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Hydrothermal Carbonization (HTC): A Pressure Cooker for Biowaste

Hydrothermal Carbonization (HTC) is a thermochemical conversion process which transforms biomass under pressure into a solid coal-like product. To assess the suitability of this technology for developing countries, a pilot HTC reactor was developed, built and is being tested at Eawag. Christian Riu Lohri[1], Zeno Robbiani[1], Christian Zurbrügg[1]

Introduction

Although HTC has been known for a hundred years, interest in it as a possible way to transform organic waste into a stable, solid, sterile and valuable product has markedly increased only in the last decade. During the HTC process, the biomass is submerged in water and heated to approximately 200 °C for several hours. The water is kept in a liquid phase by keeping the mixture under saturated pressure in the reactor, allowing the pressure to rise to roughly 20 bar. One result of the HTC process is a solid product called hydrochar or HTC coal. It can be used as an energy carrier substituting for wooden charcoal in improved cooking stoves, as functionalized carbonaceous material, for soil improvement, or even as a means for carbon sequestration.

Component	Specifications	Cost (CHF)
Reactor	• Material: Stainless steel (thickness 6.3 mm) • Volume: 21.8 L • Pressure range: 10 – 25 bar • Max. pressure: 30 bar • Temperature range: 180 – 220 °C • Max. temperature: 300 °C • Max. number of load cycles: 1 000	5 700.–
Certification	• Applied regulation: PED 97/23 EC – AD 2 000 • Category III (fluid group 1)	6 000.–
Additional equipment	• Overpressure valve (30 bar) • Drain valve to release steam after process • Heating mantle (max. power: 2 500 W)	2 400.–
Measuring devices	• Pressure- and temperature meter (data logger) • Energy consumption meter (data logger)	2 900.–
TOTAL		**17 000.–**

Table 1: Specifications and costs of prototype HTC reactor.

Advantages of HTC

Compared to other biowaste treatment methods using biological processes, carbonization has various advantages. The reaction takes only a few hours compared to the days or months needed for biological processes. Furthermore, the high process temperature eliminates pathogens and inactivates other potential organic contaminants such as pharmaceuticals. The resulting coal product is sterile and hygienic [1]. In addition, HTC can handle varying feedstocks. In principle, any kind of biowaste, e.g. organic municipal solid waste, faecal and sewage sludge, and animal manure can be hydrothermally carbonized. Material with high moisture content of 90 % or more can be used [2]. Most of the carbon in the initial substrate stays bound in the final coal product (~ 75 %), while the carbon content in the process water (20 %) and the gaseous product (5 %) are much lower [3]. The water-carbon suspension after carbonization is less hydrophilic than the initial substrate, making the dewatering process of the HTC-coal easier compared to the original biomass before processing.

The first pilot HTC plants have recently been implemented, predominantly in Germany, for treatment of problematic biomasses like industrial waste, biowaste or sewage sludge [4]. However, these high cost and high-tech solutions are feasible only for industrialized countries. Given the numerous advantages of HTC, our research explores the potential of an adapted HTC system for biowaste and faecal sludge treatment that is suitable for developing countries.

Objective and research procedure

We first looked at existing HTC technologies to develop a sound understanding of HTC processes. Based on this, we designed and constructed a small prototype experimental reactor that ensures full functionality and operational safety in accordance with the technical requirements feasible for developing countries. Next, we tested its functionality, and analysed and compared the end products with results from experiments with a HTC reactor at the Zurich University of Applied Sciences (ZHAW), using the same substrate and carbonization conditions [5].

Design selection and construction

The main design criteria for the reactor were: low cost, the use of materials available in low- and middle-income countries, a low level of complexity, ease of handling, high durability and safety. These criteria were used to assess different HTC systems. We decided to build a stainless steel reactor that would operate in a batch-feeding mode and heated by an electric heating mantle (See Photo 1). Table 1 presents the HTC reactor's specifications and costs.

The cost of the required security certificate exceeded the cost of the actual reactor. Receiving the certificate implies, however, that the reactor is safe and adheres to strict regulations regarding the design, materials and welding work. Although substantial costs were involved to meet the required material standards and regulations, the total cost of the prototype reactor is nearly six times lower than the cost of the ZHAW reactor (Grenolmatik 25 by Grenol GmbH, Germany), which is similar in size. Their reactor's higher cost is partly due to its stirring device and its fully automated thermal oil heating system, although these factors at this scale add no significant value to the process.

First experiments and results

The HTC reactor at Eawag was first tested with water. Then, rice was used as a model substrate for carbonization under standard conditions. The reactor was filled with 1 kg of rice and 16.6 L of water (TS of load: 5.3 %). The internal temperature was stabilized at

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Photo 1: Prototype HTC reactor.
(1: Heating mantle, 2: Temperature sensor, 3: Pressure sensor, 4: Overpressure valve, 5: Drain valve, 6: Bearing, 7: Identification plate with CE sign)

around 200 °C. Over the 10.2 h of total reaction time (the temperature was above 180 °C for 6.7 h), 11.8 kWh of power were needed. Table 2 shows that the process led to a reduction of both oxygen and hydrogen content, thereby, increasing the C content of the initial feedstock. Carbon mass balance indicates that 58.4 % of C was found in the solid, 30.2 % in the liquid, and 11.4 % in the gaseous product. The results concerning dry matter (TS) content, calorific value, and the composition of elements compared well to those from the ZHAW HTC reactor.

Conclusion

The research revealed that a reactor's construction costs could be significantly reduced, especially when compared to the costs of other HTC experimental reactors. However, the total cost remains relatively high and, thus, is a barrier to use in developing countries. Roughly a third of the total cost is for the security certificates required for pressure-vessels. To ensure proper functioning and safety, additional cost reduction is not possible. The prototype HTC reactor was tested with rice and the resulting coal showed a heating value of approximately 27 MJ/kg. The elemental composition is comparable with the results produced by the HTC reactor at ZHAW.

Outlook

The constructed HTC reactor will be further tested using biowaste from the canteen. Experiments on variations of solid load, carbonization temperature and duration should reveal the optimal operational parameters. The goal is to treat the maximum amount of waste per batch with the lowest energy input possible and have a positive energy balance. Experiments with faecal sludge as feedstock are also being considered.

The possibility of upscaling, and of using the waste heat to reduce the energy requirements will be researched, as well as the use of photovoltaic panels for power to avoid dependency on electricity from the grid. In addition, how to treat the still organically loaded process water requires further research. In the near future, the HTC process will also be tested in a developing country to study on-site construction and operational issues.

		Unit	Raw rice	Experiment ZHAW	Experiment Eawag
In	Feedstock	(kg)		1.1	1.0
In	Water	(L)		15.8	16.6
Out (Solids)	HTC-coal (wet)	(kg)		2.3	1.9
Out (Solids)	TS output	(%)		18.4	18.1
Out (Solids)	Higher Heating Value	(MJ/kg dry basis)	17.7	27.7	26.9
Out (Solids)	C	(% dry basis)	44.1	69.4	66.9
Out (Solids)	H	(% dry basis)	6.5	5.2	4.9
Out (Solids)	O	(% dry basis)	49.4	22.7	23.8
Out (Solids)	N	(% dry basis)	1.2	2.2	1.9
Out (Liquid)	Process water	(L)		15.1	15.1
Out (Liquid)	pH			3.2	2.7
Out (Liquid)	EC	(µS/cm)		1 038.0	1 083.0
Out (Liquid)	TOC	(mg/L)		4 933.0	7 764.0

Table 2: Comparison of results (rice experiments) between ZHAW and Eawag reactors.

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