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Short communication

Radiofrequency oxidation treatment of separated dairy manure

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ABSTRACT

An innovative radiofrequency oxidation technology was developed to treat organic slurries with high solids content. The extent of nutrient release and solids disintegration from separated solids fraction of dairy manure was examined in a pilot scale 6 kW radiofrequency system. The factors affecting the process were hydrogen peroxide dosage, heating time and power intensity of radiofrequency. The newly developed RF oxidation process was highly efficient in releasing orthophosphate and soluble chemical oxygen demand in the treated solution and found to be viable to treat dairy manure.

1. Introduction

Dielectric heating using radiofrequency (RF) has been used in food processing industry and in environmental engineering applications such as soil remediation by soil vapour extraction or biodegradation, adsorptive-catalytic off-gas treatment, thermal regeneration of drying agents in biogas or natural gas treatment, and disinfection of animal facility wastewater [1–3]. A new thermal–chemical treatment using RF-oxidation (RF/H_2O_2) for the purpose of nutrient release and recovery from waste organic streams was developed recently at the University of British Columbia. The development of the RF/H_2O_2 process at a pilot scale is a new research undertaking. No processes involving RF system to handle dairy manure slurry and recover nutrients are known to exist in literature.

The RF/H_2O_2 treatment process was comparable to microwave enhanced advanced oxidation process (MW/H_2O_2-AOP) in terms of amounts of nutrient release and degree of solids disintegration [4,5]. Similar to MW/H_2O_2-AOP, the factors affecting the performance of the RF/H_2O_2 were: hydrogen peroxide dosage, power intensity, reaction time, and acid addition.

The solids fraction of dairy manure after liquid–solids separation process results in higher lingo-cellulosic and phosphorus content than that of un-separated manure, making it a better substrate for nutrient, energy and other valuable recovery [6–11]. The objective of this study was to optimize the RF/H_2O_2 process for treating solids portion of dairy manure after solids/liquid separation. The results of this study were compared with that of un-separated manure treated using RF/H_2O_2 process under similar experimental conditions.

2. Materials and methods

A 6 kW radiofrequency unit consists of RF oven with an electrode suspended on polypropylene insulators. The system has a capacity of accommodating up to 9 L of sample in a single run at an operating temperature of up to 95 °C. Commercially available microwave safe plastic containers of 1.5 L total capacity were modified and used as reaction vessels.

Separated dairy manure after liquid–solids separation process, which had 4.4% total solids (TS), was obtained from the Dairy Education & Research Centre, University of British Columbia in Agassiz, British Columbia, Canada. The separated solids manure samples were acidified using sulphuric acid to pH 4.0 for orthophosphate release [4,5].

The experimental design using a statistical programme (MINITAB, version 16.0) is shown in Table 1 [12]. A response surface methodology using Box–Behnken design was chosen to better understand and optimize the process response. Three factors with three levels per factor, namely, input power (2, 2.7 and 3.3 kW/L), holding time (20, 50 and 80 min) and hydrogen peroxide dosage (0.5, 1 and 1.5%) were chosen to study the response. The response was expressed as the concentration of soluble parameter

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Table 1
Experimental design for surface response study.

Trial number	Power intensity (kW/L)	RF holding time (min)	H_2O_2 dose, % (v/v)
1	2.7	20	0.5
2	2.0	50	0.5
3	2.7	80	0.5
4	3.3	50	0.5
5	2.7	50	1
6	2.0	80	1
7	3.3	20	s1
8	2.7	50	1
9	3.3	80	1
10	2.0	20	1
11	2.7	50	1
12	2.7	80	1.5
13	3.3	50	1.5
14	2.0	50	1.5
15	2.7	20	1.5

(orthophosphate (ortho-P), ammonia, soluble chemical oxygen demand (SCOD) and volatile fatty acids (VFA)) in the treated solution. An input power level of 50, 60 and 70% was set in the RF unit which was equivalent to 2, 2.7 and 3.3 kW per L of manure treated, respectively; a triplicate set with sample volume of 600 mL each was used.

Total phosphate (TP), ortho-P, ammonia, total Kjeldahl nitrogen (TKN), total solids (TS), total chemical oxygen demand (TCOD), SCOD and VFA analyses were carried out according to the procedures described in Standard Methods [13]. The analytical procedures used in this study are explained in detail elsewhere [5,14].

