J. Mater. Environ. Sci. 6 (8) (2015) 2206-2220
ISSN : 2028-2508
CODEN: JMESCN

Characterization of activated sludge from domestic sewage treatment plants and their management using composting and co-composting in aerobic silos

G. El Kadiri Boutchich [1,*], S. Tahiri [1], M. Mahi [2], D. Gallart-Mateu [3], M. de la Guardia [3], A. Aarfane [1], EK. Lhadi [1], M. El Krati [1]

1. Laboratory of Water and Environment, Department of Chemistry, Faculty of Sciences of El Jadida, P.O. Box 20, El Jadida (24000), Morocco.
2. International Institute for Water and Sanitation (IEA-ONEE), Rabat, Morocco.
3. Department of Analytical Chemistry, University of Valencia, Research Building, 50th Dr. Moliner Street, 46100 Burjassot, Spain.

Received 15 Jan. 2015, Revised 30 May 2015, Accepted 30 May 2015
** Corresponding author: E-mail: ghizlane.elkadiri@yahoo.fr*

Abstract
In this work, the physico-chemical characteristics of activated sludge from domestic sewage treatment plants were first determined. The composting of waste activated sludge alone (100% w/w) and in presence of sawdust (25% w/w) during nine months was then investigated. Aerobic fermentation was monitored during the first month in reactors. After that, samples were transferred in perforated bags for eight months to reach maturation. Two aerobic composting reactors (silos) were used simultaneously and under the same conditions (air-flow 20 L/h and external ambient temperature 25±2°C). In order to control biotransformation processes, composting was monitored by determining physico-chemical and microbiological parameters. The evolution of the parameters analyzed (temperature, moisture, pH, organic matter, C/N ratio, nitrogen and carbon) during the nine months of composting process demonstrate the stability and maturity of obtained compost. In the system without sawdust material, the maximum temperature was 40°C. However, the mixture sludge/sawdust 75:25 reaches thermophilic conditions with a maximum temperature of about 58°C, thus providing a best degradation. According to germination index, waste activated sludge mixed with the aforementioned carpentry waste provided compost with visibly positive properties for agricultural use. The addition of sawdust to sludge decreases considerably the number of coliforms in compost; this is mainly due to the effect of dilution and to the level of temperature reached.

Keywords: Waste activated sludge; Sawdust; Composting; Co-composting; Process monitoring.

1. Introduction

The water consumed or used by humans in domestic and industrial fields generates inevitably wastes. Wastewaters are collected by drains and directed to wastewater treatment plants to be purified before reintroduction into the nature [1]. Activated sludge is the treatment process mainly used to achieve this objective. Wastewaters containing organic matter are aerated in an aeration basin in which micro-organisms metabolize the suspended and soluble organic matter [2]. In activated sludge systems the new products formed in the reaction are removed from the liquid stream in the form of a flocculent sludge in settling tanks. A part of this settled biomass, described as activated sludge is returned to the aeration tank and the remaining forms waste or excess sludge [3-5]. The activated sludge process has the advantage of producing a high quality effluent for a reasonable operating and maintenance costs.
The increase of the amount of sludge produced in municipal wastewater treatment plants has been recognized as a problem for many years, but recently the strict legislation concerning sludge handling has given an increasing urgency to solve the problem.
Management of activated sludge waste was the subject of various scientific researches. Biomethanisation is well known as the biological process to treat the sewage sludge by degrading organic matters, generating bio-energy and killing pathogens. This process was developed by several researchers [6,7]. The conversion of organic matter to biogas occurs in a sequence of four steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis [8].

Composting is one of the processes recommended to manage activated sludge waste. Its principle is based on the production of organic fertilizer through the degradation of organic fractions of wastes. Composting is an aerobic process of converting fermentable organic matter by many microorganisms. It provides an oxidation of the organic material with water formation, carbon dioxide production and heat release. Biochemically, composting is a continuous process in which different reactions occur both in parallel and consecutively. This process is similar to that of natural humification of organic residues to humic substances in soil. Composting allows the formation of a stabilized, hygienised and deodorized residue with high amount of humic molecules, which is called compost. Antizar-Ladislao et al. [9] specify that composting accelerates the aerobic biological transformation of organic matter involving the formation of humic substances and generating a stable product: the compost. Composting becomes increasingly practical and simple solution for the valorization of wastes. It has many advantages such as: (i) recovery of waste for the production of stable organic amendment, (ii) improvement of porosity and structure of the soil [10] (iii) increase of buffering and exchange capacity of the soil [11], (iv) reduction of the soil acidity, (v) remediation of contaminated soil [12-14], etc.

The aim of the present work is to monitor the aerobic composting in silo of sludge from wastewater treatment plants and, on the other hand, to improve the process by means of co-composting with waste wood, such as sawdust. To monitor the evolution of the composting systems, routine parameters as temperature, moisture, pH, Total Kjeldahl Nitrogen TKN, Total Organic Carbon TOC, and C/N ratio were periodically analyzed. To evaluate the suitability of the maturated composts for its use in agriculture, phytotoxicity tests and microbiological analysis were also carried out.

