IN-VESSEL COMPOSTING: I. KITCHEN WASTES

E.Işıl ARSLAN[*]
Ubeyde İPEK[*]
Erdal ÖBEK[*]
Murat TOPAL[**]
Oktay BAYKARA[***]

Abstract: In this study, in-vessel aerobic composting of kitchen wastes (KW) was investigated to suggest a solution for the environmental problem caused by huge amounts of wastes. The composting period was 22 days. The composting parameters such as temperature, carbon (C), total Kjeldahl nitrogen (TKN), C/N ratio, cellulose, volatile solids (VS), moisture, pH, electrical conductivity (EC), total coliform (TC), fecal coliform (FC), heavy metals and radioactivity were investigated. The reaction rate constant of degradation of VS was found as 0.0414 day^{-1} (R^2 = 0.99). The VS of KW decreased from 92.47 to 86.87 % after 22 days. The KW reached maximum temperature of 55°C within 2 days. C decreased from 51.37 to 48.26 %. TKN increased from 1.43 to 2.45 %. C/N ratio of the KW decreased from 35.92 to 19.69. The content of cellulose increased at the end of the process. pH value increased from 5.5 to 8.29. EC increased from 769 to 959 µS/cm. Both TC and FC decreased during process. The measured heavy metal concentrations in the obtained composts were under the standards related to heavy metal. α-radioactivity greatly decreased and also the β-radioactivity decreased at the end of the process. ^{40}K and ^{137}Cs concentrations were also determined. In-vessel aerobic composting was effective to reduce TC, FC, α-and β-radioactivity in KW used. As a result of the study, it can be said that in-vessel aerobic composting of KW would be suitable from the point of waste management and the usage of the obtained compost on agricultural soils would be a solution for the environmental problem caused by the huge amounts those thrown away.

Key Words: Kitchen wastes, Waste, Aerobic composting, Environmental problem, In-vessel composting.

Reaktörde Kompostlaştırma: I. Mutfak Atıkları

Özet: Bu çalışmada mutfak atıklarının reaktörde aerobik kompostlaştırılması, çok büyük miktardaki atıkların sebep olduğu çevresel probleme bir çözüm önermek için araştırılmıştır. Kompostlaştırma süresi 22 gün olmuştur. Sıcaklık, karbon (C), toplam Kjeldahl azotu (TKN), C/N oranı, selüloz, uçucu katı, nem, pH, elektriksel iletkenlik, toplam koliform (TC), fekal koliform (FC), ağır metaller ve radioaktivite gibi kompostlaştırma parametreleri araştırılmıştır. Uçucu katı bozunmasının reaksiyon hız sabiti 0.0414 $gün^{-1}$ (R^2 = 0.99) olarak bulunmuştur. Mutfak atıklarının uçucu katısı 22 gün sonra % 92.47' den % 86.87' ye azalmıştır. Mutfak atıkları 55°C' lik en yüksek sıcaklığa 2 gün içerisinde ulaşmıştır. Karbon % 51.37' den % 48.26' ya azalmıştır. TKN % 1.43' ten % 2.45' e artmıştır. C/N oranı 35.92'den 19.69' a azalmıştır. Selüloz içeriği proses sonunda artmıştır. pH değeri 5.5' den 8.29' a artmıştır. Elektriksel iletkenlik 769' dan 959 µS/cm'e artmıştır. Hem TC hem de FC proses esnasında azalmıştır Elde edilen kompostlarda ölçülen ağır metal konsantrasyonları ağır metal ile ilişkili standartların altında olmuştur. Proses sonunda α-radioaktivitesi büyük oranda azalmıştır ve β-radioaktivitesi de azalmıştır. ^{40}K ve ^{137}Cs konsantrasyonları da tespit edilmiştir. Çalışmanın bir sonucu olarak, mutfak atıklarının reaktörde aerobik kompostlaştırılmasının atık yönetimi açısından uygun olacaktır ve elde edilen kompostun tarım topraklarında kullanılmasının büyük miktarda atılan bu atıkların sebep olduğu çevresel problem için bir çözüm olacağı söylenebilir.

Anahtar Kelimeler: Mutfak atıkları, Atık, Aerobik kompostlaştırma, Çevresel problem, Reaktörde kompostlaştırma.

[*] Fırat Üniversitesi, Mühendislik Fakültesi, Çevre Müh. Bölümü, 23279, Elazığ.
[**] Cumhuriyet Üniversitesi, Mühendislik Fakültesi, Çevre Müh. Bölümü, Sivas.
[***] Fırat Üniversitesi, Fen ve Edebiyat Fakültesi, Fizik Bölümü, Elazığ.

