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Biodeterioration of 1, 1-dimethylhydrazine from air stream using a biofilter packed with compost-scoria-sugarcane bagasse

Yaghoub Hajizaheh, Mohammad-Mehdi Amin, Karim Ebrahim, Iman Parseh*

Department of Environmental Health Engineering, School of Health, Environment Research Center, Isfahan University of Medical Sciences, Isfahan, Iran

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ABSTRACT

This study evaluated the efficiency of a laboratory scale biofilter packed with a mixture of scoria-bagasse-compost to treat unsymmetrical 1,1-dimethyl hydrazine (UDMH) from the air. Effect of different inlet loadings (0.44–2.68 $gm^{-3}h^{-1}$), various EBRTs (30, 60 and 90s), bed height, and non-ionic surfactants Tween 80 on biofilter efficiency were evaluated during a long-term period (126 days). The average of removal efficiency (RE) and elimination capacity (EC) were 88% and 0.72 g m^{-3} h^{-1} respectively. Over 60% of the total average of RE was related to section 1 of biofilter, where the average of bacterial population (6.74 log CFU/g) and fungi population (4.95 log CFU g^{-1}) was significantly more than in the other sections. Although the effect of surfactant on the removal efficiency was negligible, the removal efficiency of was significantly increased by increase of EBRT and reduction of inlet loading. Dominant species of bacteria in the biofilter bed included *Pseudomonas*, *Acinetobacter*, and *Proteus* spp; fungi species were *Aspergillus* and *Fusarium* spp. regarding to the rapid adaptation period (9 days), suitable RE and EC, low pressure drop, and negligible compactness of media, this point is inferable that the biofilter system can be a suitable method to remove UDMH from the polluted airflow.

1. Introduction

Unsymmetrical dimethylhydrazine, $C_2H_8N_2$, (UDMH) is a colourless liquid with an odour similar to ammonia or fish. Other names for it are Dimazine, Dimazin, and 1,1-Dimethylhydrazine. Some of the most important of physicochemical properties of this compound are the following: molecular weight 60.1 g mol^{-1}, solubility 1000 g/L at of 25 °C, vapour pressure at 20 °C 103 mmHg, density 793 kgm^{-3}, and boiling point 64 °C (Baisautova, 2008; Pohanish, 2011).

UDMH may be used in (a) the manufacture of chemicals, (b) fuel additive stabilizers, (c) acid gas adsorbent in photography, (d) *N*-dimethyl-amino succinamic acid production, (e) regulation and control of the growth of plants, and (f) power generation units. It is also used as a component of jet and rocket fuel (Lewis, 1993; Lunn and Sansone, 1994; Program, 2011). The main sources of contact and exposure to UDMH are the military industry (due to the use of this article as missile and jet fuel), agricultural greenhouses (due to the use of daminozide that ultimately converts to UDMH), the chemical industry which uses it in indoor combustion (smoke and tobacco, oil, gas, etc.), the photography units, and outdoor air (due to the transfer, handling, storage and leaks from storage containers). When jets and missiles do not function properly, uncombusted fuel enters the atmosphere. As a result, toxic clouds containing fuel and oxidizer vapours are produced and, finally, at the result of the atmospheric interactions, *N*-nitrosodimethylamine (NDMA) and tetra-ethyl-tetrazine (which is carcinogenic) are produced. The important product of UDMH reaction with ozone is NDMA, which is a powerful carcinogen. Other products of UDMH reaction with ozone are formaldehyde (CH_2O), hydrogen peroxide (H_2O_2), and nitrous acid (HONO), each of which also plays a major role in the atmospheric photochemical reaction (Baisautova, 2008).

Numerous laboratory studies have proved the carcinogenic potential of UDMH for laboratory animals; nonetheless, epidemiologic data which indicate the carcinogenic effect of this is not enough for humans, and the International Agency for Research on Cancer (IARC) classified it among the possibly carcinogenic compounds (Group B2) (Cancer, 1974). Contact with this compound can occur through the respiratory tract, gastrointestinal tract and skin. The

* Corresponding author.
E-mail address: iparseh97@gmail.com (I. Parseh).

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identified impacts of this compound on human health include blood pressure increase, damage to the liver and kidney, damage to the central nervous system, damage to the respiratory tract, haemolysis, inadequate supply of oxygen to the tissues, chest pain, weakness, headache, dizziness, nausea and vomiting, damage to the gastrointestinal tract, conjunctivitis, and irritation of eyes, skin and throat (Kao et al., 2007). The National Occupational Exposure Survey reports that 2917 workers were in contact with this material in chemical manufacturing industry from 1981 to 1983. On the other hand, this chemical is classified in the 'Special Health Hazard Substance List' due to its carcinogenic, mutagenic, explosive, and corrosive properties, and so different organizations and institutions have considered strict rules to limit contact with this compound. OSHA and NIOSH levels stated value of permissible exposure limit (PEL) with this substance, respectively 0.5 ppm and 0.6 ppm, for a period of 8 h (Pohanish, 2011).

