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REACTOR AND PROCESS CONTROL FOR AEROBIC BIOTREATMENT AND DRYING OF WASTE

The application of biological prior to thermal treatment of municipal solid waste is very promising because it may facilitate the separation of inert materials and homogenization of municipal solid waste. In addition, a remarkable energetic effect can be achieved. By using the biological treatment as a drying step, the input water content necessary for a subsequent incineration could considerably be reduced and optimized. The corresponding pilot-scale tests in fixed bed and rotary reactors were carried out. Main characteristic design and control criteria are presented for a discontinuous biotreatment process in a pilot-scale rotary reactor as well as the selected test results. Based on these experiences optimal conditions for the biological process and parameters for its control can be derived.

1. INTRODUCTION

In the last years, many efforts have been made to introduce biological treatment processes into municipal solid waste (MSW) prior to disposal. Due to these processes the amount of MSW and the environmental problems related to their disposal could remarkably be reduced (BRUMMACK [1]). Meanwhile mechanical-biological waste treatment (MBWT) has become an alternative to mere disposal. Even with simple technological means the process is very effective. The large-scale application confirmed a considerable limitation of degradation processes in the disposal body and a significant increase in the waste compaction density (up to the two-fold or even somewhat more) due to improved separation of materials. Whereas also the emissions during the aerobic degradation in open windrows cause no extreme enhancement of the concentrations being of the order of or less than the disposal background (WOTTE [2]). A critical and often controversial issue is the natural (and much more the technical) limit to the reduction of the organic content. By long-term biological treatment the minimal achievable content of organic matter, expressed in terms of ignition loss,

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is about 20% of mass. This organic content may still implicate some disposal problems. Only by thermal treatment processes (e.g. incineration) the organic content could further be reduced to the values of about 5%, which are e.g. prescribed by German disposal law.

In addition, one of the major disadvantages of a biological treatment is that the energy (or organic content) accumulated in the waste is not used at all. Therefore, the combined application of biological and thermal treatment is also very promising with respect to an energetic utilization of MSW. By using the biological treatment as a drying step, the input water content for a subsequent incineration could considerably be reduced and optimized. Thus the energy efficiency compared to direct waste incineration could be improved. In addition, the structure and texture of the MSW processed biologically facilitate very much subsequent processes, e.g. separation of bulky and inert materials. In order to investigate the drying effect produced by aerobic biological treatment, several laboratory and pilot scale tests were carried out. Main objectives of these tests were to determine the amount of the reaction heat generated and the volume of air needed for a controlled biological drying process. Furthermore, the first assessment of the possible reduction in the waste moisture content and the implicated enhancement of the calorific value should be made. For the experiments both a static fixed bed and a rotary reactor were used. Main characteristic design and control criteria have been derived for a discontinuous biotreatment process in a pilot-scale rotary reactor.

Various tests have revealed the complexity of the parallel processes. The biological decomposition of organic material generates the heat of reaction. This heat and the corresponding temperature increase can be utilized for the removal of the waste moisture content. However, with the reduced moisture content certain species are suppressed or their metabolism is limited. Therefore, a significant process window has to be determined. Based on these experiences optimal conditions for the biological process and parameters for its control can be derived.

2. OBJECTIVES FOR THE APPLICATION OF MBWT PRIOR TO INCINERATION

Even by sophisticated MBWT technology, including aerobic and anaerobic processes, the organic content can only be reduced to about 20% in terms of the ignition loss or to about 7 to 10% of total organic carbon (TOC) (WOTTE [2]). This organic content still represents a long-term risk for waste disposal. A substantial risk is associated with the anaerobic degradation of organic waste components in the landfill. Characteristic intermediate and end products of this process are organic acids and methane. Primary consequences of the anaerobic degradation are emissions of methane-containing disposal gas and leaching water contaminated by organics as well as settlements of the landfill body. Secondary consequences, e.g. mobilization of heavy metals caused by the decreasing pH values, are not as easy to describe.

Therefore legislators have limited the organic content of waste to be disposed. Only by thermal treatment a drastic reduction of the organic content can be achieved. Nevertheless, this does not mean that biological processes will be obsolete in waste treatment. In fact, they can very much improve the incineration process itself by:

- Increasing the effective calorific value by moisture reduction as the main objective.
- Improving stabilization effect and facilitating intermediate storage (without negative degradation effects: odour, uncontrolled calorific loss).
- Improving homogenization of material properties (structure, moisture content, calorific characteristics). Biological treatment (usually at the temperatures up to 70 °C) detaches agglomerates or even compound materials and causes a homogenization of the waste mixture, which does not tend to block the transport mechanisms (e.g. grates, conveyors).
- Facilitating separation of inert materials, thus enabling recycling and generating an enriched high calorific waste fraction.
- Reducing mass, volume and improving compactability.
- Improving hygenisation.

