Experimental testing of some types of biologically degradable materials for processing in the SBM mechanical plant for hydrothermal treatment

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Abstract

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The SBM (stabiliser of biomass) mechanical plant model is designed for the hydrothermal treatment of biologically degradable materials with using the principle of thermal hydrolysis. The primary task of this equipment is to subject biologically degradable materials to hydrothermal treatment and to recover the materials for a further use or to eliminate them. These entities could use the mechanical plant for economic and environment-friendly methods of handling biologically degradable wastes or materials. The objective of the experiment with various types of biologically degradable materials was to establish the level for the transformation of input characteristics of tested materials after conversion in the SBM mechanical plant and to assess the suitability of the processing by using this method with respect to the use of the final product. Materials tested in the first experiments included stable manure heated or unheated during the processing and maize silage wastes in mixture with wood chips.

Keywords: biomass stabilization; thermal hydrolysis; technological equipment; biodegradable waste; mechanical-biological treatment

Rational treatment of biologically degradable materials from agricultural production as well as from the communal sphere is in line with the principles of sustainability both in economic and environmental terms. The Sixth Environment Action Programme set up a priority in the management of wastes to return most of waste back into the economy cycle, through recycling in particular. These wastes are to be returned back into the environment either in a usable form such as composts or in a harmless stabilized form (Decision of the European Parliament and of the Council No. 1600/2002/EC of July 22, 2002 laying down the Sixth Community Environment Action Programme).

Biologically degradable wastes (BDW) include wastes subjected to aerobic or anaerobic decomposition. This large group of wastes represents ca. a fifth of all wastes produced in the Czech Republic. As to types, the wastes originate mainly from agricultural and forest production, from food processing, paper and cellulose conversion, from timber conversion, leather processing, textile industry and include also biologically degradable communal waste (BDCW), waste from the maintenance of greenery but also sludge from sewage and water treatment plants and the biologically degradable packaging waste. This group of wastes represents annually ca. 7 × 10^6 Mg in the Czech Republic (Hřebíček et al. 2008). The share of the produced biodegradable communal waste from the total amount of mixed communal waste ranges from 30 to 40%. The magnitude of this weight share depends on a number of factors such as specifics of economy in the region, waste collection system etc.

Increasingly stricter legal regulations in waste management and environment protection greatly affect the strategy of handling biodegradable wastes. Communal wastes (CW) including the component of biodegradable waste materials are prevailingly disposed in landfills. For example, data published by the Czech Statistical Office for 2008 indicate that 2.27 × 10^6 Mg of communal waste was deposited in landfills in the Czech Republic in that year (Czech Statistical Office 2011). Such a method of handling communal wastes including their biodegradable components means depreciation of their high potential for use. Particularly BDCW is due to its characteristic properties an undesirable component, which needs to be sorted out from the communal waste and processed in a suitable way.

An integral part of waste management strategy is the Waste management plan of the Czech Republic (WMP CR) and consequently waste management plans of individual administrative regions. This strategic document specifies and quantifies objectives in the field of waste management for the current period 2003–2012 (Waste Management Plan of the Czech Republic 2003). Waste management plans dwell on legal regulations of the European Union. Council Directive No. 99/31/EC on the landfill of waste imposes on the EU member countries an obligation to reduce the amount of waste including BDCW deposited in landfills. The Waste management plans of the Czech Republic set up target values for the reduction and time horizons for their achievement. According to these target values, the weight proportion of BDCW in landfills should decrease to 75, 50 and 35 weight percent by 2010, 2013 and 2020, respectively as compared with the initial state in 1995 (Council Directive No. 99/31/EC; Decree No. 294/2005 Coll.). With the currently adjusted procedures, the set up target values of BDCW landfill are likely not to be achieved within the established terms. The more so because the weight proportion of BDCW in CW failed to be reduced in the last four years and the BDCW share should be reduced by more than 10 weight percent during the next year. In order to achieve the target values at all, the separate collection of BDW should be extended and adequate technological facilities should be assured for its processing that would be acceptable in both environmental and economic terms. In order to reach the required way of BDW treatment, which would lead to meeting the set up values, new facilities have to be designed and constructed for BDW treatment in line with the requirements for the application of best available techniques as an inseparable part of the integrated system of waste treatment in the given territory (Waste Management Plan of the Czech Republic 2003; Hřebíček et al. 2009).

