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Research Article

Development and Application of Agricultural Composting Reactor Experimental Apparatus

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Abstract: In this study, we have a research of the development and application of agricultural composting reactor experimental apparatus. In agriculture, conversion of straw, sludge and other junk to agricultural fertilizer have a broad market prospect, it not only benefit solid waste recycling but also increase food production and food quality. Currently, the existing composting reactor had several shortcomings in practical application process, such as uneven mixing, long composting reaction cycle, producing odor and low maturity. Considering of materials and spatial structure, ventilation system, stirring system, we designed and developed a new experimental device aerobic composting reactor with relatively simple structure. We used the material in experimental device to doing a series of experiments, it include stir even, temperature changes, moisture changes, changes of organic matter, ammonia nitrogen change, change of nitrate nitrogen, PH values and so on. Experimental results showed that standard organic fertilizer could be produced by the device. Moreover, it had more complete degradation of organic matter to improve the quality of the compost product. Experiments also showed that compared with other existing devices, using the device could ferment evenly, increase the speed of biochemical reactions and reduce the fermentation time.

Keywords: Agricultural composting reactor, development and application, experimental apparatus

INTRODUCTION

Currently, the shortage of resources and energy was more and more serious in worldwide. With the world population increases and economic growth, also garbage and other organic solid waste growing rapidly. Mason and Milke (2005) review the physical modeling of the composting environment. Zhang and He (2013) study the high precision for leaf area measurement and instrument development. Nayak (2004) have a research of the feasibility of composting combinations of sewage sludge, cattle manure and sawdust in a rotary drum reactor. Jiang (2014) have a research of the design of new age food machinery. Espinosa and Rosa (2014) study the biological recycling of used baby diapers in a small-scale composting system. Yang (2008) makes a design of the organic solid wastes compost equipment. Li *et al*. (2008) study the experimental investigation on the performance of laboratory scale aerobic composting reactor system. Külcü and Yaldiz (2014) have a research of the composting of agricultural wastes and the new parameter for the assessment of the process. From the perspective of material recycling and resource recycling of view, approach to the use of sludge composting, organic household waste and other organic solid wastes consistent with circular economy concept was a very good means of resource recycling. Agricultural applications, a large number of applications of fertilizer on soil quality had great damage and therefore the use of composting of food safety protection and improve soil were very important role. In this case, composting reactor was a good realization of agricultural composting equipment. However, the composting reaction equipment had the low degree of market and efficiency. Currently, the existing composting reactor was easy to uneven mixing, long composting reaction cycle, producing odor, low maturity and other problem in practical application process. All of these problems in some extent affected the vigorously promotion and practical application of organic solid wastes. Therefore, in order to establish a suitable device of large-scale application in the agricultural sector and solve its effective ways and means, we designed and developed a new type of composting reactor experimental device. Material processing through composting reactor can become organic fertilizer. It can effectively reduction and control environmental deterioration and strengthen human health and therefore the promotion of high value and market prospects. Typically, a relatively complete composting reactor has three major system

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configurations, which were structure reactor space systems, ventilation systems and stirring system.

In this study, we have a research of the development and application of agricultural composting reactor experimental apparatus. Considering of materials and spatial structure, ventilation system, stirring system, we designed and developed a new experimental device aerobic composting reactor with relatively simple structure. We used the material in experimental device to doing a series of experiments, it include stir even, temperature changes, moisture changes, changes of organic matter, ammonia nitrogen change, change of nitrate nitrogen, PH values and so on. Experimental results showed that standard organic fertilizer could be produced by the device. Moreover, it had more complete degradation of organic matter to improve the quality of the compost product. Experiments also showed that compared with other existing devices, using the device could ferment evenly, increase the speed of biochemical reactions and reduce the fermentation time.

