Features of the industrial composting implementation of organic waste in St. Petersburg

K G Kuznetsova, O I Sergienko, N R Molodkina and N V Kurnikova
Faculty of Biotechnologies (BioTech), ITMO University, 191002 St. Petersburg, Russia
kgkuznetsova@itmo.ru

Abstract. Relevance of the work is due to a lack of developed infrastructure in Russia for processing organic waste by composting to obtain high-quality organic fertilizer. The authors reviewed the Best Available Techniques (BAT) reference books for industrial composting. Based on the literature review, visiting the solid waste landfill and the waste processing station, two technologies were proposed for consideration: open and closed composting of organic waste. The performed ecological and economic analysis has appealed that the most effective option for processing organic waste is the use of closed composting technology in the aerobic bioreactor. The article substantiates the expediency of creating an infrastructure for industrial composting of organic waste.

1. Introduction
Russia lacks a developed infrastructure for processing of organic waste by composting. There is another, no less significant problem of the modern management of natural resources associated with human activities – the degradation of the soil cover. With the depletion of reserves of humus and biophilic elements, organic and mineral nutrition of the soil biota is disturbed in soils, general biological activity and soil fertility are disturbed; soil resistance to erosion, chemical and bacterial pollution is reduced.

Issues related to various aspects of industrial composting were considered in the research works of G. Yu. Rabinovich, A. G. Shestakov, V. Yu. Starostina, R. A. Uvarov, F. C. Miller, M. P. Bernal, and others [1-6]. To date, the environmental and economic aspects of composting waste of the agro-industrial sector are covered in a rather wide range of works, in contrast to the aspects of composting the organic fraction of municipal solid waste (MSW). However, these works can serve as an excellent foundation for considering the introduction of commercial composting of organic fraction of MSW. This approach can increase the output of organic fertilizers and help in creation of infrastructure for the treatment of organic fraction of MSW, which amounts up to 25% in the Russian cities [7]. During the last decade the organic fraction includes not only food waste but also biodegradable polymers.

Composting is carried out mainly on those organic waste that has been collected separately from other waste (selective collection) in special containers for this type of waste. Compost is used in agriculture, because it is of high quality and does not contain harmful substances [7, 8].

Annually in St. Petersburg in secondary education institutions such as schools, preschool educational institutions, as well as in catering establishments, about 292 thousand tons of organic waste are generated annually, which potentially can serve as raw materials for compost production (Table 1) [8].

As the first assumption, to provide further economic justification for the construction of a station for industrial composting of waste, it is proposed to use 5% of the total organic fraction of municipal solid waste with a share of 25%, which amounts to 14.1 thousand tons of waste [7].
Table 1. MSW generation from the considered categories of organizations.

| Organization category       | Unit     | Value | Average area, m² | Total amount of MSW, thousand tons/a |
|-----------------------------|----------|-------|------------------|--------------------------------------|
| Catering establishments     | thousand items | 8     | 200              | 843.2                                |
| Food stores                 | item     | 27    | 800              | 5.83                                 |
| Educational establishments  | thousand people | 507   | -                | 90.78                                |
| Total amount of generated organic waste |         |       |                  | 939.61                               |

The main waste disposal method in Russia is burial. From an environmental point of view, waste disposal at solid waste landfills is unacceptable for several reasons:

- loss of nutrients that can be reused.
- organic waste is the main source of sanitary and epidemiological danger and unpleasant odours; therefore, before sending waste to the landfill, it is necessary to extract the organic fraction from it, which must be subjected to biological treatment or composting [10].

The organic fraction of waste is a favourable environment for the active reproduction of flies, cockroaches, and rats, vectors of dangerous diseases and pathogens. For this reason, the organization of work on the disposal of organic waste – collection, removal, processing, and disposal – should be carried out according to a strict schedule and as soon as possible, until the process of decay and fermentation begins. Collection and removal of food waste should be carried out in special bins and containers, which, if necessary, are hermetically sealed [11].

Based on data from bibliography sources, an ecological and economic analysis of the considered technologies of industrial composting was carried out. The methodological basis of the study consists of the application of the ecological and economic substantiation of industrial composting technologies and the choice of technology in accordance with the BAT principles.

The theoretical relevance lies in determining the conditions under which large-scale use of compostable polymer materials is environmentally sound. Practical significance is in carrying out a comparative analysis of common technologies for industrial composting of organic waste and choosing the most effective one for creating an infrastructure for processing organic waste.

To determine the most environmentally and economically feasible technology for industrial composting, Russian information and technical guides on the best available technologies were previously studied. For the calculation and comparative analysis, the two most common in Russia and abroad technologies are proposed: Project No. 1 – medium-level technology – composting in open areas and Project No. 2 – technology of closed composting of organic waste in bio-drums [9, 12].

When composting in piles, considered in Project No. 1, the raw materials – organic waste, are stacked in piles with a width of 3-6 m, a height of 1.5-3 m, the length of the pile can be arbitrary. Aeration is carried out by turning the compost material with the help of a special agitator – inverter. Duration of composting is 2-4 months, depending on weather conditions [13].

