

# Modelling of the thin layer drying kinetics of pears

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## INTRODUCTION

Drying is a very widely used method to preserve foods, and stands on the removal of water to such a low level that minimizes microbial activity and reproduction as well as deterioration reactions (Doymaz, 2007). Furthermore, drying also reduces weight for transportation and space for storage, besides avoiding the need of refrigeration systems, and the cost associated to them.

Open-air sun drying has been traditionally used to dry grains, vegetables, fruits and other agricultural products. This is a common method of preserving foods and it is practiced until today in many countries where the climatic conditions are appropriate (Togrul & Pehlivan, 2004). The study of the drying processes contributes to the understanding of these operations, and eventually the establishment of appropriate operating conditions (Fadhel et al, 2005).

“Pera Passa de Viseu” denominates a traditional food product made after pears of the variety S. Bartolomeu using a traditional open-air sun drying (Barrocal et al, 2006). Even though it is quite a cheap drying method, it has many important disadvantages, such as: slowness of the process; dependency from weather conditions; deficient quality of the product due to many types of contaminations (Karathanos & Belessiotis, 1997). Therefore, the development of alternative drying methodologies assumes a pivotal role.

In previous studies the S. Bartolomeu pears have been characterized before and after sun-drying (Ferreira et al, 2001 and 2002) and the effect of ripening stage on the drying kinetics has been and on some physical and chemical properties along drying has been evaluated for three different harvest dates (Guiné et al, 2009).

The objective of this work was to fit the kinetic data to different thin layer models found in literature to describe the drying rates of food products, in order to compare the drying rates in the different systems tested and also to find out which model is best to describe the drying kinetics of these pears.

## EXPERIMENTAL

The pears used in the present study are of the Portuguese variety S. Bartolomeu, and were dried like in the traditional method after peeling but uncut. However, unlike in the traditional method the pears were not dried under open-air sun exposure, and, alternatively, were dried in three different systems: a solar stove – ESAV (Figure 1), a solar drier – ESTV (Figure 2) and a drying tunnel – UC, where the drying air is heated by a solar collector (Figure 3). All these systems intend to make use of the sun as the heating source.



Figure 1. Solar stove (ESAV).



Figure 2. Solar drier (ESTV).



Figure 3. Drying tunnel and solar collector (UC).

In the ESAV and ESTV systems, the temperature and relative humidity were variable according to the weather conditions and night/day hours during the period of drying. In the UC system, the temperature was kept constant at 40-42 °C and the drying air velocity was always 1.1 m/s. In the ESAV system the air velocity was also kept constant at 0.4 m/s.

The drying was carried out until the pears reached the desired moisture content of about 20 % (wet basis), for being the optimum content for conservation and product quality. However, in some cases the final moisture was under this reference because when the samples were analyzed their moisture had already lowered under the optimum value. The drying time was 121 hours in the UC system, 96 h in the ESAV system and 68 h in the ESTV system.

Along drying the moisture content of the pears was determined by sampling in the ESAV and ESTV systems, being measured with a Halogen Moisture Analyser, model HG53, from Mettler Toledo. In the UC system the moisture was determined by weight loss, measured by weighing the whole set of pears along drying.

## MATHEMATICAL MODELS

The experimental data was plotted in graphs of moisture ratio (MR) against drying time, where MR is given by:

$$MR = \frac{W - W_o}{W_e - W_o} \quad (1)$$

with  $W$  the moisture content at time  $t$ ,  $W_0$  the initial moisture content and  $W_e$  the equilibrium moisture content, all expressed in dry basis. To model the drying kinetics the experimental points ( $MR, t$ ) were fitted with software SigmaPlot V8.0 (SPSS, Inc.) to different thin layer kinetic models found in literature and presented in Table 1.

Table 1. Thin layer kinetic models from literature (Togrul & Pehlivan, 2004).

Equation	Name
$MR = \exp(-Kt)$	Newton
$MR = \exp(-Kt^n)$	Page
$MR = a \exp(-Kt)$	Henderson & Pabis
$MR = a \exp(-Kt) + c$	Logarithmic
$MR = 1 + at + bt^2$	Wang and Singh
$MR = a \exp(-Kt) + b \exp(-k_1t)$	Logarithmic two-term
$MR = a \exp(-Kt) + b \exp(-k_1t) + c \exp(-k_2t)$	Modified Henderson & Pabis

## RESULTS AND DISCUSSION

Figure 4 shows the experimental data for the three drying systems, as well as the corresponding fits obtained with the Newton model. From the graph is seen that the solar drier system (ESTV) gives the faster drying, presenting a bigger slope in the drying curve. On the other hand, the solar stove (ESAV) and drying tunnel (UC) systems are very much alike, and with similar drying rates. These observations are confirmed with the data presented in Table 2, which summarises the results obtained for all the fits made in the present work. In fact, it is seen that the drying constant,  $K$ , is far greater in the ESTV system (0.0614) than in the other two systems (0.0253 in ESAV and 0.0278 in UC).

