EFFECTS OF IMPROVEMENTS IN INSULATION, INCLINATION OF AXIS AND ROTATIONAL SPEED OF LABORATORY SCALE ROTARY DRUM IN COMPOSTING OF URBAN SOLID FOOD WASTES

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ABSTRACT

Urban Solid Food Wastes (USFW) generated from large establishments like hotels, shopping malls, apartments and restaurants, goes directly to landfills causing undue hardships for source separation and safe disposal. This has necessitated the authorities to go for onsite treatment of source generated organic fraction of wastes for safe disposal, instead of conventional methods of composting. Aerobic In-vessel composting which has been well articulated in literature studies is carried out in the aim of providing improvements in an indigenously developed laboratory scale rotary drum for rapid composting of municipal organic solid wastes. Three sets of trials were conducted to study the effects of insulation (Mix P1, Q1 and R1), impact of agitation for different speeds of rotation of the drum at 3 rpm, 1 rpm, and 0.5 rpm (Mix P2, Q2 and R3) and for different inclination of axis of the drum with respect to horizontal at 0°, 4°and 2° (Mix P3, Q3, and R3). Out of the three sets of trials carried out with Urban Solid Food Wastes (USFW) along with bulking agent of rice husk and cow dung, the best was identified by its maximum temperature and maximum C/N reduction at optimum insulation when the speed of rotation of drum was 0.5 rpm and inclination of axis of drum at 2° .

***Keywords**: Urban Solid Food Wastes, aerobic In-vessel composting, bulking agent, rice husk, C/N reduction*

1. INTRODUCTION

1.1 Urban Solid Food Wastes

Shopping malls, super markets, high rise apartments, restaurants, and large educational institutions which have sprung up in and around cities and towns, are going to be the main challengers of solid waste management in future. Search for the ways and means for safe disposal of the raw and cooked food wastes from such eating places have become the foremost criteria in the world today. Urban Solid Food Wastes (USFW) generated from such large establishments directly goes as mixed with inorganic plastic wastes, untreated to landfills. This causes great hardship to the authorities, for source separation and for safe disposal [5, 6]. Source reduction only has a significant future if the production of municipal solid waste is appreciated as a complex social, cultural and economic phenomenon. All paradigms provide insights into some aspect of source reduction, even if only to illustrate how difficult it can be to implement [7, 8]. However, it seems that reducing Municipal Solid Wastes (MSW) at its source is of primary concern of value in use and material flow paradigms [10, 14].

Besides from plate waste that arises from restaurants, the other forms of waste are also from the preparation of food like peelings, cut pieces, decayed vegetables, fruits etc., The pressure to maintain extensive menu choices at all times also leads to large wastage of food. This has necessitated some way of onsite treatment for rapid disposal of such source generated organic fraction of wastes which contains raw or uncooked and food wastes. More than 80% of the wastes from restaurants, canteens, hotels, theatres, wedding halls and community centers are found to be organic and sometimes contain recyclable plastics [2]. Most of the wastes that are generated do have mixed items of raw or uncooked and food wastes and this study was carried out in a laboratory scale rotary drum so that rapid disposal of such wastes are carried out. As aerobic In-vessel composting has been recognized worldwide as an environmentally acceptable method for treating municipal organic solid waste, for effective conversion, a rotary drum is chosen instead of conventional methods of composting with reference to several literature studies [1, 2 and16].

1.2. Onsite treatment of wastes using a rotary in-vessel drum

To compost the food waste and vegetable matter, it requires minimizing its unique property of high moisture content and low physical structure. It is important to mix fresh food waste with a bulking agent that will absorb the excess moisture as well as to add structure to the mix. Bulking agents with a high C: N ratio, such as sawdust, rice husk and yard waste, are good choices. Food waste is highly susceptible to odor production, mainly ammonia, and large quantities of leachate. Moisture Content (MC) in the range 70-75% under 0.6 bar pressure can be considered suitable for efficient composting OFMSW in Morocco [1, 2]. Composting is a very complex biologically based process and it is influenced by a number of factors such as temperature, aeration, MC, particle size, carbon to nitrogen ratio, pH and porosity. There is no universally applicable optimum MC for composting materials. Examined by traditional soil physics method, the moisture content at 50-55% was suitable for satisfying the degree of free air space (65-70%) of compost during the fed batch composting as per Johanun [10,11 and 12]. Most degradable organic matter was mainly consumed in the feeding stage as indicated by a higher removal rate of dry mass in all cases. This is because each material has unique physical, chemical and biological characteristics, and these affect the relationship between MC and its corollary factors water availability, particle size, porosity, and permeability [1, 2]. These factors are very inter-related and therefore they can have direct and indirect effects. The best prevention for odor is by composting them in an enclosed and well-aerated In-vessel so that it remains aerobic and free of standing water. The In-vessel includes turned bins, rectangular agitated beds, silos and rotating drums. These systems confine the composting material within a container or building and use aeration (forced air) and mechanical turning to increase the rate of the composting process[5,10 and 11]. The composting process takes seven to thirty days. Leachate can be reduced through aeration and with sufficient amounts of high carbon bulking agent.

