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ORIGINAL ARTICLE

Analytical expressions for the concentration of nitric oxide removal in the gas and biofilm phase in a biotrickling filter

Rasi Muthuramalingam [b], Sunil Kumar [a], Rajendran Lakshmanan [b,*]

[a] *Department of Mathematics, National Institute of Technology, Jamshedpur 831014, Jharkhand, India*
[b] *Department of Mathematics, The Madura College, Madurai 625011, Tamil Nadu, India*

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Abstract In this paper, a mathematical model of nitric oxide removal using biotrickling filter (BTF) packed with uniform ceramic particles under thermophilic condition is discussed. The model proposed here is based on the mass transfer in gas-biofilm interface and chemical oxidation in the gas phase. Analytical expressions pertaining to the nitric oxide (NO) concentration in the gas and bio-film phase have been derived using the Adomian decomposition method (ADM) for all possible values of parameters. Furthermore, in this work the numerical simulation of the problem is also reported using Matlab program to investigate the dynamics of the system. Graphical results are presented and discussed quantitatively to illustrate the solution. Good agreement between the solutions is presented in this paper and numerical data are obtained.

1. Introduction

Rapid increases in the emission of nitrogen oxides (NO_x) can adversely affect human health, damage crops, and are implicated in the formation of acid rain (Van Langenhove et al., 1986). Nitrous oxide, a chemical compound with the formula N_2O is one of the NO_x components which are known as laughing gas in common. It is an oxide of nitrogen. At room temperature, it is a colourless, non-flammable gas, with a slightly sweet odour and taste. Nitrous oxide is a long-lived greenhouse gas, with a direct global warming potential 298 times higher than that of carbon dioxide (Solomon et al., 2007). Therefore, even low amounts of N_2O emission are unwanted. Nitrous oxide gives rise to nitric oxide (NO) on reaction with oxygen atoms and this NO in turn reacts with ozone. Nitric oxide which is the major component of nitrogen oxide reacts with moisture in the air to form nitrous acid which is a major constituent of acid rain.

In order to control the emission of volatile organic compounds (VOC) like nitrous oxide, nitric oxide, toluene etc. from industries, biofilters are being used nowadays instead of the chemical complex absorption method (Islam and Alam, 2006; Vafajoo et al., 2012). Biofilters offer two major

* Corresponding author. Tel.: +91 9442228951; fax: +91 0452 2675238.
E-mail addresses: rasildc@gmail.com (R. Muthuramalingam), skumar.math@nitjsr.ac.in, skiitbhu28@gmail.com (S. Kumar), raj_sms@rediffmail.com (R. Lakshmanan).
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advantages to an energy-starved country like India. Their power consumption is very low (1.8–2.5 Kwh/1000 m^3) compared with other technologies. Secondly, their capital operating costs are very low which can be an added boon to our industry, which opt for high economic pollution control technologies (James and Natalve, 1996). Biofiltration is a complex process with many physical, chemical, and biological phenomena (Devinny et al., 2002). In biofiltration the contaminated air is passed through a packed bed where biodegradable gases or volatile compounds are absorbed into the biofilm (Baquerizo et al., 2005).

Biofiltration has become one of the leading technologies for controlling VOC emissions (Zarook and Shaikh, 1997; Cox and Deshusses, 1998). There are three conventional types of biofilter: biofilter, trickling biofilter and bioscrubber. Biotrickling filters have been shown in several instances to be superior to biofilters when accurate control of the environmental conditions or higher pollutant elimination rates are required (Baltzis et al., 2001). Moreover, biotrickling filters packed with better structural strength can be built taller than biofilters (Cox et al., 2001). A liquid stream trickles through the porous packed bed and provides nutrients without carbon to the micro-organisms. The micro-organism in the biofilm degrades the biodegradable pollutants in waste gas while it passes through the packed bed and diffuses through the attached biofilm. Biotrickling filters are relatively new and are still regarded as an emerging technology for air pollution control (Liao et al., 2008). Biotrickling filters require low maintenance (Deshusses Marc et al., 2004). Biotrickling filters are increasingly used in industrial applications.