Experiences (WIEMER [3], BRUMMACK [4]) teach that a waste mixture can moderately be dried by a controlled short-term aerobic biological treatment. Especially the initial intensive phase of this treatment with its high temperatures and larger heat generation can effectively be used to dry out the substrate. The process heat of the exothermal biodegradation of organic substance delivers the energy to vaporize the water in the waste mixture, thereby decreasing the moisture content and increasing the calorific value of the waste. However, if the moisture content is too low to support the transport and living processes of the micro-organisms, the biological treatment will be interrupted or at least the degradation rate will be reduced considerably. Thus, a kind of auto-inhibition coupled with a sanitation/hygenisation of the mixture will take place. That is why this effect is sometimes also called the thermo-stabilization of the substrate. Obviously the water content is very much depending on such substrate characteristics as: porosity, particle size distribution, material composition, and maximum water holding capacity. It can be proved that the minimal moisture content is well below 30 mass-% and depends on different substrate characteristics in the range of about 20–25 mass-% (BRUMMACK [4]).

3. TESTS WITH A ROTARY REACTOR

The aim of the biological drying is to provoke a net energetic and technological effect. It is important to control effectively the bioreaction/stabilization. The stabilization effect and the increase of the calorific value by the reduced moisture content should well balance the decrease in calorific value by the degradation of organic substance. Therefore all process parameters (e.g. air supply, temperature regime, usable reaction heat, mixture turning) have to be controlled and optimized. In the investigations, some of the main important process characteristics and parameters are studied.

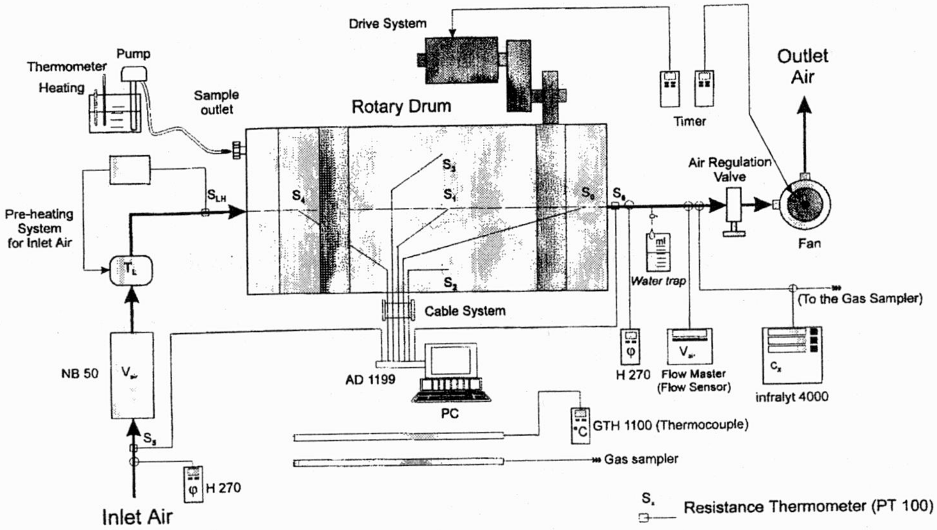

Fig. 1. Reactor test and control equipment

In figure 1, the rotary reactor used and the parameters measured are schematically sketched. The reactor has a diameter of 1200 mm and a length of 2920 mm. The thickness of the metal wall is 10 mm without insulations. The rotational speed can be controlled in the range from 0.1 to 7.2 revolutions per minute. The drum is moveable in alternating directions by a programmable automation system. The actual movement intervals (on-/off-times) are regulated by a timer. Air in the system circulates through flanges at the end walls. A side channel pump withdraws the air by suction. Operational periods (on-/off-times) can be controlled by a timer, too. The devices for the measurements of temperature, air flow, moisture content, gas components and mass permit a proper process monitoring and control. Resistance thermometers PT 100 are placed for the measurement of temperatures under the insulation and also in the inlet and outlet tubes. Thermocouples are used for the measurements within the reaction chamber. Moisture is measured by an electronic hygrometer. Data transfer to the PC is given by cables with a specially developed cable drum system, which prevents any cable from twisting by drum rotation. The exhaust gas composition is measured by a three-channel system for methane, oxygen and carbon dioxide. Air velocity is gauged electronically by hot wire anemometer.

In the pilot tests, the following issues were investigated:

- finding the appropriate parameters for an optimal drying process and its control;
- proving the effectiveness of stabilization under real conditions;
- determining water up-take by circulating air;
- determining air demand;
- deriving conclusions for the large-scale technological and equipment design as well as suitable parameters of a stable process.

