行政院國家科學委員會補助專題研究計畫成果報告

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※ Bio-fertilizer Production from Renewable ※
※ Organic Waste ※
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計畫主持人：林志高

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本成果報告包括以下應繳交之附件：

□赴國外出差或研習心得報告一份

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□出席國際學術會議心得報告及發表之論文各一份

□國際合作研究計畫國外研究報告書一份

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Bio-fertilizer Production from Renewable Organic Wastes

計畫編號：NSC 90-2211-E-009-025
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計畫主持人：林志高博士 國立交通大學 環境工程研究所

Abstract

The main tasks of the project "Bio-fertilizer Production from Renewable Organic Wastes" for the first year were determined in the meeting organized in LUA (October, 2001), the principles of composting and the possible reactor designs were discussed during meeting in Riga (February), and the results of the reporting period were discussed during the second meeting in Riga (March, 2002). The aim of the first year is to choose an optimal direction for research of bio-fertilizer production taking into account requirements of EU Directives and Regulations as well as possible composting influence on the environment and human health. Participants of all countries have chosen "sewage sludge" as common target raw material for bio-fertilizer production. The goal of our joint project is to develop an effective, rapid and controlled sewage sludge composting process that converts sewage sludge into qualitative compost and can be applied as a bio-fertilizer. Such process will not only convert waste in to a useful bio-product, but also will obtain a product promoting additional plant nutrition value.

Introduction/Literature reviews

Tasks to achieve the aim of this project:

1. Review of EU and LT, LV and Taiwan legislation on aerobic/anaerobic processes and quality requirements on sewage sludge, compost, anaerobic digestion and regulations of organic waste utilization/application on land.
2. Literature review of applicable methods for sewage sludge stabilization/treatment (aerobic and anaerobic processes).
3. Determination of quality characteristics of sewage sludge of different origin.
4. Preliminary sewage sludge decomposition experiments in anaerobic/aerobic reactor.
5. Preparation of joint design for small-scale laboratory aerobic bioreactor.

An extensive literature studies have been carried out to know the legislative documents and research publications concerning properties, and treatment of sewage sludge as well as compost quality requirements. Analysis of EU Environmental legislative documents (Directives, Regulations in force as well as their projects) showed, that quality requirements for sewage sludge, composted material and anaerobic digestion applied on land as soil improvers are becoming more stringent, especially regarding heavy metals. For example, maximum allowable concentration of Cadmium in the new draft EU Directive is reduced to 0.7 mg/kg dry matter (Class 1 for compost/digestion). The main environmental evaluation parameter in ISO 14040-14049 standard - Life Cycle Assessment - is energy consumption. So it is important for our project to choose bio-fertilizer production technology (i.e. perform composting, digestion, mixing and other stages) with possibly minimal energetic inputs. EU 2nd draft 'Biological treatment of bio-waste' requirement for composting says that: - mixing of different materials solely for the purpose of diluting pollutants shall be prohibited; - mixing of compost or digestion with other suitable materials in order to obtain high quality plant nutrients and soil improvers shall be regarded. All these requirements should be taken into account when choosing the most appropriate technological scheme for bio-fertilizer production.

Literature review showed that there is no universally accepted and used sewage sludge treatment technology. Sewage sludge can be treated using aerobic composting, anaerobic digestion or both methods can be used sequentially – anaerobic digestion and afterwards composting or on the contrary, first composting and further pasteurization. This means that we should choose the most appropriate sewage sludge treatment method and this decision should be with the elements of novelty.

Composting is aerobic, or oxygen requiring, decomposition of organic materials by microorganisms under controlled conditions. During composting the microorganisms consume oxygen while feeding on organic matter. This generates heat, carbon dioxide and water vapor, which are released into the atmosphere. Composting reduces both the volume and mass of the raw materials while transforming into composted organic material. Composting can occur at a rapid rate when optimum conditions that encourage the growth of microorganisms are established and maintained. The most important composting conditions are:

- The raw materials should be appropriately mixed to provide nutrients for microbial growth and activity, which includes balanced supply of carbon and nitrogen (the C:N ratio),
- There should be sufficient moisture to permit biological activity without hindering aeration,
- Oxygen should be at levels that support aerobic organisms,
- Temperatures should encourage active microbial activity from thermophilic microorganisms.

The factors affecting the composting process include: the physical and chemical properties of the raw material, the level of oxygen, the moisture content, the temperature and the time over which the composting process takes place.