1. INTRODUCTION

Production of organic wastes, including municipal solid waste, in modern societies is increasing while in the same regions soils lose organic matter through intensive cultivations and adverse climatic conditions (Sequi and Benedetti, 1995; Trubetskaya et al., 2001). Disposal of solid waste has become a major problem recently due to shortage of dumping sites and strict environmental laws. As a result emphasis is now on aerobic composting, defined as a microbiological process that converts waste into organic manure rich in plant nutrients and humus (Sharma et al., 1999; Singh and Sharma, 2002). The compost is a valuable commodity in agriculture because it combats erosion, increases crop yields, improves the soil structure and has moisture retention properties. The material slowly releases nutrients for the crops and probably inhibits plant pathogens (Rose, 1992).

Proper composting effectively destroys pathogens and weed seeds through the high temperature achieved through the metabolic heat generated by microorganisms (Hanajima et al., 2006). The principal requirement of a compost for it to be safely used in soil is its degree of stability or maturity, which implies a stable organic matter content and the absence of phytotoxic compounds and plant or animal pathogens (Bernal et al., 1998). Spreading immature or unstable compost can generate serious problems of hygiene and phytotoxicity (Déportes et al., 1995; Pascual et al., 1997; Jouraiphy et al., 2005).

The presence of coliform bacteria is often used as an indicator of the overall sanitary quality of soil and water environments. Use of an indicator such as coliforms, as opposed to the actual disease-causing organisms, is advantageous as the indicators generally occur at higher frequencies than the pathogens and are simpler and safer to detect (Hassen et al., 2001). The hygienic performance of bio-waste composting plants to ensure the quality of compost is of high importance. Existing compost quality assurance systems reflect this importance through intensive testing of hygienic parameters (Martens, 2005).

The presence of heavy metals in composts is the main cause of adverse effects on animal and human health, transmitted through the food chain from soil, groundwater and plants (Senesi et al., 1999; Hseu, 2004). Not only are these elements not biodegradable and become toxic at some concentrations, they tend to accumulate along the food chain where man is the last link (Dudka and Miller, 1999; Amir et al., 2005). There is a concern that heavy metals in the compost product may be a health concern as a result of the use of compost on land. Analyzing the heavy metal contents of the composts exactly is very important for the purposes of routine monitoring, risk assessment and regulation of environment (Hseu, 2004).

If the wastes including relatively higher radioactivity are directly used in the agriculture, they can affect both the ecological structure of soil and the crops grown in soil (İpek, 2001). On the other hand, the higher radioactive wastes can be introduced to ground by leaching or surface water by flow, and accumulate in the mediums of soil and water for a long time. This may cause very important hazards to living organisms including human beings.

The availability of ^{40}K and ^{226}Ra for plants and subsequent transfer to the human food chain, mainly in acidic soils, cannot be avoided (Bolca et al., 2007). Long-lived naturally occurring radionuclides may get transferred to plants along with the nutrients during mineral uptake, accumulate in various parts and even reach the edible portions. These plants or their parts when consumed by man would lead to continuous radiation dose (Pulhani et al., 2005). Thus, it is important to know the proportion of such a transfer for human and animal health points of view (Bolca et al., 2007). To our knowledge our study is one of the rare reports on radioactivity concentrations of materials in composting process met in literature.

Turkey is a developing country and wastes as kitchen wastes, grass clippnings etc. which cause environmental and aesthetics problems reach huge amounts especially in modernized cities. This situation increased the need to find sustainable and environmentally friend solutions for the disposal of these wastes This is the first part of the study which evaluated in-vessel aerobic composting. In this part of the study, in-vessel aerobic composting of kitchen wastes was examined to find a solution for the environmental problem caused by huge amounts of these wastes. The characterization of the obtained compost was also done in the present study. In the present study, it was also aimed to determine the effect of in-vessel aerobic composting on some environmental health parameters in terms of obtaining a compost product without adverse effects to human and other living organisms.