## Newton

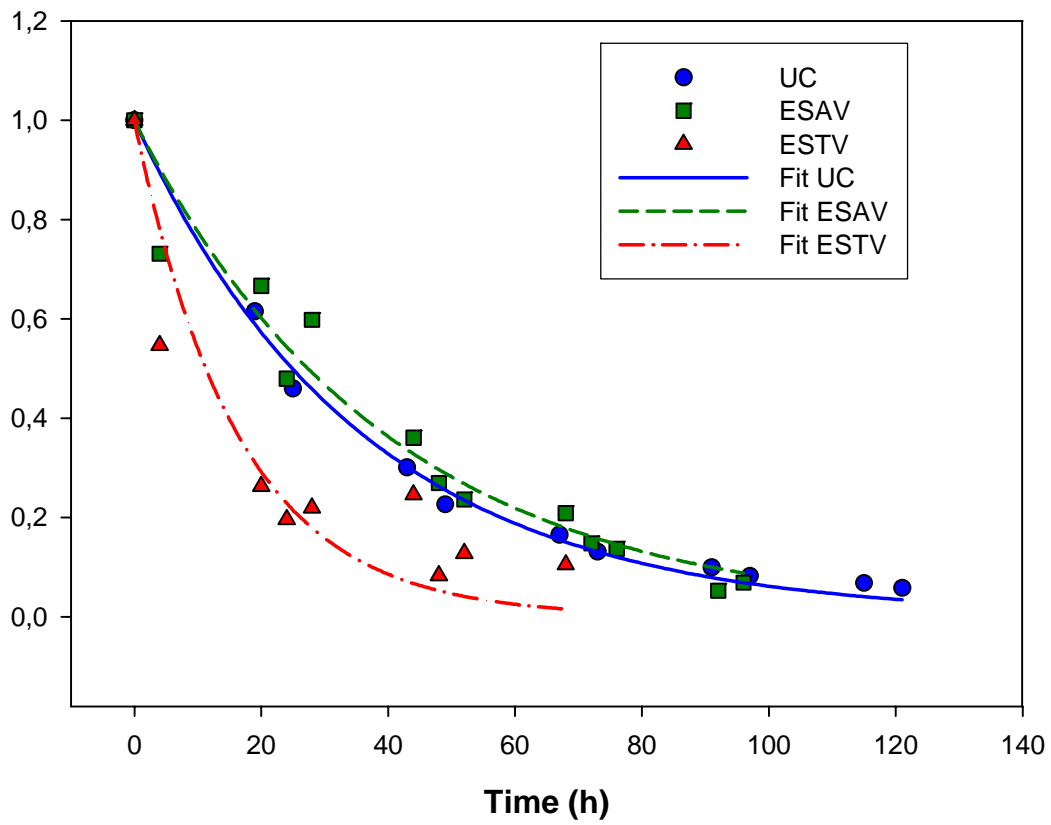


Figure 4. Fitting with the Newton model to the experimental data in the three systems: UC – drying tunnel, ESAV – solar stove, ESTV – solar drier.

Table 2. Parameters estimated and coefficients of regression for the fittings with the different models to the experimental data of the three drying systems.

Model	Drying system	R	K	k <sub>1</sub>	k <sub>2</sub>	n	a	b	c
Newton	UC	0.9971	0.0278						
	ESAV	0.9726	0.0253						
	ESTV	0.9181	0.0614						
Page	UC	0.9975	0.0348			0.9410			
	ESAV	0.9727	0.0283			0.9715			
	ESTV	0.9896	0.3305			0.4604			
Henderson & Pabis	UC	0.9971	0.0277				0.9950		
	ESAV	0.9756	0.0239				0.9443		
	ESTV	0.9369	0.0511				0.8645		
Logarithmic	UC	0.9983	0.0308				0.9725		0.0347
	ESAV	0.9786	0.0179				1.0592		-0.1364
	ESTV	0.9802	0.1745				0.8195		0.1685
Wang & Sing	UC	0.9852					-0.0203	0.0001	
	ESAV	0.9699					-0.0197	0.0001	
	ESTV	0.8710					-0.0394	0.0004	
Two term	UC	0.9971	0.0278	0.0278			0.4980	0.4980	
	ESAV	0.9756	0.0239	0.0239			0.4721	0.4721	
	ESTV	0.9904	0.0179	0.2707			0.3513	0.6486	
Modified Henderson & Pabis	UC	0.9981	0.0153	0.0355	0.0363		0.2626	0.4591	0.2860
	ESAV	0.9756	0.0238	0.0238	0.0241		0.3673	0.3240	0.2529
	ESTV	0.9904	0.0171	0.1735	0.3695		0.3381	0.2940	0.3681

Figure 5 shows the fittings for the three drying systems made with the other 6 models tested: Page, Henderson & Pabis, logarithmic, Wang & Singh, Logarithmic two term, modified Henderson & Pabis. By observing the graphs, is possible to see that the models logarithmic two terms and modified Henderson & Pabis are very similar, and produce almost equal curves. On the other hand, the worst model is Wang & Singh since it produces curves that do not reproduce accurately the final stages of drying. This result is further confirmed in Table 2, where the values of the regression coefficients of the fittings are presented, being the lowest for this model.

