Available online at www.sciencedirect.com

ScienceDirect

Bioresource Technology 99 (2008) 7270–7277

BIORESOURCE TECHNOLOGY

Simulation of tagasaste pulping using soda-anthraquinone

Jalel Labidi [a,*], Alvaro Tejado [a], Araceli García [a], Luis Jiménez [b]

[a] Chemical and Environmental Engineering Department, University of the Basque Country, Plaza Europa 1, 20018 San Sebastian, Spain
[b] Chemical Engineering Department, University of Cordoba, Spain

Received 6 October 2006; received in revised form 13 December 2007; accepted 18 December 2007
Available online 1 February 2008

Abstract

In this work, published experimental result data of the pulping of tagasaste (*Chamaecytisus proliferus* L.F.) with soda and anthraquinone (AQ) have been used to develop a model using a neural network. The paper presents the development of a model with a neural network to predict the effects that the operational variables of the pulping reactor (temperature, soda concentration, AQ concentration, time and liquid/solid ratio) have on the properties of the paper sheets of the obtained pulp (brightness, traction index, burst index and tear index). Using a factorial experimental design, the results obtained with the neural network model are compared with those obtained from a polynomial model. The neural network model shows a higher prediction precision that the polynomial model.

Keywords: Neural network model; Soda-anthraquinone pulping; Tagasaste; Paper sheet properties

1. Introduction

Demand for pulp and paper has increased significantly during the last years in many countries with limited forest resources. Total global paper-making consumption is estimated to increase from abut 300 million tones from 1998 to about 425 million tones by the year 2010 (Rowell and Cook, 1998). This is in spite of the generalization of computer and audio–visual technologies that could have gradually reduced its consumption. However, an increase in the demand for certain paper kinds by these technological innovations and environmental demand has occurred (Bayer et al., 1999). On the other hand, with the increase of population, pressure on forest land has increased and resulted in large scale destruction of those areas. With the limited and dwindling forest resources existing nowadays, it is not possible to depend exclusively on the conventional raw material for pulp and paper production.

In recent years, due to market demand and environmental pressures, the pulp and paper industry has replaced in some extent wood by non-wood and/or annual plants, and also agricultural residues (Atchinson, 1995, 1996, 1998). All fibre resources will be required to meet project demands, including fast growth plantations, increased recycling and non-wood material fibres from crop residues as well as fibre crops (Ali and Saikia, 1997; Cappelleto et al., 1999; Máximo et al., 1998; Antunes et al., 2000; Gominho et al., 2001). Some non-wood materials provide excellent fibres for making special paper and can help to alleviate the increasing shortage of wood in some zones. One of such non-wood materials is tagasaste, which is a non-food agricultural crop. This plant, formerly also called "tree lucerne" (*Chamaecytisus proliferus* (L. fil.) Link ssp. *Proliferus* var. *palmensis* (Christ)), is an endemic fodder tree-shrub from the Canary Islands which has achieved importance in agriculture around the world, particularly in several parts of Australia, New Zealand, Canary Islands and south of Spain (Francisco-Ortega et al., 1991, 1993; González, 2000). Tagasaste began to be investigated at the end of the nineteenth century but it was in 1982 that its agronomy features were determined (Snook, 1982, 1984; Webb and Shand, 1985; Twosend and Radclife, 1987). Tagasaste grows most easily on sandy soils. It tolerates low annual rain fall (the lower limit is 300 mm) in some areas of Australia and New Zealand, where this

---

* Corresponding author.
E-mail address: jalel.labidi@ehu.es (J. Labidi).

0960-8524/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biortech.2007.12.052

shrub was introduced at the end of the nineteenth century (Méndez Pérez and Almeida Falcon, 1998). Most studies about this species are focused on its biomass yield and quality, nutritive value and palatability (Tolera et al., 1997). The necessary harvesting for the suitable regrowth of plants provides trimming residues, which could be used as a paper-making raw material. These trimming residues were formed from blanches of 0.5–5 cm thickness, and have been used as a raw material for pulp and paper production only by few authors (Jimenez et al., 2002; López et al., 2002, 1980; Diaz et al., 2004).

