

# Response of low-strength phenol-acclimated activated sludge to shock loading of high phenol concentrations

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## ABSTRACT

The objectives of this study were to: (i) evaluate the growth of low-strength phenol-acclimated activated sludge, (ii) investigate the degradation pathways and (iii) model the growth and biodegradation kinetics, all under the condition of increasingly higher phenol concentrations (step-up shock loading). With the use of activated sludge acclimated to phenol concentration of 140 mg·ℓ<sup>-1</sup> (low-strength phenol-acclimated activated sludge), complete degradation of phenol with a COD removal efficiency of more than 95% was achieved up to 1 050 mg·ℓ<sup>-1</sup> of initial phenol concentration. At low initial phenol concentrations, the experimental results were indicative of the meta-cleavage pathway for phenol degradation. When the initial phenol concentration was above 630 mg·ℓ<sup>-1</sup>, the degradation results were indicative of both meta- and ortho-cleavage pathways. The values of the Haldane kinetic parameters indicated a low degree of inhibition exerted by the presence of increasing phenol concentration. This was substantiated by the observation that the rate constant of phenol removal decreased by only 33% even though the initial phenol concentration was increased by 15 times from 70 to 1 050 mg·ℓ<sup>-1</sup>. Thus, the activated sludge acclimated to only 140 mg·ℓ<sup>-1</sup> of phenol could successfully treat up to 1 050 mg·ℓ<sup>-1</sup> of phenol without experiencing complete inhibition during the degradation process.

**Keywords:** Phenol removal, low-strength phenol-acclimated activated sludge, degradation pathway, Haldane kinetic parameter

## INTRODUCTION

Phenol is found in the effluents discharged from many industries, including petroleum refining, resin and plastics, chemical and petrochemical, coke ovens, pharmaceuticals and agro-industrial industries. Because of phenol's high toxicity effects and suspected carcinogenicity to living organisms even at low concentrations, its presence, especially in aqueous media, is stringently limited by regulations. The World Health Organization (WHO) has set a limit level of 1 mg·ℓ<sup>-1</sup> to regulate the phenol concentration in drinking waters (Nuhoglu and Yalcin, 2005; Kilic, 2009).

Biological treatment processes for phenol have been shown to be more cost-effective, practical and highly reliable as they lead to a low possibility of by-product formation (Lim et al., 2013). Batch and continuous processes using either pure or mixed cultures are employed for the treatment of phenol-containing wastewaters (Buitron and Gonzalez, 1996; Yeom et al., 1997; Gonzalez et al., 2001; Gallego et al., 2003; Moharikar and Purohit, 2003; Chan and Lim, 2007; Kobayashi et al., 2007; Yang and Lee, 2007; Zhao et al., 2009; Saravanan et al., 2011). Mixed cultures have been shown to be more efficient when the emphasis is placed on the complete mineralisation of toxic organic compounds. Many pure culture studies have revealed that toxic intermediates accumulate during the biodegradation process leading to low COD removal efficiency (Saiqa et al., 1998; Wang and Loh, 1999; Dos Santos et al.,

2009; Banerjee and Ghoshal, 2010). Therefore, the treatment of phenol in industrial effluents using activated sludge process in which a mixed culture is in action would be more meaningful, informative and practical. The main advantage achieved by the microbial consortium formed is the interaction among all the species present in the floc. The structure and toxicity differences among the phenolic compounds or intermediates produced during the degradation can be further mineralised by the mixed culture containing various bacteria with specific qualities. Kim et al. (2002) had documented that the degradation of phenol and 4-chlorophenol by *Pseudomonas testosteroni* CPW301 was seriously inhibited by 2,4,6-trichlorophenol. However, a mixed culture of *Pseudomonas testosteroni* CPW301 and *Pseudomonas solanacearum* TCP114 (which could only degrade 2,4,6-trichlorophenol) could treat phenol, 4-chlorophenol and 2,4,6-trichlorophenol completely and overcome the inhibition of substrates to other microorganisms.

Industrial wastewaters can contain phenol concentrations across a wide range (1–3 000 mg·ℓ<sup>-1</sup>) (Banerjee and Ghoshal, 2010). Sudden increases of concentration (shock loads) commonly occur and are responsible for disruption in industrial wastewater treatment facilities inoculated with low-strength phenol-acclimated activated sludge. As the growth of this low-strength phenol-acclimated activated sludge towards the biodegradation of wastewater laden with high phenol concentrations is not well understood, further investigation is deemed necessary.

Aerobes are basically more efficient in degrading phenol because they grow faster than anaerobes. During aerobic degradation, phenol is initially converted to catechol. Cleavage of the catechol is typically achieved via ortho- (intradiol) or meta- (extradiol) pathways, leading to the formation of

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