It is easy to capture leachate and the captured leachate can be reapplied to the compost. Onsite treatment of USFW is the better option of source reduction of wastes; it not only reduces the volume of wastes but also reduces the cost of transportation, and derives some return of revenue from the composted wastes in addition to the aesthetic environment it provides to the city in promoting the greenery [10, 11 and 16].

2. MATERIALS AND METHODS

2.1. Development and Fabrication of a rotary In-vessel model to compost food waste

The fabrication of the closed In-vessel was carried out with a 4 feet long 8 inches diameter stainless steel pipe with two end flanges. The material was selected such that it would take care of the load and also for its non corrosive nature in the long term use in the composting process. The capacity of the vessel was worked out to be about 37.7 litres in volume so that an amount of 32 litres in volume of wastes could be tested for its compost ability.

2.1.1. Internal structure of drum

The internal surface of the drum is fitted with eight numbers of fins fixed longitudinally and bends in the radial direction for maintaining the non-clumpy nature of waste matter as it will easily form lumps during the rotation of the drum. There is an air pipe provided at the central alignment of the drum. Air is supplied through a compressor with a filter, regulator and lubricator with moisture absorbent. The supply is regulated through an inline valve and measured with the help of a rotometer. The air inlet pipe is perforated for fifty percent of its length to let air inside to provide enough amount of oxygen during the aerobic process and the remaining fifty percent perforated portion of the pipe is to bring the exhaust gases to the outlet end. Nearly 5%-10% of oxygen is kept in the inside environment for expediting the biological process with the exhaust air is sent filtered through a compost layer at the outlet.

2.1.2. Drive mechanism

The entire drum is run by a one HP motor driven by a chain with a toothed gear fixed at the centre run of the drum peripherally. A reduction gear of 1:20 ratio is fitted along with the motor in order to reduce the speed of the drum. Further the rotational speed of the drum can be varied by using a variable transformer fitted to the supply. The entire assembly is supported by four angle sections and well interconnected with angle ties. The entire 4 feet length of the drum is further supported at two points at a distance of one foot from each end with guide vanes fitted to the exterior periphery of the drum which accommodates well with the guide wheels fixed on the supporting frame. This helps to prevent the drum from slipping during the long continuous run. The rotating drums or called as cylindrical vessels are turned on a continuous basis, usually at speeds of 3 rpm or less for effective composting. The rotational speed is varied for effective microbial conversion as speed of the drum is found to affect the process [8, 9 and 16].

2.1.3. Analysis of the waste

All the trials were conducted for 14 days duration and the investigation was carried out during the conversion process for every two day interval, the physical and chemical parameters are determined to find its degree of maturity by taking a sample of 100 gm of waste. The direct measurement of chemical parameters like Total Organic Carbon (TOC) and Total Kjeldhal Nitrogen (TKN) were found to be useful in better determination of the rate of degradation and the samples were tested for it. The Volatile Solids (VS) was measured after igniting the sample at 550ºC for 2 h in a muffle furnace [3], TOC was calculated using the formula (100% ash)/1.8 and Total Kjeldahl Nitrogen (TKN) was measured using semi-micro Kjeldahl method [3, 4].

2.2. First set of three trials (P1, Q1 and R1) in rotary drum run with and without insulation cover in composting of Mixed USFW, bulking agent (Rice husk) and cow dung

2.2.1. External structure of drum

The excellent thermal insulation properties of closed-cell polyurethane foam and in-situ PUR rigid polyurethane foam are used here on the exterior surface of the drum to prevent the heat escape. In the first of First set of Trials (P1), the drum was run without any insulation cover. In the second of First set of Trials (Q1), the entire surface of the drum was covered by 15 mm thick flexible polyurethane foam to prevent the escape of temperature through the steel drum. In the third of First set of Trials (R1), the entire surface of the drum further insulated with 25mm rigid polyurethane material cast in-situ and well tucked in-between steel pipe and anodized sheet to prevent the escape of temperature from the steel drum. An inlet of 6″ x 6″ was provided for feeding the wastes into the drum and also an outlet was provided with the same size as that of inlet for collecting the processed end product. The doors were also covered by 15 mm thick polyurethane foam for insulation and provided with rubber washers to prevent leakage of air and temperature. The doors were also provided with a brass control outlet to drain any leachate that was collected in the drum [14, 15 and 16]. If leachate is present in the drum it will hinder the aerobic process and may lead the waste to anaerobic condition [5, 6 and 7].

