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EXPERIMENTAL MEASUREMENT OF HEAT OF BIODEGRADABLE WASTE

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Abstract

This paper describes the experimental heating power measurement of biodegradable waste (BW). The goal of this paper is to describe the experimental measuring device and to present the results used in the "Vývoj technologické linky pro zpracování BRO pro přímé energetické využití Multiferm" project. The used measurement is based on controlled removal of heat energy produced by reacting batch material (BW) while maintaining optimal reaction temperature inside the material. These results helped to identify the processes inside the input batch material.
Described experiment was sufficient to determine the produced heat power of the input material batch for the device design (project Multiferm). However tests will be repeated for various input material and various humidity for the academic research purposes. This can be performed on the measuring system which is fully functional after described two experiments.

Keywords: biogradable waste, measurement, Multifem, experiment

INTRODUCTION

Landfilling waste is still the most used way of disposal of biodegradable waste. Around 60 % of BW is still landfilled despite of the commitment of the Czech Republic in the Waste management plan of the Czech Republic to reduce the landfills. There was a big support of biogas production from BW mainly due to public support however with respect to legislative restrictions the number of biogas plants using waste is still small and this technology is used mainly in agriculture. Composting technologies are on rise in last several years mainly due to a support of "OPŽ" program of the ministry of environment of the Czech Republic.Main goal of this paper is to determine the heat power production of BW and find the appropriate date to help in the design of "Multiferm" technologycal line ventilation system.

The corresponding investments in organic compost production have also sparked recent innovation on compost-heat recovery, particularly in the past decade in Vermont, Canada, and Germany, where several compost scientists, engineers, and tinkerers have, independently of one another at first, but eventually through collaboration, developed several economically viable methods of recovering predictable amounts of heat from the composting process. (The Compost-Powered Water Heater, 2014)

Sardinsky (1979) finds the probable outputs from a metric ton (2200 lbs including 50 percent water by weight) of compost to be 3,375,000 Btu, 290 kg. CO_2, and 47 liters of water (in vapor) during a 21-day thermophilic stabilization period. (These are equivalent to 1530 Btu.lb^{-1} or 3.56 × 106 JI kg, 0.29 lb.lb^{-1} or 0.29 kg.kg^{-1} CO_2, and 0.0056 gai.ib^{-1} or 0.047 l.kg^{-1} water vapor.) Quantities of these elements are difficult to standardize, given the diversity of compostable materials and methodologies, but these figures provide reasonable estimates to work from in designing systems to use them (Fulord, 1990).

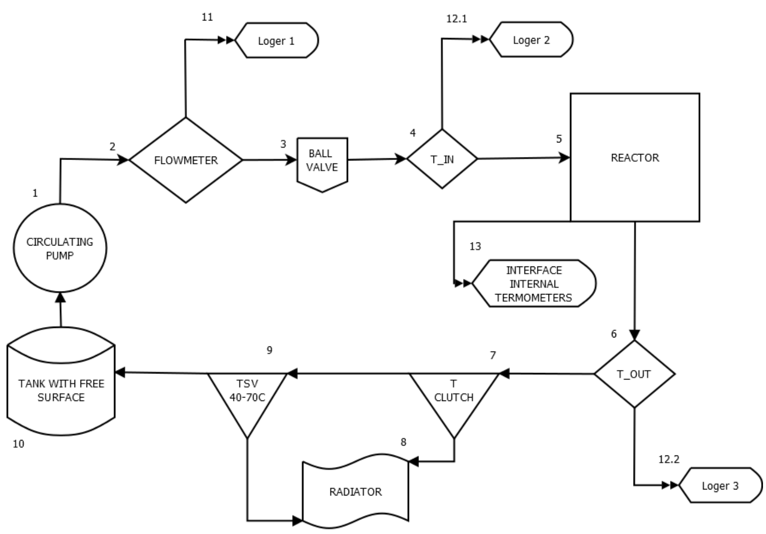
MATERIAL AND METHODS

The experimental device was assembled from widely available parts. The main idea was to have device that is simple to build and flexible to upgrade or alter its parts. Measuring system works as a calorimeter where the reactor is made out of isolated closed box generating heat from biological processes inside and this heat is removed by heat exchanger. The experimental device is equipped with forced discontinued ventilation to satisfy the sufficient amount of oxygen in the aerobic process.

Measuring system can be divided into two main branches. These branches divides in the T-junction pipe (Fig. 1) into short "hot" loop and long "cooled" loop. The short hot one is the only one interesting from the perspective of heat dynamics. This is because of thermostatic mixing valve that doesn't allow coolant to flow through long loop until the desired value of temperature is reached (30–70 °C) in the output from thermostatic mixing valve.