A necessary precondition for increasing the amount of BDW is also the guaranteed sale and use of the final product from BDW processing within the integrated system of waste management (Hřebíček et al. 2009). Another limiting factor for BDW use is adequate condition for processing. After processing and if relevant parameters required for industrial compost or fermentation residue are complied with, the final product can be used as organic fertilizer in agriculture or as renewable fuel for energy provided the parameters required in certified fuels are met. If the final product of BDW processing does not exhibit the required parameters and cannot be further used, it is subsequently deposited in landfill as treated and stabilized waste.

The trend of BDW use is to a certain extent affected also by development in heat-power engineering. BDW has a high potential for use as a renewable source of energy both in the form of producing renewable fuels (Váňa, Usťak 2009) and in the production of biogas from anaerobic transformation as a combined generation of heat and electric energy or cooling agents.

The method of hydrothermal treatment with adjusted variable pressure and temperature parameters was tested in biologically degradable materials of diverse nature namely for increasing methane production during the subsequent use of treated material in the process of anaerobic fermentation (Kumar et al. 2011). The goal of this method is to enhance the use of material components such as ligno-cellulose (Hendriks, Zeeman 2009). The method of hydrothermal treatment was tested also with sewage sludge in order to enhance its use in the process of anaerobic fermentation (Valo et al.

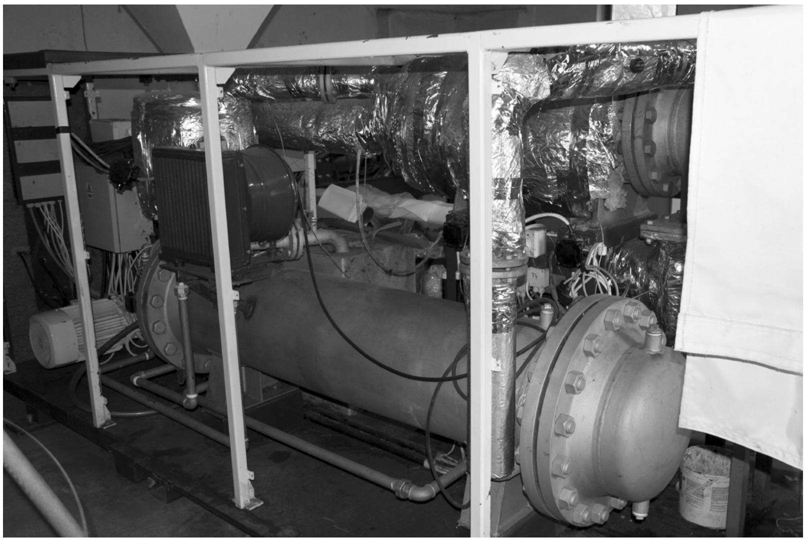

Fig. 1. The developed SBM mechanical plant model

2004; Climent et al. 2007; Bougrier et al. 2007). Wilson and Novák (2009) verified the effect of different temperatures during the hydrothermal treatment on individual components of sewage sludges. The method was applied also in the treatment of pig slurry in order to increase methane production during anaerobic fermentation (Carrère et al. 2009).

The aim of the experimental development is to design and construct a plant for the hydrothermal treatment of BDW, suitable for villages, small towns or agricultural enterprises. The developed equipment can be operated as a single facility in the communal sphere but it can also be a part of a technological line of biogas station or composting plant.

Stabilized output material from the SBM (stabiliser of biomass) mechanical plant can be characterized as a mechanically and thermally treated material suitable for further use or elimination. The subsequent treatment is conditioned by the composition of the converted input material as well as by resulting parameters of output products (Junga, Mareček 2009).

MATERIAL AND METHODS

The SBM mechanical plant model (Fig. 1) is meant for the hydrothermal treatment of waste, its current structural design being meant especially for the hydrothermal treatment of biologically degradable waste. It consists of a physical and mechanical stage of treatment – waste crushing and homogenization. This phase of treatment is ensured by the primary chain breaker, waste charging hopper and screw crusher. The proper hydrothermal treatment of waste takes place in the second stage of processing by means of three screw presses. Screw press 1 ensures dewatering of the material and it heats to required temperature (95°C). In screw press 2, the material is heated to reaction temperature (190°C) and overpressure of max. 0.6 MPa is developed. In the reactor, water vapours and volatile gases are released. Degasification of the substrate is ensured by means of expander. Water vapours are channelled into a recuperation unit where they condense and are subsequently collected in a condensation vessel. Screw press 3 provides for the finalization of the process of hydrothermal treatment. In this part of the mechanical plant a rapid drop of pressure and temperature (130°C) occurs, which breaks down the cellulose of individual materials and thus makes their cell contents readily available to microorganisms. The waste treatment in the mechanical plant takes ca. 10–17 min. Output capacity of the plant in its current design is about 0.1 Mg/h.

