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Municipal organic solid waste composting: development of a tele-monitoring and automation control system

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Abstract. The Organic Solid Waste (OSW) generation have experienced high growth in the last decades. Moreover, the treatment and management of them have become a priority in the environmental policy of many cities, due to the sanitary and environmental problems related to the OSW elimination. Between 2 and 3 metric tons per day of organic residues are generated in the local market square of Fusagasugá-Colombia, without having any transformation program or technological alternatives for their decomposition. This paper presents the design and implementation of an experimental reactor for composting that includes a measurement stage, signal conditioning, data acquisition (DAQ), and data storage, together with a control and telemetric supervision system through a Human-Machine Interface (HMI), which allows manipulation of some key variables of the composting process remotely via the Internet.

Key words: compost, aerobic, municipal wastes, humane machine interface, telemetry, environment, process control.

INTRODUCTION

A compost is a material with plenty of plant nutrients, is very useful as organic fertilizer for soil crops, and is produced by the decomposition of organic matter from plant and animal residues, done by microorganisms in an adequate humidity, pH and oxygen environment.

In recent years, considerable studies have been done on organic solid waste composting. In (Xiao et al., 2017; Wu et al., 2019) a review of recent development in solid waste composting is provided. In (Petiot & de Guardi, 2004) a method of composting is presented to manage heat balance and oxygen and moisture supply to microorganisms. A similar method is introduced in (Kadir et al., 2016; Taeporamaysamai & Ratanatamskul, 2016). However, technological processes can improve production times or production quality (Rodríguez & Córdova, 2006; Gómez, 2017; Galeano, 2018). In (Peña, 2011), it is provided that to obtain a mixture with high energy content, it is needed an adequate proportion of materials with a rich content of Carbon and Nitrogen; then those materials are chopped to improve the speed of microorganism biodegradation (Ameziane et al., 2020). As can be seen, to improve the composting time and quality it is need to control the process.

In (Luo et al., 2014; Jiang et al., 2015; Avidov et al., 2017; Soto-Paz et al., 2019b) review of turning techniques are done, that is to say, the process that homogeneously mixes the organic matter, the substrate soil and the atmosphere inside the reactor, improving the chemical properties like pH and oxygen concentration and homogenizing the temperature in its thermophile phase. In (Xiao et al., 2017), a review of recent development in biochar utilization as an additive in organic solid waste composting has been presented. Furthermore, it is founded that biochar addition in composting can improve compost mixture properties and microbial activities, reduce greenhouse gas emissions and upgrade compost quality.

Although the compost of organic matter is a natural process, ideally the compost production should be a fast, low energy process with a hygiene standard in production (Alvarado, 2018). This is achieved by controlling important variables like aeration, Carbon-to-Nitrogen ratio (C/N) and temperature and humidity (Mayorga, 2016). In (Hemidat et al., 2018) it is monitored the bio-waste composting process in Jordan to evaluate the final product quality. This control process is monitoring the temperature, moisture and oxygen content of the reactor. The effects of using remote control on the biowaste compost quality can be found in (Lozada, 2020). It is shown that this method has improved the composting time as well as its quality. In (Soto-Paz et al., 2019a) an approach to optimize the biowaste composting using machine learning methods is presented. However, in the literature it can found a gap between control process and Human-Machine Interface methods to measure stages, signal conditioning, data acquisition (DAQ), and data storage, together with a control and telemetric supervision.

For this reason, in this study to improve the composting efficiency with a control and telemetric supervision system, a new HMI system applied to the Organic Solid Waste (OSW) reactor. Furthermore, this paper shows a process of characterization for the Organic Solid Waste (OSW) produced in the local market of Fusagasugá, with both plant and animal type of residues. Similar to (Yimy Garcia et al., 2014) in this paper the prototype construction and startup are done in three phases: The first phase is a preliminary research about quantification and characterization of OSW, and a basic prototype design. In the second phase, the basic prototype is built and first laboratory experiments are done. In the third phase, a final prototype reactor is built and the basic operation manual is written.

The results of experiment approved that the compost produced adequate physical characteristics and compost quality. Due to the precise control over the composting environment inside the reactor, the process time was reduced.

PHYSICAL DESIGN OF THE EXPERIMENTAL REACTOR

A preliminary reactor structure design is designed and implemented using CAD software. Then an instrumentation system is added to the physical reactor, together with a temperature and humidity control system and a HMI for remote adjustment and supervision of the system.

The physical design is based on a drum-type closed system (Peña, 2011), because this design allows process speedup compared with an open system exposed to the atmosphere and also allows a fine control of the environment inside the reactor chamber.

This design also has a blade system for mixture homogenization inside the reactor. This physical model is presented in the Fig. 1.

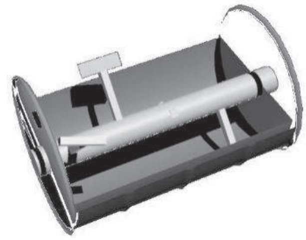

Figure 1. 3D model of the prototype reactor.

As presented in (Soto-Paz et al., 2019b), to improve the thermophilic phase peak, a reactor with a special rotation system can be used. In this rotation system a set of rotating opposite blades are connected to a rotating shaft in the center of the reactor. The 3D model of this system can be seen in the Fig. 2.