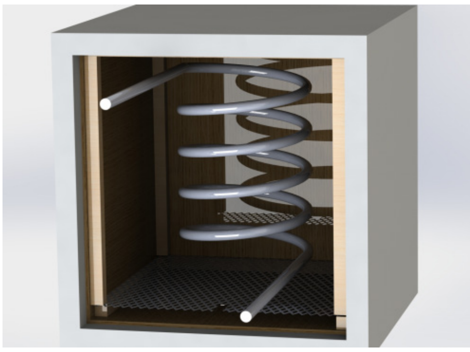
1. Circulating pump WEBERMAN type 24-40 180 – 0.2–3.5 m^3
2. Flowmeter ENBRA series EV (logic signal each 1 l)
3. Ball valve for coolant
4. RTD temperature sensor SENSIT Pt1000/3850 type TR130A-35 G3/4"/OK30
5. Heat exchanger in reactor – multilayer pipe Pex-al-pex 26 × 3 mm; length 20 m
6. RTD temperature sensor SENSIT Pt1000/3850 type TR130A-35 G3/4"/OK30
7. T-junction pipe 1" 3/21
8. Cooler – indoor radiator; dimensions 1800 × × 500 × 100
9. Thermostatic mixing valve VTA 322 30–70 °C 1"
10. Free surface buffer tank ca. 11 l
11. Logger S7021 – Two channel recorder with counter input and binary input
12. Logger S0121 – Two channel temperature recorder with display
13. Penetration radio thermometer – Codet s.r.o. BRNO

The reactor box is made out of OSB board with thickness of 18 mm and dimensions 1.25 × 1.25 m (reinforcement in corners). Maximal amount of input material is therefore 1.37 m^3. The top and front side is removable. The box is isolated with polystyrene boards with 140 mm thickness. The thickness of OSB board heat conductivity of material and heat transfer constants were used to calculate the heat transfer through the reactor wall to estimate the heat loss from the surface of the reactor. The heat loos of the reactor using the supposed temperature inside the reactor and outside temperature is 184.6 m^2.kg.s^{-3}.



1: *Measuring system block diagram*

The aeration of reactor is performed by ventilator blowing the air to the space under the material inside. There is a perforated metal plate (10 × 10 mm holes) inside the box that holds the material. To prevent the short flow around the walls of air mass the metal plate is covered with plastic foil (ca. 100 mm). The outlet of air is allowed by using the bushing with backflow prevention on the top of the box (100 mm diameter). The aeration in discontinued and is performed by timer relay. Low pressure ventilator was used (airflow 0.3 m^3s^{-1} for 300 $m^{-1}.kg.s^{-2}$



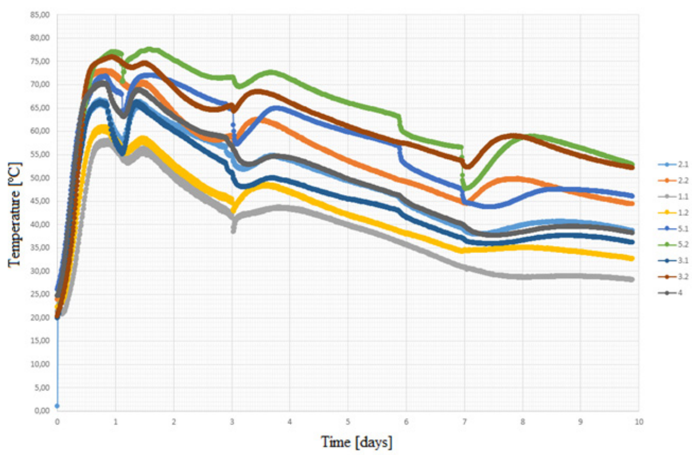
2: *Visualization of experimental reactor box construction*

I: *Table of locations of thermometers*

Temperature	Sensor number	location
1.1	8	right, back
1.2	8	middle
2.1	10	Left, back
2.2	10	middle
3.1	6	front, left
3.2	6	middle
4	4	front, right
5.1	7	right, back

II: *Table of the first experiment results using BW*

Dry matter W_{dm} [%]	Water content W_w [%]	Loss on ignition W_{lol} [w. % dm.]	Rest of LOI W_{rol} [w. % dm.]	Ash matter ω_{popel} [%]	Total carbon C_{celk} [%]	Nitrogen
61.62	38.38	65.28	34.72	21.39	27.35	7.98



3: *Temperature curve inside the reactor for the first experiment* pressure). The heat is removed from the material while venting it. Calculated heat flow with venting was 2.715 k $m^2.kg.s^{-3}$.

The location of thermometers in material was chosen in the way to measure the temperature in all the important places in material. Thermometers are numbered and oriented from the bottom to the top. Locations are in the Tab. I while looking on the front side of box.

RESULTS AND DISCUSSION

Only two complete measurements were performed due to time requirements of experiments. The goal of the first one was to prove the functionality and find design flaws. Another goal was also to get used to a measuring itself. The density of input material was ca. ρ_1=393 $kg.m^{-3}$. The results are in the Tab. II.

The Fig. 3 shows temperatures inside the reactor during first 10 days of first experiment.

The first experiment proved the functionality of the measuring system itself. There was an air leakage through the top side of the box in the meantime between ventilation. This was not completely eliminated by weighting the top. This was caused by a stack effect of reactor and lowering the density of air after venting caused by rising temperature (up to ca. 60 °C) and air humidity.

The main goal of the second experiment was to determine the heat power generated by BW by aerobic processes. Determination of the airflow amount during ventilation was needed. . The density of input material was ca. ρ_1=393 $kg.m^{-3}$. The results are in the Tab. III.

