

HEAT RECOVERY IN COMPOST PILES FOR BUILDING APPLICATIONS

by

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This work proposes an estimation of the possible heat recovery of self-heating compost piles for building applications. The energy released during the aerobic composting of lignin and cellulose-based materials is computed by solving an inverse problem. The method consists first in an experimental phase with measurement of the temperature within the heap, then a numerical procedure allows for the inverse identification of the heat production due to the chemical reaction of composting. The simulation results show a good accordance with the experiments for the chosen source-term model. Comparing the results to the theoretical values for the energy released by aerobic composting provides an estimate for the efficiency of the reaction. The reached temperatures and recovered energy fit with the order of magnitude of building needs.

Key words: *heat recovery, aerobic composting, inverse identification, lignin*

Introduction

In numerous countries, the recent evolution of the building construction and retrofitting regulations sets a trend towards more local, distributed energy production system vs. centralized ones, as well as renewable energy targets [1]. This inclination could be part of a solution in order to reduce the 30% contribution of the European housing sector to GHG emissions [2]. In the French context, the building sector consumption is responsible for 43% of the GHG [3] and the new building regulation orientates the market towards a more sober residential sector, with overall energy consumptions ranging between 0-50 kWh/m² per year [4].

In the frame of this work, we will not consider anaerobic composting in bioreactors leading to CH₄ production. This topic is studied for example in [5, 6], whereas aerobic composting for heat recovery purposes is less often examined. Aerobic composting is usually done at larger scales in cooperation with local communities providing degradable waste, heat recovery being possible such as in [7, 8]. Aerobic composting hence provides an alternative for decentralized, biosourced energy. The temperature range of 25 to 80 °C fits well for building applications such as air heating, floor heating or domestic hot water service. This technique was however already explored: in the mid 1970's [9], the self-made scientist called Jean Pain described a method for retrieving thermal energy from a heap of shredded plant waste, mainly

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From our experience and from skilled in the art person, leaves are subject to flocking together under the effect of humidity and own weight, which leads to volumetric variation during the process of degradation as well as the formation of hardly air-permeable *strata* inhibiting the reaction by limiting the oxygen supply. Experiments 2 and 3 will allow the investigation of shredded plants with a higher porosity and a lesser dependency to shrinking during the reaction.

Shredded wood – Experiences No. 2 and 3

Experience No. 2 was made of freshly shredded wood of average size 3 cm. It shows a noticeably higher temperature peak than experience 1, as presented in fig. 7. The discrepancy between simulation and measurements can possibly be explained by the uneven diffusion of oxygen and water, which insufficiency limit the reaction of aerobic composting. Indeed, after the end of the experiment, we noticed that only the lower 15 cm of the heap had properly broken down into compost, the upper part of the heap being conveniently aerated but very dry, which means the contained energy amount is to be higher, as discussed at the end of this section.

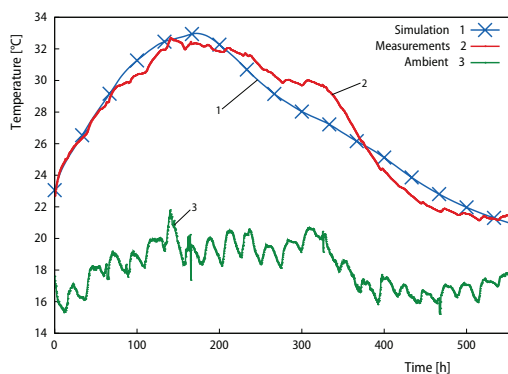


Figure 6. Experiment and numerical results, temperature vs. time at point 43, 34, 50 cm for exp. No. 1

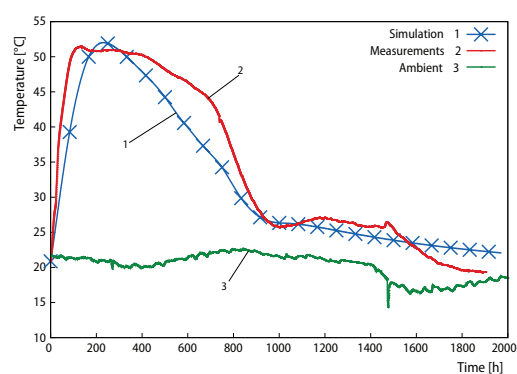


Figure 7. Experiment and numerical results, temperature vs. time at point 43, 34, 50 cm for exp. No. 2

Experience No. 3, also composed of freshly shredded wood, shows a similar shape and the model show a correct accordance with the measurements, fig. 8. Both experiences 2 and 3 peak values are similar, however the reaction's duration is much shorter: after 300 hours (less than 2 weeks), the heat production is insignificant, whereas for exp. 2 it takes about 900 hours (6 weeks) for the reaction decrease to temperatures close to the ambience.

Analysis of the experiments

Interestingly, the behaviors of all three tests have different shapes, as presented on fig. 9 where the previous three measured temperatures are displayed with the same time and temperature scales. The lower temperatures stand for leaves-based test (experiment 1), the higher ones for shredded wood (experiences 2 and 3).