3. Results and discussion

3.1. Nutrient release

Orthophosphate concentrations of untreated separated solids varied widely, which could be due to anaerobic decomposition during storage of the manure (Table 2). After RF/H_2O_2 treatment, orthophosphate concentration ranged from 39 to 75% of TP, while 58 to 91% of TP as ortho-P was observed in the treated solution from un-separated manure (Table 3). Albeit different substrates, it was obvious that orthophosphate increased significantly after RF/H_2O_2. For both types of manure, the percent ortho-P/TP was the highest from trial 13 (3.3 kW/L power intensity, 50 min holding time and 1.5% H_2O_2 dose). This could be because the operating conditions used in trial 13 were very close to the optimum conditions predicted for both manures. Separated manure has more organic-P components that are difficult to digest unlike those in un-separated manure [6]. The results of RF/H_2O_2 were comparable to the MW/H_2O_2-AOP [15]. Notwithstanding, the different substrates and environmental conditions, the results were quite comparable to microwave treatment [16,17].

The experimental data was fitted to a second order equation to construct a regression model; the regression model proposed for ortho-P released in the treated solution is given in Equation 1 and the response surface profile is shown in Fig. 1.

$$Y = 536 - 5.3T - 128D - 166P + 0.01T^2 + 20D^2 + 18P^2 + 1.4DT + 1.3PT - 1.5PD \quad (1)$$

where Y is orthophosphate (mg/L), P is power intensity (kW/L), T is holding time (min) and D is H_2O_2 dose (%). The correlation coefficient (R^2) was 52%; the low R^2 value may be due to the fact that different starting materials were used to cover all the fifteen trials and the orthophosphate content in the untreated manure samples varied widely (Table 2).

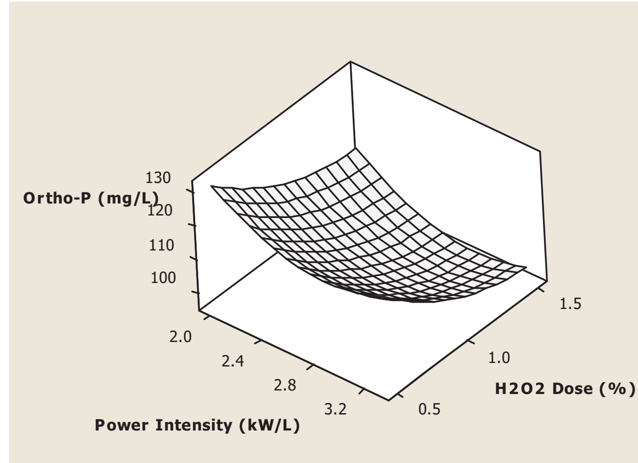

Fig. 1. Response surface profile showing ortho-P with respect to power intensity and H_2O_2 dosage.

From Eq. (1), it was found that an increase in hydrogen peroxide dosage would decrease the release of orthophosphate. Power intensity and holding time also had negative effect on orthophosphate concentration. The interaction between hydrogen peroxide dosage with power intensity and holding time with power intensity were found to be significant factors for orthophosphate release. The magnitude of factor affecting orthophosphate was found to increase in the following order: power intensity > H_2O_2 dose > second order effect of H_2O_2 dose. The optimized operating conditions for orthophosphate were a power intensity of 2.9 kW/L, holding time of 55.9 min and H_2O_2 dose of 1.1%.

Ammonia is produced as one of soluble products from the RF/H_2O_2 process; percentage TKN released as ammonia ranged from 35% to 57%. For both un-separated manure and separated solids, trial 13 resulted in higher ammonia/TKN ratio and trial 1 resulted in the lowest ratio. The regression model proposed for the concentration of ammonia in solution is:

$$Y = 868 - 17T + 401D + 70P + 0.1T^2 - 271D^2 - 44P^2 + 1.2DT + 3.3PT - 12DP \quad (2)$$

where Y is ammonia (mg/L); The correlation coefficient (R^2) was 63%. In order to achieve a high ammonia release in the treated solution, the process should be conducted at a higher hydrogen peroxide dosage, shorter holding time and high power intensity (Eq. (2)). The magnitude of factor affecting ammonia concentration was found to increase in the following order: H_2O_2 dose > secondary effect of H_2O_2 dose > power intensity. Holding time had negative influence on ammonia. This was also similar to previous studies on RF and MW treatment of dairy manure; hydrogen peroxide dosage was a significant factor affecting ammonia solubilization [18]. The optimum condition for ammonia concentration was predicted to be 2.6 kW/L power intensity, 51.5 min of holding time, and 0.8% of H_2O_2 dosage.

3.2. Solids disintegration

SCOD and VFA concentration in the treated manure represent the degree of solids disintegration from the RF/H_2O_2 process. The regression model equation obtained for SCOD concentration in the treated manure is as follows:

$$Y = 33786 - 464T - 13724D - 10140P + 3.2T^2 + 2841D^2 + 1557P^2 + 122TD + 43PT - 85PD \quad (3)$$