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CONTROL OF HEAT COLLECTION AND AIRING PROCESS DURING COMPOSTING WITH COMPACTRIO CONTROLLER[1]

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ABSTRACT

Composting of biological waste constitutes an exothermic process. Some heat generated during composting is required to maintain the process and possible batch disinfection. The compost heap temperature increases often during the process up to 80ºC. According to the literature, the most advantageous composting temperature of the thermophilic phase is the temperature of 55ºC. However, excessive heat collection may be used at another location. Yet temperature inside the composting material shall not decrease below 50ºC as it may cause slowing down or even inhibition of the composting process. During composting, air supply (oxygen) is crucial to ensure optimum conditions for microorganism growth. Therefore the proper control of heat collection and airing process is required. The paper presents the fuzzy logic and LabView language based application that ensures control of the composting process. Conducted tests of the workstation and application confirmed heat collection of 101 MJ and pumping 0.68 m^3 of water.

Introduction

Composting relates to the natural process that enables processing of biologic waste and conversion into a natural fertilizer. Such a natural process follows spontaneously. However, in case of a large quantity of waste the process may be improved with some intentional actions. Composting process depends on the main three following factors.

C/N ratio of charge. Impact of this parameter on the composting process has been described in many papers – (Peigne, 2002; Rosik-Dulewska, 2010). The optimum carbon to nitrogen ratio during composting shall be between 25 and 35. If this parameter is out of this range the composting process will follow very slowly or release will follow of ammonia large quantity (Guo et al., 2012).

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Compost internal temperature. The temperature increase during composting relates to a natural process. Depending on the mass of the composted material, temperature of the composting bed may be over 80ºC. Proper temperature during composting process shall be approx. 55ºC, and at the same time, the higher the temperature the higher release of ammonia and carbon dioxide follows (Pagans et al., 2006), and on the second hand the decrease of the temperature results in slowing down the composting process and inhabitation in extreme cases as well.

Composting bed airing. In case of natural composting, airing follows during heap overturning provided on regular basis – and the composting process follows properly often also without overturning. Yet it results in the long total time of composting (often over 6 months). Intense airing shortens composting up to approx. 30-60 days depending on the composition and volume, and simultaneously reduces ammonia release (e.g. Yang et al., 2013). According to Wang et al. (2013) a single composting session takes a few weeks, around 60 days depending on the additives applied to improve compost properties. Whereas according to Guo et al. (2012) the composting process takes around 40 days. Excessively intensive airing causes the temperature decrease inside the bed and simultaneously reduces heap moisture – which results in a longer period of the composting process or inhibition of the process in extreme cases (Puyuelo et al., 2010; Kulcu and Yaldiz, 2004).

To sum up – for the proper composting process, the proper control should be provided regarding substrates/composition purposed for composting to ensure appropriate C/N ratio– it may also be improved with the use of special additives – (Dach et al. 2009) – although sometimes it may not be possible. Also proper temperature shall be maintained inside the bed – according to the literature the most advantageous temperature for the second (thermofilic) phase of composting is 55°C. The higher temperature ensures disinfection of the obtained humus (Lashermes et al., 2012; Raj and Antil, 2011) – but not all materials purposed for composting require disinfection, e.g. the agricultural industry wastes, mowed grass, fallen leafs etc. In case of composting this type of material, it is possible to collect the excessive heat to ensure internal bed temperature of 55°C, whereas the collected heat may be used at other location – e.g. for heating the ground of a greenhouse. Intensity of provided airing shall also depend on the phase of the composting process.

According to the above information, the following assumptions have been made regarding control – the input values included:

Internal bed temperature, intensity of heat collection and airing, and potential dependent output values included: intensity of airing and intensity of heat collection.

The designed control system was based on the fuzzy logic. The world literature included some examples of the fuzzy logic used for this purpose (Castelli and Ferrari, 2007). Whereas the fuzzy logic based control system for the composting process only has been referred to in other papers (Giusti and Marsili, 2010; Qin et al., 2007; Xi et al., 2008). The general input regarding the fuzzy logic based control systems has been described in many works, e.g. (Gerla, 2005; Mamdani, 1977; Muhamad and Ali, 2008) and many others.

The objective and the scope of the research

The objective of the paper was to provide the control system for the process related to heat collection, airing and the internal bed temperature based on the fuzzy logic, integrated with the process parameters archiving and performance verification.