Figure 2. 3D model of the turning system.

Figure 3. Prototype reactor.

After confirming the results of simulations, the prototype reactor is built. In order to build this system, a 42 US gallons barrel with an isolated anti-corrosive coating is used as the reactor base. In this system, the rotating blades are made of 12-sheet metal and the rotating shaft is made of 2-caliber steel pipe (Fig. 3). Both the blades and the shaft have an isolated anti-corrosive coating.

ORGANIC MATTER TRANSFORMATION PROCESS

OSW characterization phase

To implement the composting process of the OSW produced in the local market of Fusagasugá, several methods for residue management are studied to get approximate characteristics and conditions of the generated OSW destined for a composting process. For the quantization and characteristics of the OSW a grouping based on the residue type (organic or inorganic) is done by using awnings, plastic bags, gloves, a scale, a residue crusher, the prototype reactor, a thermometer, a PH meter and a humidity sensor. The results are shown in the Table 1.

Table 1 shows that in municipal residues, the amount of organic waste is greater than the inorganic residues. The organic part includes shells, husks, fruits, vegetables, leafs, seeds and aromatic herbs. These residues are crushed to a size of 1 to 6 cm (Herodes et al., 2018). This allows a better decomposition of microorganisms, as well as homogeneous materials are also obtained at the end of the process.

Table 1. Results for separation and characterization of OSW

No. Garbage cans 3		Total weight: 140.35 kg
ORGANIC WASTE		INORGANIC WASTE
No. Weighing	Weight, kg	Type
1	14.3	Polystyrene, Plastic, Bottles
2	14.85	Metals, porcelains, cable
3	11.32	Paperboard and paper
4	15.79	wood
5	12.02	Others (soap)
6	12.54	
7	26.59	Total Inorganic Waste 9.43 kg
Leafs	22.43	
Animal waste	1	
Total organic waste	130.84	

In the Fig. 4, it is shown the separation and weighting process for OSW, for this step, it was necessary to use plastic bags, gloves and a scale.

Figure 4. Separation and weighing of organic residues.

At a municipal level, specifically for the OSW generation in Fusagasugá, according to studies of garbage collection routes done by the Fusagasugá public utility Emserfusa in 2011, each habitant generates 0.6 kg per day averagely. Comparing the characterization described before in Table 1 with the characterization at municipal level done by the integral solid waste management government program (in Spanish Programa gubernamental de Gestión Integral de los residuos Sólidos - PGIRS) in Table 2, both are similar although it is found that a bigger proportion of OSW is found in the local market.

Table 2. Municipal solid waste separation (Galeano Barrios, 2018)

Material	%
Recyclables material	
Plastics	6.03
Paperboard	1.98
Recyclable paper	11.35
Textile	0.11
Glass	11.35
Bone	0.18
Burnable material	0.0
Wood	0.84
Organic matter	64.67

Regarding the final garbage disposal, up until a few years ago, the town used a 7-hectare open-air landfill to store solid garbage generated by the residents. However, the Autonomous Regional Cundinamarca Corporation (CAR) canceled the authorization for garbage disposal in this site, attending to Resolution 1045 of 2003, which establish the shutdown of all open-air landfills. Later then, collected garbage is done in the Nuevo Mondoñedo landfill, with higher transportation costs for 72 metric tons a day of solid residues (Galeano, 2018).

According to the PGIRS (Galeano, 2018), the Fusagasugá city hall is wasting the opportunity to get additional income due to OSW recycling. It is shown that more than 55% of OSW can be recycled to produce useful materials for different productive sectors; some of them can be processed by different options like composting or biogas production.

Particularly, in the space study that is the local market called 'La Galería', the local waste disposal service company (Emserfusa) informs that about 2 to 3 tons of OSW are produced daily, and unfortunately, this company does not have a proper waste management and recycling program.

Crush and triturate phase of organic material

Particle size is a key factor at the beginning of microbiologic activity for composting process, and for the result of the processed compost. In a compost with homogeneous particle size and shape, the microorganisms have better capacity for organic degradation; bigger particles have little contact surface for the degrading action of microorganisms and extending the processing time. Ideal particle size is between 3 cm to 6 cm (Alcantara & Roxana, 2018).

Due to the size of the organic materials previously characterized in the previous step, in order to improve the microorganism decomposition, process the organic material must have a bigger contact surface (Malat'ák et al., 2016). For this purpose, the OSW must be crushed and shredded through some mechanical treatments shown in Fig. 5. Type and intensity of the mechanical treatment depends on the structure, shape and size of the residues.

Figure 5. Organic material crusher (left) and plant material disposed in the reactor (right).