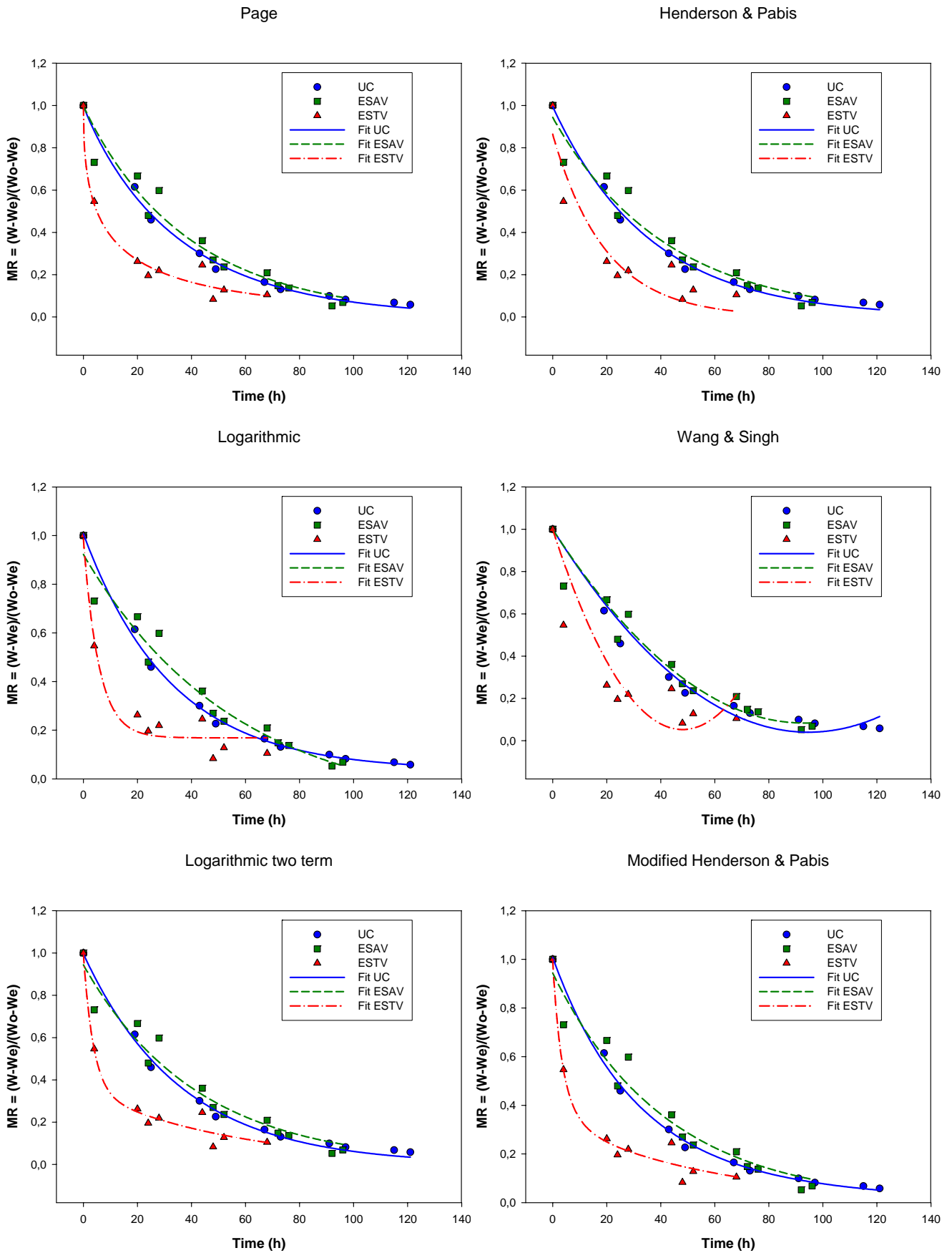


Figure 5. Fittings for the three drying systems made with the models: Page, Henderson & Pabis, logarithmic, Wang & Singh, Logarithmic two term, modified Henderson & Pabis.