The Fig. 4 shows temperatures inside the reactor during first 10 days of experiment.

There were some unpredictable complications during the experiments with the electrical power outages. These can be seen as a temperature rise in the reactor (Fig. 4). The most important part from the perspective of heat production is mainly the starting thermophilic phase after start. This is the reason why only first six days are discussed later in the text.

Measurement description:

- Day 0–1: (start 15:30); approximately from the day 0.5–1.2 there was electrical power outage; ventilation only for 3 s in 30 min;
- Day 1–1.75: thermostatic mixing valve set to 5; circulating pump set to III; ventilation set to 6.5 s every 30 min;
- Day 1.75–2.9: ventilation set to 3 s
- Day 2.7: thermostatic mixing valve set to 4.5; ventilation set to 6.5 s
- Electrical power outages: till the 1st day, 1.2–1.75 day; 3.2–4 day; 5.3–5.5 day

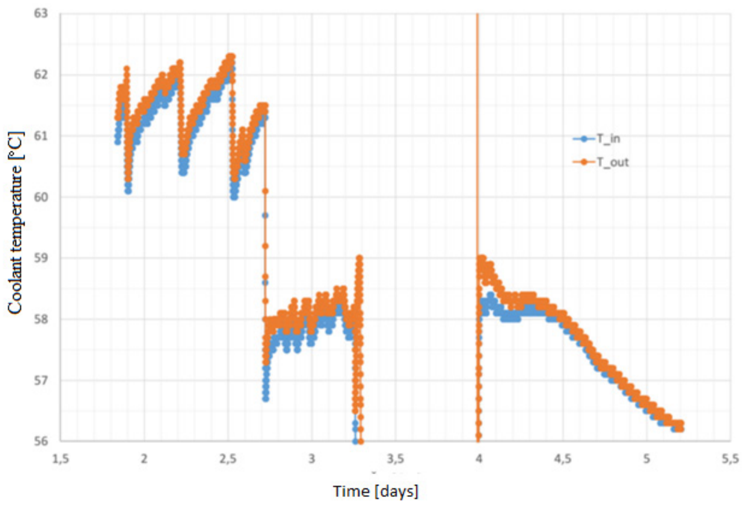
Fig. 5 shows the temperature curve of coolant (water) and it is divided into two sections.

Measured section 1

Section 1 is in the time from 5. 11. 11:37 ie the day 1.84 till 6. 11. 8:46 ie the day 2.72.

The coolant flow was stable without variation. The average value of minute values was mch = 0.311 $kg.s^{-1}$.

This section represents fully developed thermophilic phase.



4: *Coolant temperature*

Measured section 2

Section 1 is in the time from 8. 11. 1 : 20 ie the day 4.41 till 8.11 20:20 ie the day 5.2.

The coolant flow was stable without variation. The average value of minute values was mch = 0.308 kg.s^{-1}.

This section represents process near the end of thermophilic phase.

Heat production calculation of BW aerobic processes

$Q_{BRO} = Q_k + Q_p [W]$

Q_k – Calculated values of heat power from calorimetric measurements.

Q_p – Calculated values of heat power from venting of the reactor.

Measured section 1

Q_{BRO} = 316 + 126.5 = 442.1 m^2.kg.s^{-3}

Measured section 2

Q_{BRO} = 76 + 142.3 = 218.3 m^2.kg.s^{-3}

(Svoboda, 1978).

Not even one of the measured sections can fully characterize and be used in the calculations for the design of the future device. The final equation for the heat power production respects the power outages and measured values.

$$Q_{BRO} = \frac{2}{3} Q_{BRO}^{usek1} + \frac{1}{3} Q_{BRO}^{usek2} = \frac{2}{3} 442.1 + \frac{1}{3} 218.3$$
$$= 367.5 \approx 370\, m^2.kg.s^{-3}$$

The volume of the second experiment input material batch was 1.01 m^3. The heat power production was related to this volume and the weight of dry matter (212 kg). If we consider the heat transfer from the reactor to the surroundings into the total produced heat power it would be this:

$$Q_{BRO}^{+loss} = Q_{BRO} + Q_z = 367.5 + 184.6 = 552.1 m^2.kg.s^{-3}$$

Q_z – Heat transfer through the wall

(Koiš, 2014)

It is important to mention that the input material batch is static in this experimental. It will not be static in the technological reactor. The supply of oxygen is also not even in this static case. The aeration will be more effective in the conditions of the future technological reactor, hence the specific heat power production will be larger. Here used thermodynamic calculations of ventilation system use more conservative values of heat power production. The possible larger heat power production in the future technological reactor will be a benefit in the perspective of energetic demands of the system.

CONCLUSION

The heat power production of BW aerobic processes was determined from given experiments. These results can be used to design the ventilation system of “Multiferm” technologycal line. This was also the main goal of given experiments.

Described experiment was sufficient to determine the produced heat power of the input material batch for the device design (project Multiferm). However tests will be repeated for various input material and various humidity for the academic research purposes. This can be performed on the measuring system which is fully functional after described two experiments.

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