WATER RESEARCH 40 (2006) 311–322

Available at www.sciencedirect.com

SCIENCE DIRECT®

journal homepage: www.elsevier.com/locate/watres

Development of a tubular high-density plasma reactor for water treatment

Derek C. Johnson[a], *David S. Dandy*[a,*], *Vasgen A. Shamamian*[b]

[a]*Department of Chemical & Biological Engineering, Colorado State University, Fort Collins, CO 80523, USA*
[b]*Dow Corning Corporation, Auburn, MI 48611, USA*

ARTICLE INFO

Article history:
Received 25 April 2005
Received in revised form
9 November 2005
Accepted 10 November 2005

Keywords:
Reaction kinetics
Tubular high-density plasma reactor
MTBE
BTEX

ABSTRACT

Experiments have yielded a number of important insights into the energy distribution, sparging and oxidation of methyl *tert*-butyl ether (MTBE), benzene, ethylbenzene, toluene, *m*- and *p*-xylene, and *o*-xylene (BTEX) in a dense medium plasma reactor (DMPR). It has been found that the DMPR transferred a relatively small amount of electrical energy, approximately 4% in the form of sensible heat, to the surrounding bulk liquid. Rate constants associated with plasma initiated oxidation, interphase mass transfer and photolysis were determined using a combination of non-linear least squares analysis and MATLAB® optimization for each species. The rate constants developed for the DMPR, in conjunction with a species mass balance on a prototype tubular high-density plasma reactor, have been applied to determine the removal rates of MTBE and the BTEXs when operating in batch and continuous flow configurations. The dependence of contaminant concentration on parameters such as treatment time, the number of pin electrodes, electrode gap, and volumetric flow rate has been determined. It was found that, under various design specifications and operating conditions, the tubular high-density plasma reactor may be an effective tool for the removal of volatile organic compounds from aqueous solutions.

1. Introduction

Plasma treatment of contaminated water appears to be a promising alternative for the oxidation of aqueous organic pollutants. A discussion of reactor configurations employing both thermal and non-thermal plasma reported in the literature is included as Supplementary Materials. This work, however, is focused on the dense medium plasma reactor (DMPR) illustrated in Fig. 1. The DMPR was developed by Denes and coworkers (Denes and Young, 1996) to react liquid/vapor phase species in an induced plasma state using low-temperature plasma chemistry. The DMPR has been investigated as a tool for the disinfection of microbial contaminated water. Experiments conducted by Manolache et al. (2001) focused on quantifying the inactivation of specific bacteria and the mechanisms within the DMPR responsible for the disinfection. Water was artificially contaminated with 16 Gram-positive and Gram-negative bacterial species. To reduce the voltage required to initiate a plasma discharge, oxygen or argon was bubbled through the plasma zone. With 20 s of argon plasma treatment, 91% of the colony forming units (cfu) per mL of solution were either inactivated or destroyed. This increased to greater than 98% when the solution was treated for 60 s. The results were slightly better with an oxygen plasma treatment. After 20 s, 98.8% of the cfu/mL were disinfected, with only a slight increase of 0.13% and 0.53% for an additional 40 and 100 s of treatment, respectively. The additional disinfection capability of the oxygen plasma

*Corresponding author. Tel.: +1 970 491 7437; fax: +1 970 491 7369.
E-mail address: dandy@colostate.edu (D.S. Dandy).
0043-1354/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.watres.2005.11.015