2. Materials and methods

2.1 Samples

Three activated sludge samples were collected from the drying beds of the wastewater treatment plant of Bouregreg (Rabat, Morocco). The sampling of the three sludges (1), (2) and (3) was carried out in March 2011, December 2013 and April 2014, respectively.

Sawdust is the waste product resulting from wood processing. Red fir sawdust was collected from a carpentry workshop in El Jadida (Morocco) and was used as a co-composting material.

2.2 Composting process

Sludge was composted using aerobic reactor (silo) in the absence and presence of sawdust. It was manually mixed with the carpentry waste by means of a shovel in order to obtain an homogeneous product. In our study, two samples were composted: 100% wet sludge and 75% wet sludge mixed with 25% sawdust.

A small-scale pilot system was installed in the laboratory. It consists of two reactors of polyvinylchloride (volume: 10 liters), thermally insulated by a layer of glass wool on their external lateral surface. These reactors are fed at their bases by an air inlet provided by a common compressor. The degree of filling of the aerobic composting silos was about 60%.

The aerobic composting silos are used simultaneously under the same conditions (air-flow 20 L/h and external ambient air temperature 25±2°C). The measurement of the temperature inside the reactors is carried out continuously by using two thermometers placed at the center of the mass to be composted. At the reactors outlet, we placed (i) two absorber tubes of silica gel which retains water vapor, (ii) an absorber tube containing lime soda to trap CO_2, and (iii) an erlenmeyer flask containing H_2SO_4 N/10 to collect NH_4^+ formed in the bioreactor (See Figure 1). Fermentation of sludge and its mixture with sawdust was monitored during the first month in reactors. After that, samples were removed from the reactors and were then transferred in perforated bags for eight months.

During the first month, reversal of the matter composted in the silos was conducted once every three days. However, reversals become less frequent in the bags (every 15 days on average).

2.3 Analysis

For mineral analysis of samples and their mapping, an environmental scanning electron microscope equipped with an EDAX system PHILIPS XL 30 ESEM (Einhoven, Neederlands) was used. Attenuated Total Reflectance Infrared ATR-IR spectra were also recorded using a Tensor 27 FTIR spectrometer from Bruker (Karlsruhe, Germany) equipped with a DLaTGS detector. Spectra were obtained by coadding 50 scans at a resolution of 4 cm^{-1} and a scanner velocity of 10 kHz HeNe frequency, from 4000 to 550 cm^{-1}. For instrumental and measurement control, spectra treatment and data manipulation, it was employed the OPUS program (version 6.5) from Bruker. Spectra recorded are the average of 4 spectra of each sample with a smoothing of 9 points.

A D5005 powder diffractometer from Bruker (Karlsruhe, Germany) was used to obtain the x-ray diffraction spectra of raw and thermal treated sludge. In order to develop the thermal treatment a muffle furnace was used. In this sense, four portions of sample were placed inside crucibles and submitted to 150˚C, 550˚C, 750˚C and 1000˚C before being analysed.

Samples for analysis were taken each month during composting. They were dried in an oven for 24 hours at 40°C and then grounded and sieved to 2 mm size.pH was determined on a suspension of each sample in water (l0 g/25 ml) according to the standard method AFNOR X 31-103. Content of total organic matter was determined using the mass loss after calcination of samples with known moisture, at 550 °C for 16 h (Loss on ignition method MA 1010 - PAF 1.0). Organic carbon content was determined after hot temperature oxidation in the presence of $K_2Cr_2O_7$ according to the AFNOR X 31-109 norm. Total nitrogen content was determined after mineralization in a hot concentrated acid medium and in the presence of catalyst according to AFNOR standard X 31-111. Moisture content (%) was calculated from the sample weight obtained before and after drying at 105°C according to the AFNOR X 31-102 norm.

Mineral content of samples was determined in samples using an Optima 5300 dv Inductively Coupled Plasma Optical Emission Spectrometer ICP-OES from Perkin Elmer (Massachussets, USA). The device is equipped with a Cross Flow nebulizer and an auto sampler AS 93-plus. Argon C-45 (purity higher than 99.995%) supplied by Carburos Metalicos (Barcelona, Spain) was employed as plasmogen and carrier gas. A multi-elemental trace elements standard of 100 µg/mL (100% purity) for atomic absorption (AA), in nitric acid 0.5 mol/L and a Ca, Mg, K and Na 1000 µg/mL (100% purity) standard for AA obtained from Scharlau (Barcelona, Spain) were used.For standards, nitric acid 69% for trace analysis provided by Scharlau was used. In all cases, the chemicals employed were of analytical grade and the water used for sample and standard preparation had a maximum resistivity of 18.2 MΩcm and was obtained from a Milli-Q Millipore system (Bedford, MA, USA). For sample digestion, hydrochloric acid 37%, reagent grade and sulfuric acid 95-97% reagent grade provided by Scharlau were used. A set of eight standards, for trace elements, of 0, 0.05, 0.1, 0.25, 0.5, 1, 2.5 and 5 µg/mL was prepared by dilution of 100 µg/mL multi-elemental stock standard. A set of thirteen standards, for Ca, Mg, K and Na, of 0, 0.05, 0.1, 0.25, 0.5, 1, 2.5, 5, 10, 20, 40, 60 and 80 µg/mL were been prepared by dilution of 1000 µg/mL mono-elemental analytical standards.