2. MATERIAL AND METHODS

The compost reactor that was made of fiberglass and covered with glass wool for insulation was with internal diameter of 30 cm and height of 50 cm (Figure 1). The top and bottom of the reactors had lids and apertures, respectively. The air was given to the reactors by a compressor from the apertures. The time of the airflow was 1.5 minutes in each 8 minutes period which controlled by timer and selonoid valve. The airflow rate (10 L/min) was measured by a flow meter and controlled by pressure regulator. The KW were obtained from restaurant of Fırat University campus (Elazıg, Turkey). Two kilograms of biological treatment sludge from the activated sludge treatment plant of the Elazıg city was added as inoculum. Sawdust (3.5 kg) from a carpenter' s shop was used to increase the porosity and carbon content of the mixtures. The composting period was 22 days. The reactor was turned before taking every sample. The samples were taken for every three day. The samples taken from reactor were dried at 65 ^{o}C during 48 hours for heavy metal (Cr, Cd, Zn, Mg, Cu, Co, Fe, Ni, Mn) determinations and 105 ^{o}C for 24 hours for the other determinations, except TC and FC. The dried samples were ground in a coffee mill after they were homogenised in a blender and then ground to pass through a 60 mesh (0.250 mm) sieve for analyses. In the study, all determinations were done by three replications. Moisture and VS were determined as described in Standard Methods (APHA et al., 1989). Cellulose was performed according to the AOAC Methods (AOAC, 1990). TKN was determined as described in Methods of Soil Analysis (SSSA, 1996). C was calculated according to Adams et al. (1951). pH and EC were measured in the compost-water (1:10 w/v) extract by using a pH probe (WTW pH 330) and an EC probe (WTW LF 330), respectively. Temperatures were daily measured using thermometers placed in five locations on the compost reactor. TC and FC analyses were conducted with raw samples according to Standard Methods (APHA et al., 1989) by the MPN method. Heavy metal determinations were done according to Hseu (2004) by nitric acid digestion method that partly modified from that of Zheljazkov and Nielson (1996). An ATI UNICAM Model 929 flame atomic absorption spectrophotometer equipped with ATI UNICAM hollow cathode lamp was used for the heavy metal determinations. The samples were prepared for radioactive counting by adding distilled water before treating the samples with ultraviolet light. Then, they were exposed to 360 nm wavelength ultraviolet light to stick the sediments in the 1.9 cm diameter planchettes. The dried sediments were ready to be counted directly with radiation detector. Three planchettes from each sample were prepared and counted for 3.000 s. Each count was corrected for the background counts which were consecutively taken for the same time (Doğru et al., 2001). The radioactivity concentration in the prepared samples was determined by using a β-radiation-sensitive plastic scintillator (2059 plastic scintillator from NE Tech. Inc.) supported by a suitable photo multiplier tube and SR-8 Low Level Radiation Counter from the same company. β-radiation sensitive plastic scintillators are more preferable for use for this purpose than the other solid state detectors (Doğru, 1997). The α-radioactivity concentration was determined by using a ZnS(Ag) scintillator detector with Low Level Alpha Spectrometer from NE Tech. Inc. and calculated by using ''equation (1)''. The β-activity concentration in the samples was calculated by using ''equation (2)'' (Canbazoğlu et al., 2000). The potassium concentration was determined by gamma spectroscopy with NaI(TI) detector.

$$A_{\alpha}=(NxECF)/2.22 \quad (1)$$

$$A_{\beta}=(0.391 \text{ X } \underline{R} \text{ X } \underline{N}_{m})/\underline{N}_{0} \quad (2)$$

where, A_{α} and A_{β} is the alpha and beta radioactivity in pCi, N is the sample net count per minute for alphas, ECF is the efficiency correction factor, $\underline{R}$ is the net β-count in minutes, $\underline{N}_{m}$ is the specific mass of samples in mg cm^{-2}, $\underline{N}_{0}$ is the count obtained from a calibration curve (Alkan, 1989).

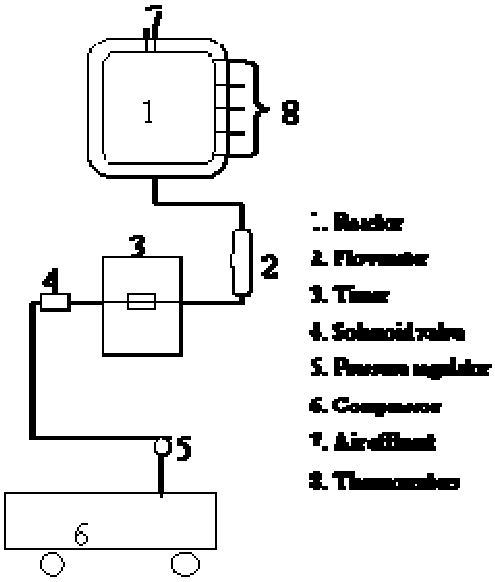

Figure 1:
Composting system.

3. RESULTS AND DISCUSSION

3.1. Temperature

Temperatures were given in Figure 2. The thermometer heights mentioned in the figure are from top to the bottom of the reactor. Temperature is considered the most important indicator of the efficiency of the composting process (Imbeah, 1998; Brito et al., 2008). Stentiford (1996) suggested that temperatures between 45 °C and 55 °C gave maximum biodegradation rates (Brito et al., 2008). The maximum temperature reached in our study was consistent with these values. The KW reached maximum temperatures of 55°C within 2 days. The thermophilic phase ended after 7 days. After then, temperatures decreased to mesophilic values. Similar to our results, in the study of Brito et al. (2008), during composting of solid fraction of cattle slurry, initially the temperature of composting piles rose as a consequence of the rapid breakdown of the readily available organic matter and nitrogenous compounds by micro-organisms (thermophilic phase). As the organic matter became more stabilised, the temperature decreased gradually to ambient levels (Brito et al., 2008).