2.2.2. Preparation of feedstock

The wastes were sorted manually to ensure that it contained no oversized and undesirable materials and then was shredded manually to a size of 20-30 mm to give better exposure for microbial treatment and to expedite the ensuing metabolic process. The moisture content of the waste collected was relatively high due to food wastes and to prevent excess moisture, bulking agents were added. The main function of the bulking agents is to increase the proportion of free airspace and to assist in providing optimum moisture content, besides providing stability and satisfying the energy requirements, before composting. For optimal composting performance, a C/N range of 25 to 30 is recommended in the literature. This study primarily investigated the effect of insulation given to the rotary drum and its effects in C/N ratio reduction and in temperature rise. Three trials were run in the First set of Trials, P1, Q1 and R1, with the initial Mix C/N ratios within the range of 25-30 as per the literature. The first of First set of Trials was carried out in a stainless steel drum without any insulation which stands as control (Mix P1). The second of First set of Trials (Q1) was carried out with stainless steel drum provided with a polyurethane foam cover of 15mm. The third of First set of Trials (R1) was carried out with stainless steel drum with rigid polyurethane material well tucked in-between and covered by anodized steel sheets. All the trials were carried out with bulking agent (rice husk) and cow dung. The mix ratios for the First set of Trials are given in Table 1.

Table 1. Mix ratios of feedstock and type of insulation given (First set of Trials)

Mix ratios	***Materials and composition***			***Insulation***
	Materials	***Ratio***	***Quantum of wastes***	***Type of insulation***
Mix-P1 (Input C/N ratio around 30 (Control Mix)	Mixed USFW (uncooked and food wastes) with rice husk as bulking agent and cow dung as inoculum	10:5:1	20 litres of USFW, 10 litres of bulking agent (Rice husk) and 2 litres of Cow dung	Stainless Steel drum without insulation
Mix-Q1 (Input C/N ratio around 30)				Stainless Steel drum with an Insulation of a 15mm polyurethane foam sheet cover
Mix-R1 (Input C/N ratio around 30)				Stainless Steel drum with 25mm rigid polyurethane cast in-situ material well tucked in-between steel pipe and anodized sheet.

2.3. Second set of three trials (P2, Q2 and R2) in rotary drum with different rotational speeds of 2, 1 and 0.5 rpm in composting of Mixed USFW, along with bulking agent (rice husk) and cow dung

Wastes were sorted manually to ensure a size of 20-30 mm to give better exposure for microbial treatment and to expedite the ensuing metabolic process. The moisture content of the waste was kept at 65%. The bulking agent helps to increase the proportion of free airspace and to assist in providing optimum moisture content, besides providing stability and satisfying the energy requirements. The study primarily investigated the effect of rotational speed of the drum on C/N ratio reduction and the temperature rise during the initial few days. Three trials (P2, Q2 and R2) were run with the initial Mix C/N ratios within the range of 25-30 as per the literature studies. The first of Second set Trials was carried out with a speed of 3 rpm (Mix P2).The second of Second set of Trials was carried out with a speed of 1 rpm (Mix Q2). The third of Second set of Trials was carried out with a speed of 0.5 rpm (Mix R2). All the trials were carried out with bulking agent (rice husk) and cow dung. The mix ratios for Second set of Trials are given in Table 2.

Table 2. Mix ratios of feedstock and speed of rotation (second set of trials)

Mix ratios	*Materials and composition*			*Speed of rotation*
	Materials	*Ratio*	*Quantum of wastes*	*RPM*
Mix -P2 (Input C/N ratio around 30) (Control)	Mixed USFW with rice husk as bulking agent and cow dung as inoculum	10:5:1	20 litres of USFW, 10 litres of bulking agent (Rice husk) and 2 litres of Cow dung	2
Mix -Q2 (Input C/N ratio around 30)				1
Mix -R2 (Input C/N ratio around 30)				0.5

2.4. Third set of three trials (P3, R3 and Q3) with different inclination of axis of rotation of drum from its horizontal axis in composting of the Mixed USFW along with bulking agent and cow dung

For optimal composting performance, a C/N range of 25 to 30 is kept with 65% moisture. The study investigated the effect of inclination of axis of rotation of drum from its horizontal on C/N ratio reduction and the temperature profile of the substrate [14, 15]. Three trials (P3, Q3 and R3) were run with the initial Mix C/N ratios kept within the range of 25-30 as per literature. The first of Third set of Trials carried out with the axis of rotation of drum kept horizontal (angle of inclination of axis of drum with horizontal = 0°) was taken as control (Mix P3). The second of Third set of Trials was carried out with inclination of axis of drum at 4° to the horizontal. The third of Third set of Trials was carried out with an inclination of 2° to the horizontal. All the trials were carried out with bulking agent (rice husk) and cow dung. The mix ratios for Third set of Trials are given in Table 3.

