PRELIMINARY STUDY ON THE SPOUTED BED DRYING OF CORK STOPPERS

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Abstract. *The spouted bed is a particular type of fluidized bed able to handle coarse particles. It is commonly used to dry granular particles as it displays some special characteristics which render it capable of performing cyclic operations, with particles that are very difficult to fluidize under a different type of bed.*
A basic study on the characterization of the drying performance of port wine cork stoppers was carried out in a laboratory scale spouted bed.
Characteristic drying curves were determined with 29×21 (mm×mm) cork stoppers under several opperating conditions, covering different air flows and temperatures.
Through the observation and treatment of experimental data a correlation for the stoppers drying rate is presented.
The available information on the charateristic drying rates of cork stoppers is still very limited in the technical andscientific literature, and until now no published data was found on the spouted bed drying of cork stoppers.

Keywords: *spouted bed, cork stoppers, drying, characteristic curves*

1. Introduction

The drying of cork stoppers is an important step in their production cycle involving usually fixed bed drying processes with the all encompassing questions concerning mass transfer (Martins et al, 1994; Pinho and Santos, 1997), pressure drop problems (Rangel et al, 2001, 2001a), as well as the quality control of the final product.

In the typical jargon of the cork industry the dryers were usually called greenhouses because initially the drying process was solely based on solar drying techniques. Although this approach was the correct one, as far as the environment and the quality of the final product were concerned, it was time and space consuming. Nowadays, productivity requirements demand faster drying rates and the dryers started to evolve from the initial greenhouses to simple heated rooms inside which bags full of stoppers were left during pre-determined time periods, towards fully automated moving bed dryers, were the degree of humidity of the output corks is continuously monitored, Pinho and Santos (1997).

The spouted bed drying of cork stoppers is a particular situation only used for the processing of very small batches of stoppers, to fulfill some special orders of high grade costumers. This non conventional type of fluidized bed known as spouted bed (Geldart, 1973; Mathur and Esptein, 1974; Geldart, 1986; Kunii and Levenspiel, 1991) is a technique commonly used for drying of solids (Viswanathan, 1986; Pallai et al., 1995; Mujumdar and Devahastin, 2003), or for handling of solids in another technological processes (Mathur and Epstein, 1974; Markowski and Kaminski, 1983; Passos et al., 1987; Olazar et al., 1993; Yang, 2003).

The approach that has been followed so far, by builders of equipment for the cork industry, has been purely empirical and the available technical and scientific data concerning the cork drying process is limited.

The absence of a minimum of reliable scientific and technical data on cork stoppers drying lead to the development of a small number of research studies on fixed bed (Martins 1990; Martins et al., 1994) and lately on the spouted bed drying of cork stoppers (Costa and Landel, 1998; Magalhães, 2004; Magalhães and Pinho, 2004).

2. Experimental details

The experiments were carried out in a laboratory scale spouted bed installation, composed by a centrifugal fan to supply the fluidizing air, a calibrated orifice plate for the measurement of the air flow, an electrical heater composed by four 3 kW electrical resistances and the bed itself. Figure 1 presents an overall scheme of the experimental set up while on Fig. (2) are shown the main dimensions of the bed.

To define the experimental setup the recommendations of Markowski and Kaminski (1983) were adopted and it can be seen from Fig. (2) that the size of the conical part of the bed is small compared with the cylindrical region. Total maximum bed height, including the conical part, was of 175 mm, i.e., a shallow bed of stoppers was always used. Cork stoppers are rather large particles but with low density and consequently as soon as they are fluidized they are projected by the jet flow high above the bed, in a such a way that the installation of a secondary cylindrical part of 500 mm length, above the original cylindrical portion Fig. (3), was required with the sole purpose of keeping the stoppers inside the reactor. A basket made of a stainless steel mesh contained the particles and allowed their simple extraction from the bed, during the drying experiments. In the first part of the experiments the bed spouting conditions were characterized and more information on the experimental procedure and results can be found in Magalhães and Pinho (2004).