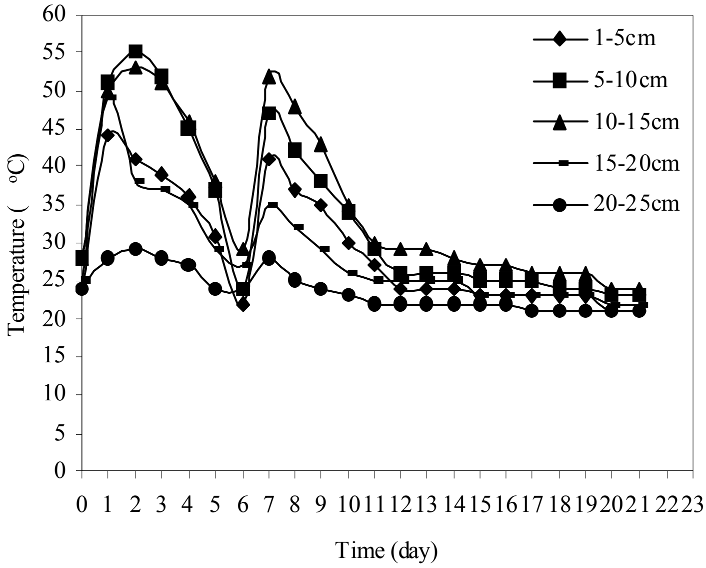

Figure 2:
Changes in temperatures during composting.

3.2. pH and EC

The initial pH value was 5.5. pH values significantly increased (Figure 3). Increases in pH values were indicated that organic acids, as well as the presence of ammonia formed during mineralization, were released as an effect of the microbial decomposition (Faure and Deschamps, 1990; Eklind and Kirchmann, 2000; Ferrer et al., 2001). Contrary to our results, in the study of Brito et al. (2008), a decline in the pH value from 9 to approximately 7 was observed during the first two weeks of composting in static piles, but pH subsequently increased after this period, probably as a result of the degradation of organic acid compounds (Peigné and Girardin, 2004; Brito et al., 2008). In the study of Zorpas and Loizidou (2008), after the rapid increase at first day, pH decreased gradually to seven, contrary to our result. Then, in their study, pH reached relatively constant values after approximately 75 days. This period is too long compared to that seen in our study. In our study pH reached stabile values after 15 days.

In the study of Brito et al. (2008), in the final compost the pH ranged from 7.5 to 8.5 and this high pH reaction was probably due to the buffering effects of bicarbonates in agreement with our result (Cáceres et al., 2006; Brito et al., 2008).

EC reflects the salinity of the composting products and their suitability for plant growth (Zorpas and Loizidou, 2008). EC value increased from 769 to 959 µS/cm (Figure 4). Similar pattern to our result were reported by Zorpas and Loizidou (2008). In their study, EC increased from 957 to 1001 µS/cm for 70% w/w dewatered anaerobically stabilized primary sewage sludge + 10% w/w sawdust plus 20% w/w clinoptilolite.

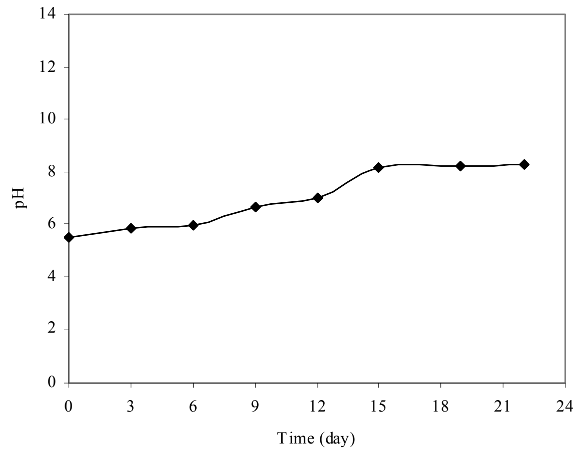

Figure 3:
Changes in pH contents during composting.

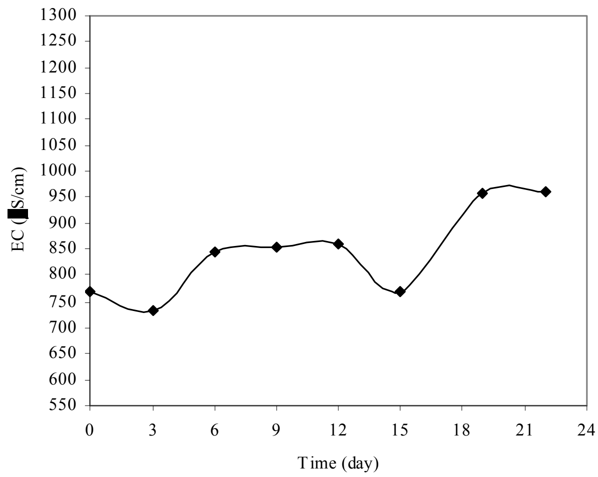

Figure 4:
Changes in EC contents during composting.

3.3. Carbon, TKN, C/N, Cellulose

Carbon decreased from 51.37 to 48.26 % (Figure 5). C loss during composting is attributable to the mineralization of organic matter resulting in the evolution of CO_2 and heat (Pullicino et al., 2007). Carbon losses from some composting studies include 45 to 62 % for feedlot manure (Eghball et al., 1997), 45 to 74 % from sawdust-amended and 54 to 79 % from straw-amended dairy manure (Michel et al., 2004), and 44 % (Sommer and Dahl, 1999) and 40 to 49 % (Sommer, 2001) for deep-litter dairy cow manure. C loss that was seen in our study was significantly lower than the reported values.