Table 3. Mix ratios of feedstock and angle of inclination of axis of rotation of drum With the horizontal (Third set of Trials)

Mix ratios	*Materials and composition*			*Inclination given*
	Materials	*Ratio*	*Quantum of wastes*	*Degrees*
Mix-P3 (Input C/N ratio around 30) Control)	Mixed USFW with Rice husk and cow dung as inoculum	10:5:1	20 litres of Mixed USFW, 10 litres of bulking agent (Rice husk) and 2 litre of Cow dung	0°
Mix-Q3 (Input C/N ratio around 30)				4°
Mix -R3 (Input C/N ratio around 30)				2°

Fig. 1. Rotary drum covered with an insulation of 15mm Polyurethane foam cover

Fig. 2. Rotary Stainless Steel drum covered with an insulation of 25mm rigid polyurethane cast in-situ material well tucked in-between steel pipe and anodized sheet

3. RESULTS AND DISCUSSION

3.1. Temperature profile and reduction of C/N ratio (First set of Trials P1, Q1 and R1) – Effect of insulation provided to the drum

3.1.1. Temperature

Three sets of trial mixes were tried in the laboratory scale In-vessel with the aim of attaining reduction in C/N ratio of around 30 for the effective degradation of the substrate. The rise in temperature was not observed in the first trial (P1) and this is a strong indication of ineffective microbial degradation, due to loss of temperature. The internal temperature of the wastes for effective microbial degradation was not sustained due to the subsequent cooling due to constant air flow. The air flow was maintained constant such that more than 5% of oxygen was present to the substrate. Fig.3 shows the variation of substrate temperature with time duration for the three mixes. In the second trial (Q1) and the third trial (R1), the pattern of substrate temperature profile was similar, with the substrate temperature increasing up to 3 days and then showing a decreasing trend till 14 days. For both these trial mixes, the decrease in temperature beyond 10 days was minimal. The grading of trial mixes from the point of view of increase in substrate temperature is Mix R1 > Mix Q1 > Mix P1. Al the three mixes had almost the same input C/N ratios of around 30. The temperature of the substrate at the beginning of the composting process in all the three mixes was in the range 32ºC to 34.5º C. The highest temperature of 64ºC was attained only on the 3rd day in Mix C, which indicates a good growth of microorganisms to a certain extent and in all the other mixes slowing down of the composting process due to the improper insulation provided to the drum resulting in heat loss from the system. The temperature rose to a maximum of 58ºC on 3rd day in case of Mix Q1. Mix P1 did not show any improvement from the beginning to the end of the trial period as the temperature of the substrate remained almost flat with very marginal variations. The optimum mix of C/N ratio around 30 with raw or uncooked waste, with a bulking agent of rice husk and cow dung as a starter has been found to be an ideal combination because of the double insulation given to the drum in Trial Mix R1.

3.1.2. C/N ratio

The rate of reduction in C/N ratio which is indicative of the rate of decomposition of the waste is found to be maximum for the Mix-R1 having an input feedstock C/N ratio around 30, as it is well brought down from 29.84 to 16.83 as shown in Fig.4. But, the variation in the rate of reduction in C/N ratio in the Mix-P1 was not as much but however Mix Q1 is found to have a greater reduction with the C/N ratio brought down from 29.91 to 21.2 [10,13 and 16]. The ranking of mixes in terms of rate of reduction of C/N ratio indicated by the R-squared value and the fitted linear equation is in the order: Mix R1 > Mix Q1 > Mix P1. Hence, it is concluded Mix R1 having the maximum insulation cover gives the optimum performance.

3.2. Temperature profile and reduction of C/N ratio (Second set of Trials P2, Q2 and R2) - Effect of speed of rotation of the drum