MATERIALS AND SPACE STRUCTURE

Material balance calculations: In the process of re-fermentation about sludge and other organic waste, some of the weight change was difficult biological degradation and small, its material decrease was mainly played solid material degradation caused by gas and water evaporation. Therefore, according to the material balance Eq. (1), we can use the change of volatile solids content to reflect the degree of degradation of organic material:

$$TS_m = TS_p + VS_l \quad (1)$$

In the formula (1), TS_m representative compost feedstock total solid mass (kg), TS_p is compost product representative total solids mass (kg) and VS_l representative Quality compost refers to the process of volatile solids loss (kg). Among them, the volatile solids mass loss was equal to the composting process compost material minus the dry compost product quality. As shown in Eq. (2):

$$VS_1 = S_m X_m - S_p X_p \quad (2)$$

In the formula (2): S_m represents the compost feedstock dry matter content (%), S_p represents the dry matter content of compost product (%) and X_m represents the weight of the wet compost materials (kg). Under normal circumstances, biodegradable volatile solids in the composting process was biodegradable; K_v represents the degradation rate was the ratio of VS_1 and VS_m. As shown in formula (3):

$$K_v = VS_1/VS_m = (S_m X_m - S_p X_p) / V_m * S_m * X_m \quad (3)$$

In the formula (3), VS_m represents the compost feedstock volatile solids mass (kg), V_m represents the mass percentage of the number of the total solids in volatile solids (%); In the composting process, organic material and molecular oxide in bacteria, CO_2, H_2O and other substances. According to the Bureau of material balance, we can calculate the mass of solid material in the composting process losses.

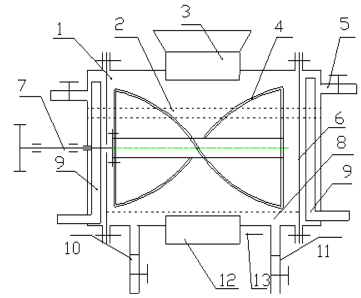

Fig. 1: Composting reactor spatial structure
1: Layer of gas reservoirs; 2: Adsorption filler material; 3: Inlet of material port; 4: Stirring teeth; 5: Gas intake buffer; 6: Heating bar; 7: Stir shaft; 8: Discharge port; 9: Heating bar; 10: Gas discharge; 11: Air intake; 12: Material discharge; 13: Layer of gas intake

Determining of volume: In this study, the new composting reactor design fully into account the material balance, uniform mixing, testing, sampling and other aspects of demand. According to the characteristics and nature of the sludge and other organic matter, the use of the material balance and thermodynamic principles designed aerobic composting reactor. The composting reactor using a cylindrical, to ensure mixing of the premise, both to meet the volume required to maintain the temperature was conducive to laboratory experiments. We set the reactor length 81 cm, volume of 100 L, the capacity of the composting material is 320 k/m^3, the total reactor charge material 86 kg, the reactor area of 0.41 m^2. When the reactor volume of 100 L, Capacity of 300 k/m^3. These were consistent with the calculation based on the mass balance machine thermodynamic conditions, the reactor can meet the needs of the pile to heat up and maintain the temperature.

Spatial structure design: Account the needs of the experiment requirements and stability of the reactor main body of stainless steel material, the insulation layer selection sponge. The main spatial structure shown in Fig. 1, Include the insulation layer, adsorption filling layer, gas feed layer, rotating shaft, the stirring blades, intake manifold, a gate, Vent compost warehouse and so on. The lid after filling material covered. Cover the body set up set gas reservoir and a small pore sieve, so that the body can be bullied compost full uniform. Vent connected with the outside world, setting the damper pressure device, when the pressure reaches a certain level auto exhaust.

The bottom of the compost bin also set up the network, the main screen was easy to permeate collected. The device was specially designed waste collection containers, when a certain capacity automatic drain, you can manually switch. In fact, the discharge port of compost was very important to facilitate efficient composting excluded. According to the principle of gravity, the discharge port located in the lower part of the tank wall, the same set with a closed circle it closely integrated with the barrel wall, in order to avoid leakage and leakage.

Seamless steel pipe as a shaft, on the seamless steel tubes welded stirring blades. Because composting problems often insufficient stirring, the blade was divided into two parts. Part of the helical blades can make the loop around the filler, the blade was then welded on the rotating blade, the filling material can be cut along the drum cartridge was rotated and stirred. This design can be sufficiently stirred filler, to prevent caking and improve the efficiency and reduce the fermentation the fermentation period.