NO removal by applying some thermophilic microorganisms in various temperatures was studied experimentally by Flanagan and Lee (Flanagan et al., 2002; Lee et al., 2001). Besides, theoretical modelling studies regarding NO removal in BTF reactor are very limited due to the non linear character of mass balance equations over the biofilm phase. Caceres, Song and Zarook analysed the BTF modelling on removal of volatile organic compounds (Caceres et al., 2012; Song and Kinney, 2002; Zarook and Shaikh, 1997). Liang et al. (2012) developed a mathematical model for nitric oxide removal in a biotrickling filter under thermophilic conditions. Matlab software package was employed to acquire the numerical solution of the model. However to the best of our knowledge, no rigorous analytical expressions of concentration of nitric oxide in the gas phase and in the biofilm phase have been reported (Liang et al., 2012). The purpose of this communication is to derive the approximate analytical expressions for the nitric oxide concentration in both the phases using the Adomian decomposition method.

2. Mathematical modelling

The experimental setup for the BTF reactor is given in Fig. 1. The BTF was constructed with cylindrical plexiglass. The height and diameter of the reactor were 50 and 8 cm, respectively. The packing space was at the height from 10 to 40 cm calculated from the bottom of the BTF. The outer layer of the reactor was shielded with a heat tape which is covered with a layer of fibreglass insulator. The reactor temperature was maintained at 50 ± 1 °C. The experiment was conducted in two experimental phases. In the first phase, the characteristics of *Chelatococcus daeguensis* in anaerobic environment in the presence of nitrate were found out. In the second phase, the potentiality of immobilization material in the biofilter which could adsorb NO_2 gas effectively as well as possess good bacterial immobilization capacity was identified (Islam and Alam, 2006). Let us consider the mass balance equations for

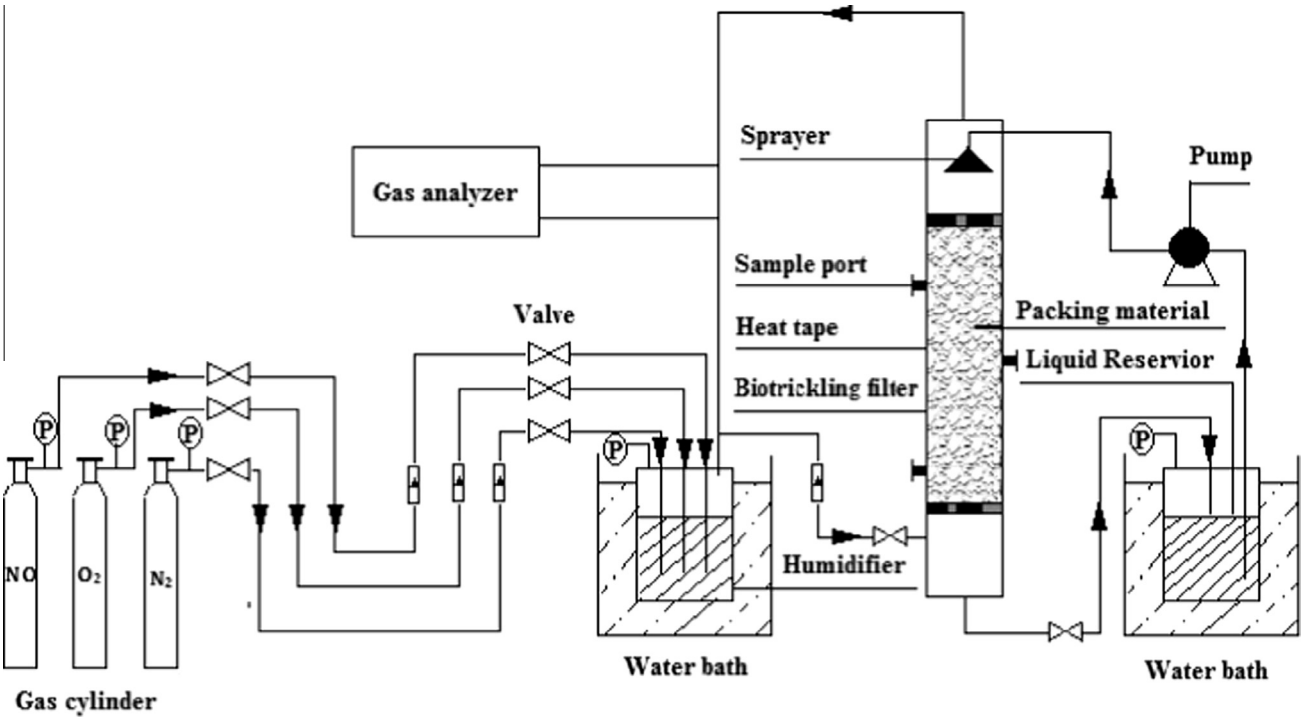

Figure 1 Experimental setup of a biotrickling filter system (Liang et al., 2012).