Carbon Nitrogen ratio (C/N)

The two essential elements involved in the composting process are Carbon and Nitrogen; its correct balance allows getting a high-energy mix. In order to get this desired high-energy mix, an adequate proportion of materials rich in Carbon and Nitrogen. Eq. (1) allows calculating the weight proportion between Carbon-rich material and Nitrogen-rich material. Eq. (2).

$$^{\mathrm{C}}/_{\mathrm{N}} > 30 \tag{1}$$

$$^{\mathrm{C}}/_{\mathrm{N}} < 30 \tag{2}$$

$$x = \frac{(30 \cdot N_N) - C_N}{C_c - (30 \cdot Nc)} \tag{3}$$

where x = weight amount of Carbon-rich material; N_N = % of Nitrogen, in the Nitrogen-rich material; C_N = % of Carbon, in the Nitrogen-rich material; N_C = % of Nitrogen, in the Carbon-rich material; C_C = % of Carbon, in the Carbon-rich material.

The optimal Carbon-to-Nitrogen ratio (C/N) for composting process is 30 to 1. For experimentation, trials with rice husks was used with a C/N of 30.02.

$$x = \frac{(30 \cdot\ 2.12) -\ 44.07}{30.42 -\ (30\ \cdot\ 0.78)} = 2{,}782 \tag{4}$$

From the results shown in Eq. (4), a mix with a ratio of 2.8 weight parts of rice husks by 1 weight part of OSW must be used. However, the husk volume was not adequate and it gives a medium carbon contribution to the mix.

For the last two trials, a mix with sawdust gave excellent results because of their C/N ratio; sawdust has 51.90% of Carbon contribution.

$$x = \frac{(30 \cdot 2.12) - 44.07}{51.90 - (30 \cdot 0.06)} = 0.398 \qquad (5)$$

According to Eq. 5), a mix of 0.4 weight parts of sawdust by 1 weight part of OSW must be used. Using this mix, the sawdust gives an adequate volume for the compost and a high Carbon contribution to the mix, an essential element for microorganism energy source. Using sawdust, an initial C/N ratio between 25 and 30 can be obtained for the beginning of the composting process, enough to get a mature compost with a final C/N ratio between 12 and 15. It is said that a compost with a final C/N ratio below 12 is ideally used for agricultural use (Bazrafshan et al., 2016; Romero-Cuero et al., 2016).

Humidity - temperature behavior

Using two physicochemical variables, temperature and humidity, the composting process can be evaluated and controlled (Robledo, 2018).

As shown in Fig. 6, the comparison between a reference pile covered by plastic and the compost processed by the proposed reactor with the sufficient physical conditions for composting process are performed.

The results of the experiments show that the compost in the prototype reactor reaches a temperature of 60 °C, while this temperature reaches 55 °C by the reference pile. This temperature cannot be maintained for a long time, because when the temperature reaches 50 °C, the rotation process takes place in order to supply oxygen to the microorganisms of the compost (Benjawan et al., 2015). As can be seen in Fig. 6, the temperature stabilizes after 12 days.

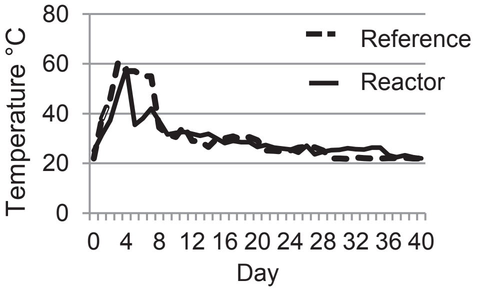

Figure 6. Composting Temperature vs Time.

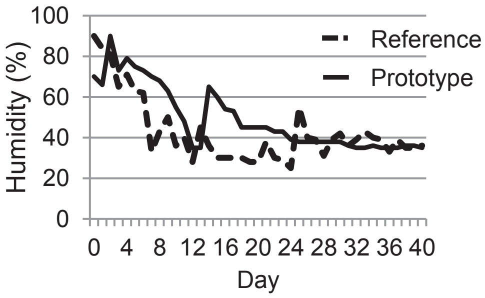

Figure 7. Composting Humidity vs Time.

As shown in Fig. 7, the humidity content of the materials used in the trials is high. However, from day 24 humidity in the prototype reactor is stabilized, as opposite to the reference pile that is stabilized up to day 38.

Physical Variables- Microorganisms Correlation

It is essential to correlate the Temperature (°C) and the amount of CFU g^{-1} of sample throughout the composting process. Due to this, a descriptive graph of the three phases of composting was made together with the Temperature reached in each of these as observed in Fig. 8.

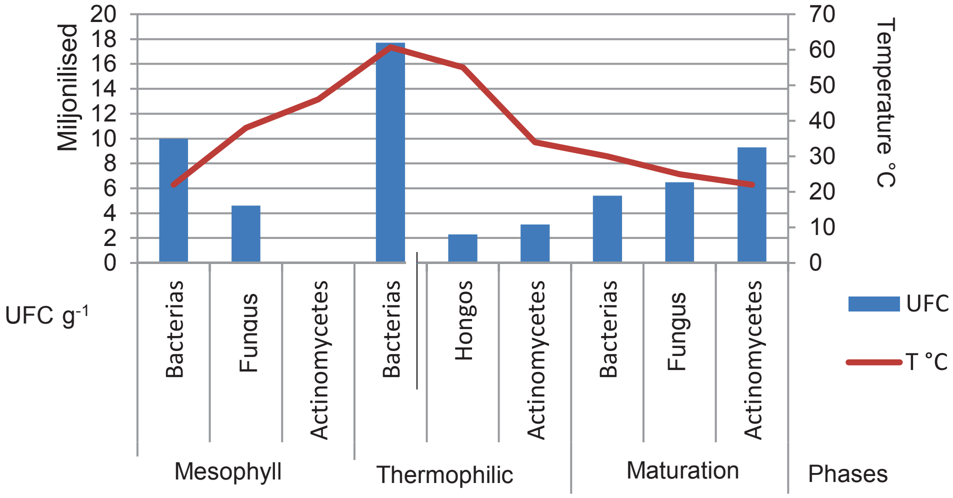

Figure 8. Compost temperature vs. Amount of CFU in each Phase.