Soda pulping consumes large amounts of bleaching chemicals. However, it is a promising and environmentally friendly method compared to sulphur based processes: Kraft and Sulphate (Khristova et al., 2002). On the other hand, soda pulping also produces paper of similar or improved properties, compared with an equivalent hardwood pulp (Law and Jiang, 2001).

Most of the published works concerning the pulping of trimming materials, annual plants or agricultural residues (holm oak, brewer's spent grain, abaca, olive wood, tagasaste, vine shoots, wheat straw, sunflower stalks) present empirical correlations of pulp and paper properties with the pulping conditions (López et al., 2000, 2002, 2003, 2004; Diaz et al., 2004; Alaejos et al., 2006; Mussatto et al., 2006; Jiménez et al., 2001, 2005, 2006). With these types of correlations it is difficult to distinguish clearly the effect of each variable on the measured properties. Furthermore, the obtained equations can not be used to simulate the entire process of pulp and paper production.

On the other hand, the development of a pulping process simulation requires a variety of data that are not usually measured. Among them, the deglinification reaction and its kinetic are crucial aspects to develop the simulation properly, but only a limited number of works have tackled this issue.

To overcome these problems, the usage of an artificial neural network (ANN) model to simulate the operation of the pulping reactor was proposed. Artificial neural networks have been used for a variety of applications in the field of pulp and paper, especially for process control (Laperrière et al., 2001, 2003; Karrila and Rezak, 2002; Jin Hee and Hak Lae, 2001; Aguiar and Filho, 1998; Furumoto, 1995; Verikas et al., 2000; Smith, 1996). The ANN model has several advantages over the empirical model, as it can be easily integrated into a process simulation and, at the same time, allows identifying the contribution of each individual parameter.

In this work, a simulation of the pulping process of the tagasaste with soda-AQ using a neural network model of Cadsim Plus (Aurel System Inc., 1984–2007) has been developed. The influence of the operational variables, namely soda concentration, AQ concentration, liquid/solid ratio, temperature and time process, on the brightness, breaking length, burst index and tear index of paper sheets made from it, was studied with the aim to optimize the pulping process.

2. Methods

2.1. Pulping

The pulping reaction was carried out in a 15 L batch reactor electrically heated (López et al., 2002). The obtained cooked material was ground in a wet beater while uncooked residues were separated from the pulp. From the obtained pulp, a paper sheet was prepared by means of an ENJO-F-39.71 former, according to the TAPPI 220 standard method. The analysis of produced paper sheets was done according to the following methods: brightness (UNE 57-062), traction index (UNE 57-054), burst index (UNE-57-058) and tear index (UNE 57-033).

2.2. Experimental design

To minimize the number of experiments, an experimental design around a central point was performed to determine the influence of the independent variables of the pulping process (temperature, liquid/solid ratio, time, soda concentration and AQ concentration) on the pulp properties: brightness, traction index, tear index and burst index. Three different values were selected for the five input variables. The selected experimental pulping conditions are shown in Table 1. This design satisfies the general requirements which allow the estimation of all parameters of the mathematical model without an excessive number of experiments (Montgomery, 1991). For this study with five independent variables, 27 experiments were carried out. The table shows the experimental data of the all experiments carried out by Lopez et al. (2004).

2.3. Polynomial model

The experimental data (Tables 1 and 2) were fitted to a second-order polynomial model defined by the following equation:

$$Y = a_0 + \sum_{i=1}^{n} b_i X_{ni} + \sum_{i=1}^{n} c_i X_{ni}^2 + \sum_{i=1;j=1}^{n} d_{ij} X_{ni} X_{nj} \tag{1}$$

where Y is the dependent variable concerned (brightness, traction index, tear index and burst index), X_i denotes the independent variables normalized with Eq. (2) and a_0, b_i, c_i, and d_{ij} are unknown coefficients that must be estimated from experimental data.

The independent variables are normalized from -1 to $+1$ in agreement with the equation:

$$X_n = 2^* \frac{X - \overline{X}}{X_{\max} - X_{\min}} \tag{2}$$

where X_n is the normalized variable, X the absolute value of the independent variable concerned, $\overline{X}$ the average value of the variable and $X_{\max}$ and $X_{\min}$ are its maximum and minimum values, respectively, of the variable.

For the central combination, all the normalized independent variables equal to zero.