The design of the sensor: Temperature, humidity, oxygen and other parameters of the reaction were important parameters for composting and therefore these were fixed in the drum wall of a variety of sensors. Stirrer blades installed in the steel walls of the compost body with sensors spaced apart to avoid damaging the normal use of the sensor.

Heater bar: The most important parameter was the temperature of the composting reaction. When the indoor temperature could not reach the fermentation reaction temperature yes, you can enable the heating rods compost heated. At the bottom of the compost bin set up a Heater bar, because the heating would have some damage microorganisms, so the temperature was generally less than 60° was appropriate. In short, the composter experimental device designed complete feed, gas, temperature control, sampling, drainage, mixing and others functions and it has a reasonable spatial structure, complete functions.

Design of ventilation system: Composting was a biochemical reacted process, oxygen was need in the course of microbial decomposition and synthetic organic substances. In the real experiment composting process, there were four general ventilation effect, oxygen, heat, to the water, deodorant. Complete ventilation system including ventilation structures and devices. Fan provides air source, calculated air volume and speed at runtime. At the same the fan pressure was also a major factor to consider.

Determine the amount of atmosphere: Because the volume of the apparatus as the experimental apparatus was not large, the amount of cooling air can be ignored. Ventilation to remove moisture and odor, although there was a certain amount of influence, but under normal circumstances the impact was negligible. Therefore, the design of the apparatus main consideration was the amount of oxygen in the air.

On the basis of theoretical oxygen and heat balance, we use extremes law of equation to solve the amount of oxygen that composting required for the reaction. It was show in formula (4) and (5):

$$m_{O2} = O_s \cdot m_s \cdot (1 - x_s) \cdot y_s + O_a \cdot m_a \cdot (1 - x_a) \cdot y_a \cdot k_a \quad (4)$$

$$V = m_{O2}/0.232p_0 \quad (5)$$

In the formula (4) and (5):

m_{O2} = Organic matter oxygen demand in materials that can be biochemical degraded (kg)
V = Organic compounds amount of ventilation in material that can be biochemical degraded (m^3)
O_s, O_a = The values of organic waste and aerobic conditioning agent
m_s, m_a = The wet weight organics and modifiers (kg)
x_s, x_a = A water content of the organic waste (%)
y_s, y_a = The amount of volatile organic in conditioning agent of organic waste (%)
k_a = Organic compounds degradation coefficient in waste and conditioning agent
0.232 = The mass of the O_2 content of air (23.2%)
p_0 = The density of dry air. At 20°C
p_0 = 1.18 kg/m^3

Therefore, the total amount of wind as shown in Eq. (6):

$$V_T = V^*V^*1.066 \; Q = V_T/t \quad (6)$$

V_T represents the total amount of ventilation of compost needed (m^3); Q represents the ventilation rate Average daily pile needed (m^3/day); t represents the time required for composting. Finally, using the formula (5) to calculate the amount oxygen ventilation was 0.9982 kg, So V_1 = 0.549/0.232*1.18 = 3.64 m^3.

Choice of blowers: Composting reactor ventilation equipment is blowers, so the fan selection is very important. First, the meter connect to fan, air was blown through pipes directly inside the heap. In the design in order to reduce the pressure loss, minimize the length of the pipe. According to the fan cylinder composting reactor characteristics, combined with gas pressure loss through the composting material, estimating cylinder pressure required for aerobic composting reactor was 1.58×104 (Pa). It using pipe diameter of 15 mm silicone tube as a vent pipe. Flow meter selected high transparency LZB-4WB type. Blower selected GA-61Y electromagnetic type air compressors.

Design of the ventilation device: In the design of the ventilation device, consider the intake, exhaust, buffering, composting reaction chamber, drying nets, packing material, etc. adsorption of various devices. The main airflow path was showed as Fig. 1. As can be seen from the figure, first of all, from an air compressor compressing the gas to reduce the moisture in the air oven and then the gas through the gas pre-heater thermostat different seasons can maintain the same temperature, experiments are performed. Then, the gas enters through the air flow meter buffer layer and then finally into the fertilizer into the drying nets reaction warehouse full contact with the material. Finally, the gas full contact with the material again and then through drying nets and emissions exhausted gas through the adsorption layer of packing.

