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Crotonaldehyde removal from polluted air using a biofilter packed with a mixed bed

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ABSTRACT

This study investigated the performance of a biofilter to remove crotonaldehyde from air. Total average of removal efficiency (RE) and elimination capacity (EC) were 88% and 0.73 g m^{-3} h^{-1}, respectively. Nearly 57% of the RE was occurred in the first 20 cm of the biofilter, where the bacterial population (7.42 log_{10}CFU g^{-1}) and fungi population (5.25 log_{10}CFU g^{-1}) were significantly more than the other sections. Predominant species of bacteria in the biofilter bed were *Pseudomonas*,*Acinetobacter*, and *Proteus* spp. Finally, it can be inferable that the biofilter can be a suitable method to remove crotonaldehyde from air.

Introduction

Crotonaldehyde (2-butenal, β-methyl acrolein, propylene aldehyde; CAS RN 123-73-9) is a colourless liquid with a pungent odour. It has two isomer including *cis*-crotonaldehyde and *trans*-crotonaldehyde. The commercial product consists of >95% *trans*-isomer [1]. It is an aliphatic aldehyde that has a carbon–carbon double bond conjucted with the carbonyl group [2]. Crotonaldehyde has a molecular weight of 70.1 g mol^{-1}, a density of 846 kg m^{-3}, a boiling point of 219 °F, a freezing point of −101 °F, a vapour pressure of 30 mm Hg at 25 °C, and a specific gravity of 0.87 [3].

The main use of crotonaldehyde is in the production of sorbic acid [4]. It also has been used in locating breaks and leaks in pipes [5], in the preparation of rubber accelerators, in leather tanning, and as a stabilizer for tetraethyl-lead [6]. It is also used for the synthesis of chemicals, dyes, pesticides, pharmaceuticals, rubber antioxidants [1,5]. The main sources of exposure to crotonaldehyde are exhaust from tobacco from jet, from gasoline and diesel engines, from the combustion of polymers and wood [1]. It was detected in exhaust gases from cigarette smoke at 10–228 μg per cigarette, from gasoline engine at 0.26–3.8 mg m^{-3} [7,8], and from wood-burning fireplaces at 6–116 mg kg^{-1} [9]. It is also emitted from natural sources such as volcanoes, the Chinese arbor vitae plant, and pine and deciduous forests [1,10].

Crotonaldehyde can cause eye, respiratory, and skin irritant [11]. Short exposure to 45 ppm was very unpleasant [12]. In high concentrations, it can cause a burning sensation in the respiratory tract, lacrimation, coughing, bronchoconstriction, pulmonary edema, and deep lung damage [13]. Although no adequate data were available on the carcinogenicity of it, crotonaldehyde is probable or known human carcinogens [14]. Accordingly, an occupational exposure limits for crotonaldehyde of 2 ppm (5.7 mg m^{-3}) were recommended by the Occupational Safety and Health Administration (OSHA), the National Institute for Occupational Safety and Health (NIOSH), and American Conference of Governmental Industrial Hygienists (ACGIH) [1].

Bioreactors are effective and economical technologies that treat many waste gaseous vapours at relatively low concentration. These techniques use microorganisms to degrade pollutants existing in air as a source of carbon and energy. Biofilters are the most widely used bioreactor configurations in order to treat polluted air [15,16]. Biofilters are reactors in which a moist polluted air stream is passed through a porous medium on which a mixed culture of microorganisms is naturally immobilized [17]. Biofilters remove the pollutants through various mechanisms like absorption, adsorption, diffusion, and biodegradation; the pollutants is converted to harmless products like CO_2 and H_2O [18].

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Many studies have been done in the field of biofiltration of polluted air [19–25]. Only very few studies focused on the biofiltration of the aldehyde polluted air. These study focused on formaldehyde removal [24,26]. According to the library and internet searches, no study was done in the field of biofiltration of crotonaldehyde from polluted airstream.

Selection of the media type for a biofilter is an important step; it is based on the ability to support microbial growth [27]. Some characteristics that can affect the choice of biofilter media are low cost, good absorption capacity, pH buffering capacity, good pore structure, and good mechanical stability over time [28]. Compost and peat are most widely used in biofilters [24]. In the present study, a mixture of compost, scoria, and bagasse was selected as new biofilter bed.

The main focus of the present study is to investigate the RE of crotonaldehyde, as an important industrial pollutant, using a biofilter packed with a mixture of compost–scoria–bagasse, as a new biofilter bed. Effects of different operating conditions including various inlet loadings (IL), various EBRTs, bed height, and the addition of non-ionic surfactants Tween 80 on biofilter efficiency were evaluated during a long-term period operation.