Many physiochemical methods have already been used to control air pollution, including heat treatment, catalytic oxidation, adsorption, scrubbers, filtration, and distillation (Hassan and Sorial, 2010a; Rene et al., 2012; Zehraoui et al., 2012). Chemical methods require high amounts of energy and chemicals (oxidants and catalysts). Physical methods are also not able to mineralize pollutants and only transfer them from one environment to another. In comparison with the physicochemical one, biological treatment (biofilters) is a cost-effective, efficient, and environment-friendly option. In addition, this method has a lower power consumption and also produces fewer hazardous by-products. On the other hand, the important disadvantage of this method is the need for continuous maintenance and operation, the large size of the system, and its sensitivity to variable gas flow (Delhoménie and Heitz, 2005; Devinny et al., 1998; Hassan and Sorial, 2010b; Mohammad et al., 2016). In the biofiltration process, pollutants are transferred from the gas phase to a liquid phase, and are further decomposed by microbes. In this biological technique, pollutants are convert to water, carbon dioxide, and organic biomass (Ferdowsi et al., 2017; Quigley et al., 2004). This air pollutants may be organic or inorganic and can be used as an energy source—and sometimes carbon source—by microorganisms (Devinny et al., 1998).

Owing to the high vapour pressure of UDMH (103 mmHg at 20 °C) (Baisautova, 2008; Pohanish, 2011), probably the most important route of human contact with the UDMH is through the air. So, the main objective of this study is checking the Scoria fibre-filled compost biofilter performance for removing this contaminant from the air stream. Although the biodegradation of UDMH from soil and water is done in a limited manner, but according to library studies and our internet searches, yet a study is not performed in the field of biofiltration of UDMH from the air flow. So this might be the first study in the field of biofiltration of this toxic substance from the air flow.

2. Materials and methods

2.1. Biofilter media and inoculation

Biofilter media consisted of 60% scoria, 20% bagasse, and 20% compost. The reasons for choosing this material as a biofilter media were (a) providing adequate porosity (by using scoria and bagasse), (b) providing a part of nutrients (by using bagasse), and (c) providing a part of the microbial mass as well as providing buffering capacity (by using compost). Much of the microbial mass was supplied by fresh activated sludge from the wastewater treatment of south of Isfahan, Isfahan, Iran. Some of the characteristics of the media used as biofilter bed are shown in Table 1.

Table 1
Physical and chemical characteristics of the media before filtration.

Properties	Scoria	Compost	Bagasse
Particle size (mm)	5–11	0.6–5	3–16
Initial moisture content (%)	2>	30	12
Dry bulk density (kg m^{-3})	453	310	215
Field capacity (g H_2O/g dry sample)	0.42	1.2	0.95
pH	7.6	8.1	7.3
Porosity (%)	65	61	75
Carbon content (%)	0.23	31.28	36.53
Nitrogen (%)	ND	10.20	3.35
Hydrogen (%)	0.12	5.11	5.21
Sulfur (%)	0.10	0.76	1.17

2.2. Chemicals and nutrients

UDMH was obtained from Sigma-Aldrich Company. Other chemicals, including hydrochloric acid, phosphomolybdic acid, nutrients, Tween 80, and other chemicals used in biochemical tests (culture media and consumed reagents), were obtained from Merck Company. The nutrient solution contained the following composition per litre of water: 0.5 g NaCl, 0.1 g $NaHCO_3$ (used to control pH of the liquid medium), 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 C_lNH_4, 0.03 g $MnSO^4$, 0.03 g $ZnSO_4$. About 240 ml of the nutrient solution was added to the biofilter 2 times a day. Also, tween 80 was applied in 0.2 of its CMC. The critical micelle concentration (CMC) of the surfactant is 13–15 mg/L (Hill et al., 1989).

2.3. Biofilter design and operation

The biofilter consisted of a steel column, the total and effective height of which was respectively 140 and 80 cm, and the inner diameter was 11.5 cm. This pilot scale biofilter was divided into four sections (height of each section was 20 cm). Between these sectors, there was an empty space of 10 cm for sampling the gas, and at the top and bottom of the biofilter, there were free spaces of 15 cm respectively to add nutrients and to collect leachate. In order to avoid interferences between sections of the biofilter media and to increase the radial distribution of gas between classes, perforated steel trays were placed in the bottom of each section. Two sampling openings are embedded in each section, one for gas and one for the media. The biofilter temperature was controlled in the range of 27–31 °C by wrapping a heating element wire around the biofilter. Inlet air was supplied by a 150-L compressor. A column of activated carbon was used to remove impurities (like oil and aerosols) from the inlet air. Then filtered air from two directions was entered into the pilot (one after passing the humidifier, and the other after passing through the bubbler containing UDMH pollutants). The bed humidity was supplied through the inlet wet gas and addition of the nutrient solution (Fig. 1).

After the start-up period, biofilter performance under different operation conditions was measured during the long-term operation (126 days in 6 phases). In order to evaluate the effect of surfactants on removal efficiency, non-ionic surfactant Tween 80 was used in three of the total six phases. Operating conditions of each phase including the addition of a surfactant, EBR, UDMH concentration, time of each phase, and inlet loading are summarized in Table 2.

2.4. Measurement of media characteristics

To measure the amount of carbon, hydrogen, nitrogen and sulfur (CHNS) of biofilter media, an automated thermal elemental analyser (ECS 4010 CHNS-O analyser) was used. In order to calibrate the