Experiments 2 and 3 have similar amplitude, however, their durations show a ratio of approximately five. It may thus prove to be interesting for low energy buildings needs, based on the reached temperature level which fits well with the current low temperature central heating systems, e. g. experiment 2 on fig. 9 shows a potentially useful temperature plateau around 50 °C for about a month. At the contrary, it may fail to provide such conditions, see experiment

- ***, Agency for the Environment and Mastering Energy Demant, Building's key figures (in French), 2013 ADEME Batiment, 2013
- Molle, D., Patry, P.-M., RT 2012 and RT for Existing Buildings: Thermal Regulation and Energy Efficiency Construction and Retrofitting (in French), Eyrolles, Paris, 2013
- [5] Sandip, T. M., *et al.*, Enhancement of Methane Production and Bio-Stabilisation of Municipal Solid Waste in Anaerobic Bioreactor Landfill, *Bioresource Technology*, 110 (2012), 7, pp. 10-17
- [6] Qiyong, X., *et al.*, Methane Production in Simulated Hybrid Bioreactor Landfill, *Bioresource Technology*, 168 (2014), SI, pp. 92-96
- [7] Rada, E. C., *et al.*, Sewage Sludge Drying by Energy Recovery from OFMSW Composting: Preliminary Feasibility Evaluation, *Waste Management*, 34 (2014), 5, pp. 859-866
- [8] Allain, C., Energy Recovery at Biosolids Composting Facility, *Biocycle*, 48 (2007), 10, pp. 50-53
- [9] Pain, I., Pain, J., *The Jean Pain Methods or an another Garden* 8th ed., (in French), Paris, 2008
- [10] Hatakka, A., Biodegradation of Lignin – Lignin, Humic Substances, and Coal, in: *Biopolymers* (Eds. M. Hofrichter, A. Steinbuechel), Wiley-VCH, Weinheim, Germany, Vol. 1, pp. 129-180
- [11] de Guardia, A., *et al.*, Characterization and Modelling of the Heat Transfers in a Pilot-Scale Reactor during Composting under Forced Aeration, *Waste Management*, 32 (2012), 6, pp. 1091-1105
- [12] Zambra, C. E., *et al.*, Heat and Mass Transfer in Unsaturated Porous Media: Moisture Effects in Compost Piles Self-Heating, *International Journal of Heat and Mass Transfer*, 54 (2011), 13, pp. 2801-2810
- [13] Luangwilai, T., *et al.*, Biological Self-Heating in Compost Piles: A Semenov Formulation, *Chemical Engineering Science*, 101 (2013), 14, pp. 533-542
- [14] Sidhu, H. S., *et al.*, A Simple Spatial Model for Self-Heating Compost Piles, *ANZIAM Journal*, 48 (2006), C, pp. 135-150
- [15] Hasan, K. M. M., *et al.*, Study on the Quality and Stability of Compost through a Demo Compost Plant, *Waste Management*, 32 (2012), 11, pp. 2046-2055
- [16] Barron, G. L., Predatory Fungi, Wood Decay, and the Carbon Cycle, *Biodiversity*, 4 (2003), 1, pp. 3-9
- [17] Navi, P., Heger, F., Thermo-Hydro-Mechanical Behaviour of Wood (in French), Presses Polytechniques et Universitaires Romandes, Lausanne, Switzerland, 2005
- [18] Raven, P. H., *et al.*, *Vegetal Biology* 3rd ed., (in French), De Boeck, Louvain-la-Neuve, Belgium, 2014
- [19] Dashtban, M., *et al.*, Fungal Biodegradation and Enzymatic Modification of Lignin, *International Journal of Biochemistry and Molecular Biology*, 1 (2010), 1, pp. 36-50
- [20] Abdel-Hamid, A. M., *et al.*, Insights Into Lignin Degradation and its Potential Industrial Applications, *B. Advances in Applied Microbiology*, 82 (2013), 1, pp. 1-28
- [21] ***, Mathworks. Matlab R2012b Documentation The Mathworks, 2012
- Talib, A. T., *et al.*, Effects of Aeration Rate on Degradation Process of Oil Palm Empty Fruit Bunch with Kinetic-Dynamic Modeling, *Bioresource Technology*, 169 (2014), 3, pp. 428-438
- [23] Barrena, R., *et al.*, Prediction of Temperature and Thermal Inertia Effect in the Maturation Stage and Stockpiling of a Large Composting Mass, *Waste Management*, 26 (2006), 9, pp. 953-959
- [24] Weppen, P., Process Calorimetry on Composting of Municipal Organic Wastes, *Biomass and Bioenergy*, 21 (2001), 4, pp. 289-299
- [25] Walker, L. P., *et al.*, The Role of Periodic Agitation and Water Addition in Managing Moisture Limitations during High-Solids Aerobic Decomposition, *Process Biochemistry*, 34 (1999), 6, pp. 601-612
- [26] Kalamdhad, A. S., Kazmi, A. A., Effects of Turning Frequency on Compost Stability and Some Chemical Characteristics in a Rotary Drum Composter, *Chemosphere*, 74 (2009), 10, pp. 1327-1334
- [27] Pagliarini, G., *et al.*, Hospital CHCP System Optimization Assisted by Trnsys Building Energy Simulation Tool, *Applied Thermal Engineering*, 44 (2009), 3, pp. 150-158