Composting in a drum bioreactor, which is proposed for Project No. 2, is a technology of a higher level, the process duration is reduced to 3 days, due to continuous aeration, temperature control, and carbon dioxide release. An important stage is the process of maturing the compost in heaps to stabilize it. The compost ripening period is 7-10 days [4, 14].
3. Results
To determine the most cost-effective project, the calculation of capital and operating costs for installations, equipment, and technical means was carried out, based on the features of each technology.

The estimated volume of the finished product for both projects will be 28.2 thousand m³ or 8.45 thousand tons.

The average market value of the finished compost ranges from 60 to 103 USD per one ton. The price of compost for the implementation of Project No. 1 will amount to 90 USD, and that for the implementation of Project No. 2 – 103 USD. Firstly, this is due to the relatively high capital expenditure for Project No. 2. Secondly, this is because the second project proposes the use of a higher-level technology; therefore, the quality of the final compost after the drum reactor will be higher.

The calculated economic indicators are shown in Table 2 and Figure 1.

Table 2. Economic indicators of the technologies under consideration.

| Economic indicator                                | Value                      |
|--------------------------------------------------|----------------------------|
| Project No. 1                                    | Project No. 2               |
| General investment (I₀), USD/year                 | 606721.82                  | 949837.13                  |
| Operating costs, USD/year                         | 315776.89                  | 262140.4                   |
| Net annual savings (B), USD/year                  | 400336.09                  | 563583.25                  |
| Payback period (PB), years                        | 1.51                       | 1.77                       |
| Dynamic payback period (DPB), years               | 2.35                       | 2.25                       |
| Net present value (NPV), USD                      | 692683.56                  | 955959.15                  |
| Profitability index (PI)                          | 1.14                       | 1.01                       |
| Internal rate of return (IRR)%                    | 28                         | 27                         |
| Cost of 1 ton of the finished compost, USD        | 77.56                      | 90.49                      |

With relatively high capital expenditures for the Project No. 2, the volume of operating costs is lower by almost 4.2 million roubles. This is due to the high costs of fuel for technical equipment during the implementation of Project No. 1. For both projects, the indicator of IRR is above 20%; hence, both projects are profitable and cost-effective.

When determining the environmental efficiency of the projects, the volume of the generated greenhouse gas CH₄ methane was considered for each project. Methane is the most dangerous greenhouse gas; therefore, according to the legislation, a fee for negative environmental impact is set in the amount of 1.76 USD per one ton [15].

Composting is an aerobic process, therefore, the volume of methane generated will be significantly lower than with an anaerobic process, but with a free oxygen concentration of < 5 %, anaerobic zones may appear in the compost system.

According to the literature data, during the decomposition of 1 kg of organic waste at the landfill, 77.26 g of methane (CH₄) are formed; therefore, 14094 tons of waste will release 1120 thousand tons of CH₄ [16]. According to the data obtained in the works of Sanchez A. et al., when composting in an open way, about 3.28 kg of methane is formed from 1 ton of organic waste, and when composting in closed drum-type bioreactors – 0.26 kg. Based on the literature data, the volume of methane emissions for each project was calculated (Table 3, Fig. 2) from 14094 tons of organic waste [17].

The payment for the annual volume of methane emissions will be 97.1. USD per a year for the Project No 1 and 6.3 USD for Project No 2. Based on calculations of methane emissions during composting of organic waste at open and closed-type units, it can be concluded that composting of organic waste in closed-type reactor, which is used in Project No. 2, proceeds more evenly in aerobic conditions, and, therefore, it is more environmentally efficient.
Figure 1. Comparison of the economic indicators of the Projects No. 1 and No. 2.

Figure 2. Specific methane emissions within the projects, kg CH$_4$ per one ton of compost.

Table 3. Calculation of methane emissions for the Projects No. 1 and No. 2.

| Parameter                                      | Project No. 1 | Project No. 2 |
|------------------------------------------------|---------------|---------------|
| Output of methane from one ton of raw materials, kg | 3.28          | 0.26          |
| Total output, tons/year                        | 46.228        | 3.664         |
| Specific methane production per one ton of finished compost, kg CH$_4$ per one ton of compost | 5.5           | 0.41          |
4. Conclusion
Within the framework of this work, environmental and socially significant issues of processing organic fraction of the municipal solid waste have been considered. The necessity of creating a special infrastructure for processing the organic fraction of waste into a safe and hygienic organic fertilizer (compost) has been substantiated.

It is found that composting in drum bioreactors is the most environmentally and economically viable way of processing organic waste. This technology complies with the BAT principles and is recommended for implementation.

The widespread replacement of traditional plastics with compostable ones is not well developed in our country. The use of compostable packaging materials is environmentally and economically justified only if the infrastructure for processing organic waste into safe fertilizer is created.

The creation of an infrastructure for industrial composting of the organic fraction of municipal solid waste will increase public interest in environmental issues, will become the foundation for the introduction of widespread waste processing, and will allow solving important problems: obtaining organic fertilizers, reducing the anthropogenic impact of MSW on the environment.

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