3.2.1. Temperature

Three trial mixes were tried in the laboratory scale rotary drum with the aim of reduction of C/N ratio for the effective degradation of the substrate by varying the speed of the drum. Fig. 5 shows the variation of substrate temperature with time duration since the commencement of composting process for different trial mixes Mix P2, Mix Q2, and Mix R2. The pattern of microbial degradation for all the three mixes was similar up to three days as indicated by the rapid increase in temperature. The degradation of waste got slowed down very much in just one day duration and after the third day in the case of Mix P2 (3 rpm rotational speed) which is indicated by the rapid reduction in temperature from 37.3°C to 36°C. Thereafter, the temperature of the substrate was hovering around 34.5°C. The pattern of variation in temperature for Mix Q2 and Mix R2 were not very similar but Mix R2 was performing better than Mix Q2 with higher rate of increase in temperature build up to the third day. This shows that the degradation was effective in both mixes Q2 and R2. The temperatures of the substrate at the beginning of the composting process in all mixes were in the range 32ºC to 34.5ºC. The highest temperature of 64.5ºC was attained only on the 3rd day in Mix R2, which indicates a growth of microorganisms to a greater extent due to the slow speed of rotation of drum at 0.5 rpm. The temperature rose to acceptable conditions to a maximum of more than 55ºC [16] on 3rd day for Mix Q2 but less than that of Mix R2. Mix P2 did show some improvement from the beginning to the end of the trial period. From the results and the preceding discussion, it is found that the optimal rotational speed for effective degradation is found to be 0.5 rpm. The gradation of mixes from the point of view of effective composting is Mix R2 > Mix Q2 > Mix P2.

3.2.2. C/N ratio

The rate of reduction in C/N ratio which is indicative of the rate of decomposition of the waste is found to be maximum for Mix R2 having an input feedstock C/N ratio around 30. The C/N ratio is well brought down from 29.95 to 16.41 in 14 days as shown in Fig. 6. The rate of reduction in C/N ratio Mix P2 was not much and can be considered insufficient to have been composted as the C/N ratios are only brought down from 30.09 to 22.38 [10,13 and16]. The ranking of mixes in terms of rate of reduction of C/N ratio indicated by the R-squared value and the equation is in the order: Mix R2 > Mix Q2 > Mix P2. Hence, it is concluded that Mix C4 with an optimum rotation speed of 0.5 rpm is found to be the best in composting of USFW with rice husk and cow dung.

3.3. Temperature profile and reduction of C/N ratio (Third set of Trials P3, Q3 and R3) - Effect of varying the inclination of axis of drum to its horizontal

3.3.1. Temperature

Three trial mixes were studied in the laboratory scale In-vessel with the aim of reduction of initial C/N ratio around 30 by varying the inclination of axis of the rotary drum for the effective degradation of the substrate. Fig. 7 shows the variation of substrate temperature with time duration since the commencement of composting process for different trial mixes (Mix P3, Mix Q3 and Mix R3) with input C/N ratios around 30. The temperatures of the substrate at the beginning of the composting process in all mixes were in the range 32ºC to 34.5ºC. The highest temperature of 65ºC was attained on the 3rd day in Mix R3, which indicates good growth of microorganisms while in the other two mixes (Mix P3 and Mix Q3), the temperature rose to 54°C and 55°C respectively on the third day. The rise in temperature in the first two days since the beginning of composting was very less in Mix P3. Hence, Mix R3 (USFW with rice husk and cow dung) composted in the rotary In-vessel run with an inclination of axis of rotation of 2° to the horizontal is found to be the best as it has developed the highest temperature.

3.2.2. C/N ratio

The rate of reduction in C/N ratio which is indicative of the rate of decomposition of the waste is found to be maximum for Mix R3 having an input feedstock C/N ratio around 30. The C.N ratio is well brought down from 29.73 to 15.66 as shown in Figure 8. The rate of reduction in C/N ratio Mix P3 was not much and can be considered inadequate to have been composted as the C/N ratio as it is only brought down to 19.81 from the initial 30.42 [10,13,and 16]. The ranking of mixes in terms of rate of reduction of C/N ratio indicated by the R-squared value and the fitted linear equation is in the order: Mix R3 > Mix Q3 > Mix P3. Hence, Mix R3 (USFW with rice husk and cow dung) composted in the rotary In-vessel drum run with inclination of axis of rotation of 2°

to the horizontal is found to be the best as the reduction in C/N ratio was maximum at the end of 14 days[18,19].

4. CONCLUSION

1. In the First set of Trials, the Mix R1 (USFW with a bulking agent of rice husk and cow dung) with initial C/N ratio around 30 has been found to generate the highest rise in temperature because of the 25mm insulation given to the drum. Similarly, the Mix R1 showed maximum reduction in the C/N ratio due the maximum insulation cover.

2. In the Second set of Trials, the Mix R2 (USFW with a bulking agent of rice husk and cow dung) is found to generate the maximum rise in temperature at a rotational speed of 0.5 rpm given to the drum. Similarly the Mix R2 also depicted maximum reduction in C/N ratio.

3. In the Third set of trials, the Mix R3 (USFW with a bulking agent of rice husk and cow dung) is found to generate maximum rise in temperature when the drum is rotated at an inclination of 2° to the horizontal. Similarly, the Mix R3 also depicted maximum reduction in C/N ratio.