Design of stirring system: Stirring device was also one of composting reactor core components, under normal circumstances stirrer device choice according to the viscosity of the material, volume, stirring intensity and other factors. At present, common stirrer device was easy lead to uneven mixing and can't be reasonably effective response.

The main reason was unreasonable paddle design, so that the material was stirred in the local area near the paddle mixing materials fully, but easy to caking, lateral movement was not sufficient, stockyard easy stir wrapped, compost warehouses stirring dead and other issues. Therefore, it was difficult to achieve the purpose of stir that even composting reaction can't run properly.

Typically screw rod stirrer with leaf strip roll and then agitator blades, welded to the rotary shaft. It was suitable for high viscosity and high solids content of the material mixing, heat transfer and reaction. And had a strong ability to loop around, for the use of mini-reactor. So, composting reactor used a ribbon blender was an effective means of screw material agitation. With stirring agitator rotation shaft spirally welded double channel and based on the effective volume of the reaction apparatus. The diameter of the stirring shaft was 40 mm, the speed change output shaft diameter of 20 mm, an outer diameter of stirred cell 23 cm, stirring was effective height 46 cm.

Stirring means was composed of four blades, uniformly at 90° welded to the agitator shaft. During the trial run of the reactor by adjusting the frequency and period of agitation, agitation intensity together to find a suitable stirring time, stirring to ensure uniform material line. The driving system was driven by a motor and transmission of the reactor cylinder to rotate. It driver a spiral blade stirring materials, to achieve the purpose of uniformly mixed materials. The reactor system consists of a drive motor and drive components and to realize the drive system is controlled by automatic control means. Ultimately cylinder time and stirring speed, the direction control.

APPLICATIONS AND EXPERIMENTAL RESULTS

Test of stirring uniformity: The role of stirring and turning was turning, transportation and supplemental oxygen in Composting reactor. The spiral blade and the shaft movement was a complex multi-faceted campaign in composting process, it can help to improve uniformity and reduce oxygen compost local temperature. In this uniformity testing, we observed visually tracking form by adding red roses. We had set four different mixing time 3, 5, 10 and 15 min, respectively. We can see the material has been basically mixing when it reached 3 min, it mixed very well at minutes and remain keep good mixed state at 10 and 15 min. So, the device can be considered in comparison with similar products mixed more with certain obvious advantages. So we think this device had some distinct advantages compared to similar products.

Composting experiment by time: The Experimental period was 30 days. According to the experimental requirements and laboratory measurement method to measure the indicators, remove 30 g material every day. Then we analyze the degradation of materials and substances into the case.

Temperature change: Normally, microorganisms at a temperature of 50-60°C should not survive. Figure 2 was a temperature change material in the composting reactor. From the first four days the temperature rose to about 50°. It showed that the device had some advantage of heat up faster, high temperature and material adequate response.

Moisture percentage change: After joining the mud and straw and other materials, the material itself as well as some water and microbial degradation will produce water. There was also a part of the water vapor and exhaust pipe at any time. As can be seen from Fig. 3, the percentage of water in the reactor throughout the compost materials are maintained in a suitable range, the reaction control effect was good.

Organic matter changes: It can be seen from Fig. 4, the degradation of organic matter content of compost materials from the initial 6.57 to 91.33%, more significant degradation.

