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Effects of a static magnetic field on phenol degradation effectiveness and *Rhodococcus erythropolis* growth and respiration in a fed-batch reactor

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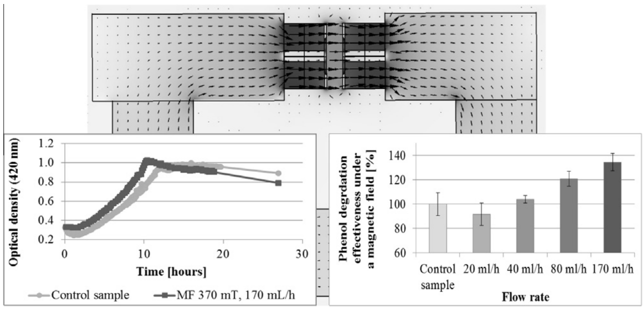
HIGHLIGHTS

- Static magnetic field (SMF) affects growth and respiration of *R. erythropolis.*
- Short-term, frequent exposure to SMF increases effectiveness of bioprocesses.
- Influence of SMF depends on system geometry and recirculation flow.

GRAPHICAL ABSTRACT



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ABSTRACT

The aim of this study was to evaluate the impact of short-term repeated exposure to a static magnetic field (induction 370 mT) on the *Rhodococcus erythropolis* cells. Specifically, it was ascertained the magnetic field's potential to influence degradation of a phenol substrate, cell growth and respiration activity (oxygen consumption) during substrate biodegradation. The experiment took place over 3 days, with *R. erythropolis* exposed to the magnetic field for the first day. During the experiment, different recirculation rates between the reactor and the magnetic contactor has been tested. Use of the magnetic field at higher recirculation rates (residence time in contactor was less than 7 min) stimulated substrate (phenol) oxidation by around 34%; which, in turn, promoted *R. erythropolis* growth by around 28% by shortening the lag- and exponential-phases and increasing bacterial respiration activity by around 10%.

1. Introduction

Present efforts to improve existing wastewater treatment plants have concentrated on improving biological wastewater treatment processes. It is generally agreed that the new methods being tested should be inexpensive and should not require complete reconstruction or crucial changes in present treatment methods or technologies. One of the novel methodologies presently being assessed is the use of a magnetic field (MF) to improve the effectiveness of biological treatment processes. A number of studies on the general effects of (electro)magnetic fields on such processes have already been undertaken by Fojt et al. (2009) and Hunt et al. (2009). However, while the effects of high static MF (SMF) of around 5–15 T have been relatively well studied (e.g. see Houpt et al., 2003; Gao et al., 2005; Potenza et al., 2004; Heinrich et al., 2011), relatively few (e.g. see Łebkowska et al., 2011; Ji et al., 2009, 2010) have been focused on low SMFs of

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7–500 mT. In general, the impact of a SMF will depend on its flux density and while strong fields of >1 T can inhibit physiological processes in organisms (Ji et al., 2009; Pingping et al., 2007; Guevorkian and Valles, 2006; Miyakoshi, 2005), weak fields can actually increase physiological process activity. This can result in positive effects that can be of use in wastewater treatment (Niu et al., 2013; Ji et al., 2010). A number of recent studies have addressed such improvements; Łebkowska et al. (2013), for example, showed that use of a 7 mT SMF had a positive impact on treatment of industrial wastewater from a urea–formaldehyde resin production plant, with treatment with activated sludge resulting in 20–30% higher chemical oxygen demand (COD) removal in a reactor exposed to an MF. In an earlier study, Łebkowska et al. (2011) also observed a 25% increase in formaldehyde biodegradation efficiency using activated sludge and a MF with a flux density of 7–8 mT. In these studies, the MFs had a positive effect on activated sludge biomass growth, resulting in higher COD removal than controls without a MF. The authors proposed that the effects of the MF were strongly influenced by magnet layout and MF geometry (Łebkowska et al., 2011). A study using airlift reactors (Raja Rao et al., 1997) showed that the influence of MF enhanced the degradation of phenolic waste liquors by submersed microorganisms at a MF intensity of 22 mT. Alternatively, other studies have shown that a low SMF can have a negative effect on bacterial growth. Filipič et al. (2012) found that a moderate SMF of 17 mT negatively influenced growth, but positively influenced enzymatic activity, of *Escherichia coli* and *Pseudomonas putida*.