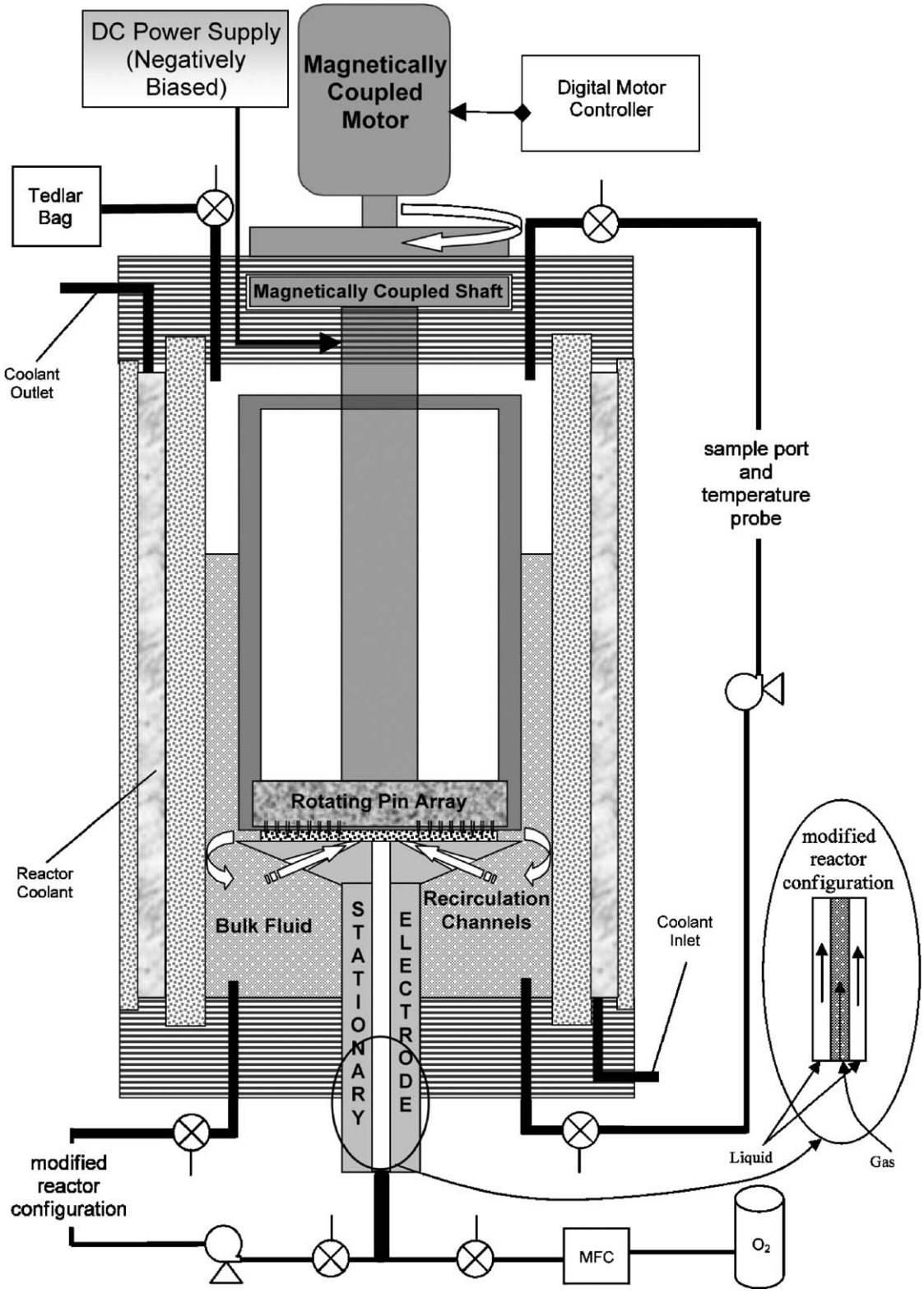

Fig. 1 – A schematic of the DMPR and a modified reactor configuration implemented by Johnson et al. (2003). A more detailed description of the reactor can be found in Manolache et al. (2001, 2004).

can be attributed to the formation of ozone, a powerful disinfectant.

The oxidation of methyl *tert*-butyl ether (MTBE) and formation of oxidation products in a DMPR have also been explored (Johnson et al., 2003). It was found that carbon dioxide was formed due to electron-impact dissociation reactions in the oxygen plasma, while acetone, *tert*-butyl formate and formaldehyde were formed as a result of