4. Thus the maximum temperature and maximum reduction in C/N ratio for effective composting of USFW with rice husk as bulking agent and cow dung as inoculum have been obtained when the rotary In-vessel is given improvements by providing 25mm thick rigid polyurethane cast in-situ material as insulation and when run at a rotational speed of 0.5 rpm with its axis of rotation inclined at 2° to the horizontal. The resultant C/N ratio reduction have been effected for Mix R3 to 15.66 for a 14 days duration trial which is maximum out of all the three trials and is in the order of R3<R2<R1.

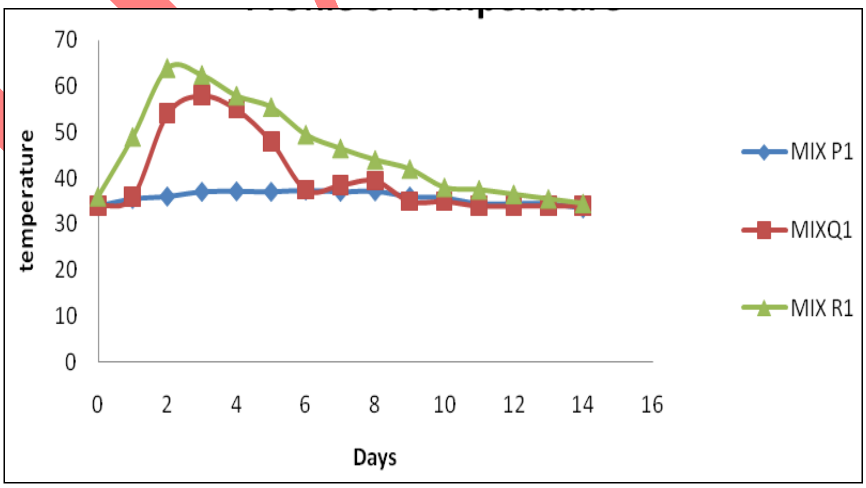

Fig. 3 Temperature profile of Mixes (P1, Q1 and R1) composted in In-vessel with different insulation covers

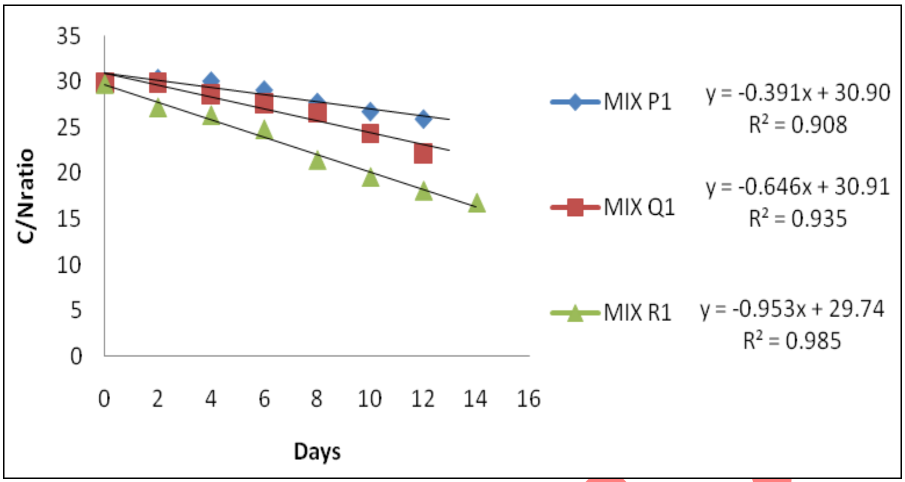

Fig. 4 C/N ratio of Mixes (P1, Q1 and R1) composted in In-vessel with different insulation covers

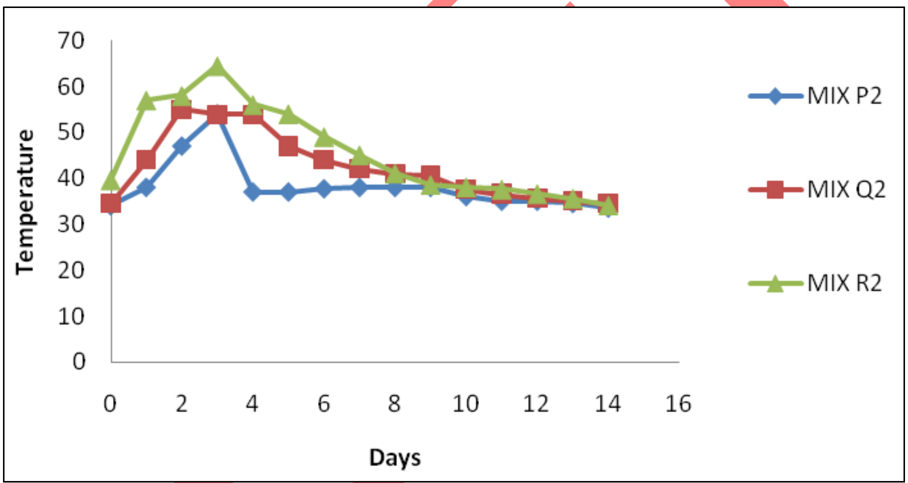

Fig. 5 Temperature profile of Mixes (P2, Q2 and R2) composted in In-vessel with different rotational speeds