The obtained compost will posses a higher content of humic substances - the end product of decayed matter, and usually contains large quantities of trace minerals. The compost quality must meet requirements of the "Technical Guidance on Composting Operations" The final product - bio-fertilizer from composted sewage sludge must have fertilizing and/or conditioning effect to soil, and do not contain any toxic and noxious and/or persistent substance at dangerous concentrations for soil, crops, animals, man and environment. The product could be as powder, solid (pellets, granules, etc), liquid. The most interesting applications on land for agricultural uses, as fertilizer, amendment and/or conditioner, as well as for other uses on land: forests, public parks, plant nurseries, roadsides, golf courses, lawns and home gardens, or growing grass, crops, flowers.

The main experimental results

The lab-scale experiments of anaerobic and/or aerobic sewage sludge fermentations have been carried out in all three countries.

The activated sludge is obtained from the waste treatment plants (WTP) in own countries. Sludge, used in Taiwan, is the sludge cake - a product obtained after the raw sludge treatment by digestion (stabilization), conditioning, and dewatering. Presently in most WTP in Latvia and Lithuania the stabilization process of the raw sludge is not carried out (except Kaunas WTP) and the obtained sewage sludge for further composting must follow the anaerobic fermentation under certain conditions. Even when in the largest WTPs the stabilization process will be realized, in all other - small WTPs, this stage will not be carried out in due time, and it will be necessary to carry out the anaerobic fermentation of the sludge. The investigations and optimization of this process is extremely significant in Latvia and Lithuania.

The physico-chemical characteristics of raw sludge are variable and have been controlled at the beginning and during the anaerobic and aerobic fermentations to find out the optimal fermentation conditions. The general physico-chemical characteristics have been determined: moisture content, bulk density, volatile solids, pH, organic carbon, total nitrogen, phosphorus, potassium and C:N ratio, etc. The heavy metal: Hg, Cd, Ni, As, Pb, Cu, Cr, and Zn content in sewage sludge from Nei-Hu, Di-Hua, Min-Shen, and Pa-Li wastewater treatment plants has been determined. Heavy metal analysis in Lithuania showed that especially problematic is cadmium: its concentration in Kaunas city sewage sludge reaches 69.7 mg/kg DM, and also the unknown origin of great fluctuation of its content in wastewater. This metal defines the lowest III Category and Kaunas sludge application on land under Lithuanian and EU regulations is practically restricted (MPC is 6 ppm). Different situation is with Raseiniai sewage sludge that is relatively clean and can be used for composting with other organic renewable wastes following production of bio-fertilizer. Changes in heavy metal content and N, P, K have been investigated in Kaunas sludge (piled in the special storing area) depending upon depth (0-10cm, 10-20cm and 40-50cm) and storing time (10 months, 4 months and 2 weeks). Results showed that during storing N, P and K amounts reduces slightly. Concentrations of heavy metals as well as biogenic elements and moisture content apparently increases in the lower sludge layers, presumably due to downward migration and leaching processes, as well as mineralization and evaporation from the surface layers (in case of nitrogen).

The reactors used are different in all three countries. The reactor applied in Latvia is original as both fermentation stages - anaerobic and aerobic - are carried out in the same equipment. In Lithuania is used the reactor for anaerobic fermentation, but in future aerobic fermentation will be carried out in a reactor similar to the one in Latvia. The volumes of the reactors are different – 3 l in Latvia, 18 l in Lithuania, and 35 l in Taiwan. Nevertheless, it was decided to use the existing reactors in this phase of investigations for optimization of the conversion process. The results of these lab-scale investigations will be necessary to realize the composting of sewage sludge in windrows. Decision on the joint final scheme of aerobic reactor should be accepted by all partners in the nearest future, so that sewage sludge aerobic composting experiments could be started in the second year.

During anaerobic and/or aerobic fermentation as amendmets have been used: saw-dust and wastes from ethanol production (in Latvia), meat bone meal and cement kiln dust (in Lithuania), rice hull, wood dust, and bamboo dust (in Taiwan). Preliminary research on acidic treatment of meat-bone mass of ruminant showed, that optimal concentration of extractive (45%) phosphorus acids is 20% calculating from the taken meat-bone mass. This concentration is sufficient to accomplish protein denaturation. Quality characteristics (related to plant nutrients) of the acidic processed mixture (pH 4.65, total N - 106% DM, available P - 2.7% DM) showed that meat-bone meal can be used as a valuable source of plant macro-element phosphorus. Preliminary experiments also showed that addition of acidic modified meat-bone mass to the anaerobic digestion mixture with sewage sludge markedly (2-2.5 times) increased the amount of generated biogas, calculated on the basis of dry matter added; also increased the percentage of methane in biogas. Addition of meat-bone mass not only intensifies anaerobic digestion process, but also increases the total amount of phosphorus. These preliminary results show that anaerobic digestion of meat-bone mass together with sewage sludge can be successfully used as the first stage before further composting, thus refusing presently in Lithuania applied meat-bone mass utilization technology, which is expensive (high energy consuming) and air pollution (due to greenhouse gas emissions). Inorganic cement wastes (cement kiln dust) can be used as an additive for bio-fertilizer production. Data showed that these wastes can be applied not only as a stabilizing agent, but also as a potential source of potassium in bio-fertilizer. Furthermore, preliminary results showed that after alkaline stabilization, mobility of heavy metals (and at the same time their bio-availability) decreases notably.