In Fig. 8, the temperature line is starting with an ambient temperature where mesophilic bacteria and fungi initiate the degradation of organic matter until achieving homogeneity and accelerating the process during the first days. There the matter is acidified and the temperature later in the thermophilic stage reaches up to about 61 °C. When the temperature decreases, Actinomycetes continue to reproduce, unlike the bacteria that disappear due to the demand for food and energy that they suffered at the end of the thermophilic stage. The variation of temperature in the piles is one of the most important factors. In this study, the Correlation Coefficient (r) is 0.953. This value that is between 0.9 and 1.0 indicates that the variables Temperature and CFU g^{-1} are highly correlated.

TEMPERATURE AND HUMIDITY SENSORS

Instrumentation is a process based on the signal conditioning from the sensors used in a controlled environment. It is necessary to set the sensors optimal range of operation, with the maximum and minimum values. Once the sensors are selected for this application, sensor operation is analyzed and conditioning circuits for them are designed.

Humidity sensor

A common sensor is used to obtain humidity as shown in Fig. 9. Using this sensor, two parameters can be obtained namely the analog voltage corresponding to the humidity, and the digital output as an adjustable threshold.

Due to the high humidity content of the organic matter used in the prototype reactor, it is not necessary to use an additional system to supply water to the mix. However, a drying process controlled by HMI is required to reduce the humidity content of the mixture. The controller is such that an alarm is triggered when the humidity exceeds below the desired level (about 55%).

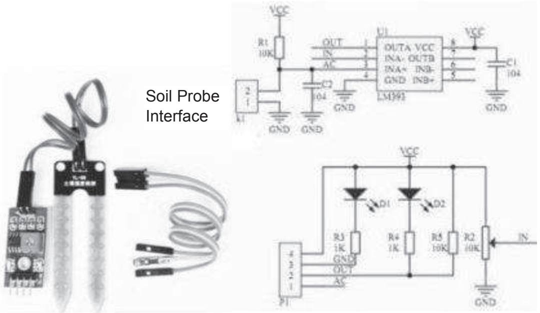

Figure 9. Humidity sensor used in the prototype.

Temperature sensor

A PT100 sensor is used due to its simple structure and lineal behavior. However a Wheatstone bridge is used, in order to increase its sensitivity (García, 2014). The 1NA106 is also used to amplify voltage of Wheatstone bridge. This amplifier has the ability to increase the voltage 10 times and is suitable for connecting this signal to a microcontroller or development board like Arduino.

Because the desired temperature of the organic matter is regulated by microbial action and artificial heating, a controlled water supply system using a 12-volt electric pump, along with a valve, a water tank and a nebulizer system are used to water the organic matter as homogeneous as possible. The control system of the water circuit is shown in the Fig. 10.

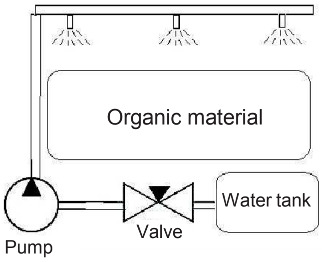

Figure 10. Irrigation system.

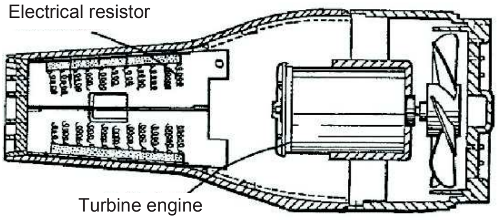

Figure 11. Temperature actuator.

A hot air circulatory system to perform the aerobic process. This system is responsible for controlling the oxygen level and temperature of the organic matter in the reactor. As can be seen from the Fig. 11, the heating system adjusts the system temperature using electrical resistors. These resistors can provide a maximum of 1,440 W of heat power and are controlled by a AC-AC PWM converter. In addition, using a turbine, airflow is created in the direction of the reactor.

The existence of this process with constant airflow and variable temperature over time is essential to accelerate the degradation of OSW.

Design and implementation of the temperature control

In the natural composting process, the temperature is not uniform. The higher temperatures are produced in the middle of the pile and lower temperatures at the ends. In addition, there is a maximum temperature difference in the thermophile stage. Asmentioned, the activity of microorganisms decreases at low temperatures. For this purpose, a temperature control system has been designed to maintain a constant temperature in all parts of the pile. In order to design the controller, the system under review becomes linear by using the IDENT tool in MATLAB (Fig. 12). As a result, the transfer function achieved and an appropriate PID controller with a delay time of 40 seconds designed to control the system (Fig. 13).

