STEADY STATE SIMULATION OF A ROTARY KILN FOR CHARCOAL ACTIVATION

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Abstract — This work presents a mathematical modeling and steady state simulation study of the pilot scale rotary kiln behavior, which was designed to activate charcoal obtained from the raw materials of region of Cuyo-Argentina. The proposed model aims for acquiring useful information to select operating conditions and design parameters. It is a simplified mathematical model that consists of a system of nonlinear differential and algebraic equations, including a simple kinetic expression as well. Its solution, using the finite differences method, allows for obtaining solid flow rate, solid temperature, gas, and wall temperature profiles under a variety of operation conditions and as a function of the kiln’s length. Parameters such as burn off and production yield were analyzed and the results were compared with characteristic data taken from the literature. This model, once adjusted with experimental data, will allow to adjust the kiln’s operation in order to optimize both the energy usage and product quality.

Keywords — rotary kiln, activated carbon, activation, modeling, simulation.

I. INTRODUCTION

Activated carbon (AC) is a well known adsorbent material, which finds its usage in chemical, mining and food industries, and in other important applications such as purification and deodoration processes, water treatment, and medicine as well (Yehaskel, 1978; Bansal et al., 1988). In Argentina, there is an increasing interest in the development of a technology to cope with the local demand.

Much research on activated carbon has been undertaken at the National University of San Juan-Argentina during the last decade, such as coal gasification, production of AC by chemical and physical activation from several raw materials and AC characterization (Deiana et al., 1998). Using those data, approximate kinetic expressions were also developed (Martínez, 1998). Besides, a pilot-scale rotary kiln was built to study the physical activation of charcoal obtained from regional raw materials.

Although rotary kilns are widely used by the chemical industry, they still remain among the pieces of equipment most difficult to be properly analyzed due to the complexity of internal phenomena (e.g., heat, mass, and momentum transfer) along with the eventual chemical reaction phenomena (Barr et al., 1989). Rotary kilns are used by almost all the most important AC world manufacturers (Norit & Co.). However, studies about the modeling of processes to activate charcoal with steam in rotary kilns have not been published. Due to the specificity arising from each raw material and the difficulties associated with proposing general-type kinetics for the process, there are not published studies of the activation reaction kinetics, either. Thus, the majority of published works on activation and re-activation at pilot scale are empirical (Smith, 1979; Laine et al., 1991) and a mathematical model to predict the stationary and dynamic performance of rotary kilns for the activation of charcoal is lacking at present.

The present work introduces mathematical modeling of the steady state operation of such a kiln, aiming to obtain valuable information for the proper selection of operating conditions and design parameters.

The achieved results allow for gaining understanding about the rotary kiln steady state performance. Such information, together with experimental data and the study of the process dynamics will allow for the proper kiln operation and control.

II. PILOT ROTARY KILN

A pilot rotary kiln is basically a cylinder which rotates around its longitudinal axis and operates essentially as a heat exchanger. The cylinder is lightly inclined (i.e., slope about 2-6%) to facilitate the axial displacement of the solid bed, which moves towards the discharge end as the hot gases circulate counter-current mode. Figure 1 shows an outline of the rotary kiln. The solid feed is a carbonized matter obtained from a variety of raw materials (e.g., eucalyptus wood). The hot gases, which arise from a central burner and are originated by combustion of natural gas, supply the necessary energy for the activation reaction. Steam is used as the activation agent and is injected in co-current mode.

Most of the raw materials are relatively pure solids, with moisture contents around 5 to 10%. Raw material grain size was 6-20#ASTM, which is equivalent to an average particle size of 0.002 meter. Usually, the content of impurities in the carbonized solid was 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 traverse direction as the cylinder rotates.

The geometric parameters (i.e., $L_{cs}$, $L_{cu}$ and $L_{li}$) were determined as a function of the solid flow rate, residence time, and rotary kiln dimensions, by means of geometric relationships and iterative calculation (Coul-