Adsorption technology in waste water treatment processes utilizing activated carbons as adsorbent materials prepared from waste vehicular tires: Recent research and trends in the removal of various toxic and persistent organic and inorganic pollutants

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Abstract
Various toxic contaminants when are present in the environment pose a threat to the inhabitants of natural ecosystems owing to their non-biodegradable nature that increases their high toxicity towards non-target organisms. The large mass of solid wastes that are generated from waste rubber tires unquestionably consists a serious threat of environmental pollution around the world. Consequently, scientific interest has focused on several recycling strategies and practices converting them into more valuable products such as adsorbents widely utilized for the removal of several different inorganic and organic compounds from environmental samples. Hence, the main objective of the present study is to review all the data in the available published bibliography concerning the recent research and future trends on using granulated adsorbent materials and activated carbons obtained and prepared from waste tires and afterwards applied for the removal of persistent and residual quantities of pollutants.
Keywords: Waste rubber tire, adsorption isotherm, remediation, persistent contaminants, recycled discarded tires

1. Introduction

Waste tires resulting from their use by a variety of different automobile means of transportation have become a serious source of environmental pollution worldwide. It has been estimated that the quantities of used tires that are generated each year in the European Community, North America, and Japan are $1.5*10^6$, $2.5*10^6$ and $0.5*10^6$ tonnes, respectively [Gupta et al., 2011a], whereas more than 330 million waste tires are discarded per year and accumulated over years throughout the world [Ariyadejwanich et al., 2003]. They are considered as a major environmental issue, due to their unique characteristics of non-biodegradability, large volume and their currently improper disposal into the environment [Aisien et al., 2013].

The potential of using activated carbon adsorption materials from waste vehicular tires has been evaluated by several researchers. The adsorption characteristics of the produced adsorbent materials that are obtained after the pyrolysis method, including adsorption capacities, mesopore volumes, and BET surfaces have been investigated, compared and improved by numerous researchers throughout the years [Gupta et al., 2011a,b]. Hence the main purpose of the present work is to review all the available data concerning the recent research and trends in the removal of various toxic organic and inorganic contaminants contained in water and wastewater matrices by utilizing activated carbons prepared from waste tires.

2. Main Findings and Conclusions

The present review showed that several research efforts regarding the employment of adsorbent materials obtained by waste rubber tires in the relevant literature have focused on the adsorption practice [Aisien et al., 2002, 2003, 2013; Gupta et al., 2011a,b]. Findings of the current review highlightened that, not only low cost and readily available materials have been studied like rubber granules (for the removal of phenol from industrial wastewater, and in oil pollution control), and rubber ash (for the adsorption of lead contained in aquatic solutions) [Aisien et al.,2002 2003, 2013; Mousavi et al., 2010], but also surveys using high cost and not easily generated for large-scale applications products that are obtained by different pyrolysis techniques such as activated carbons and carbon black have been carried out as well. Despite their economical drawbacks and practical restricts, the improved adsorption behavior of those pyrolyzed- or carbonized-adsorbents is much better in terms of surface area and therefore adsorption capacity. Numerous studies conducted either by batch adsorption method or by fixed-bed column method have demonstrated the feasibility of converting waste or discarded rubber tires into recyclable adsorbent substrates of high adsorption efficiency and very promising results for the removal of a variety of inorganic and organic contaminants, among which are included PAHs, dyes, metals and other hazard chemicals (Table1).

Table 1. Selected studies evaluating the potential application of adsorbents obtained from waste vehicle tires in the removal of organic and inorganic pollutants from aquatic solutions. References are reported in chronological order.

Type of adsorbent	Adsorbent preparation method & Particle size	Tested pollutant	Adsorption method and kinetic studies	Main findings-Conclusions	Referen
Rubber granules from scrab tire	Washed (with H_2O), dried (air), cut (with knives and electric grinding machine), mechanically sieved, washed (with distilled H_2O) by agitation (mechanical shaker at 150rpm for 3h), and dried (oven at 60°C for 5h) • 0.212mm • 0.425mm • 0.60mm • 1.18mm • 2.36mm	Phenol (UV–visible spectrophotometer at λ=248 nm)	**-Batch method** (mechanically agitated 250mL Erlenmeyer flasks containing 100mL of phenol aqueous solution & adsorbent appropriate dose) **-Langmuir and Freundlich adsorption isotherm models**	• Adsorption process was affected by operational parameters: contact time, initial concentration of phenol, adsorbent dosage and solution temperature • Equilibrium time: 60min for initial concentration of 700mg L^{-1}→ Fast kinetics adsorption process • Decrease in granules' particle size from 2.36 mm to 0.30mm increased adsorption capacity from 5 mg g^{-1} to 10.6 mg g^{-1} and percentage removal of phenol from 20.5% to 40% • Increase in temperature from 5°C to 45°C decreased the adsorption capacity from 13.4 mg g^{-1} to 9.9 mg g^{-1} • Conditions for maximum adsorption: pH=8.5; Adsorbent dosage:4g • Langmuir isotherm constants: Q_o=15.6mg g^{-1} (maximum sorption capacity), b=87.09L mg^{-1} (sorption constant) (R^2=0.995)→Better fit of experimental data→ Mono-layer type of adsorption • Freundlich isotherm constants: K_f=2.710mg g^{-1} (constant related to adsorption capacity), n=6.369 (constant related to adsorption intensity) (R^2=0.721)	Aisien et al., 2013
Mesoporous activated carbon material	Cleaned, washed (with deionized H_2O), dried (oven at 100 ◦C for 2 h), heated for carbonization (500 ◦C for 5 h), oxidized with H_2O_2 solution (for 24 h at 60 ◦C), washed with deionized H_2O (x3 times) and dried (at 110 ◦C for 2 h in vacuum oven), activated (to 900 ◦C for 2 h in a covered silica crucible by heating in amuffle furnace), cooled (in a desiccator). treated with 1 M HCl solution (to remove the ash content), washed (with deionized H_2O), dried (at 100 ◦C for 24 h), and sieved. • 100–150 μm • 150–200 μm • 200–250 μm	Acid Blue 113 azo dye (UV–visible spectrophotometer at λ=580 nm)	**-Batch method** (250mL Erlenmeyer flasks containing 100mL of dye aquatic solution & adsorbents appropriate dose agitated in an orbital shaker at 100 rpm) **and Fixed-bed columns** method (glass column with length 30 cm and 1 cm internal diameter, filled with weighed amount of RTAC having particle size 200–250 μm) **-Langmuir and Freundlich adsorption isotherm models**	• The dye adsorption depended on both the surface properties as well as the porous properties • Higher adsorption capacity was observed for larger mesopore volume of the prepared activated carbon than its commercial counterpart, even though the commercially activated carbon possessed a higher micropore volume and a higher surface area • Bulky adsorbate like Acid Blue 113, mesopore volume of the activated carbon played an important role in the adsorption phenomenon • Kinetic studies indicated that the adsorption process followed first order kinetics • The rate determining stage of the adsorption phenomenon was particle diffusion and increased mobility of adsorbate was observed with increasing temperature • Overall, the investigated adsorbent "waste rubber tire"–adsorbate system was evaluated as cost effective, efficient and fast for the removal of dyes from contaminated wastewater	Gupta et al., 2011b

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