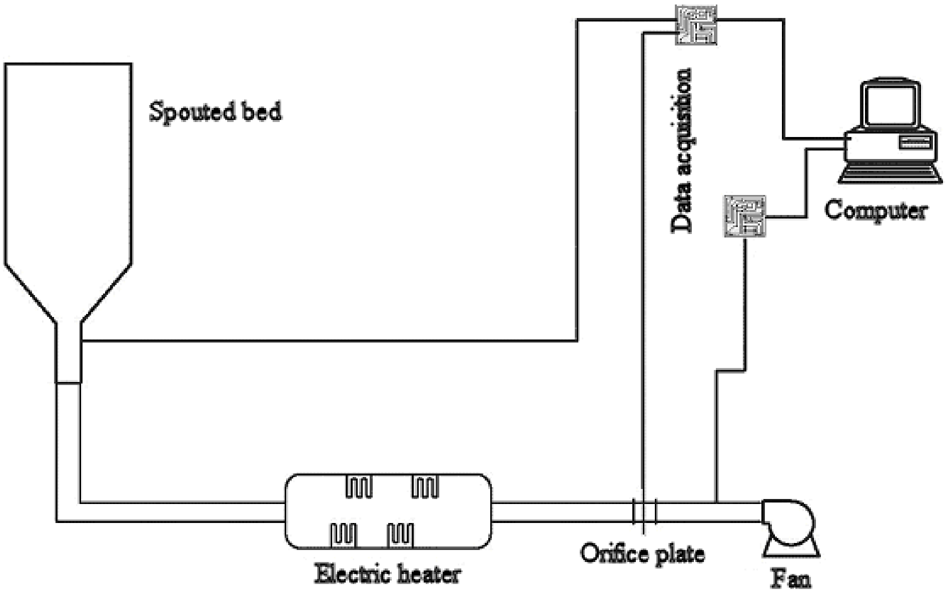

Figure 1 – Schematic layout of the experimental set-up.

A data acquisition system installed in a personal computer was connected to differential pressure transducers measuring the pressure drop in the orifice plate for flow rate calculations, as well as to differential pressure transducers installed in the spouted bed to measure the evolution of pressure differentials as the fluidization was carried out. Fluid temperatures were measured through T type thermocouples. Temperatures were measured for the ambient air, air flow between the centrifugal fan and the orifice plate, hot air between the electrical heater and the spouted bed and in the spouted bed. The influences of ambient temperature and pressure fluctuations, upon the measured value of the fluidizing air flow rate were accounted for through calibration procedures.

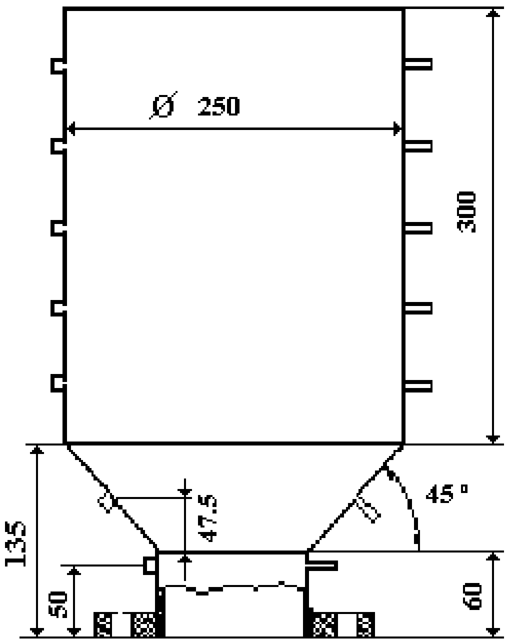

Figure 2 - General dimensions (in mm) of the spouted bed dryer.

The data acquisition system had an internal board connected to two external boards for signal conditioning. All the boards were from Advantech. The used acquisition software was the GENIE, release 2.12, also from Advantech. The internal board reference PCL-818L had eight differential analog inputs and a resolution of 12 bits. The differential pressure transducers were connected to a PCLD-8115 external board and the thermocouples to a PCLD-789D external board, equipped with cold junction temperature compensation.

