Development and study of automatic monitoring system of temperature and humidity in a bioreactor

I V Volkov¹, M P Kuhktik¹, N I Lebed¹ and A M Makarov¹,*

¹Volgograd State Technical University, 28, Lenina Avenue, Volgograd, 400005, Russia

*E-mail: amm34@mail.ru

Abstract. The aim of this work is to develop the automated system of organic waste processing. The existing devices have been analyzed and their disadvantages have been revealed with the aim to create more perfect system. The construction of robot system of organic waste processing has been developed. A mathematical model of physical processes inside a bioreactor has been developed. Optimal parameters for effective, fast and high-quality conduct of the process have been revealed during the modeling. The experimental plant has been created for carrying out the study. All that allows to create modern, functional and autonomous system, which will meet all requirements of environmental security.

1. Introduction

There is many technologies of organic waste processing in the world practice. However, application of most of them leads to accumulation of gaseous, liquid and solid components, which cause inconvertible environmental intervention, in nature.

Creation of technologies of organic waste processing, which meet the following principles, is way out:

- nearly complete return of waste components to industrial and agricultural production;
- creation of marketable and valuable products, which are able to offset the costs, as a result of processing.

Vermicomposting is a technological process when population of technological earth worms is used for organic materials processing (usually organic waste) into material like a humus, which is known as a vermicompost. Its aim is to process a broad range of organic waste and to get organic fertilizers for improvement of soil fertility and plant cultivation [1, 2].

It is necessary to choose suitable kind of compost worms for keeping and maintaining of a vermiculture. It needs to observe the following five conditions for their successful cultivation:

- to create «friendly» ambient for compost worms, which is usually called base substrate or supporting substrate, which must differ in high level of absorbing capacity, good incompactness and required carbon to nitrogen ratio;
- to have source of food or feed, which is called feeding substrate, which can be dunnage cow manure, horse and swine manure, poultry manure, potato waste, food waste, brewery waste, spent mushroom substrate, municipal plant waste, sewage sludges (at that it is necessary to study features of application of each kind of feeding substrate);
- to maintain optimal humidity of habitation substrate;
• to create optimal aeration;
• to maintain optimal temperature.

The main control parameters are temperature and humidity in a bioreactor.

Most methods, which are used in modern systems of organic waste processing, are harmful enough for environment and activities of the human being. The most acceptable and safe methods are unprofitable and not always beneficial. Therefore, now one of tendencies is a search of safe and at the same time profitable processing method. This will have a positive impact both on ecology and human health and on the issue of waste storage.

2. Robot system of organic waste processing

Several key disadvantages were mentioned during studying the devices of organic waste processing [3-5]:
• Working area height for supply of feed by manual method is significantly reduced at the expense of increase of feeding area height.
• System of gantries hinders gathering both of a biohumus and worms due to presence of support stands significantly.
• High labor costs of staff in relation to necessity of low speed bursting of a surface layer.
• High degree of some devices metal intensity.
• Low degree of process automation.
• Low quality of processed raw material and high reject rate.

The essence of the proposed utility model is explained by figure 1, at which the scheme of fermenting device construction is represented [6].

![Figure 1. The fermenting device.](image)

The fermenting device is the bioreactor 1, which walls are made of concrete, which has at least two layers of waterproofing. The device of air supply 2 consists of the non-lube compressor 3 with the receiver 4, the main electric valve 5 and the air-preparation unit 6. The bioreactor 1 contains the area of raw material processing 7, in the lower part of which the pipeline system 8 with the distributive electric valves 9 and the air metering devices with the compensated emitters 10 is. The gantry robot 11 is located at the rails 12, which are installed at the longitudinal walls of the bioreactor 1, and contains the control unit 13. The temperature measuring device 14, which is mounted on the probe 15, is located at the gantry robot 11. This device 14 consists of at least three heat sensors, which are located at equidistance from each other along the full length of the probe, which is installed with the possibility of cross movement along the overhead crane 16 and vertical movement with the help of the...
vertical traverse device 17. The ring 18 is installed at the vertical traverse device for cleaning of the probe from adhering.

The unique feature of this device is the probe, which was developed for measurement of temperature and humidity in the entire volume of a biohumus.

Also operation principle is represented at functional diagram of this device (figure 2).