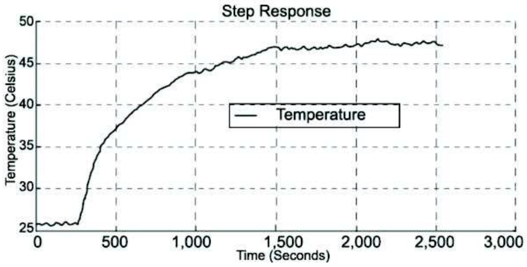

Figure 12. Step response for temperature.

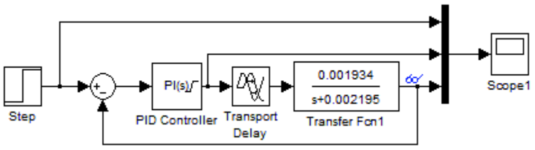

Figure 13. Simulink model controller.

HUMAN MACHINE INTERFACE (HMI)

The HMI for the reactor prototype is defined for monitoring and controlling the system parameters (airflow, watering and heating) via the Internet. The HMI diagram can be seen from the Fig. 14 and Fig. 15. In this study similar to (García, 2014), it is used Labview software to create HMI.

At the geographic location of the workshop, it is possible to use an Ethernet-based local area network (LAN) to connect the workshop and the Arduino module. For this purpose, a UDP-based communication is used because of its simple structure and fast response.

The sample time of the control system is 2 minutes, Due to the slow dynamics of the prototype reactor system. In addition, for the remote communication the 'Web Publishing Tool' tool of the LabVIEW is used. This tool runs a web server in the computer running the HMI that serves an HTML page with the same content visualized in the HMI. Therefore, users

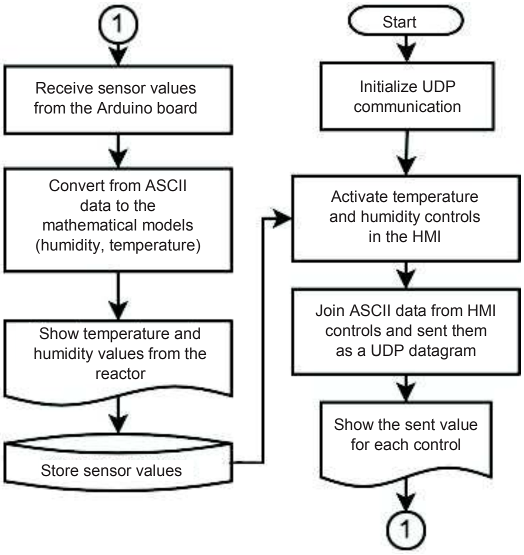

Figure 14. HMI Flowchart.

can view all stages of development in real time. The panel control viewed can be seen from the Fig. 16.

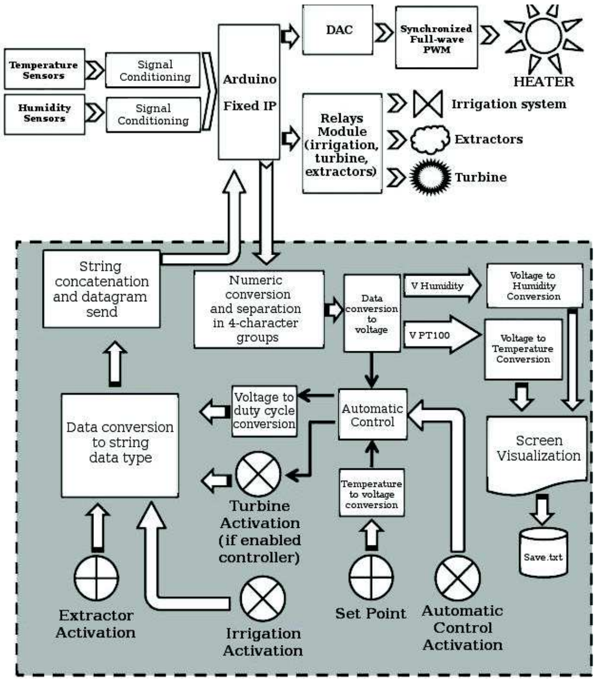

Figure 15. HMI Block Diagram.


Proceso De compostaje

Aqui su basura se convierte en abono

Figure 16. View of HMI control panel from a web navigator.

DISCUSSION

Microbiological analysis of the mesophilic phase for composting in the prototype reactor

Nowadays, composting process is a complex activity that farmers do to obtain an organic fertilizer. However, for agricultural use this fertilizer need a certain quality level that depends of, among many things, microbiological activity on the composting process. For that reason, in the non-industrial scale it is essential to know each composting phase and characterize the microorganism responsible of OSW decomposition process (Ahmadi et al., 2020).

In Table 3, it is shown the laboratory analysis results from the first phase of composting; these results are shown in terms of colony-forming units (CFU) for bacteria, fungus, pseudomonas and yeast. This analysis of the first composting phase, mesophilic phase, was done in the laboratory 'Dr. Calderón' in Bogotá D.C., Colombia on March 2014.

