OPTIMAL OPERATION PROFIT OF A PILOT ROTARY KILN FOR CHARCOAL ACTIVATION

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***Abstract*— This work presents an optimization study of a pilot rotary kiln steady state operation, used to manufacture activated carbon (AC) from eucalyptus wood and, a sensitivity analysis on the optimal solution. The main goal is the maximization of a process operating profit function, considering constraints on the optimization variables as: residence time, solid feed, activation steam and heating gas flow rates, for maintaining product quality and maximum production yield. Bounds on optimization variables have been previously defined by a sensitivity analysis of the kiln performance carried out via simulation of the steady state mathematical model. Due to the kind of equality constraints, the optimization problem was solved coupling the optimization code with a differential equation solver in a Matlab™ framework. Results attained allow getting valuable information for design, operation policy, regulation and reactor scale-up in order to develop a local technology for activated carbon production using a regional raw material.**

***Keywords*– activated carbon, rotary kiln, optimization, operating profit.**

I. INTRODUCTION

Activated carbon (AC) is an adsorbent material widely used in different industrial and purification processes. The physical activation procedure of charcoal with steam is the core of production plants of activated carbon from cellulose materials. The transformation process is strongly endothermic and involves the gasification reaction of carbon with steam within the particle at temperatures between 1073 and 1373 K (Yehaskel, 1978). The direct-heated rotary kiln is broadly used for physical activation. The pilot rotary kiln is a cylinder that rotates around its longitudinal axis and essentially operates as a heat exchanger (Ortiz *et al.*, 2003a). It has a diameter of 0.30 m with 3.70 m length and is covered with 0.15 m of insulation material. The cylinder is lightly inclined (*i.e.*, slope about 2-6%) to help the axial displacement of the solid bed, which moves towards the discharge end as the hot gases circulate in counter-current mode. The rotational rate is 0.5-2.5 rpm. Figure 1 shows a scheme of the rotary kiln. The solid feed is carbonized matter obtained from a variety of raw materials such as eucalyptus wood.

The hot gases originated by the combustion of natural gas, which arise from a central burner, supply the necessary energy for the activation reaction. Water vapor is injected as the activation agent in co-current mode. Most of the raw materials are relatively pure solids, with moisture contents around 5 to 10%. Usually, the content of impurities in the carbonized solid is negligible. It is supposed that the solid bed moves as a pseudo fluid with axial displacement and without retro - mixing, and it rolls or slides in transverse direction as the cylinder rotates. Table 1 shows the main dimensions and nominal operating conditions of the pilot rotary kiln. The mathematical model and steady state simulation of the kiln operation has been previously reported by Ortiz *et al.* (2003a).

Optimization studies for different kind of rotary kilns have been reported in the open literature. The production yield optimization of a rotary kiln used in the coke calcination process has been carried out by means of simulation of a steady state mathematical model (Bui *et al.*, 1993). Stylianides (1998) has reported a model which allows developing an optimal plan to increase the clinker production capacity. The net present value (NPV) of the cash flow generated in the installation of new kilns has been used as objective function. An optimization model for geometry design of a laboratory-scale rotary kiln pyrolyser of municipal solid wastes (MSW) and the optimum solutions have also been approached by Li *et al.* (2002). In that work, the objective function is the minimal space occupied by the kiln and constraints are imposed by the practical operating variables (rotational speed and kiln slope). The bounds on manipulated variables come from: desired material volumetric flow (MVF), complete pyrolysis time, design of the kiln (exit dam and internal structures), heat transfer and the experimental limitation on the relation length/radius of the kiln.

This single objective constrained nonlinear optimization problem was solved by means of sequential quadratic programming (SQP) in Matlab™ Toolbox (MathWorks, 2002).

In a previous work (Ortiz *et al.*, 2003c), the operation of the pilot rotary kiln under study has been optimized using the production yield as objective function and a simplified model for the constraints which assures the product quality. On the other hand, a complete study on the dynamic behavior has been accomplished by means of Simulink™ – Matlab™ in Ortiz *et al.* (2005).