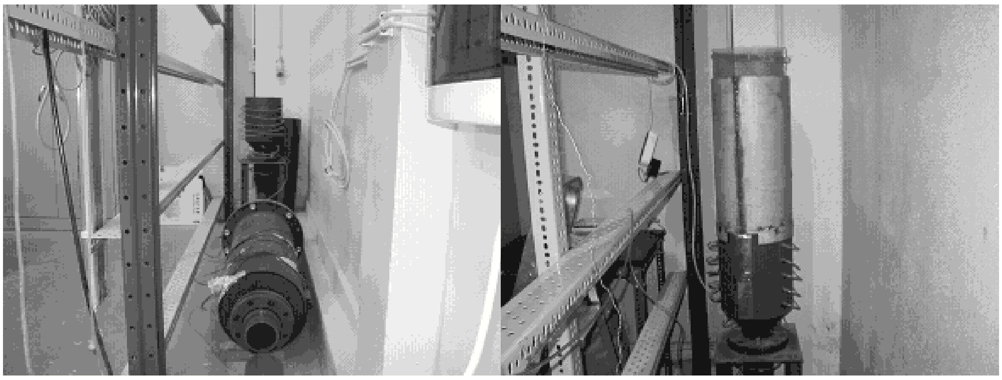

Figure 3 – Images of the experimental layout.

Pressure measurements were carried out with differential pressure transducers from Series T of Modus Instruments, Inc. Two different transducers types were used, according to the pressure range being measured. Transducers T1008EXB were for –1 kPa to + 1 kPa pressure range, while transducers T1009EXB were for – 2 kPa to +2 kPa pressure range. These transducers have an accuracy of ±1 % of span including linearity and hysteresis. Their output signal of 0-10 VDC was send to the data acquisition board. The transducers outputs were checked towards U-type water manometer readings.

To change the air flow rate sent to the spouted bed, the centrifugal fan was controlled by means of a frequency variator from ABB, model ACS401000932, with a resolution of 0.1/50 Hz.

The spouted bed was equipped with tappings in the cylindrical entrance pipe, on the conical and on the main cylindrical body, to measure static pressures. For the definition of the spouting conditions during the drying experiments, pressures were measured on the entrance cylindrical pipe, with an internal diameter of 114.8 mm, 50 mm above the flange, Fig. (2). A jet diameter of 60 mm was used.

Corks to be dried were previously humidified in an aquarium of 250×60×350 (mm×mm×mm), inside which they were kept for 5 to 5 hours and 30 minutes, inside water at 50 ºC. After this wetting period, the stoppers were left inside hermetic plastic bags to rest for a week, in order to guarantee a uniform distribution of water inside them (Martins et al., 1994). Only Port wine stoppers of 29×21 (mm×mm) in batches of 320 stoppers were dried, thus the bed height in such circumstances was of 175 mm. This bed height was chosen by taking into account previous fluid dynamic studies for the characterization of the spouted bed dryer (Magalhães and Pinho, 2004; Magalhães, 2004).

During the drying experiments, a batch of wet stoppers was placed inside the stainless steel mesh basket into the spouted bed working at a given temperature and air flow rate. The bag was then periodically extracted from the bed and the stoppers are weighted in a Kern balance, model EW6000-1M, with a resolution and precision of 0.1 g. The air flow rate and temperature, as well as the ambient air temperature, pressure and relative humidity were monitored during the experiments. When stoppers were outside the spouted bed dryer, for the weighting procedure, the chronometer was stopped. The weighting operation composed by the corks extraction from the bed, the weight measurement and the corks replacement inside the bed, took around 45 to 60 seconds, a time interval small enough to be considered negligible, when compared with the drying time required for the batch (above 5400 seconds). The time interval between successive weight measurements increased through the experiment. During the initial phases of the drying process, stoppers were weighted every minute, afterwards this interval changed to two minutes and in the final stages of the drying experiments the intervals were of five minutes.

Table 1 – Characteristics of tested stoppers.