![Functional diagram of the robot system of organic waste processing.](image)

**Figure 2.** Functional diagram of the robot system of organic waste processing.

Main units are the control unit and the control system. The control unit is connected with the displacement sensors (DS1-DS3), weight, temperature and humidity sensors (WS, TS1-TS5 and HS). The safety sensor (SS) interacts with the control unit as well. Signals from the position sensors come to cross, longitudinal and vertical drives.

The control system interacts with the control unit by wireless communication. Also data from the air temperature and humidity sensors (ATS and AHS) come to it for supply of optimal air mixture in the entire volume of a biohumus.

### 3. Modeling of physical processes inside a bioreactor

The 3D model of a bioreactor was created for more detailed consideration of its construction before beginning of laboratory prototype assembly. The model was built with the help of CAE subystem instruments of the SolidWorks CAD software (figure 3). It includes a wooden form, which is filled by a biohumus. A pipeline for supply of dry or humidified air is located along the form ground.
The first carried out experiment was test of temperature distribution in the entire volume of a biohumus. As it is seen from figure 4, optimal temperature of 36-37 °C is achieved when compressed air, which was heated to temperature of 55°C, is supplied under a pressure of 1.5 atmospheres.

Temperature versus time of a biohumus heating to optimal temperature was plotted according to the values obtained (figure 5).
As it is seen from the plot, time, which was spent from initial conditions to the achievement of optimal values, equals to 15 minutes. At that this result is achieved throughout thickness of a biohumus.

The next object of analysis is humidity distribution in the bioreactor. The data obtained are represented at figure 6. It is seen from this figure that uniform humidity within the range 30-40 % is maintained in the entire volume practically.

The experimental plant was made and assembled on the basis of the earlier created 3D model (figure 7). It includes the hopper with the platform, at which the linear bearings are fastened. The screwed shafts, along which the platform is moved, are installed in the bearings. The stepper motor transmits rotation to the shafts with the help of the belt-tooth gear, what puts the platform in motion. The servo drive, which moves the probe with the sensors, is installed at the platform.
Figure 7. The experimental plant.

The plant is a scaled-down model of the real device. In the following it is planned to use operation algorithms in real processes using similarity coefficient. The plant can be used for point watering of a biohumus [7].

4. Conclusion

The developed device has higher indices in contrast to analogues, namely high quality of output raw material, low reject rate, high level of automation and low labor costs of staff. This increases speed of organic waste processing and economic efficiency of the process.

The next development stage can be change-over to multidrive steering gantry robot, which will secure steered measurement in point set at once in one operation along the supports at the expense of optimal control of manipulator with temperature sensors. At that set of optimal control problems of multidrive systems on one, several or complex optimality criteria of executed motion, which include energy efficiency, sensor acceleration, forces in drives etc., will occur.

5. Acknowledgments

The authors would like to acknowledge administrative and technical support, which has been provided by the Volgograd State Technical University.

The study has been carried out under the sponsorship of RSF (project No. 18-71-10069).

References

[1] Ali U, Sajid N, Khalid A, Riaz L, Rabbani M M, Syed J H and Malik R N 2015 Environ. Prog. & Sustain. Energy 34(4) 1050-1062
[2] Embalzado Jr E, Samaniego Jr L, Cortez Z, Justimbaste K G, Naidas J M L and Polido M C 2019 Proc. of IEEE 11th Int. Conf. on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (Laoag) 9072843
[3] Gao L, Lin Y, Lin H, Jia X, Lin J and Lin J 2014 Appl. Mech. and Mater. 472 171-175
[4] Lim K-T, Patel D K, Seonwoo H, Kim J and Chung J H 2019 Biochem. Eng. J. 150 107258
[5] Theodoropoulos C and Sun C 2019 Bioreactor Models and Modeling Approaches Engineering Perspectives in Biotechnology (Comprehensive Biotechnology vol 2) ed C Webb (Oxford: Pergamon) chapter 2.45 663-680
[6] Volkov I V, Makarov A M and Ermishov V V 2015 Useful model of the Russian Federation No 154518 IPC C05F3 / 06
[7] Makarov A M, Volkov I V, Khar’kin O S, Gladkov V M, Ivanyuk A K and Starkov V V 2018 Meas. Tech. 61(1) 37-41