Table 3. Laboratory Analysis results mesophilic phase

Results No.	Scientif name	Population
1	Fungus	< 10 CFU g^{-1}
2	Yeast	11×10 E 7 CFU g^{-1}
3	Mesophilic Bacteria	24×10 E 7 CFU g^{-1}
4	Pseudomonas	17×10 E 5 CFU g^{-1}

In the Table 3 it is shown in detail that the result 3 from the mesophilic bacteria is the highest, meaning that these bacteria has the largest population measured in CFU in this phase. A brief explanation for this largest population is that these bacteria are responsible of the decomposition of lignin and other nitrogen-rich compounds to transform in Carbon. The thermophile bacteria use this Carbon in the next phase (thermophilic phase), those bacteria require high amounts of Carbon to raise the temperature in this phase. It must be noted that these bacteria are essential for initialize and activate all the process needed for composting, without mesophilic bacteria, it is impossible to degrade the organic matter.

The second highest microorganism population in terms of CFU for the first composting phase are the Pseudomonas. These microorganisms are important in the mesophilic phase for the decomposition of plant material like fruits, stems and leafs. It should be noted that pseudomonas also causes some plant diseases and those are initially found in past infected crops. Then in the thermophilic phase, its higher temperature (over 60 °C) kills the pseudomonas. Compost quality highly depends on this thermophilic phase because any pseudomonas that keep alive after this phase could cause plant diseases transmitted from the compost fertilizer.

Last in the result table, it is shown that both items 1 and 2 (fungus and yeast) had lower CFU because these microorganisms are not involved in organic matter decomposition and remain dormant until the decomposition of nitrogen-rich matter (Escobar et al., 2020). In the next two phases, it is observed an exponential growth of these two microorganism groups.

Quality and elaboration time of the compost

In order to check the quality and elaboration time of the compost, a comparison was done between a monitored conventional composting pile and the proposed prototype reactor with all the instrumentation, data acquisition and the manual turning mechanism. In many composting techniques it is unknown which microorganisms are responsible of organic material decomposition, and therefore the physicochemical factors involved in this process (Porras, 2016). Based on this, it can be said that the success in a composting process depends on the correct management of the physicochemical conditions inside the designed prototype reactor. A quality control analysis from a compost test produced was done; the results are show in Table 4.

The first quality parameter was the apparent density; according to (Storino et al., 2014) and its work on organic residue management, it can be considered that an ideal compost with adequate particle distribution and organic content had an apparent density between 0.2 and 0.5 g cm^{-3}. Compost produced in the tests done in the prototype reactor were around 0.2 g cm^{-3}, therefore it is in the ideal range.

The next quality parameter is the pH; measured values in the tests done were of 7.5, this value can be seen as near neutral or that it tends to neutrality. Moreover, in (Arregui Arellano et al., 2018) work about substrates composition in agriculture, they proposed that the electrical conductivity, as an indicator of salts concentration in a substrate for soil adjustment, should not exceed 100 dS m^{-1}. Measured electrical conductivity was around 23.8 dS m^{-1}, therefore it can be said that the compost met ideal characteristics by having low salt concentration, essential for a substrate used in agriculture.

Table 4. Compost Quality Control Analysis

Parameter	Value	Unit
Dry-Bulk Density	0.200	g cm^{-3}
Ph Satured paste	7.54	%
E.C Saturation Extract	23.80	dS m^{-1}
Moisture	31.89	%
Ashes	25.87	%
Acid Insoluble Residue	16.71	%
Cation-exchange capacity or CEC	31.19	meg/100
Total Nitrogen	1.47	%
Total Potassium	2.13	%
Total P2O5	0.68	%
Total MgO	0.44	%
Total K2O	2.56	%
Total CaO	1.98	%
Total Calcium	1.41	%
Total Magnesium	0.27	%
Total phosphorus	0.30	%
Sulfur	0.06	%
Boron	0.005	%
Cupper	0.001	%
Manganese	0.03	%
Iron	0.39	%
Zinc	0.007	%
Sodium	0.18	%
Total Oxidizable Organic Carbon	16.31	%
Carbon-to Nitrogen Ratio C/N	11.09	
Moisture Retention	147.58	%
volatilization losses	42.24	%

Another quality parameter is relative humidity; its measurement was found below 30% that means the substrate has an adequate stability conditions). Furthermore, mention the ash content that is related to mineral content, with an 18% being a good mineral content. Substrates obtained in the tests measured around 25.87% of ash content, which means a very good mineral content.

Regarding the Total Oxidizable Organic Carbon, the laboratory ‘Agrilab’ in Bogotá states that the minimum value for an organic fertilizer should be around 15%, elaborated compost in the tests is slightly higher showing adequate contents of humic and fulvic acids. In addition, about C/N ratio proposes a value between 25 and 30 as the ideal proportion. However, the elaborated compost in the tests had lower proportions and it was necessary to add carbon-rich materials like rice husks, sawdust or other materials with high carbon content. Quality measurement of this C/N ratio for the elaborated compost returned a value of 11.09. In (Ballardo et al., 2017), a compost reactor with enhanced biopesticide properties through solid-state fermentation of biowaste is presented. The process time of this reactor is about 50 days to reach to its ideal results. In (Zhang & Sun, 2016) the bacteria and fungi peak values can approximately reach to

19 ($\log_{10}$ CFU g^{-1}) and 10 ($\log_{10}$ CFU g^{-1}). The time needs to reach the final result in (Jalili et al., 2019) is about 60 days. in the mentioned study, the PH value after composting process the PH value finds a value of approximately 7.75. Furthermore, the C/N ratio has a value of 13. By comparing the results obtained in this investigation with the mentioned studies, it can be find that by applying the proposed control method in compost production, not only the time required for compost production is reduced but also the quality of the obtained results is improved. These benefits will also reduce energy consumption and improve the overall efficiency of the system.