Cork stopper L×Ø (mm×mm)	Equivalent diameter (mm)	Sphericity (-)	Density (kg/m^3)	Particle diameter (mm)
29×21	26.8	0.866	164.8	23.2

2. Experimental results

With the adopted experimental set up, measurements of the superficial temperature of the particles were not possible due to their constant movement and consequently no heat or mass transfer coefficients could be determined. However, the temperature of the drying air at the exit of the spouted bed could be monitored and this was a good indication of the temperature evolution during the experiments. Figure 4 is a typical example, after some five minutes the output temperature stabilizes and no strong variations are found in this output temperature, meaning that the weighting process did not affect the stability of the drying test. This curve corresponds to an experiment at 60 ºC with a superficial velocity of 1.43 m/s. At the first instant temperature difference between air inlet and outlet temperature is of 8 ºC and this differential reduces up to 2 ºC at the end of the experiment, thus drying tests could be considered nearly isothermal. Referred values for the drying air superficial velocity were always calculated for the cylindrical portion of the bed, considering ambient pressure and temperature conditions reigning inside it.

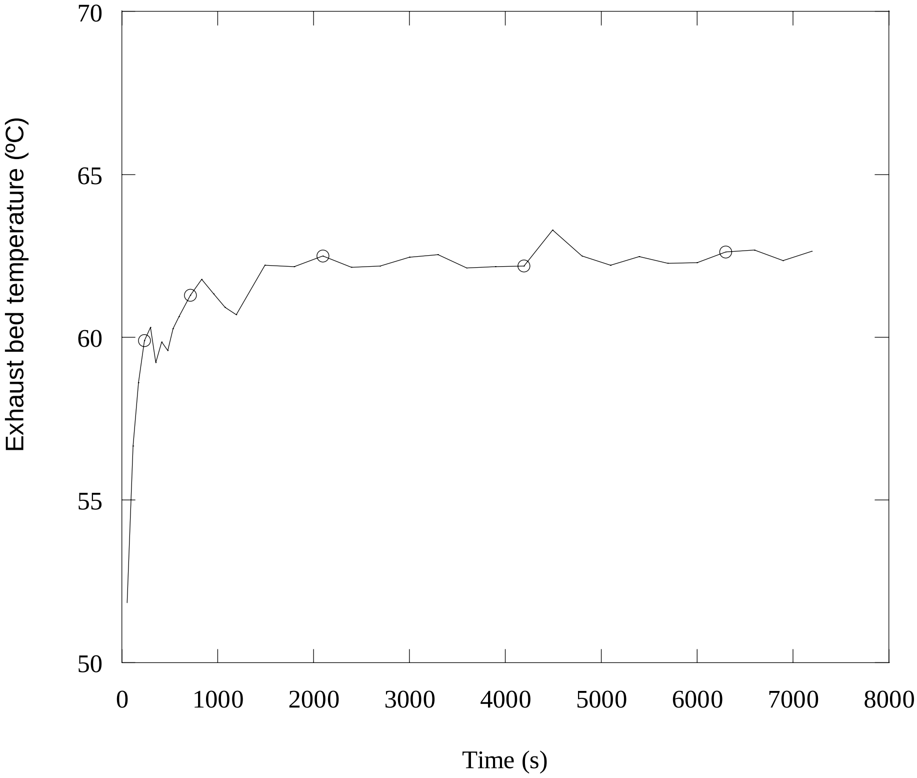

Figure 4 – Evolution of air exhaust temperature for an entrance temperature of 60 ºC and $U = 1.43$ m/s.