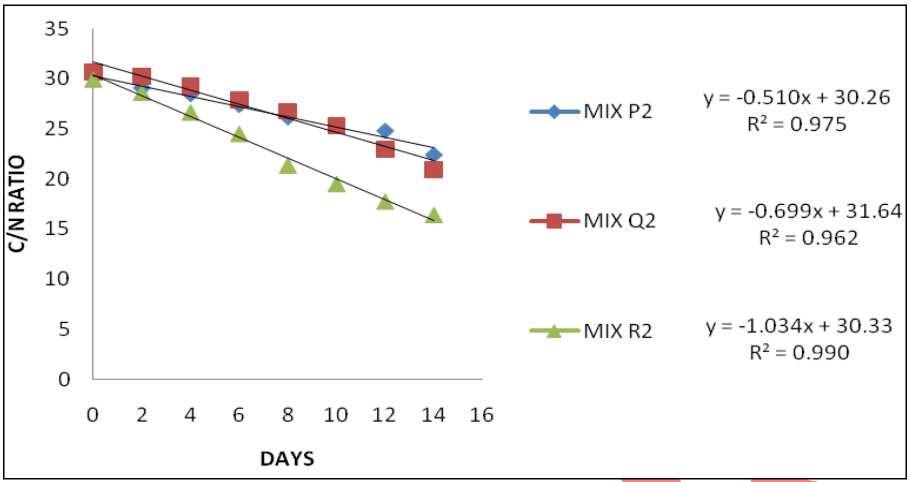

Fig. 6 C/N ratio of Mixes (P2,Q2 and R2) composted in Rotary In-vessel drum with different rotational speeds

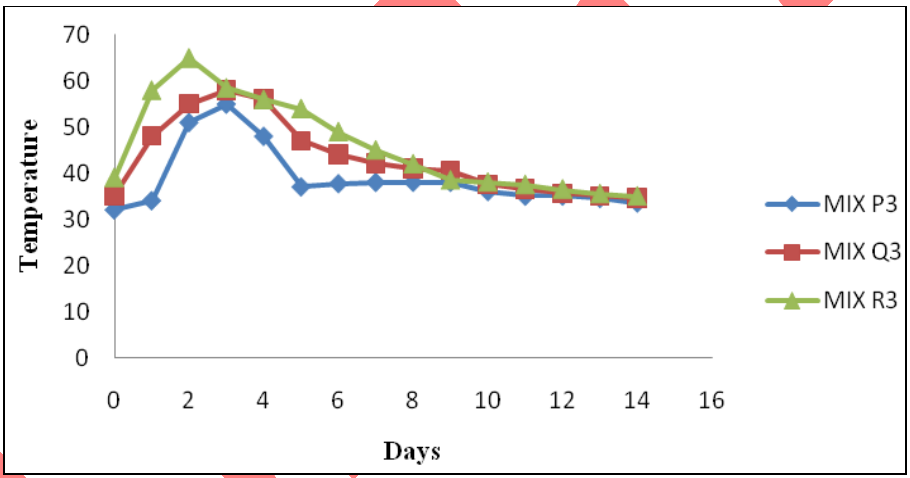

Fig. 7 Temperature profile of Mixes (P3, Q3 and R3) composted in Rotary In-vessel drum with different inclination of axis of rotation with the horizontal

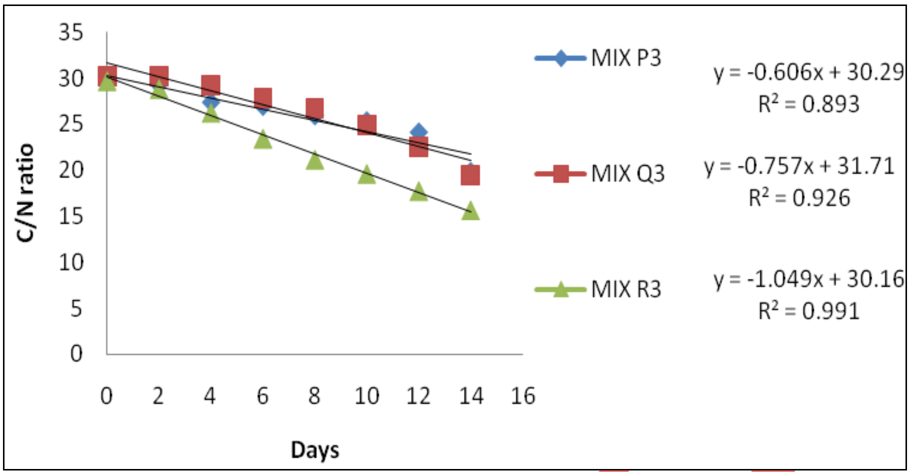

Fig. 8 C/ N ratio of Mixes (P3,Q3 and R3) composted in Rotary In-vessel drum with different inclination of axis of rotation with the horizontal