CONCLUSIONS

This paper showed that the implementation of a closed system for compost elaboration minimized the climatic induced variations compared to the traditional composting piles. The installed controller could reduce the temperature variations inside the experimental reactor due to the composting process. Continuous measurement and data storage of the temperature and humidity by the HMI showed that environmental conditions affect organic material inside the reactor, particularly in the compost surface regions.

The experiment approved that the compost produced in this project maintained adequate physical characteristics like smell, color, C/N ratio and particle size; and it could be stated that this compost had a high quality standard. Because of the precise control over the composting environment inside the reactor, the process time was reduced up to 30%; from 65 days on the reference pile to 45 days in the experimental reactor. Furthermore, microbiological analysis performed from samples of experiments made in the prototype reactor showed the presence of bacteria, fungus and particularly actinobacteria; essential microorganisms for the decomposition process involved in quality composting production. This was evidenced by the laboratory analysis done in the certified laboratories 'Dr.Calderón' in accordance with the national standard NTC5167.

This project demonstrated to the local merchants of the local market 'La Galería' that it is possible to reduce the environmental impact due to the organic residues produced there. Future work will be focused in the automation of the turning process, the design and implementation of a large-scale reactor and the implementation of an OSW management program for the Fusagasugá local market 'La Galería'.

REFERENCES

Ahmadi, T., Casas, C.A., García Y.E. & Escobar, N. 2020. Prototype reactor to compost agricultural wastes of Fusagasuga Municipality. Colombia. *Agronomy Research* **18**(2), 314–323.

Alcantara, I. & Roxana, J. 2018. Efficiency of the treatment of organic livestock residues in composters by means of efficient micro. *Revista Chilena.* **34**(2), 59–98 (in Spanish).

Alvarado, R.L. 2018. Managment of poultry by composting. *Rev. PuertoNol* **2**(5), 131–134 (in Spanish).

Ameziane, H., Zouahri, A., Khamar, M. & Nounah, A. 2020. Composting olive pomace: evolution of organic matter and compost quality. *Agronomy Research* **18**(1), 5–17.

Arregui, M.J., Alcívar, M. & Indelira, M. 2018. E Evaluation of bio-fertilizers obtained from animal waste from the Camal Municipal de Guaranda, Escuela Superior Politécnica de Chimborazo. *Revista UMNG* **3**, 81–94 (in Spanish).

Avidov, R., Saadi, I., Krassnovsky, A., Hanan, A., Medina, S., Raviv, M., Chen, Y. & Laor, Y. 2017. Composting municipal biosolids in polyethylene sleeves with forced aeration: Process control, air emissions, sanitary and agronomic aspects. *Waste Management* **67**, 32–42.

Ballardo, C., Barrena, R., Artola, A. & Sánchez, A. 2017. A novel strategy for producing compost with enhanced biopesticide properties through solid-state fermentation of biowaste and inoculation with Bacillus thuringiensis. *Waste Management* **70**, 53–58.

Bazrafshan, E., Zarei, A., Mostafapour, F.K., Poormollae, N., Mahmoodi, S. & Zazouli, M.A. 2016. Maturity and stability evaluation of composted municipal solid wastes. *Health Scope* **5**. doi: 10.17795/jhealthscope-33202

Benjawan, L., Sihawong, S., Chayaprasert, W. & Liamlaem, W. 2015. Composting of biodegradable organic waste from Thai household in a semi-continuous composter. *Compost science & utilization* **23**, 11–17.

Escobar, N., Arenas, N.E. & Marques, S.M. 2020. Characterization of microbial populations associated with different organic fertilizers. *International Journal of Recycling of Organic Waste in Agriculture* **9**(2), 173–184.

García, M.Á.P. 2014. Electronic instrumentation. Ediciones Paraninfo, pp. 8–11 (in Spanish).

Gómez, L.J. 2017. Use of recyclable solid waste in the municipality of Pereira. *Revista Luna Azul* **8**, 101–113.

Garcia, Y., Restrepo, C.C. & Cedeño, K. 2014. Design of a telemetric monitoring system for temperature and humidity in an experimental prototype compost manufacturing plant. *INTERCON* 14, pp. 18–21 (in Spanish).

Hemidat, S., Jaar, M., Nassour, A. & Nelles, M. 2018. Monitoring of composting process parameters: A case study in Jordan. *Waste and Biomass Valorization* **9**, 2257–2274.

Herodes, K., Haiba, E., Nei, L., Lillenberg, M. & Ivask, M. 2018. On the degradation of metformin and carbamazepine residues in sewage sludge compost. *Agronomy Research* **16**(3), 696–707.