To nondimensionalize the plotting of the experimental results a dimensionless water content (Keey, 1978, 1980, 1982), the characteristic moisture content, is defined as,

$$\Phi = \frac{X - X_e}{X_{cr} - X_e} \tag{1}$$

where X is the average dry base mass water content of the stoppers in the batch, X_{cr} is the critical dry base mass water content of the cork stoppers (Mujumdar and Ménon, 1995) and X_e is the corresponding dry base mass equilibrium water content. Because there is no period of constant drying rate for the cork (Martins, 1990, Martins et al., 1994), a critical value for the water content of the cork could not be used, it was used instead the initial water content of the cork stoppers. At the same time, although the equilibrium water content of the cork is known (Martins 1990; Martins et al, 1994), for practical reasons such value was not used in the present calculations and it was replaced by a reference value, taking into account the recommended water content desired by cork stoppers producers and users, to guarantee adequate elastic properties for the cork. The required range for the output dry base mass water content of the stoppers is from 4 to 10 %. Consequently, the adopted reference value was of 8 %, so that the present experimental data could be easily compared with those obtained by Martins (1990) and Martins et al. (1994) and also because one of the main objectives of this work was to find out reliable design data,

$$\Phi_p = \frac{X - X_{ref}}{X_i - X_{ref}} \tag{2}$$

In the above equation X_i is the dry base initial mass water content of the cork, X_{ref} is the dry base reference mass water content value and Φ_p is a practical characteristic moisture content.

Figure 5 shows the evolution of the practical characteristic moisture content for some experimental conditions. The drying air was caught in the environment and no recirculation was used in the experimental setup. Some conclusions can be drawn from that figure. Temperature and its closely connected relative humidity, are the most important factors influencing the drying rate. As can be observed from Fig. (5), raising the incoming drying air increases the drying rate and reduces the time interval necessary to achieve a certain dryness fraction.

As far as the air velocity is concerned for low temperature drying (40, 50 and 60 ºC) differences in this parameter are not influential upon the drying rate. On the other end, for drying air temperatures of 70 and 80 ºC, the influence of the air velocity becomes important. The low dependence of drying time with the air velocity, at lower temperatures, is a clear indication of how important are the heat and mass transfer mechanisms inside the cork, for the control of the drying process. When the drying temperature raises, the higher heat and mass transfer rates taking place inside the cork stoppers, lead to a decrease of importance of these phenomenon in the cork inner body. Thus, there is an increase of the importance of transfer mechanisms outside the cork. This results in an increase of the drying rate sensitivity with the variation of the external air velocity.