COD changes: In composting reactor mass, the content of water-soluble COD was the main factor to determine

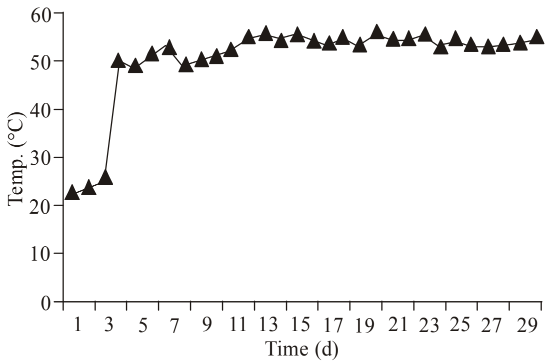

Fig. 2: Temperature change of the material

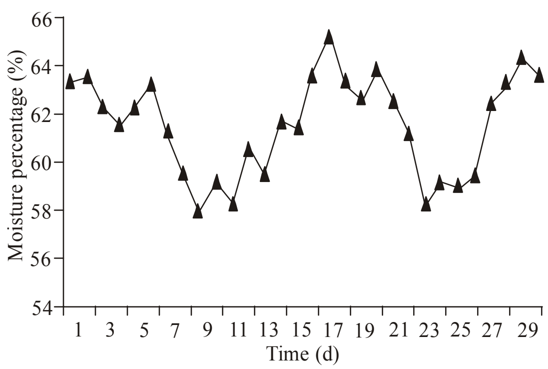

Fig. 3: Humidity change of the material

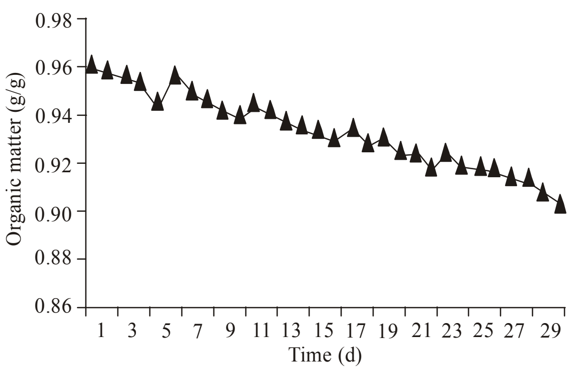

Fig. 4: Organics change of the material

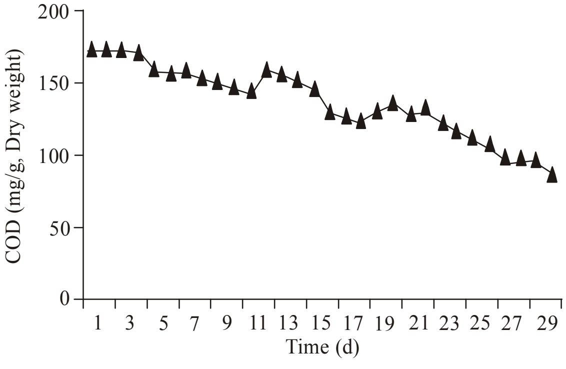

Fig. 5: COD change of the material

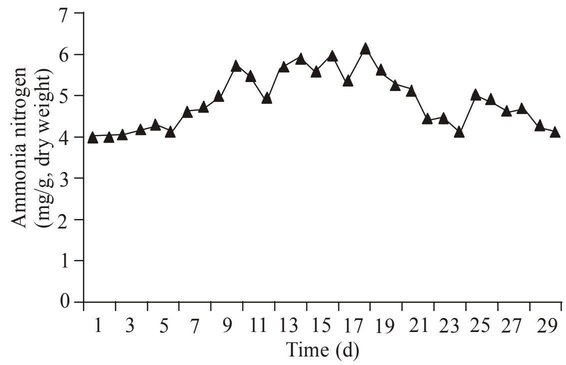

Fig. 6: Ammonia nitrogen change of the material

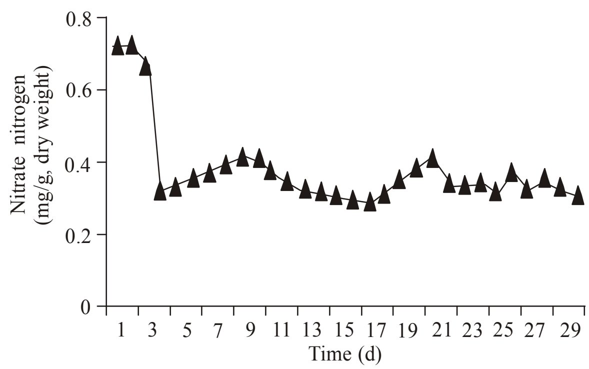

Fig. 7: Nitrate nitrogen change of the material

microbial activity within the reactor to changing circumstances. This was also an important criterion for judging the success of the composting reactor design.