A wide range of parameters have been tested and discussed (HIEKE [4], BRUMMACK [5], TITTEL [6]). Different mixtures of municipal solid waste, source separated organic waste and sewage sludge were tested. Table 1 shows the percentage range of the individual constituents at input. In table 2, there is given an example of the change of the main input parameters compared to the output parameters after about 4 days. The experimental calorimeter values are given for the gross and net calorific heats in the continuous phase. The bulky materials as well as the larger, calorific components, e.g. plastics, bags, have been separated. These substances are not subjected to the biodegradation. In addition, they cause sampling problems, because it is rather difficult to take a representative sample from those larger components with respect to the mass content of the different fractions.

Table 1

Percentage range of input waste constituents

Main constituents	Range [mass-%]
Organic waste	20–40
Plastics	10–20
Textiles	5–25
Paper & cardboard	15–25
Metals & inert materials	5–10
Sewage sludge	0–40

Table 2

Example for main parameters of an aerobic biodegradation test in the rotary reactor

Parameter	INPUT	OUTPUT
Mass [kg]	500.2	386.3
Reactor filling ratio [volume-%]	60.0	
Moisture [mass-%]	48.3	36.2
Ignition loss [mass-%]	65.3	68.7
Gross calorific heat in the continuous phase [MJ/kg]	13.6	13.5
Net calorific heat in the continuous phase [MJ/kg]	5.9	7.7

For the tests selected the temperature curves are plotted in figure 2. Some characteristic process phases can be distinguished. Under the chosen process conditions a longer initial phase of up to about 120 hours was observed in the temperature range of about 40 °C to 50 °C characteristic of mesophilic microorganisms. The duration of this phase is apparently dependent on the initial and/or actual moisture content. In the tests, the moderate temperature plateau could only be surpassed if the moisture contents are greater than 53 mass-%. However, then the temperature rose quite quickly, ranging from 65 °C to 70 °C, which is characteristic of thermophilic microorganisms. This phase lasting some 150 hours is again fairly stable and leads to a continuous reduction of moisture in the substrate. Only with the decreasing moisture content, the temperature drops again, obviously due to the limitation of the microbiological activity. However, an effective moisture reduction taking place due to the heat energy accumulated in the substrate could still be measured.

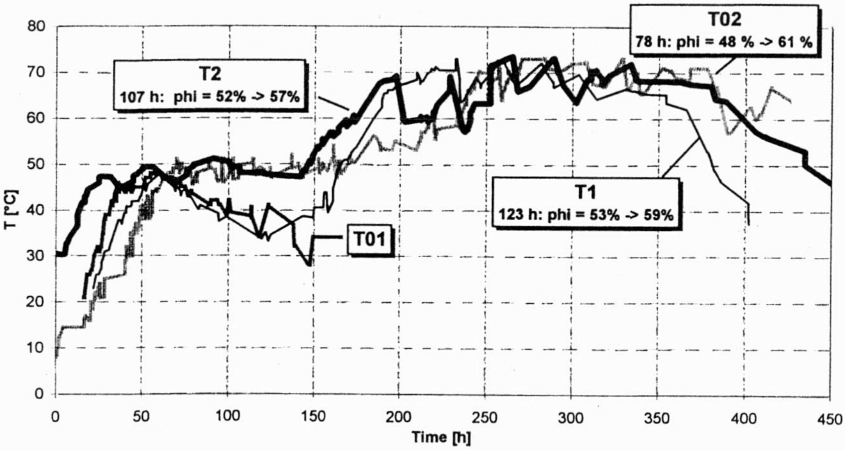

Fig. 2. Temperature in aerobic tests
(Tests T01, T02, T1, T2)

The results discussed on the basis of the temperature curves are also supported by the other parameters measured (TITTEL [6]). Summarizing the test results, in figure 3 there are given some of the main characteristic tendencies in relative quantities compared to the maximum values in the tests. In a relatively short starting phase of about 50 hours or less, temperature rises to about 45–50 °C. However, at that level the bioactivity is just reduced to that degree, which is just stabilizing temperature. Number of the colonies forming units, their respiration rates as well as heat generation are reduced. The pH value is continuously increasing from about 6 to 8.5. Though during this rather stable stage a moisture reduction is still possible, it is rather low. Without any interference, the process proceeds for some 100–120 hours. Thus, the moisture content can be decreased to less than 40 mass-%, but by consuming too much organics and reducing calorific value of wastes. A further temperature increase could only be reached by holding or again increasing the substrate moisture content (by sprinklers) to about 55% or more. Then, in a period of some 50 hours, an increase in bioactivity and temperature up to about 70 °C and more can be observed. This is evidently related to a lack of active thermophilic microorganisms and/or a deviation from their optimal metabolic conditions. It may be caused by the reduction and exchange in a nutrient supply due to the reduced moisture. So far, a final explanation cannot be given. Both intervals of the mentioned process might be summarized in the formation phase of developing the optimal moisture reduction conditions.

