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Research Paper

Airflow versus pressure drop for a mixture of bulk wood chips and bark at different moisture contents

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Moist irregular wood chips or wood bark are used in packed beds for reducing odour and other gaseous emissions from waste gases. Moisture control of packing materials is essential for effective waste gas treatment. Therefore, simple experiments have been carried out to determine the influence of moisture content in a biofiltration bed made up of a mixture of irregular wood chips and wood bark in proportion 50:50 by mass on the pressure drop of air flowing through that bed. Nine moisture content levels varying from 8.1% to 64.5% (w.b.) were tested. The limiting empty bed residence time (EBRT) has been determined for each level. The influence of moisture content on true density, porosity and specific surface of the bed was determined. Above the moisture content of 28.3% (w.b.) there was a drastic change in the physical parameters of the biofilter packing. For moisture contents ≤28.3% (w.b.) the pressure drop increased slightly, while at values greater than 28.3% (w.b.) the opposite trend was observed. The Ergun equation was used to describe the relationship between the pressure drop through the bed and the superficial air velocity. For moisture contents ≤28.3% (w.b.) an approximate Ergun-type equation was proposed to describe pressure drop through the bed and the superficial air velocity.

1. Introduction

Media obtained from industrial waste may find wide application in public and industrial sectors of the economy, usually as a packing in columns used as biofilters for cleaning air polluted by odorous substances and specific volatile organic or inorganic compounds (Chun, Cooke, Eheart, & Kang, 2009; Hartung, Jungbluth, & Buscher, 2001; Lau & Cheng, 2007; Mann, De Bruyn, & Zhang, 2002; Oh, Song, Hwang, & Kim, 2009; Van der Heyden, Demeyer, & Volcke, 2015). Odorous substances can in particular disturb people who live in the vicinity of livestock farms.

In order to reduce odours emitted from livestock farms packed beds made of moist wood chips or wood bark (or their mixture) may be applied. This method of gaseous pollutant removal has widely been employed due to its low cost, simple process control, low energy requirement and more complete degradation of pollutants as compared with other methods (Ndegwa, Hristov, Arogo, & Sheffield, 2008; Sun et al., 2002).

The choice of a proper biofilter packing is of primary importance for biofilter cleaning efficiency (Chen & Hoff, 2012; Kristensen, Kofman, & Jensen, 2003). Desirable packing properties should include (Swanson & Loehr, 1997; Williams & Miller, 1992): 1) a suitable environment for microorganism to

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Nomenclature

a	specific surface, $m^2\ m^{-3}$
A	Blake-Kozeny-Carman constant (=554) in Eq. (3)
B	Burk – Plummer constant (=4.2) in Eq. (4)
A_S	total surface area of particles, m^2
d_e	equivalent diameter, m
d_h	hydraulic diameter (=$4\varepsilon/a$), m
d_S	Sauter mean diameter (=$6V_S/A_S$), m
H_b	fixed bed depth, m
M	moisture content, % w.b.
$\Delta P/H_b$	pressure drop per unit bed depth, Pa m^{-1}
V_P	volume of non-spherical particle, m^3
V_S	volume of particles, m^3
v_S	superficial air velocity, m s^{-1}
Greek symbols	
β_j	product-dependent coefficients in Eq. (2), kg $m^{-3}\ s^{-1}$ for $j = 1$ and kg m^{-4} for $j = 2$
β	product-dependent coefficient in the approximate Ergun type equation (Eq. (11)), kg $m^{-3}\ s^{-1}$
ε	porosity, $m^3\ m^{-3}$
η	air viscosity, kg $m^{-1}\ s^{-1}$
ρ	air density, kg m^{-3}
ρ_b	bulk density, kg m^{-3}
ρ_t	true density, kg m^{-3}

thrive, including sufficient amount of nutrients and moisture and unlimited carbon supply, 2) large surface area to maximise the attachment area, sorption capacity and the number of reaction sites per unit media volume, 3) stable compaction properties to resist media compaction and channelling, 4) high moisture holding capacity to retain higher absorption and active microorganisms, 5) high pore space to maximise empty bed residence time and minimise pressure drops, 6) low bulk density to reduce media compaction potential.