Jalili, M., Mokhtari, M., Eslami, H., Abbasi, F., Ghanbari, R. & Ebrahimi, A.A. 2019. Toxicity evaluation and management of co-composting pistachio wastes combined with cattle manure and municipal sewage sludge. *Ecotoxicology and Environmental Safety* **171**, 798–804.

Jiang, T., Li, G., Tang, Q., Ma, X., Wang, G. & Schuchardt, F. 2015. Effects of aeration method and aeration rate on greenhouse gas emissions during composting of pig feces in pilot scale. *Journal of Environmental Sciences* **31**, 124–132.

Kadir, A.A., Ismail, S.N.M. & Jamaludin, S.N. 2016. Food Waste Composting Study from Makanan Ringan Mas. *IOP Conference Series: Materials Science and Engineering* **136**, 012057.

Lozada, P.T., Rebellón, L.F.M., Giraldo, C.A., Zapata, K.F. & Paz, J.S. 2020. Effect of the incorporation of star grass on the improvement of the process and the quality of the bio-waste composting product. *Revista EIA* **17**, 321–325 (in Spanish).

Luo, W.H., Yuan, J., Luo, Y.M., Li, G.X., Nghiem, L.D. & Price, W.E. 2014. Effects of mixing and covering with mature compost on gaseous emissions during composting. *Chemosphere* **117**, 14–19.

Malat'ák, J., Bradna, J. & Velebil, J. 2016. Combustion of briquettes from oversize fraction of compost from wood waste and other biomass residues. *Agronomy Research* **14**, 525–532.

Mayorga, E.M. 2016. Acceleration and decomposition of organic substrates in compost making through the use of different substances (sugar, molasses, sugar cane). UTEQ **31**(1), 23–41 (in Spanish).

Peña, J.-R.A. 2011. How to make compost, Editorial Paraninfo, 106–111 (in Spanish).

Petiot, C. & Guardia, A. 2004. Composting in a Laboratory Reactor: A Review. *Compost Science & Utilization* **12**, 69–79.

Porras, Á.C. 2016. Use of organic agricultural and forestry waste in Ibero-America. *Revista Academia y Virtualidad* **9**, 6 (in Spanish).

Robledo, T. 2018. E iological indicators on waste water. *Journal of Alive Sciences* **14**,198–201.

Rodríguez, M. & Córdova, A. 2006. Municipal composting manual: urban solid waste treatment *Compostaje municipal* **9**, 131–133 (in Spanish).

Rodríguez, M. & Córdova, A. 2006. Manual de compostaje municipal: tratamiento de residuos sólidos urbanos. *Manual de compostaje municipal* **9**, 131–133 (in Spanish).

Romero-Cuero, J.M., Calderón-Maya, J.R. & Marmolejo-Uribe, A.M. 2016. Base Guidelines for Developing a Comprehensive Urban Solid Waste Management Plan in Ixtlahuaca, State of Mexico. *Quivera Revista de Estudios Territoriales* **18**, 89–115 (in Spanish).

Soto-Paz, J., Alfonso-Morales, W., Caicedo-Bravo, E., Oviedo-Ocaña, E.R., Torres-Lozada, P., Manyoma, P.C., Sanchez, A. & Komilis, D. 2019a. A New Approach for the Optimization of Biowaste Composting Using Artificial Neural Networks and Particle Swarm Optimization. *Waste and Biomass Valorization* **8**, 1–15.

Soto-Paz, J., Oviedo-Ocaña, E.R., Manyoma, P.C., Marmolejo-Rebellón, L.F., Torres-Lozada, P., Barrena, R., Sánchez, A. & Komilis, D. 2019b. Influence of mixing ratio and turning frequency on the co-composting of biowaste with sugarcane filter cake: a mixture experimental design. *Waste and Biomass Valorization* **6**, 1–15.

Storino, F., Arizmendiarrieta, J., Ganuza, E., Muro, J., Aparicio-Tejo, P. M. & Irigoyen, I. 2014. Comparison of small and large scale composting: Study of the process and of the compost obtained. *Spanish Composting Network* **10**, 40–44 (in Spanish).

Taeporamaysamai, O. & Ratanatamskul, C. 2016. Co-composting of various organic substrates from municipal solid waste using an on-site prototype vermicomposting reactor. *International Biodeterioration & Biodegradation* **113**, 357–366.

Wu, P., Ata-Ul-Karim, S.T., Singh, B.P., Wang, H., Wu, T., Liu, C., Fang, G., Zhou, D., Wang, Y. & Chen, W. 2019. A scientometric review of biochar research in the past 20 years (1998–2018). *Biochar* **1**, 23–43.

Xiao, R., Awasthi, M.K., Li, R., Park, J., Pensky, S.M., Wang, Q., Wang, J.J. & Zhang, Z. 2017. Recent developments in biochar utilization as an additive in organic solid waste composting: A review. *Bioresource Technology* **246**, 203–213.

Zhang, L. & Sun, X. 2016. Improving green waste composting by addition of sugarcane bagasse and exhausted grape marc. *Bioresource Technology* **218**, 335–343.