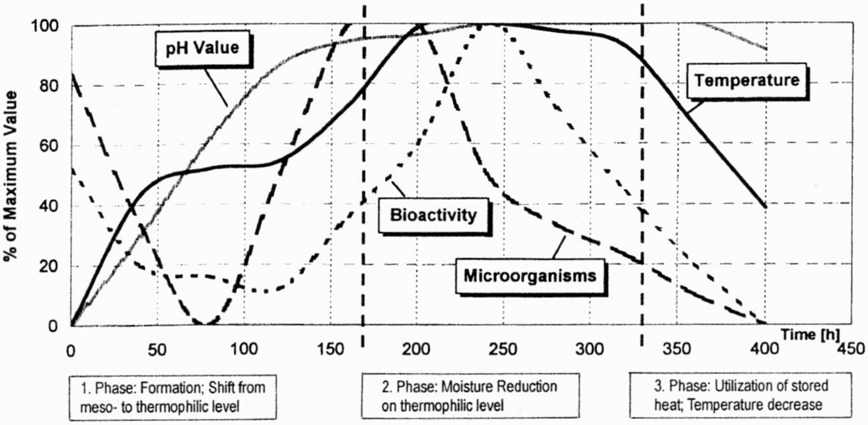

Fig. 3. Principal tendencies in aerobic reactor tests
(T, pH, CFU, bioactivity over time)

Once the temperature level of about 65 °C to 70 °C is reached, even severe changes of oxygen supply and the reduction of moisture to about 35–40% will not strongly reduce temperature and bioactivity. Thus, it seems also to be a stable phase, which is true for the pH, too. This phase can be used for active moisture reduction. Only then, after about 150 hours, the temperature and bioactivity are decreasing with the reduction of readily digestible organic material. Also pH is dropping again. In this stage the stored heat energy of the substrate might effectively be utilized for a further moisture reduction without consuming too much organics.

All expectations for the material properties derived from the long-term MBWT windrow process (BRUMMACK [1]) could be confirmed. Compound materials and aggregates have been detached despite the comparably short (6–20 days) process duration. Though this duration is still too long for an effective application. However, separation of inert and metallic materials is very much improved! Indeed, the degree of homogenization and stabilization of the processed waste is appropriate for a direct incineration feed or an intermediate storage. During the tests the reactor design and operation could be optimized. Solutions for insulation, sampling and process control are currently tested to optimize and facilitate energy recovery and technology scale-up.

4. SUMMARY AND CONCLUSIONS

It was demonstrated in different pilot-scale tests in a rotary reactor specially designed that biological-mechanical processes contribute to and facilitate a complex and waste management concept. They can effectively be used as preparation, stabilization, homogenization and drying processes prior to incineration. The tests of aerobic degradation of waste in the rotary reactor confirm the possibility of further improving the waste structure and characteristics. The moisture content of a waste mixture can remarkably be reduced. However, the range of operating conditions is very narrow. Especially the transition from mesophilic to thermophilic regimes has to be further studied. The respective milieu for the microbial strains and metabolism must be investigated. This should lead to the improved process control and the increase in calorific properties. The output material is homogenized and stabilized. Separation of inert and metallic materials and destruction of compound articles and aggregates are facilitated! The results achieved are very promising in an effective large-scale application as a pre-treatment for direct incineration or intermediate storage. However, the process duration is still too long to be economically applied on a technical scale. The process acceleration and optimisation have to be investigated thoroughly in the near future. Improved design and technological solutions will be tested to optimize the energy balance and to facilitate the energy recovery.

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BIOLOGICZNA PRZERÓBKA METODĄ TLENOWĄ ORAZ TERMICZNA UTYLIZACJA ODPADÓW STAŁYCH – STEROWANIE PARAMETRAMI PROCESU

Zastosowanie procesu biologicznego przed termiczną przeróbką stałych odpadów komunalnych ułatwia oddzielanie obojętnych materiałów i ich homogenizację. Dodatkowo można uzyskać korzystny efekt energetyczny. Wprowadzając przeróbkę biologiczną jako etap suszenia, można znacznie ograniczyć początkową zawartość wody w odpadach przed późniejszym ich spopielaniem. Przeprowadzono badania w skali pilotowej z wykorzystaniem złóż unieruchomionych i reaktorów obrotowych. Przedstawiono podstawowe parametry projektowe i kryteria sterowania nieciągłym procesem biologicznym w skali pilotowej z wykorzystaniem reaktorów obrotowych. Na podstawie uzyskanych wyników opracowano warunki optymalnego prowadzenia procesu biologicznego.