The development of the new SBM mechanical plant model aims at a possible use of harvested stabilized material as renewable fuel or its component or as compost component in the case that the required qualitative parameters of renewable fuel cannot be achieved.

At this stage, the experimental development of SBM mechanical plant model dwells namely on monitoring the effect of properties of tested input materials with different chemical and physical parameters with a focus on the required parameters of the final product of hydrothermal treatment. Operational and exploitation parameters are studied of mechanical parts of the experimental mechanical

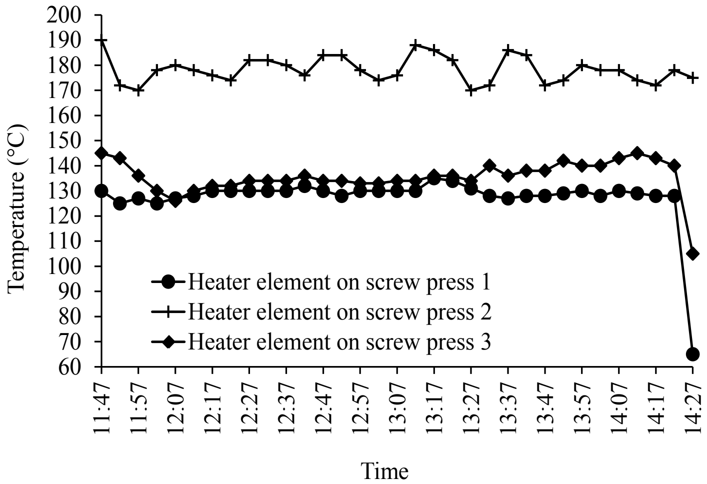

Fig. 2. Course of temperatures during the process of stable manure hydrothermal treatment with heating

plant and the influence of their design on the process of stabilization during the treatment of selected biodegradable materials including their mixtures.

The material intended for processing in the SBM plant is visually assessed, crushed to the required particle size, blended and homogenized. Material samples are taken to establish prescribed variables in the accredited laboratory.

The prescribed variables to be determined are moisture by weight and dry matter of the material pursuant to standard ČSN ISO 11465 (1998). Other parameters to be ascertained are pH, temperature during pH measurement, C:N ratio pursuant to standard ČSN 46 5735 (1991) industrial composts, non-degradable admixtures pursuant to standard ČSN 46 5735 (1991) industrial composts, combustibles (350°C) and total nitrogen according to Kjeldahl pursuant to standard ČSN ISO 11261 (1998).

The principle of the process of hydrothermal treatment in the experimental SBM mechanical plant model is a continual movement of the tested material by means of a system of worm conveyors under the simultaneous action of temperature and pressure by which the moisture mass of suspensions or colloids is eliminated.

During the process of hydrothermal treatment, temperature and its changes are monitored for individual kinds of material during their advancement through the mechanical plant. The temperature is measured in individual three sections of the screw press. The course of temperature is presented in Figs 2–4.

At the end of the hydrothermal treatment, the final product is measured for the same variables as the material before the stabilization in order to evaluate changes of qualitative parameters in the processed material.

The level of change in the defined variables of experimental materials after the process of hydrothermal treatment is assessed through the statistical analysis by means of the pair t-test for selected indicators – dry matter (DM), moisture by weight, non-degradable admixtures, combustibles and total nitrogen.

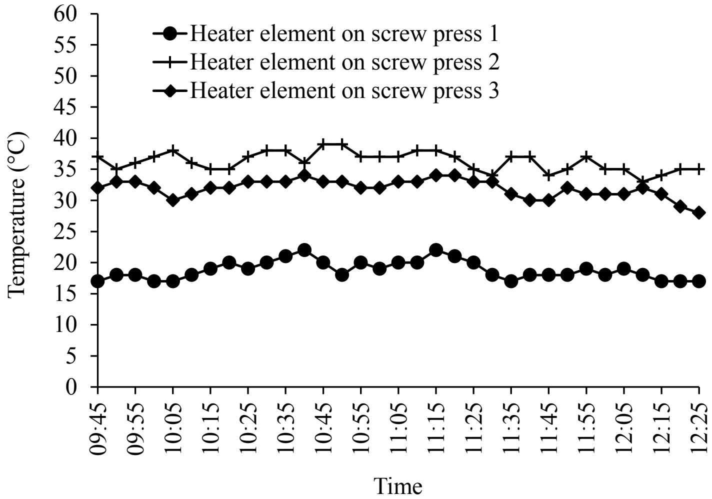

Fig. 3. Course of temperatures during the process of stable manure hydrothermal treatment without heating