As can be seen from Fig. 5, material of COD was continuous decline and weight decreased from the beginning of the 173.25 to 67.93 mg/g dry weight, the degradation rate was 60.54%. Adding materials and other reasons, COD sometimes fluctuate. The results can explained, the composting reactor had good degradation effect on the compost material.

Ammonia nitrogen changes: As the pile body temperature rises and degradation of inorganic nitrogen, it will generate a lot of ammonium nitrogen. After entering the stable, biodegradable organic nitrogen reduction and then converted to ammonium nitrate nitrogen. Another part of the form of ammonia volatilization led to a reduction of ammonium nitrogen content. We can see from Fig. 6, the content ammonia nitrogen remained unchanged, a slight fluctuation in the middle, mainly due to changes in temperature.

Nitrate nitrogen changes: From the Figure of experimental variation compost weight nitrate nitrogen can be seen (Fig. 7), When the temperature rises of pile body, the nitrate nitrogen content dropped obviously, the latter it keep in a more stable volatility changes. Its local fluctuations can be considered was the role of anaerobic denitrification produced locally.

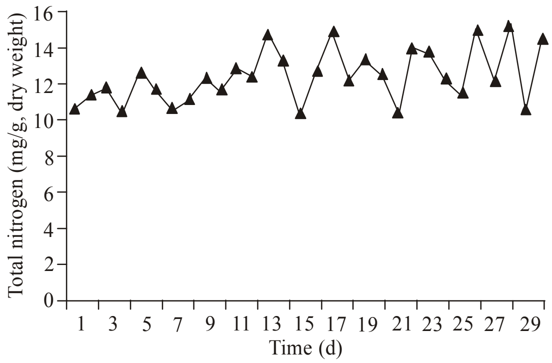

Fig. 8: Total nitrogen change of the material

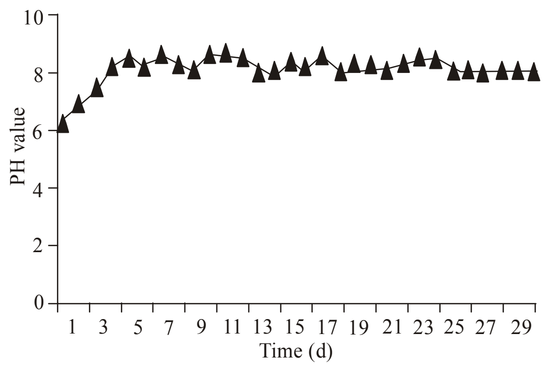

Fig. 9: PH value change of the material

Total nitrogen change: As can be seen from Fig. 8, the total content of nitrogen was slowly rising. Which have some fluctuations, mainly due to the composting process in the decomposition of mineralized organics matter; loss of CO_2, water evaporation will cause an increase in total nitrogen.

PH value changes: Figure 9 was the body of the compost trends PH values. Throughout the composting process, the initial value was 6.13, with the compost conduct, HP value gradually increased. At the end of composting the PH value of the material was about 7.9. As can be seen, PH value of the materials decreased first and then increased and finally stabilized.

CONCLUSION

According to the existing problems and demand of experimental reactor composting devices in practical application, an aerobic composting of organic solid waste reactor was designed, which includes a leachate collection layer, compost warehouse, packing layer adsorption, gas collection room, port of out and in the air, port of outlet and equipped with stirring teeth, outside insulation.

Experiments indicated that this device had several advantages. First, materials could be mixed sufficiently with water and air (oxygen) and to make fermentation maintain a uniform state; Secondly, increasing the probability of microbial contact with the material during the rotation of the shaft, greatly reducing the fermentation time; Third, the probability of microbial contact with the air could be increased in the opposite direction of air and material movement and using the dynamic frictional heat generated by rapid heating of the reactor materials to promote the biological and chemical reaction rate; Lastly, the reactor device have simple structure and could be run continuously.

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