In Figure 6 the experimental data for the faster drying system (solar drier) is fitted with all the models, being clear that the ones that fit better the experimental data, giving higher values of the regression coefficient ( $R = 0.9904$ ) are the two term and modified Henderson & Pabis, which originate practically coincident curves. As previously seen, the model that is less good to predict the drying kinetics of these pears under the drying conditions mentioned is the Wang & Singh, which has the lowest regression coefficient ( $R = 0.8710$ ).

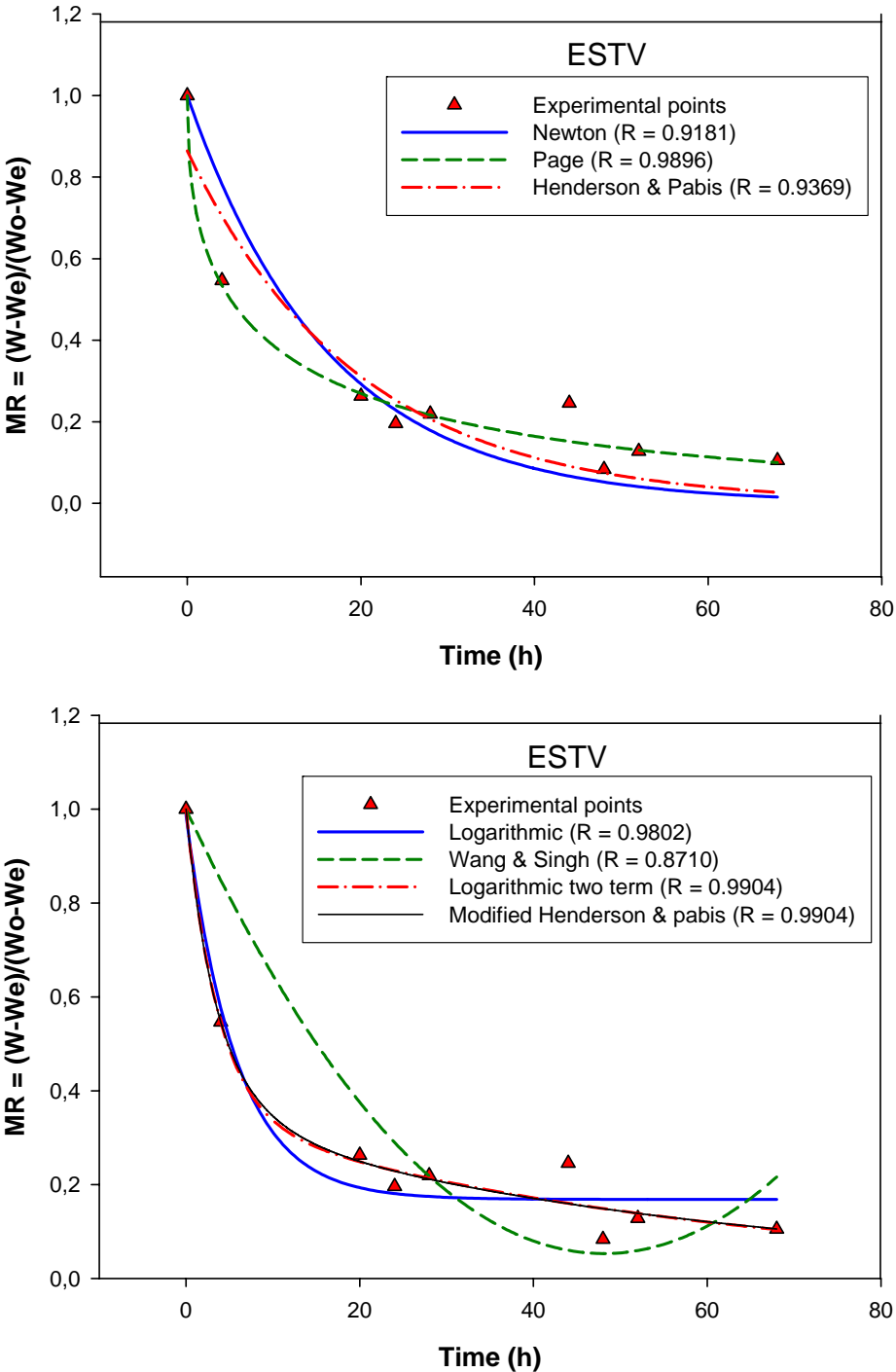


Figure 6. Fitting of the experimental kinetic data in the solar drier (ESTV) with all the models tested.

## CONCLUSION

The present work allowed to conclude that the solar drier system (ESTV) is faster to dry the pears, when compared to the other two systems tested, the solar stove (ESAV) and the drying tunnel (UC), which originate similar drying rates. As to the different kinetic models tested, it was concluded that the models logarithmic two term and modified Henderson & Pabis originate practically coincident curves, and revealed to be the better ones to fit the experimental data, while the Wang & Singh model proved to be the less good.

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