Materials and methods

Biofilter setup and Inoculums

A pilot scale biofilter, which schematically illustrated in Fig. 1, was used to treat crotonaldehyde from air stream. It consisted of a steel cylinder (total height of 140 cm, effective height of 80 cm, and inner diameter of 11.5 cm) packed with a homogeneous mixture of compost–scoria–sugarcane bagasse in a 6:2:2 volume ratio. The volume of the packing material was 0.0083 m^3. Scoria was chosen as the main component (60%) of the biofilter bed due to its suitable characteristics including low pressure drop, inertness, and sufficient porosity. Also bagasse and compost were chosen in a same ratio (2:2) due to their suitable characteristics including supplying a part of nutrients for the biofilm (by using bagasse), and supplying a part of the microbial agent as well as providing buffering capacity (by using compost) [15]. Microbial mass was supplied by inoculum obtained from fresh activated sludge from secondary clarifier of the South Wastewater Treatment Plant of Isfahan, Iran. Some of the characteristics of the media used as biofilter bed is shown in Table 1. The biofilter system was equally divided into four sections of 20 cm. There was an empty space (10 cm height) for sampling the gas. Also, there was a free space of 15 cm at the top and bottom of the biofilter for nutrients addition and leachate collection, respectively. Perforated steel trays were placed at the bottom of each section to (a) avoid the media interference and (b) increase the radial distribution of the gas stream. There were two sampling openings in each section, one for gas and another for bioflter media sampling. Temperature of the biofilter media was adjusted in the range of 25–28 °C by covering the heating element wire around the biofilter cylinder. A 150-l compressor supplied air entering the biofilter. In order to treat impurities such as oil and aerosols, an activated carbon column was placed in flow direction. Treated air was transferred to the biofilter in two directions, one after passing the humidifier and the other after passing through the bubbler containing Crotonaldehyde. Moisture of the biofilter bed was provided by (a) moisturizing the inlet gas and (b) adding the nutrient solution. The biofilter efficiency was evaluated during a long-term operation of 126 days (in 6 phase). Non-ionic surfactant Tween 80 (purchased from Sigma–Aldrich Co.) was used in three of the total six phases. It has been widely used in environmental and biochemical applications in order to solubilize pollutants. The critical micelle concentration (CMC) of the surfactant Tween 80 is 13–15 mg l^{-1} [29,30]. Due to the toxic effects of the non-ionic surfactant on the biofilm [31], it was added to nutrient solution at concentration of 3 mg l^{-1}. Operating conditions of each phase are summarized in Table 2.

Chemicals

Crotonaldehyde and 2,4-dinitrophenylhydrazone (DNPH) were obtained from Sigma–Aldrich Company. Other chemicals including hydrochloric acid, hexane, dichloromethane, nutrients, Tween 80, and all chemicals used in biochemical tests (microbial plate count and identification tests) were obtained from Merck Company. The nutrient solution consist of the following composition per litre of water: 0.5 g NaCl, 0.1 g $NaHCO_3$, 0.15 g KH_2PO_4, 0.3 g $MgSO_4$, 0.01 g $FeSO_4$, 0.5 g NH_3SO_4, 1.9 g ClNH4, 0.03 g $MnSO_4$, 0.03 g $ZnSO_4$ [19].

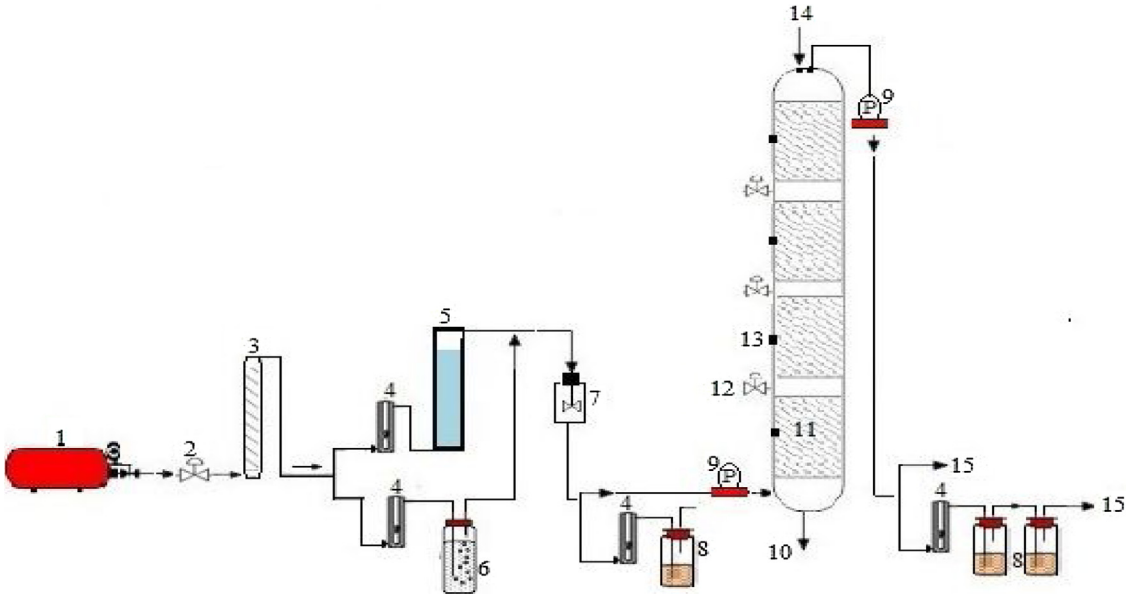

Fig. 1. Schematic diagram of the biofilte (1, air compressor. 2, control valve. 3, carbon filter. 4, rotameter. 5, humidifier. 6, crotonaldehyde container. 7, mixing container. 8, sampling set. 9, pressure gauge. 10, leachate valve. 11, biofilter bed. 12, gas sampling valve. 13, bed sampling port. 14, nutrient addition. 15, treated gas).