Environmentally sustainable treatment and valorization of manure-based digestate using hydrothermal carbonization

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1. Introduction

Wet-organic waste streams from dairy farms (e.g., manure) have been commonly treated using anaerobic digestion (AD) to produce biogas. AD also produces a secondary liquid effluent (digestate), which contains a mixture of dissolved organic carbon, microbes/pathogens and a high load of nutrients (mainly N and P) (Bonetta et al., 2014; Monlau et al., 2015). The digestate is widely used as a soil amendment or fertilizer due to high P and N contents (Möller and Müller, 2012; Weiland, 2010), often leading to environmental and health problems (Monlau et al., 2015). Leaching contaminants and nutrients into the environment might cause severe pollution of soils, water bodies and air. Another typical waste from the dairy industry is whey, a by-product of cheese and yogurt making, that contain high organic matter and nutrients with estimated annual global production >145 million tons. While half of the produced whey is reused, half is disposed without appropriate treatment and causes environmental pollution. Hydrothermal carbonization (HTC) is becoming a promising thermochemical treatment, suitable for wet-organic waste. HTC takes place under a typical temperature range of 180–250 °C and reaction times varying from minutes to several hours (Funke and Ziegler, 2010). The process is conducted in a closed vessel; therefore, the internal pressure naturally increases with the temperature. Anoxic or low oxygen concentrations are preferred to reduce oxidation of carbon to CO_2, or in other words to recover more carbon as a solid product (hydrochar), thus improving efficiency. The high temperatures also ensure sterile products. Therefore, we hypothesize that the management and valorization of anaerobic digestate and whey can be solved by use of HTC as a post-treatment followed by potential use of the hydrochar as a solid soil amendment and the HTC-aqueous phase as a liquid fertilizer. Consequently, the aim of this study was to produce pathogen-free stable hydrochar and nutrient-rich aqueous phase. The specific objectives were (1) to characterize the properties of HTC products that are produced under various temperatures and liquid feed (either water or whey); (2) to investigate the potential of digestate-derived hydrochar as a slow-release solid fertilizer/soil amendment and nutrient-rich aqueous phase for use as liquid fertilizer to support plant growth.

2. Material and methods

Cow manure digestate (57% dry weight solids) that was produced under mesophilic conditions (35 d retention times) of AD was used as feedstock for the HTC process. In addition, whey (properties are not shown here) was taken from a dairy farm located at the southern Negev of Israel. The HTC process was carried out in 50-mL stainless steel mini-batch reactors. A sample of dry waste feedstock was loaded into each reactor, maintaining a constant dry solid-to-liquid (either distilled water or whey) ratio of 1:3. The HTC runs were conducted in triplicates under three different temperatures ranging from 180–240 °C. After 60 min the reactors were immediately cooled in ice to quench the reaction. The hydrochar was separated from the aqueous phase by centrifugation, oven-dried at 105 °C and kept for further use.

3. Results and discussion

The physicochemical properties of the feedstock and HTC products (hydrochar and aqueous phases) are presented in Table 1. The use of whey (compared to water) with digestate significantly increased the hydrochar yield, and its carbon content. Digestate derived hydrochars were produced >43% ash content due to the organic matter converted into biogas, and therefore it might not be suitable to use as a solid fuel. However, the produced hydrochar contained 1.3–1.8% total phosphorous, indicating its potential use as phosphorus-rich slow-release solid-fertilizer/soil amendment. The aqueous phase contained dissolved nitrogen (N), phosphorus (P), potassium (K) ranging from 1,774–2,750, 10–792, and 2,420–5,075 mg/L, respectively, which could be used as liquid-fertilizer. Therefore, their potential agricultural use is currently under investigation in a planter experiment.

Table 1. Physicochemical properties of feedstock and HTC products (hydrochar and aqueous phases). Values are presented as average ± standard error.

Parameters		Digestate	Digestate+water			Digestate+whey		
	Digestate	+whey	180 °C	210 °C	240 °C	180 °C	210 °C	240 °C
Hydrochar								
Ultimate analysis:								
C (%)	26.8±3.6	28.2±1.1	28.9±1.4	31.4±0.9	32.5±0.6	36.7±0.3	35.5±0.7	37.7±0.7
N (%)	1.7±0.2	1.7±0.1	1.8±0.1	1.9±0.1	1.9±0.0	2.3±0.0	2.1±0.1	2.2±0.1
P (%)	1.0±0.0	1.0±0.0	1.3±0.1	1.6±0.0	1.8±0.0	1.4±0.0	1.6±0.0	1.7±0.1
Proximate analysis								
Mass yield (%)	-	-	80±0.4	76±0.1	66±0.4	87±0.3	82±0.2	69±0.6
Ash (%)	44.8±2.0	45.7±1.2	49.5±0.8	53.7±0.8	58.6±0.5	43.4±0.5	44.6±1.5	49.9±0.5
HTC aqueous phase								
pH	9.5±0.0	8.8±0.0	7.6±0.0	7.4±0.0	7.6±0.0	5.2±0.0	5.7±0.0	7.1±0.0
EC (dS/m)	12.9±0.1	14.7±0.2	20.9±0.2	23.2±0.2	23.9±0.1	30.1±0.1	30.9±0.1	29.5±0.2
DOC (g/L)	14.3±0.3	30.5±0.3	27.6±0.3	24.0±0.3	22.2±0.3	33.7±0.2	31.8±0.2	28.4±0.4
N (mg/L)	1,205±7	1,774±20	2,719±29	2,557±24	2,354±39	2,742±34	3,095±22	2,742±33
K (mg/L)	1,407±33	2,088±47	2,296±33	2,532±40	2,420±42	4,780±23	5,075±53	4,580±42
P (mg-L)	503±35	792±22	148±3	39±2	10±1	414±9	93±10	13±3

4. Conclusion and future works

A sterile and stable nutrient rich hydrochar and nutrient-rich aqueous phase were produced from HTC of anaerobic digestate of cow manure mixed with either water or whey. Both hydrochar and aqueous phases have the potential to improve soil fertility, support plant growth and replace synthetic fertilizers. Better understanding of the agricultural properties of HTC products is needed and currently undergoing by our research team.

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