Description of the control system structure

The control system has been based on fuzzy logic with the use of:

- CompactRIO NI 9024 controller, provided with an incorporated drive that cooperates with LabView based applications purposed for control, registration and analysis of the measurement data, as well as for uploading the control program, reading of the measurement data, fitted with USB port and RS232 serial port;
- Extension NI 9113, with FPGA system, fitted with 4 slots for any cRIO module and possibility of automatic control, as well as signal conversion with LabView.
- 2 multi-function modules NI 9217 to be connected to Pt 100 sensors
- NI 9381 module, with 8 channels 12-bite analogue inputs, from 0V to 5V where an inverter and a flow meter are to be connected;

The application was developed with LabView 2012 software. The first step is related to programming of all above mentioned elements of a driver. After selecting PPM option, drop down menu of Project Untitled is displayed, where you can add CompactRIO NI 9024 controller and then add Reconfigurable Embedded Chassis NI 9113. Next insert twice NI9217 module.

NI 9381 module shall not be inserted to the software in the same way as NI 9217 modules.1

To use NI 9381 multifunction module, firstly FPGA Target should be defined. Upon system configuration regarding hardware proceed to create a new Virtual Instrument (VI).

NI 9381 module subprogram

As NI 9381 module is fitted with analogue inputs and outputs, as well as digital inputs and outputs, an additional control subprogram need to be developed.

Flat Sequence structure is within While Loop – Fig. 1 – analog.vi. Sequence follows with four steps:

1. Time loop – 500 ms
2. Functions FPGA I/O NODE, to which specific inputs were assigned. Elements that control inputs are the outputs of analogically controlled devices. The value of device analogue output will be inserted at Numeric Control (in airing, in heat collection).
3. Time loop – 500 ms, ensures conversion from analogue into digital of the input data and conversion from digital into analogue of the output data. Interrupt – makes for the key element of a subprogram. Actually it is a simple alternative of FIFO for data transfer to a proper software. When a signal is present in the second sequence, next activation follows of Interrupt which enables the data transfer to the proper program. Next the proper program upon logic functions completion provides for data conversion and sends data back to Interrupt, which gives approval and sends data to the analogue device outputs (fourth sequence).

4. Functions FPGA I/O NODE, to which specified outputs are assigned. Control of outputs is provided with inputs of the analogue controlled devices. Value of analogue device input is shows on Numeric Control (out airing, out heat collection).

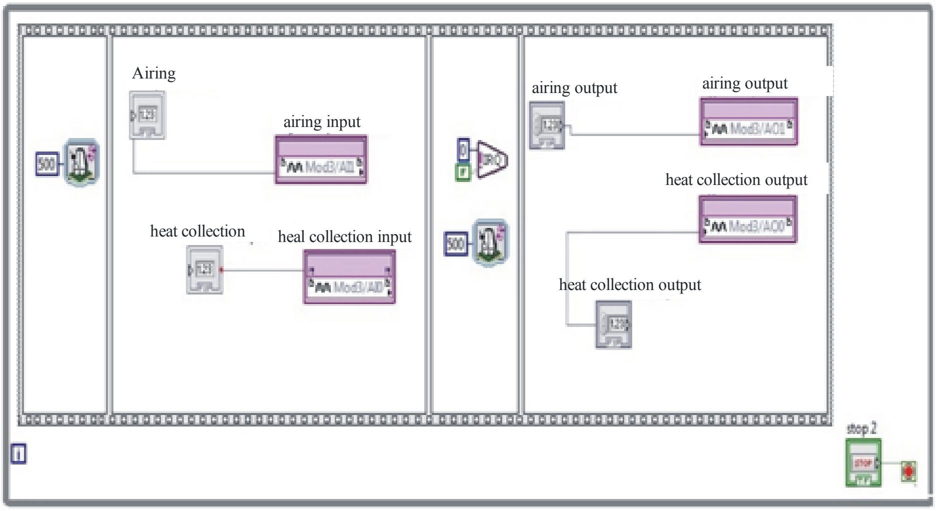
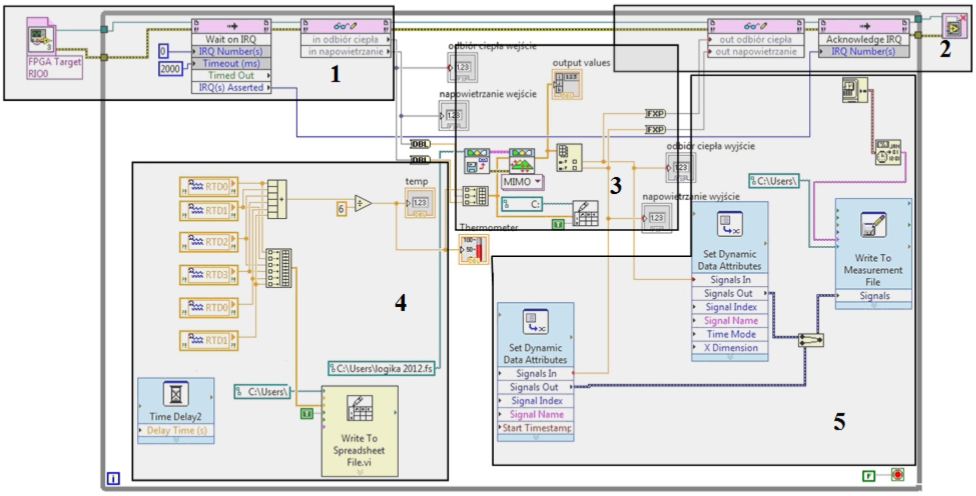