Results from the operation and experiments of the pilot plant in Taiwan: appropriate moisture content, C/N ratio and amendment ratios obtained from lab- scale experiments, were scaled up and verified through 5 ton scale pilot plant, the aeration rate, turning frequency, the comparisons between aerobic conditions and anaerobic conditions, and the extent of maturity were optimized, the best experimental conditions have been determined. Composts produced from different sludge and wood dust ratio and under aerobic or anaerobic conditions were compared. The maturity period for anaerobic composting requested more than 70 days, and the effects of adding urea to increase the C/N ratio insignificantly were not further used for application. Under aerobic conditions, recycled a certain ratio of product adding as an amendment will increase the number of microorganism as well as the rate of composting, in which the nutrient of the feed is reduced the temperature of the active composting period was lower, but the concentration of P_2O_5 and K_2O were increased. Under suitable aeration rate most of the compost produced met the specifications as follows: In pot plantation when the mixing ratio of compost in the soil exceeded 5%, a positive result was obvious shown.

To promote the composting process was applied two *Trichoderma* strains and nitrificator association that regulated the circulation of nitrogen - ammonification and nitrification processes. Both *Trichoderma* strains were isolated from soil in Latvia. *Tr. lignorum* is more active splitter of cellulose substrates, but *Tr. viride*,– mainly is the producer of the trichodermine (plant protection agent against plant diseases), and by the way also a splitter of cellulose. When the wastes from the ethanol production were rich with nitrogen (100 g waste/88–92 g of betaine and amino acids, and 4–5 g of albumen and peptides) the composting process parameters were different when applying one or other *Trichoderma* strain. Possibly, the different cell metabolism and more or less favorable growth conditions elucidate these results. Applying *Tr. viride* in composting media the C:N ratio was 25–30. Nitrogen was not inhibited and that provided the increase of microorganism growth and thus composting process become more efficient. The quality of the compost applying *Tr. viride* possibly is be better than in case of *Tr. lignorum*.

Analyzing the samples of compost with *Tr. viridae* and/or *Tr. lignorum* by means of IR-spectroscopy the characteristic absorption bands were identified in the region 700-900 cm^{-1} - two separate lines. Even that the intensity of these lines is not very strong, they are characteristic, as are not influenced by absorption of other components. Intensity changes and shape of these lines allow to evaluate the growth intensity of strains and to determine the prevailing strain. Comparison of IR spectra of two samples with *Tr. viridae* and *Tr. lignorum* showed that under composting conditions *Tr. lignorum* prevails, but the growth conditions are more suitable for *Tr. viridae.* Changes in the number of total bacteria cell count was in good correlation with the IR-spectroscopy results and once more proved that our isolated fungi strain *Tr. lignorum* is the most active splitter of cellulose substrates. The active destruction of sawdust considerably increased the total carbon content and thereby the C:N ratio would reach approx. 99. Such high rate of C:N inhibited the utilization of nitrogen and the growth of microorganisms and their biomass considerably would decrease.

New approach in compost quality assessment was application of Toxikit microbiotests. It was shown that the strain - splitter of cellulose – *Tr. lignorum* in the compost accumulates the toxic substances, inhibiting usage of nitrogen and simultaneously the growth of microorganisms. The quality of the compost applying *Tr. viride* possibly is be higher than in case of *Tr. lignorum.* These results were in good agreement with the previous results of IR-spectroscopy and microbiological analyses. Our experimental studies showed that it is very important to determine and form the “composting mass” with optimal concentrations of organic wastes, added nitrogen and also cellulose splitters and nitrificator association. Of essential importance is the optimal rate of raw materials and additives to provide efficient composting and promote the growth of microorganisms

Taking into account the results of the reporting period further investigations are planned to determine the conditions of aerobic fermentation/composting providing the necessary compost quality. The usefulness and possibilities to apply *Trichoderma* strains during composting will be evaluated. Furthermore, more detailed experiments optimizing anaerobic digestion process (as first stage for biofertilizer production) should be continued in the Baltic States.

The experimental work in all countries was in agreement with the Guidelines, ISO standards, patents and information from the Internet (see p.16, References, and Addendum).