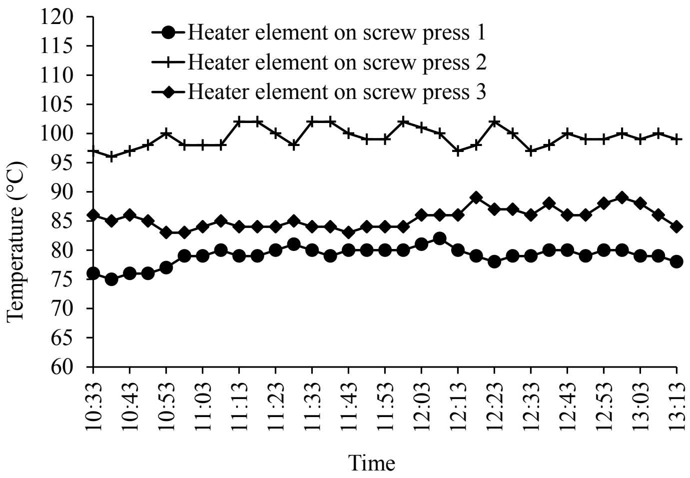

Fig. 4. Course of temperatures during the process of hydrothermal treatment of maize silage with wood chips

At this stage of the development of SBM mechanical plant model, the values of defined variables of the product of hydrothermal treatment are compared with requirements stipulated in the Decree No. 341/2008 Coll. on details of biodegradable waste management and on the amendment of the Decree No. 294/2005 Coll. on conditions for the deposition of wastes in landfills and their use on the terrain surface and on the amendment of the Decree No. 383/2001 Coll. on details of waste management. The comparison is made with the values presented in Appendix No. 5 of the Decree No. 341/2008 Coll. – characteristics of compost for soil reclamation (Table 1). In this Decree, the compost for soil reclamation is defined as a stabilized output from the aerobic conversion of biological wastes, intended for the maintenance or improvement of soil properties, utilizable outside agricultural and forest soils.

Materials and their mixtures tested for their properties within the first series of experiments included stable manure and maize silage waste in a mixture with wood chips.

RESULTS AND DISCUSSION

The experiment with stable manure

In the experiment with stable manure, the process of hydrothermal treatment was modified in two variants: with/without the supply of thermal energy (with/without heating the material). It was found out that by processing the material in the SBM plant, the material's moisture content is reduced even without heating the substrate with natural heat being generated by processes taking place in the individual sections of the screw press. Intracellular fluid is released already during the material crushing and homogenization due to the disturbance of cell walls of the organic material.

A higher reduction of relative moisture content of the processed material is achieved by the stabilization of stable manure with heating.

Having compared the properties of the stabilized substrate with heating and without heating with requirements stipulated in the Decree No. 341/2008 Coll. (Table 1). We can conclude that stable manure processed without heating meets all quality parameters stipulated for the soil reclamation compost except for moisture content, which was higher (69.9%) in the resulting substrate. Stable manure processed with heating showed the values of studied parameters within the range of stipulated quality parameters with the exception of the C:N ratio (55). Based on the statistical analysis carried out by using the pair *t*-test in order to verify the level of change in the studied parameters of experimental materials after the hydrothermal treatment, we can conclude that qualitative parameters of the output material resulting from the stabilization of stable manure in the SBM plant with heating or without heating significantly differ. Values of dry matter, moisture content by weight, non-degradable admixtures and total nitrogen exhibited a highly significant change. Results from the paired *t*-test statistical analysis in studied indicators for stable manure with heating are presented in Table 2 and results from the paired *t*-test statistical analysis in studied indicators for stable manure without heating are presented in Table 3.

The above presented experimental results demonstrated that stable manure is a material suitable for treatment in the SBM mechanical plant model. Manure composition is an important fact, especial-

Table 1. Quality characteristic of compost for soil reclamation according to requirements stipulated in Decree No. 341/2008 Coll.

Moisture (wt. %)	from the detected value of combustibles up to its double; min. range 40–65
Combustibles in dried out sample (wt. %)	min. 25
Total nitrogen as N converted to the dried-out sample (wt. %)	min. 0.60
C:N ratio	min. 20 (max. 30)
pH value	6.0–8.5
Non-degradable admixtures (wt. %)	max. 2%

ly the optimal blending of litter (straw or sawdust) with excrements, creating a favourable mixture without a necessity of adding other materials.

