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Review

Regeneration of carbonaceous adsorbents. Part II: Chemical, Microbiological and Vacuum Regeneration

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ABSTRACT

Due to their excellent adsorbent properties, porous carbonaceous materials are employed in separation applications, especially in the purification of polluted liquid and gaseous streams. The progressive accumulation of pollutants on the surface of these materials reduces their adsorption capacity until they are finally exhausted. The regeneration of these carbonaceous adsorbents is an economically and environmentally attractive option. Numerous regeneration methods have been developed, but until now, they had not been properly classified or deeply reviewed. In this work, all existing methods are described in-depth, and a double-criterion is proposed to allow clear and rigorous classification of current and future regeneration methods. This classification is based on the traditional division which distinguishes among Thermal, Chemical and Microbiological Regeneration, and a fourth major group, Vacuum Regeneration, is added. Thermal Regeneration has already been considered in a previous review. This second review considers both Chemical Regeneration (within which Regeneration with Liquid Water and NaOH, Electrochemical, Solvent, Supercritical and Oxidative Regeneration are identified) and Microbiological and Vacuum Regeneration.

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1. Introduction

The excellent adsorbent properties of porous carbonaceous materials, such as activated carbons (ACs), are responsible for their extensive use in many fields. Polluted gaseous and liquid stream purification is the most common application and consumes the most ACs. During these treatments, pollutants continuously accumulate on the adsorbent surface. As a result, the adsorption capacity is progressively reduced until the material is finally exhausted. After saturation, the exhausted ACs are replaced with fresh materials and the used ACs are burnt or disposed of in landfills, but this option entails important environmental and economic setbacks. The regeneration of these materials is an alternative to disposal that allows them to be re-used. Regeneration attempts to remove pollutants retained on the ACs' surfaces to restore adsorptive capacity without modifying porosity or causing adsorbent mass losses. By this way, Regeneration produces valuable products and avoids the contamination that disposal of this solid residue would cause.

The relevance of this process is reflected in the numerous methods developed and published investigations concerning the regeneration of carbonaceous adsorbents. Despite this interest, to our knowledge, no article has yet strictly classified or deeply described existing regeneration methods. Therefore, the main goals of this review are as follows: (i) establishing criteria to classify existing regeneration methods in a clear and rigorous manner and (ii) describing all of these methods in-depth.

This review maintains the traditional division of regeneration methods, which distinguishes among three major groups: Thermal, Chemical and Microbiological Regeneration. A fourth major group, Vacuum Regeneration, is added. To classify regeneration methods included within each of the four main groups properly, the following double criterion focused on two fundamental aspects is proposed [1]:

1. The mechanism of regeneration: the regeneration pathways involved in the removal of the adsorbates retained on the ACs.
2. The type of regenerating agent: the primary agent that induces regeneration is not considered in isolation. The presence of a secondary agent, such as a catalyst or ultraviolet radiation, modifies the regeneration process and consequently, represents a different method.

Within the four major groups, each method represents a unique "*regeneration mechanism-regeneration agent*" combination that differentiates it from the others. Table 1 displays the general classification of the regeneration methods along with the mechanisms and regeneration agents included within each major group. This criterion also allows any future methods to be properly classified.

Thermal Regeneration, which involves heating the spent adsorbents, was analyzed in a previous review [1]. Chemical, Microbiological and Vacuum Regeneration are considered in this review.

Chemical Regeneration employs an extensive variety of reagents to remove adsorbates. The main characteristic of Microbiological Regeneration is the employment of microorganisms as the regeneration agents. Vacuum Regeneration shifts the adsorption equilibrium towards desorption through pressure changes in adsorption-regeneration cycles.

2. Important definitions

It is necessary to describe a number of concepts that will appear throughout this study:

- AC forms: different types of AC have differing morphology and particle size. These materials include granular activated carbon (GAC), powdered activated carbon (PAC), activated carbon fibers (ACFs), carbon nanotubes (CNTs), cloths, monoliths, composites and extruded or pellet forms.