Figure 1. NI 9381 module control subprogram

Core control application

Figure 2 describes the core control application.



Source: Own graphics prepared with LabView software

Figure 2. Core application

For the purpose of transparency, the application was divided into 5 areas which were described one by one. Figure 2 related to 1 area and FPGA Target sequence (Open FPGA VI Reference), which enables data transfer activation from the subprogram (Figure No. 1). When connected to Invoke Method it plays a function of waiting for Interrupt (waiting until data appears for conversion). Read/Write Control ensures reading of input data.

The software part covered with area no. 2 Read/Write Control provides recording of outputs in charge of airing and heat collection, whereas Invoke Method ensures approval for transfer of the proper data sent to the Subprogram on inputs of the analogue devices. Close FPGA VI Reference closes the communication between the Subprogram „analog.vi”. Open and Close FPGA VI Reference are outside structure of While Loop and are used only during new activation of software and deactivation.

Heat collection, input/output and airing input/output make for the Numeric Indicator blocks located within area no. 3 that display values of input and output on analogue channels of controller. Data from heat collection and airing input is transferred to Build Array table along with an average of six temperature sensors inside bioreactor. Values from table are saved in Write To Spreadsheet File block on spreadsheet. Next dataset is forwarded to FL Fuzzy Controller that plays a function of a regulator and converts data on the basis of the inserted principles. The recorded principles are taken up from external file with the use of FL Load Fuzzy System. Upon leaving the regulator data is sent to Index Array block, which breaks up the structure of spreadsheet for particular data. Output values ensure displaying of output data, for the purpose of verification at this phase.

Elements within area no. 4 – Time Delay2 is in charge of the application operation interval. Outputs of pt100 resistance sensor temperature from two analogue NI9217 modules, send values of temperature to the Compound Arithmetic block, where summing follows, and then are forwarded to Divide function where are divided according to the number of temperature sensors. Before summing of temperature values, they are inserted on Array Table and recorded in a spreadsheet. Moreover graphic displaying was provided of average temperature with the use of the analogue thermometer and digital with the use of a numerical block. Area 5 – Set Dynamic Date Attributes assign a subheading for data. Current timer and date is assigned by Get Date block, and next Format Date changes data type into String. Output data is recorded with Write To Measurement File block.

Layout of input and output variable data sets, as well as the fuzzy logic principles set were used as referred to in the paper of Neugebauer et al. (2014).

Research results and analysis

Upon assembly of the workplace the test was carried out. The drum of a bioreactor was filled with water and heated with electric heater at ambient temperature of 20ºC. For the test water was used at quantity of 180 dm^3 at output temperature of 8.94ºC, heater 900 W. Water heating to temperature 55ºC took 15 hours. Heat collection followed for 40 hours. Upon 55 hours the heater was turned off and measurements followed during cooling – up to 70.5 h. The results were as follows:

– 101 MJ of heat collected on a cooling system;

– 0.687 m^3 – qty of water pumped by heat exchanger.

Figure 4, 5 and 6 presents diagrams of average temperature, airing and heat collection values during the test.