The experiment with maize silage waste in a mixture with wood chips

The experiment was carried out from maize silage waste in a mixture with wood chips at a 10:5 ratio. Chips sized 25–35 mm were added to the maize silage waste in order to modify the content of DM so that the DM content of this tested material could reach the level of stable manure DM. The statistical assessment made by using the paired *t*-test showed that differences between all studied variables of maize silage waste in a mixture with wood chips on the input and variables of the final product of hydrothermal treatment were highly significant. Results from the paired *t*-test statistical analysis in studied indicators for maize silage waste in a mixture with wood chips are presented in Table 4.

The experimental testing of selected types of biologically degradable materials and operational experience with the SBM mechanical plant model confirmed that structure and moisture content are crucial features of the processed material. It is therefore useful to mix biodegradable materials of adequate characteristics and structure in order to obtain a final product of required properties.

The material most suitable for hydrothermal treatment in the SBM mechanical plant model is material of input moisture by weight ranging between 70–75%. Under this condition, moisture by weight of the final product on the output from the plant will be 35–40%. Adequate material structure has to be ensured for its problem-free processing in the mechanical facility and for the achievement of product characteristics suitable for further use. If the material mechanical pre-treatment by crushing and homogenization is insufficient on the material input into the plant, technical problems can be expected e.g. blocking. Inadequate mechanical pre-treatment may be also responsible for imperfect homogenization of the stabilized product.

Measured characteristics of final products demonstrated that the final products meet criteria stipulated by the Decree No. 341/2008 Coll., i.e. the criteria set up in Table 1. Problematic appears the C:N parameter (which however depends on the composition of the processed material) and a higher moisture content of the final product in the case of testing stable manure without heating. It is possible to conclude that the final products of hydrothermal treatment exhibits material characteristics similar to those of industrial compost.

Table 2. Paired *t*-test statistical analysis of indicators for stable manure with heating (degrees of freedom = 9.0000)

	Difference				*t*-statistics	Two-way probability
	cases	average	standard deviation	standard error		
Dry matter	10	–31.8100	0.7400	0.2340	–135.9269	0.0000
Moisture by weight	10	31.8100	0.7400	0.2340	135.9269	0.0000
Non-degradable admixtures	10	0.3200	0.1229	0.0389	8.2319	0.0000
Combustibles (550°C)	10	–1.5700	18.9305	5.9864	–0.2623	0.7990
Nitrogen according to Kjeldahl	10	–4991.0000	4835.1731	1529.0160	–3.2642	0.0098

Table 3. Paired t-test statistical analysis of indicators for stable manure without heating (degrees of freedom = 9.0000)

	Difference				t-statistics	Two-way probability
	cases	average	standard deviation	standard error		
Dry matter	10	–7.5900	0.5705	0.1804	–42.0730	0.0000
Moisture by weight	10	7.5900	0.5705	0.1804	42.0730	0.0000
Non-degradable admixtures	10	0.2400	0.0699	0.0221	10.8544	0.0000
Combustibles (550°C)	10	–4.8000	0.1414	0.0447	–107.3313	0.0000
Nitrogen according to Kjeldahl	10	–18320.0000	20.5480	6.4979	–2819.3885	0.0000

Table 4. Paired t-test statistical analysis of indicators for maize silage waste in a mixture with wood chips (degrees of freedom = 9.0000)

	Difference				t-statistics	Two-way probability
	cases	average	standard deviation	standard error		
Dry matter	10	–36.7500	1.0341	0.3270	–112.3772	0.0000
Moisture by weight	10	36.7500	1.0341	0.3270	112.3772	0.0000
Non-degradable admixtures	10	–0.9500	0.0850	0.0269	–35.3499	0.0000
Combustibles (550°C)*	10	–3.1000	0.4372	0.1382	–22.4243	0.0000
Nitrogen according to Kjeldahl	10	15112.0000	34.8967	11.0353	1369.4240	0.0000

*difference between averages = –3.1000; 95% confidence interval = –3.4127 <> – 2.7873

CONCLUSION

The SBM mechanical plant model is at a stage of advanced development. The fact is to a certain extent affected by the amount of conducted experiments as well as by the range of analyzed biologically degradable materials or their mixtures. This paper brings experimental results from the first tests of selected materials and their mixtures.

The carried out experiments and analyses demonstrated technical possibilities of the SBM mechanical plant model on the basis of testing the variants of different biodegradable materials in relation to a possible use of final products in the sense of valid legislation. The level of material stabilization is highly statistically significant.

Properties of these final products of hydrothermal treatment are similar to those of compost for soil reclamation and quality characteristics of these final products meet requirements imposed by the Decree No. 341/2008 Coll.

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