibrium temperature in the interval from  $t = 4$  h to  $t = 10$  h. The spatial moisture content profiles for  $T_w$  at 45 and 65 °C for  $t = 1$  hour (on left hand) and 10 hours (on right hand) are shown in Fig. 3.

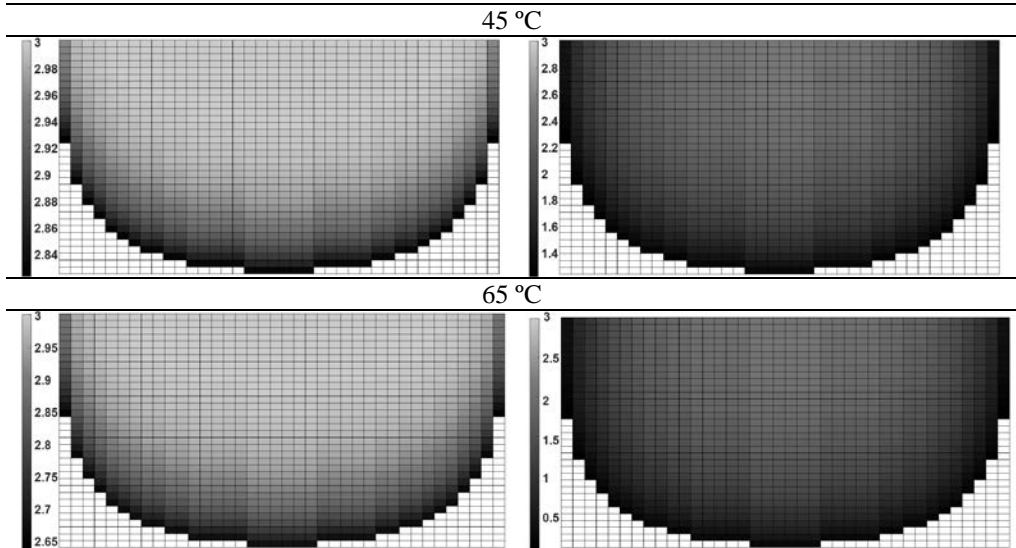


Fig. 3. Spatial moisture profiles (kg/kg-ds) of a sugarcane bagasse bed in a horizontal drum with temperature of the wall drum at 45 and 65 °C.

The mass flux was observed in the radial direction from the wall to the surface of the bed. The presence of the air in the headspace promoted discrete variation on the moisture content in the surface of the bed because the air was partially saturated on water vapor and its capacity to carry water was reduced. After 10 hours of process, the simulated profiles show that the system is near to the mass equilibrium.

The verification of the model is shown in Fig. 4 and 5 for the temperature and moisture profiles, respectively, for  $T_w$  at 45 and 65 °C. Good agreements were observed between experimental and predicted profiles and them were supported by statistical indicators ( $R^2 > 0,95$  and  $RMSE < 0,62$ ).

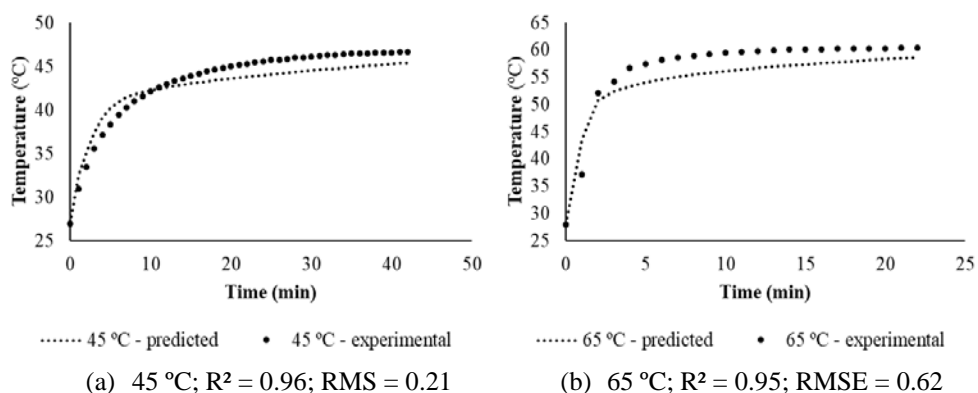


Fig. 4. Predicted and experimental temperature profiles in a horizontal drum partially filled by fibers of sugarcane bagasse ( $T_w = 45$  °C (a) or 65 °C (b);  $T_0 = 25$  °C).

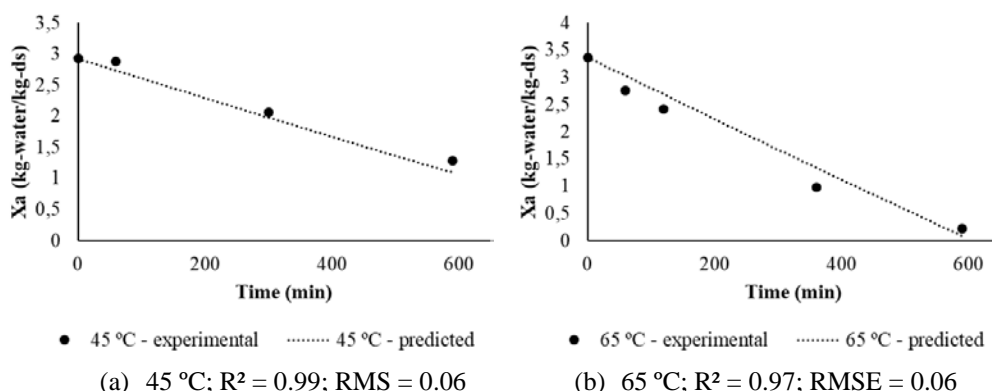


Fig. 5. Predicted and experimental moisture profiles in a horizontal drum partially filled by fibers of sugarcane bagasse ( $T_w = 45$  °C (a) or 65 °C (b);  $T_0 = 25$  °C).

#### 4. Conclusions

The proposed model to describing the simultaneous heat and mass transfer in a sugarcane bagasse bed in a horizontal drum presented great adjustment with the experimental data ( $R^2 \geq 0.95$  and  $RMSE \leq 0.62$ ) for temperatures of the drum wall at 45 and 65 °C. The temporal temperature profiles shown that the thermal equilibrium is reached and the problem could be solved just through a isotherm mass balance. The loss of water in the regions near to the drum wall was visible in the spatial moisture profiles, indicating that the mass balance is sensible to increase in the temperature.

#### 5. Nomenclature

$C_p$	specific heat		$J Kg^{-1} K^{-1}$
$D_{eff}$	effective diffusivity		$m^2 s^{-1}$
$f$	air capacity to carrier water		$Kg Kg^{-1} air^{-1}$
$K$	effective thermal conductivity		$W m^{-1} K^{-1}$
$r$	radial coordinate		$m$
$t$	time		$s, min$ or $h$
$T$	temperature		$^{\circ}C$
$V$	velocity		$m s^{-1}$
$X$	moisture content in dried basis		$Kg Kg^{-1} ds^{-1}$
Greek letters			
$\alpha$	convective heat transfer coefficient		$W m^{-2} K^{-1}$
$\beta$	convective mass transfer coefficient		$m s^{-1}$
$\rho$	density		$Kg m^{-3}$
$\lambda$	latent heat of evaporation of water		$J Kg^{-1}$
Subscripts			
0	initial	$i(\theta)$	surface
$\infty$	headspace	s	solid
a	air	r	radial direction

b            bed                            w            wall  
eq            equilibrium

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