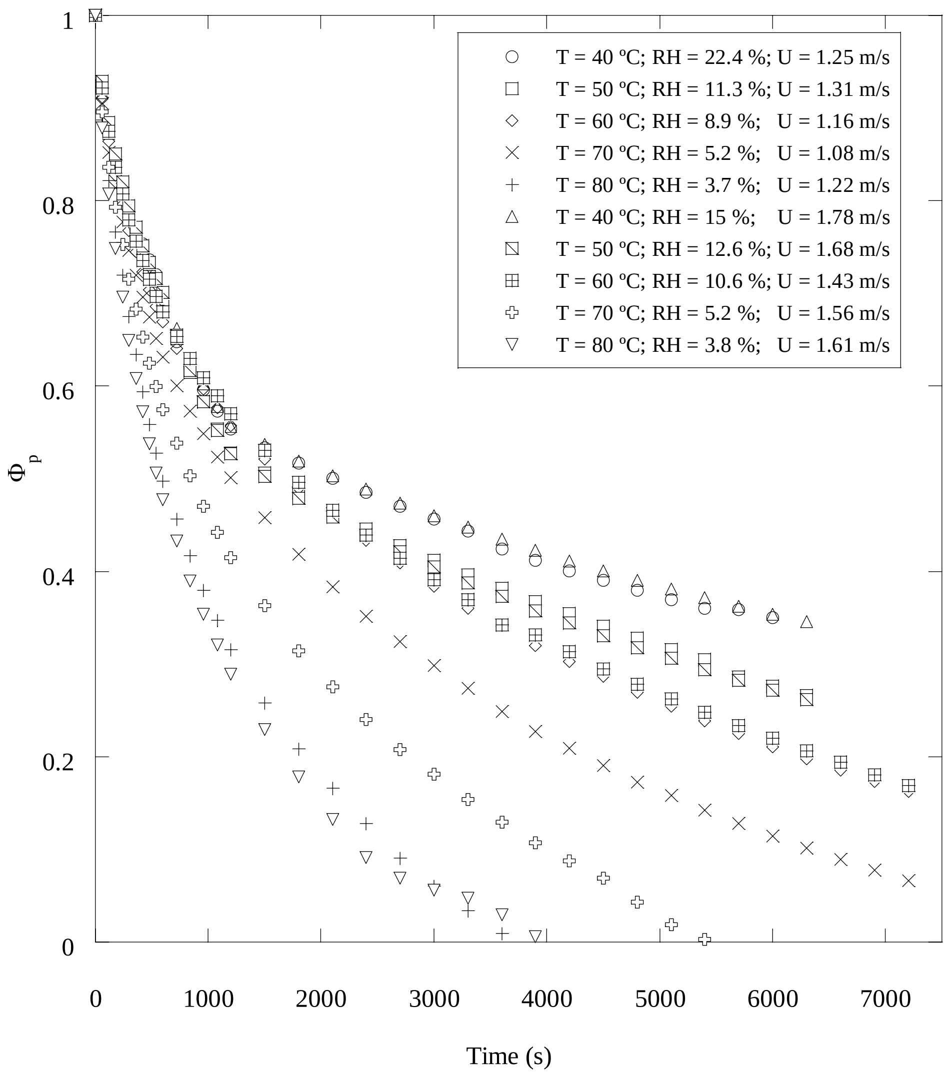

Figure 5 – Time evolution of the practical characteristic moisture content for the cork stoppers.

In the case of Martins (1990) and Martins et al. (1994) works, the air velocity range was between 0.75 and 1.5 m/s for packed bed drying experiments, thus no influence of the drying air velocity could be detected. In fact, only in the present situation where the corks fluidization requires high air flows, the influence of the velocity could be detected, but only for the higher drying temperatures, when internal transport mechanisms start to be less important.

Through the observation of the characteristic drying curves it is detected an exponential evolution of this parameter with the drying time. According to several authors (Martins, 1990; Nadeau and Puiggali, 1995) a simple model can be applied to the drying curves,

$$\Phi = \exp\left(-k\, t^{n}\right) \tag{3}$$

where k and n are functions of the drying air temperature and velocity, i.e., $k = f\left(T, U\right)$ and $n = g\left(T, U\right)$.

Applying this model to the experimental data obtained in the present study, and using a data fitting software, the following correlation was obtained,

$$\Phi_p = \exp\left[-6284\, T^{-3.27} U^{-0.78} t^{\left(0.0063 T^{1.1} U^{0.25}\right)}\right] \tag{4}$$

This correlation is for the drying air superficial velocity *U* in m/s and temperature *T* in ºC. In Tab. 2 are presented the validity conditions for this equation and it must be borned in mind that the practical characteristic moisture content Φ_p was calculated according to Eq.(2), that the reference cork moisture content was of 8 % dry basis mass fraction and finally that the equation is only suitable for 29×21 (mm×mm) cork stoppers.