REFERENCES

[1] Abdelhadi Makan, Omar Assobhei, and Mohammed Mountadar, "Effect of initial moisture content on the in-vessel composting under air pressure of organic fraction of municipal solid waste in Morocco," Iranian J. Environ. Health Sci. Eng., 10(1): 3, 2013.

[2] K. Adhikari Bijaya, Suzelle Barrington, Jose Martinez and Susan King, "Characterization of food waste and bulking agents for composting," Journal of Waste Management, Elsevier Publications, 28(5), pp. 795-804, 2008.

[3] APHA-AWWA., "Standard Methods for the Examination of Water and Wastewater," 20th edn. APHA /AWWA/WPCF, Washington. DC, 2005.

[4] ASAE. "Standards Engineering Practices Data American Society for Agricultural Engineers," The Society for Engineering in Agriculture, 2005.

[5] J. Bonhotal, M. Schwarz, and G. Feinland, "In-vessel Composting Options for Medium-scale Food Waste Generators," BioCycle, 52(3): 49, 2011.

[6] T. Chakrabarti, M.P. Patil, and Sukumar Devotta, "Status Report on Management of Hazardous Waste in India, 2006," National Environmental Engineering Research Institute, Nehru Marg, Nagpur 440 020, India, http://www.envis.neeri.res.in/testnew.php, 2006.

[7] Daniel Aslam, www.calrecycle.ca.gov/lea/Conference/07Conf/.../Compost101/Aslam.pp.

[8] R.B. Dean, "European Manufacturers Display Systems at Kompost '77," Compost Science, 19(2), pp.18-22, 1978.

[9] Duane Dellecker:\002565-SWANA\035884 - Carbon\Carbon County Final Report 1_16_06.doc

[10] R.T. Haug, The Practical Handbook of Compost Engineering. Boca Raton: Lewis Publishers; 1993.

[11] B. Jolanum, S. Tripetchkul, C. Chiemchaisri, P. Chaiprasert, and S. Towprayoon, "Effect of moisture content on fed batch composting reactor of vegetable and fruit wastes," Environ. Technol., 26(3), pp. 293-301, March 2005.

[12] C.C. Monson, A. Murugappan, and M. Govindarajan, "Effects on Rate of Degradation in Vegetable Solid Waste Composting in a Rotary in-vessel with Varying Periods of Rotational Spells," International Journal of Earth Sciences and Engineering ISSN 0974-5904, Vol. 2, No. 5, pp. 458-466, October 2009.

[13] C.C. Monson and A. Murugappan, "Combined Thermophillic Composting and Vermicomposting in the Bioconversion of Vegetable Market Waste," International Journal of Applied Engineering Research, ISSN 0973-4562, vol. 5 no. 5, pp. 785-794, 2010.

[14] Pushpam Kumar, "The Economics of Ecosystems and Biodiversity: Ecological, United nations Environment programme," Published by Routledge, an imprint of Taylor and Francis group, 711, Third avenue, New York, 10017, p.91, 2012.

[15] Robert Spencer, "What's New – In-vessel Composting," BioCycle, vol. 48, no. 5, p. 21, May 2007.

[16] R.M. Rynk, G.B. van de Kamp, M.E. Wilson, T.L. Singley, J.J. Richard, F.R. Kolega, L. Gouin, D. Laliberty Jr. Kay, D.W. Murphy, H.A.J. Hoitink, and W.F. Brinton, "On-farm Composting," Northeast Regional Agricultural Engineering Services, Ithaca, New York, SAS. 2002.

[17] The Appendices to the Canada GAP Food Safety Manuals.

[18] S.M. Tiquia, N.F.Y. Tam, and I.J. Hodgkiss, "Microbial activities during composting of spent pig-manure sawdust litter at different moisture contents," Bioresour Technol. 55, pp. 201-206, 1996.

[19] A. Trémier, C. Teglia, and S. Barrington, "Effect of initial physical characteristics on sludge compost performance," Bioresour Technol. 100(15), pp. 3751-3758, 2009.