TKN values increased from 1.43 to 2.45 % (Figure 6). Ferrer et al. (2001) were composted compressed grape waste without and with hen droppings by pile turning aeration. Similar to our result, the initial nitrogen percentage increased at the end of the process by 24 % and 25 %, for piles without and with hen droppings, respectively, versus the N percentage before composting of 1.73 %. Such an increase may be due to the fact that some non-symbiotic soil microorganisms fix nitrogen (Tisdale et al., 1993; Ferrer et al., 2001) in addition to a concentration effect as a consequence of strong degradation of organic C compounds, which reduced the weight of the dry mass (Tiquia and Tam, 2000a,b).

C/N ratio decreased from 35.92 to 19.69 (Figure 7). Changes in C/N ratios were as a result of the changes in organic matter and nitrogen contents. Similar to our results, in the study of Ferrer et al. (2001), the C/N ratio decreased considerably during the process from 26.94 to 17.62 and 13.57 for grape waste without and with hen droppings, respectively, which represents a 35 % and 50 % reduction, respectively, due to the decrease in the percentage of carbon and the increment in the percentage of N throughout the process. Similar reductions were obtained by Shuval et al. (1991), for sewage water and agro-industrial wastes, in which the average C/N ratio decreased from 25 at the beginning of the process to 17 at the end of it (Ferrer et al., 2001). This situation is consistent with our observation.

Cellulose contents increased at the end of the process (Figure 8). Contrary to our study, Degli-Innocenti et al. (1998) were reported full mineralization of the substrate after 45-50 days for cellulose.

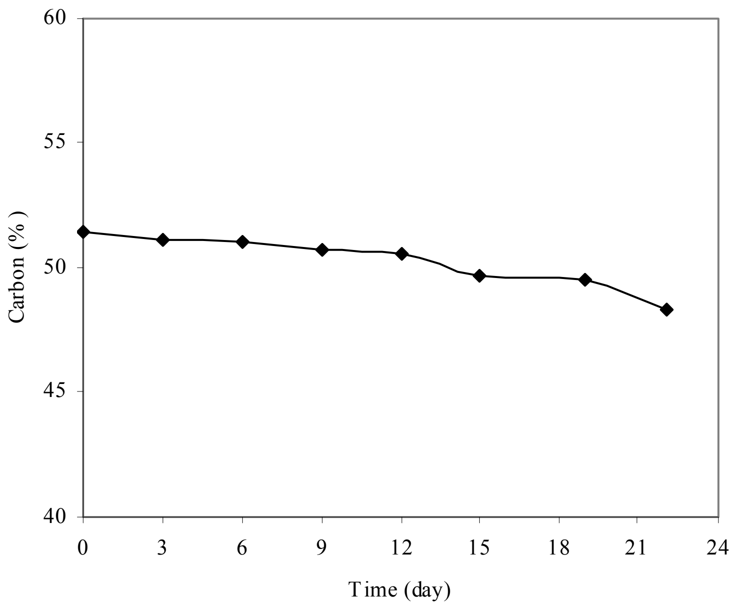

Figure 5:
Changes in carbon contents during composting.

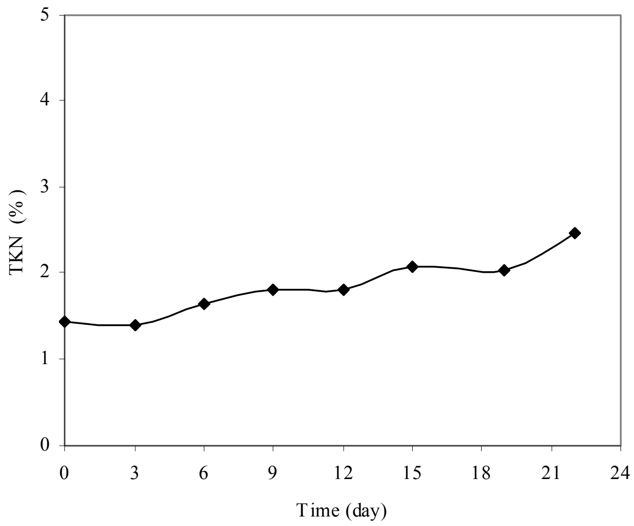

Figure 6:
Changes in TKN contents during composting.