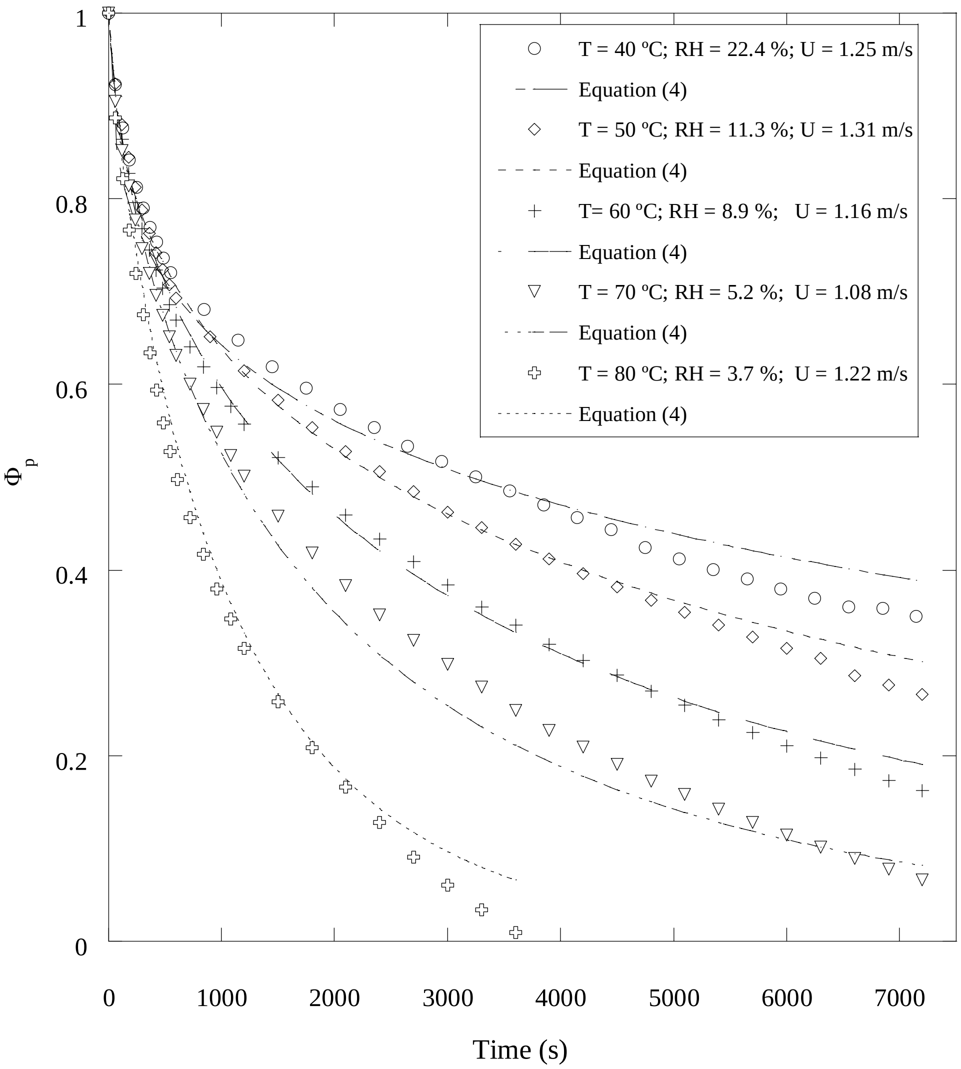

Figure 6 – Correlation for practical characteristic drying curves and corresponding experimental data.

Table 2 – Validity conditions of Eq. (4).

	Φ_p (-)	T (ºC)	RH (%)	U_o (m/s)
Minimum	0.0033	40	3.8	1.08
Maximum	1.00	80	22.4	1.78

Figure 6 shows the evolution of some characteristic drying curves calculated by means of Eq.(4), as well as the corresponding experimental results. The maximum average deviation found between the characteristic drying curves calculated with Eq. (4) and all the experimental curves obtained in the present work, which were already shown in Fig. (5), is of 11 %.

3. Conclusions

Experimental studies of the determination of the characteristic drying curves of Port wine cork stoppers (29×21 mm×mm) in a laboratory scale spouted bed dryer were described.

With the used experimental setup and testing procedure, the most important physical parameter affecting the drying rate is the incoming air temperature. Tested temperatures were of 40, 50, 60, 70 and 80 ºC, but in the industrial practice temperatures above 60 ºC are usually avoided to minimize cork damage. Typical drying times go from 1.5 hours (5400 s) to 2 hours (7200 s), the shorter drying times are obtained for a drying air temperature of 70 and 80 ºC.

The superficial air velocity has only some influence upon the stoppers drying rate for tests at 70 ºC or 80 ºC, situations were the heat and mass transfer mechanisms inside the cork begin to loose their dominant influence. In other words, at and below 60 ºC, the transport mechanisms inside the cork control the drying process.

Through a simple kinetic model (Nadeau and Puiggali, 1995), a correlation for the practical characteristic moisture content was determined, giving a maximum mean deviation towards the experimental curves of 11 %.

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