Aside from the above studies, the influence of MFs on cell populations has still received relatively little attention. In particular, there has been a lack of research regarding the difficult process of organic compound biodegradation using, for example, bacterial populations of *Rhodococcus erythropolis*. The very high enzyme system diversity of *R. erythropolis* cells results in an enormous amount of bioconversion and degradation relative to other cell populations (Margesin et al., 2005). In addition, *R. erythropolis* cells display strong resistance to extreme temperature changes and are able to survive extreme salinity. Bioremediation measures using different bacterial strains of this genus have already proved to be a promising option (Čejková et al., 2005) for clean-up of highly polluted sites (Jirku et al., 2006) and, in combination with MF treatment, use of this cells could also result in a significant increase in wastewater treatment efficiency.

Electromagnetism may affect organisms in both negative and positive manner which includes acceleration of growth and metabolism. The biological effects have been found to depend on field strength, frequency, pulse shape, type of modulation, magnetic intensity, and length of exposure (Rai, 1997). As it follows from the recent research results, a spatial configuration and topology of the EMF may also have significant impact on processes in living cultures (Hunt et al., 2009). The use of static and oscillating (electro)magnetic fields has a potential for the enhancement of cell proliferation, metabolite production and cell cultivation for biomass production (Hunt et al., 2009).

The aim of this study, therefore, was to determine the effect of a SMF on growth and respiration activity of *R. erythropolis*, and on the cell's ability (potential) to biodegrade phenol in a fed-batch bioreactor.

2. Methods

2.1. Static magnetic field (SMF)

The experiment used a steel, horseshoe-shaped fixture with neodymium magnets on the ends (dimension of neodymium ring magnets: 30 mm outer diameter, 6 mm inner diameter and 10 mm thick) to create MF, samples were placed in the gap (Fig. 1). The gap in the 'horseshoe' could be varied, allowing the MF to be varied between 200 and 800 mT. Absolute flux density values within the gap remain approximately the same, meaning that samples were affected to the same degree over their volume (note, the MF is more homogenous in the lower gap). The SMF used in experiments was set at a value of 370 mT, using a 15 mm diameter contactor. A GM08 Gauss meter (Hirst Magnetic Instruments Ltd., United Kingdom) was used to measure magnetic flux density.

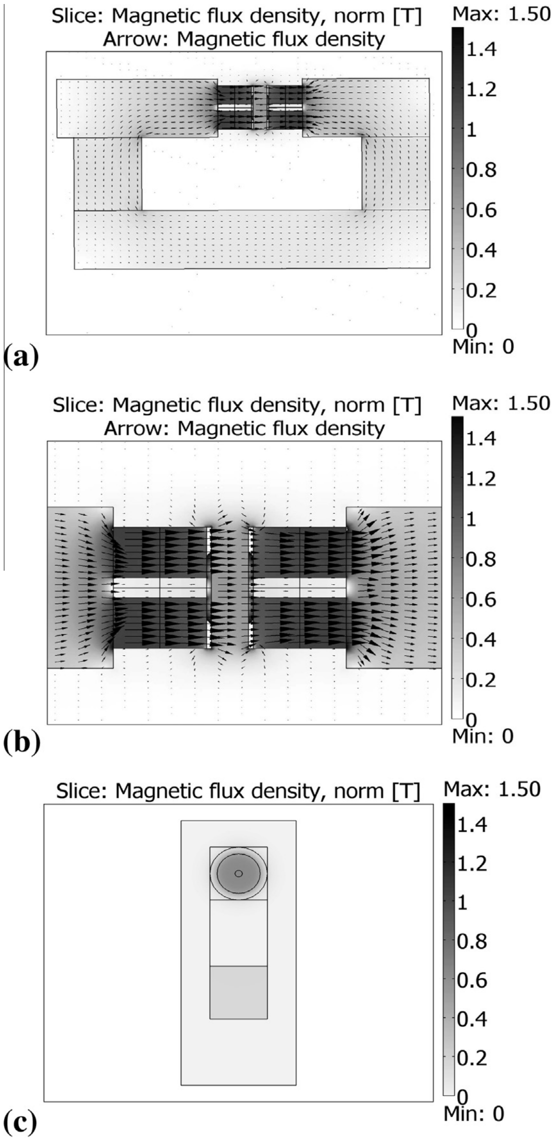

Fig. 1. Simulation of the flux density from the magnetic horseshoe used in the experiments (a) Flux density in front view plane; (b) Detail of magnetic flux density near the neodymium magnets; (c) Flux density in side view plane.

2.2. Experimental design

The 370 mT magnets were attached to the exterior of the contactor body and the bioreactor, pump and probes were located at least 0.5 m away from the contactor to avoid any magnetic effect. The intensity 370 mT was chosen based on preliminary screening experiment as the optimal one (the most proven sensitivity of cell consortia).

The reaction medium was recirculated between the bioreactor and the contactor using a peristaltic pump (i.e. a fed-batch bioreactor; Fig. 2). The experiments were performed at a temperature of