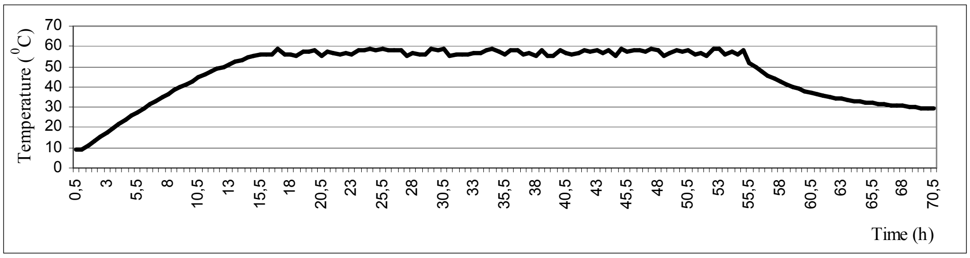


Figure 4. Temperature values in fermentation tank during tests with water

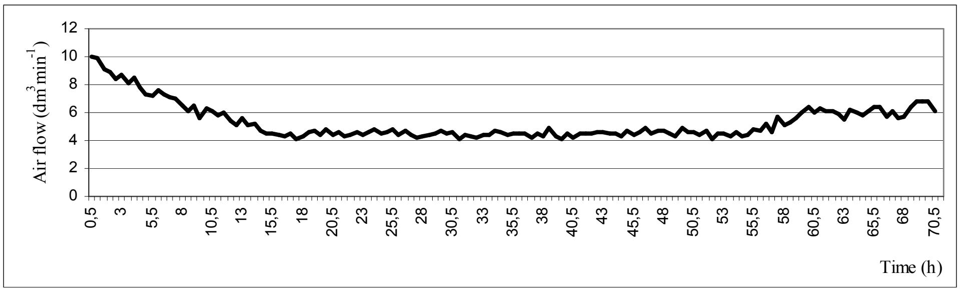


Figure 5. Intensity of airing in fermentation tank during tests with water

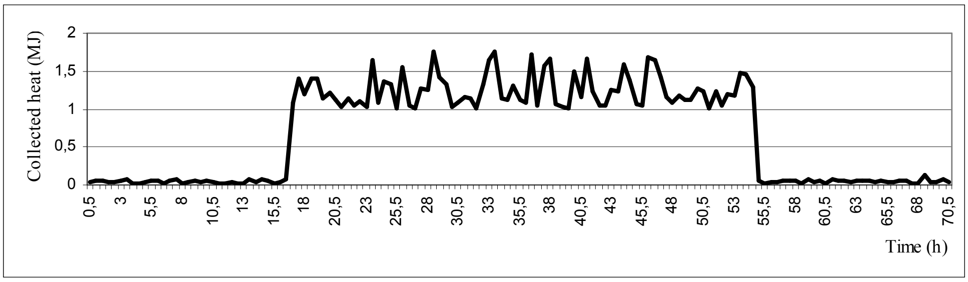


Figure 6. Heat collection in fermentation tank during tests with water

Conclusions

1. The conducted initial research indicated usefulness of the developed control system and application for control of biological wastes composting process.
2. For the purpose of full control over biological wastes composting process, sensors may be connected to the control system for the measurement of moisture and oxygen content in the air discharged from bioreactor.
3. Thanks to the use of CompactRIO controller and LabView software, possibility was ensured for smooth and quick modification of the control system parameters.

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STEROWANIE PROCESEM ODBIORU CIEPŁA I NAPOWIETRZANIA W PROCESIE KOMPOSTOWANIA PRZY POMOCY STEROWNIKA COMPACTRIO

Streszczenie. Proces kompostowania odpadów biologicznych jest procesem egzotermicznym. Część powstającego w procesie kompostowania ciepła jest potrzebna dla podtrzymania samego procesu i ewentualnej higienizacji wsadu. W pryzmie kompostu w czasie procesu temperatura wzrasta często do 80ºC. Według literatury najkorzystniejszą temperaturą kompostowania w fazie termofilnej jest temperatura 55ºC. Nadmiar ciepła może być jednak odebrany z kompostu i wykorzystany w innym miejscu. Nie należy jednak dopuścić do tego, aby temperatura wewnątrz kompostowanego materiału spadła poniżej 50ºC ponieważ może to spowodować zwolnienie lub nawet wstrzymanie przebiegu procesu kompostowania. W trakcie kompostowania trzeba dostarczać powietrze (tlen), aby zapewnić mikroorganizmom optymalne warunki rozwoju. Wynika z tego potrzeba sterowania procesem odbioru ciepła i napowietrzania. W pracy przedstawiono aplikację sterującą procesem kompostowania napisaną w języku LabView i wykorzystującą logikę rozmytą. W trakcie prób stanowiska i aplikacji, w układzie odbioru ciepła odebrano 101MJ ciepła i przetoczono 0,68 m^3 wody.

Słowa kluczowe: kompostowanie, sterowanie procesem kompostowania, logika rozmyta; odbiór ciepła