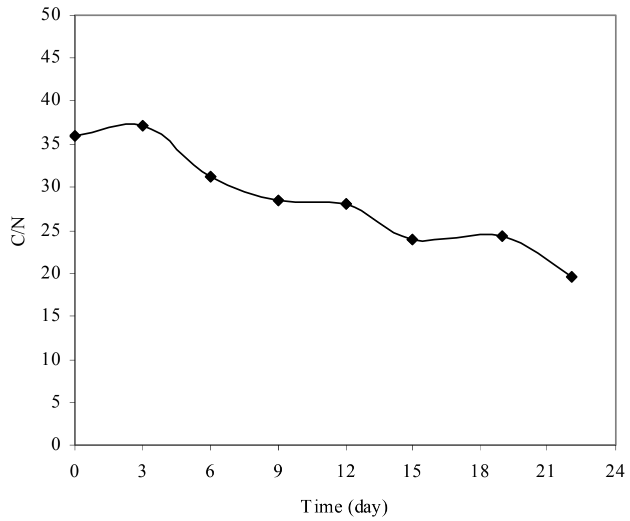

Figure 7:
Changes in C/N during composting.

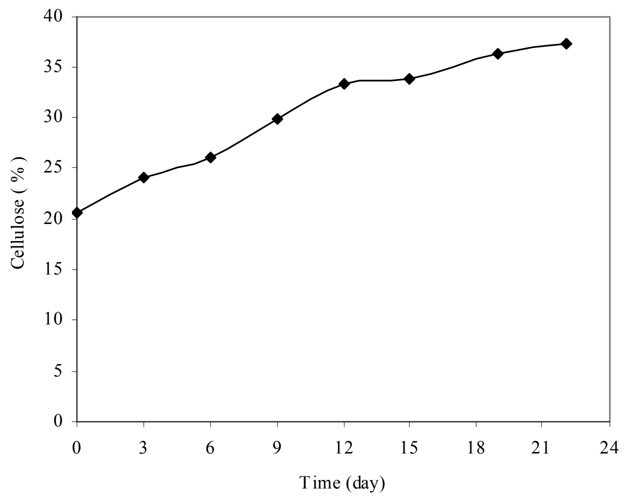

Figure 8:
Changes in cellulose contents during composting.

3.4. Moisture and VS

The contents of moisture were given in Figure 9. When the moisture content of the solids exceeds 70 %, thermophilic temperatures may not be attained, since oxygen movement is restricted (Brito et al., 2008). In our study, KW had the appropriate moisture values for sufficient composting during the process. In the active phase moisture contents were between 48-53 %. When Kulcu and Yaldız (2007) composted goat manure and wheat straw with pine cones, the moisture contents of the samples decreased continuously during composting. This variation is considerably different from our results.

The VS in the KW decreased from 92.47 to 86.87 % (Figure 10). In agreement with our result, in the composting study of Marhuenda-Egea et al. (2007), organic matter decreased from 91.7 % to 84.8 %, 88.5-81.5 and 82.3-73.6 in pile 1, 2 and 3, respectively (Pile 1 was prepared with mixtures of grape stalk, grape marc, exhausted grape marc and sewage sludge, while Pile 2 and Pile 3 were elaborated using exhausted grape marc, cow manure and poultry manure, respectively). These losses were near to the VS loss (6 %) that obtained from our study.

The results indicated that the VS degradation in composting could be expressed as first-order kinetics by using “equation (3)”.

$$dC/dt = -kC \quad (3)$$

where, C is the quantity of VS at any time in kg, t is the time in days, k is the reaction rate constant (d^{-1}). Integrating “equation (3)” and letting $C=C_0$ at t=0 gives “equation (4)”.

$$\ln C/C_0 = -kt \text{ or } \log C/C_0 = -kt/2.303 \quad (4)$$

The reaction rate constant of VS degradation was 0.0414 day^{-1} ($R^2 = 0.99$).

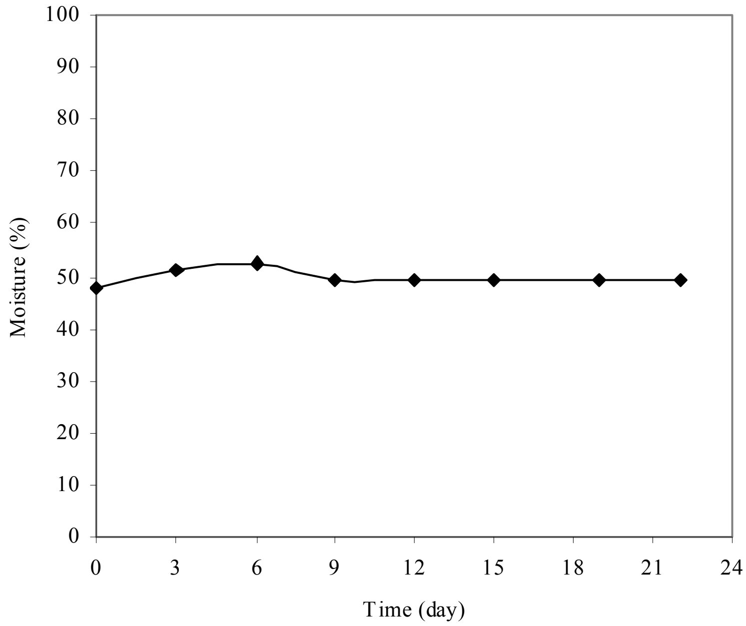

Figure 9:
Changes in moisture contents during composting.