It should be pointed out that the choice of a biofilter packing is not simple as it requires simultaneous fulfilment of the all above listed requirements.

So far biofilters have been packed with different materials, both organic and non-organic (Akdeniz, Janni, & Salnikov, 2011; Gabriel, Maestre, Martin, Gamisans, & Lafuente, 2007; Kennes & Veiga, 2002; Ramirez-Lopez, Corona-Hernandez, Avelar-Gonzalez, Omil, & Thalasso, 2010). In order to minimise the operating and capital biofiltration costs, it is advisable to predict the packed bed pressure drop (Kristensen & Kofman, 2000; Yazdanpanah et al., 2011) and use cheap and locally available materials such as, for example, wood chips or wood bark (Andres, Dumont, Le Cloirec, & Ramirez-Lopez, 2006; Chen et al., 2008; Kafle, Chen, Neibling, & He, 2015; Nicolai & Janni, 2001).

Moisture content in biofilter media is one of the most important parameters for biofilter operation deciding of pollution reduction (Baquerizo et al., 2005; Chen, Yin, & Wang, 2005).

It is desirable not only to keep microorganisms active, but this can cause negative changes in the physical properties of the media. Too much moisture can clog some of the pores in the media, causing channelling, restrict airflow through the media and the barn, and limit oxygen flow through saturated areas in the media, thus creating anaerobic zones in the biofilm. Excessive moisture is generally not a problem because moisture either drains through the media or evaporates due to the airflow. Hence, the optimal range of moisture content depends on the biofilter media (Chen & Hoff, 2009; Goldstein, 1999; Sun et al., 2002).

Data dealing with the influence of moisture on pressure drop and sorption capacity of 10 common packing materials (coconut fibre, pine leaves, peat and heather, compost, polyurethane foam, immature coal, lava rock, a hybrid material, commercial activated carbon, sludge-based carbon) under wet and dry conditions are available (Dorado, Lafuente, Gabriel, & Gamisans, 2010). It can be expected that an increase in the moisture content of packing materials will lead to an increased pressure drop through the bed.

The problem of a single-phase flow (gas) through a packed bed has been the subject of many papers (Agullo & Marenya, 2005; Kashaninejad, Maghsoudlou, Khomeiri, & Tabil, 2010; Mellmann, Hoffmann, & Furll, 2014; Nalladurai, Alagusundaram, & Gayathri, 2002; Nemec & Levec, 2005). However, the limiting superficial air velocity and the impact of moisture content on its value have not yet been widely discussed. This appears to be of key importance since knowledge of the limiting range of the superficial gas velocity for a flowing gas through a medium is indispensable when analysing the biofilter dynamics. Moreover, the impact of the moisture content, within a wide range of its values, on physical properties of a medium consisting of irregular wood chips or wood barks (or their mixture) has been neglected.

As has been mentioned above, the influence of the moisture content on the permeability of powders can be complex. It can increase bonding between particles, but on the other hand, it may also lubricate them and even reduce their electrostatic charge, reducing the bonding between particles.

In response to the problems connected with the controversial impact of moisture content, attempts have been made to explain its influence on the properties of the biofilter packing consisting of irregular wood chips and bark, with a special emphasis on its specific surface.

These investigations were conducted with the following objectives:

1) to determine the pressure drop through a bulk wood chips/bark bed at different levels of the airflow superficial velocity, bed depth and moisture content,
2) to develop equation describing pressure drop as a function of airflow rate,
3) to determine physical properties (true density, bulk density, bed porosity, specific surface) of the wood chips/bark bed at different moisture content.

2. Materials and methods

2.1. Sample preparation

The biofilter packing that was used in this work is prepared as a 50:50 by mass mixture of beech wood and oak-wood chips