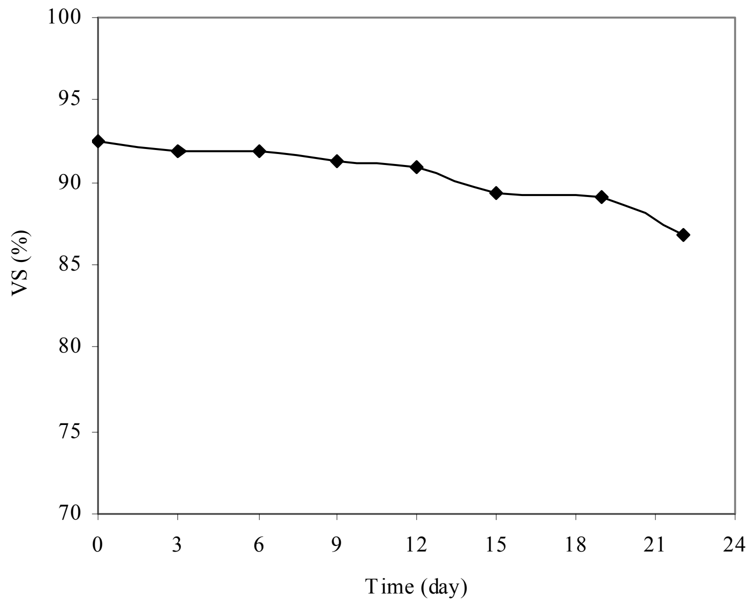

Figure 10:
Changes in VS contents during composting.

3.5. TC and FC

A decrease in TC and FC was observed at the end of the process and perhaps especially of high temperatures at thermophilic stage and loss of organic matter at last stage (Figure 11 and 12). Similar to our results, Sesay et al. (1997), Tiquia et al. (1998), Tiquia and Tam (2000a,b) were reported that FC bacteria declined significantly at the end of the process. The high temperatures reached during composting may potentially limit the survival of pathogenic microorganisms (Mandelbaum et al., 1988; Shuval et al., 1991; Ferrer et al., 2001). In the study of Hassen et al. (2001), the number of FC decreased considerably during the thermophilic phase. This decrease was presumably the result of the high temperature (60–65°C) and of the unfavorable conditions established during the thermophilic phase. However, a phase of resurgent growth appeared from the ninth week contrary to our results. This secondary growth of FC, also observed by other authors, may be due to recontamination or redistribution during the turnings (Alberti, 1984; Hachicha et al., 1993; Hassen et al., 2001).

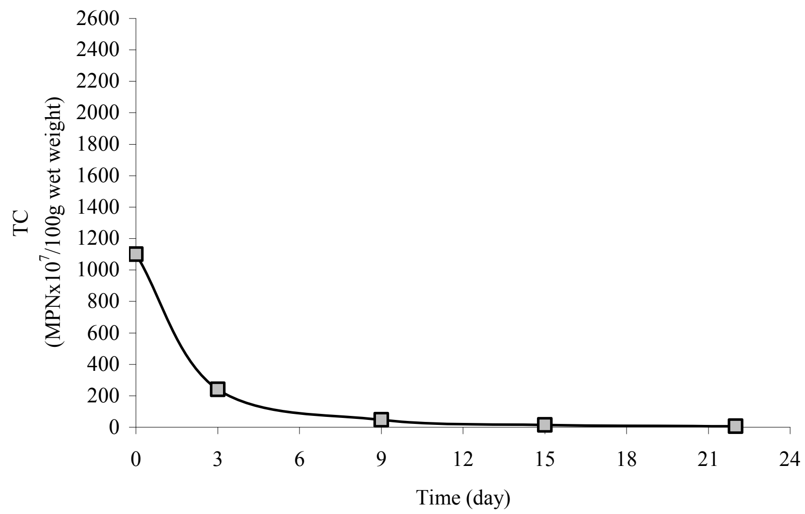

Figure 11:
TC numbers during composting.

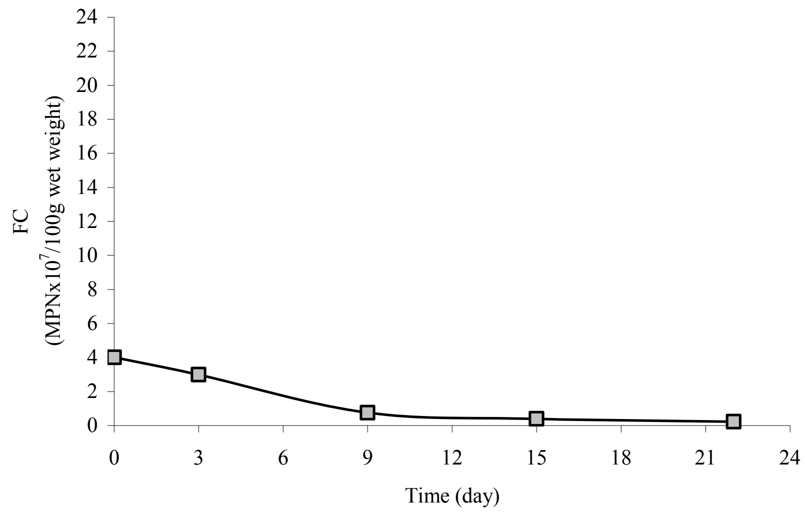

Figure 12:
FC numbers during composting.

3.6. Heavy metals

An important aspect of the usage of the composts is the heavy metal contents of them. Co, Cd, Ni, Cr, Zn, Mn, Hg, Cu and Pb inhibit the photoshentesis and germination in most of the plants, cause nekrozis and chlorosis and damage the hormonal balance. Measured heavy metal contents (Cr, Cd, Zn, Mg, Cu, Co, Fe, Ni, Mn) of the compost were given in Table I. Measured concentrations of Mg, Co, Fe and Mn could not compared with the limits of regulations of various countries. Because the limits of mentioned heavy metals do not exist in the regulations of these countries. Cr, Cd, Zn, Cu and Ni concentrations of the final composts were below the limits established by several legislations (Table II). In Turkey, Regulation of Control of Soil Pollution does not include heavy metal limit values for composts those used in soil. But, there is heavy metal limit values for stabilized treatment sludges those used in soil (Table II). The values obtained by our study were below those values. The increases in the concentrations of the heavy metals at the beginning and end of the process could be explained by loss of mass.

Table I. Heavy metal contents of the composts (mg/kg)

	Cr	Cd	Zn	Mg	Cu	Co	Fe	Ni	Mn
KW Day 0	13.2	*	166.8	823.2	17.225	5.0	1353.10	14.80	49.73
KW Day 22	22.4	*	190.7	1563.5	35.000	7.7	2641.75	15.53	94.30

* Below detection limit

Table II. Heavy metal concentration limits for compost in various countries (mg/kg)

Heavy metal	USA*	Canada*	Australia*	Denmark*	Turkey**
Zn	2800	1850	-	-	4000
Ni	420	180	-	-	400
Cr	-	-	150	100	1200
Cd	39	20	4	1.2	40
Cu	1500	-	400	1000	1750

*(İpek, 2000).

**These values are in Regulation of Control of Soil Pollution for stabilized treatment sludges those used in soil.

3.7. Radioactivity

The α radioactivity in the composting materials was exist contrary to the results of study of İpek et al. (2002). In that study, there was no α activity in the samples. The variations of the β-radioactivity concentration at the beginning and end of the process for KW were given in Table III. The β-radioactivity in KW decreased at the end of the process similar to the study of İpek et al. (2002). It was suggested that β-radioactivity in the analyzed materials had arisen from ^{40}K. Potassium activity was decreased in range of 33% which is clearly seen that in Table III. The potassium radionuclide makes a biggest contribution to the total background dose which rate is approximately 35%. Therefore, decrease of potassium concentration in environmental sample (soil, building materials, waste etc.) is very important to human health. With deposited of ^{137}Cs increases the levels of radiation in the human environment. But, the concentration of ^{137}Cs was very low. Concentrations of this radionuclide decreased by process. This study indicated that gross alpha and gross beta radioactivity in KW could be reduced by in-vessel aerobic composting.

Table III. The radioactivity levels of raw materials and obtained compost

Sample	Gross α-radioactivity (Bq/g)	Gross β-radioactivity (Bq/g)	^{137}Cs (Bq/g)	^{40}K (Bq/g)
KW Day 0	0.5481 ± 0.0119	0.0218 ± 0.0007	0.0218 ± 0.0004	0.930
KW Day 22	0.2100 ± 0.0179	0.0170 ± 0.0006	0.0044 ± 0.0002	0.626

4. CONCLUSIONS

Biodegradable organic wastes which do not have any economical value added to environment by various sources (municipal, household, agriculture etc.) and cause lots of problems associated with public health. Composting of these wastes support the environmental and public health and economics by eliminating pathogens, and preventing pollution and protecting resources.

In our study, C/N ratio decreased from 35.92 to 19.69. The final value of the C/N ratio was suitable for application of the composts to the soil. The contents of cellulose increased at the end of the process. pH values increased at the end of the composting process. EC values increased from 769 to 959 μS/cm. KW had the appropriate moisture values for sufficient composting during the process. The reaction rate constant of VS degradation was 0,0414 day^{-1} (R^2 = 0,99).

Indicators examined in this study decreased during the in-vessel aerobic composting process. The obtained composts contained heavy metals under the standards related to heavy metal. α-radioactivity greatly decreased at the end and also the β-radioactivity decreased. In-vessel aerobic composting was effective to reduce TC, FC, α-and β-radioactivity in waste used. According to these parameters, if such composts are in soil, a risk for human health could not arise.

5. ACKNOWLEDGEMENT

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