A microwave system Ethos SEL from Milestone (Sorisole, Italy) equipped with a thermocouple for automatic temperature control and an automatic gas leaks detection system was used for microwave assisted digestion of sludge and compost samples before their analysis by ICP-OES. Ten high pressure vessels of 100 mL inner volume were used, operating at a maximum exit power of 1000 W. All Teflon digestion vessels were previously cleaned in a bath of 10% (v/v) nitric solution for 48 h to avoid cross-contamination. Amounts of 0.5 g of each sample, per duplicate, were weighted accurately and treated with 5 mL of sulphuric-nitric mixture (2:1 v/v) until complete digestion. The digested residue was reconstituted in HCl 2% dissolution and transferred quantitatively to a 25 mL volumetric flask. 1/25 dilutions from the aforementioned solutions were measured together with non-diluted ones in order to obtain data for major, minor and trace elements.

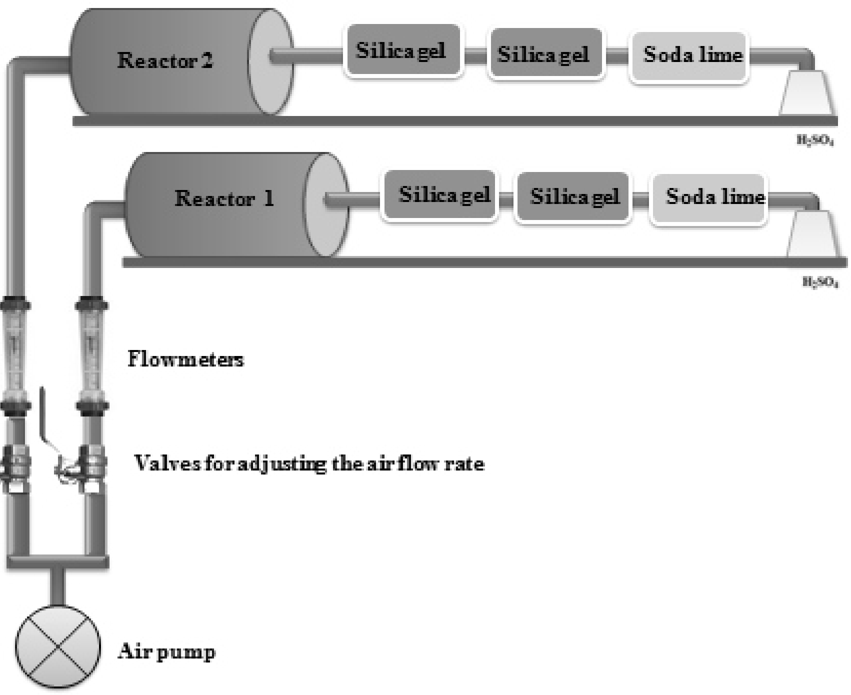

Figure 1: Laboratory pilot plant used for composting.

2.4 Germination index

Phytotoxicity evaluates the maturity of composts. For this purpose, the effect of aqueous extracts of compost on the germination of wheat seeds was measured from germination index defined GI. Germination is the process by which a plant grows from a seed. The compost extract was prepared by the method DI.VA.PRA (1998). Germination index was calculated based on the following formula [15]:

$$GI = \frac{S_s\ R_s}{S_c\ R_c} 100 \qquad \text{(Eq. 1)}$$

Where S_s is the number of seed germinated in sample extracts, S_c is the number of seed germinated in control, R_s the average root length in sample, and R_c is the average root length in control.

2.5 Microbiological analysis

Enumeration of microorganisms, namely total coliforms (TC) and fecal coliforms (FC) was performed according to the method of the most probable number (MPN) which is an important technique in estimating microbial populations in soils, waters and agricultural products. The methodology for the MPN technique is dilution and incubation of replicated cultures across several serial dilution steps. One gram of sample was homogenized in 9 mL of sterile physiological water and the mixture was diluted several times (10^{-2}, 10^{-3}, 10^{-4} and 10^{-5}). For each dilution, the enumeration of the microorganisms was achieved by seeding 0.1 ml of prepared suspension in two sterile petri-dishes. Tergitol 7 was used as culture medium; it was incubated at 44 °C/48h for FC and at 37 °C/48h for TC. After incubation, measurements were done by counting the colonies.

3. Results and discussion

3.1 Characterization of sludge and sawdust

The physico-chemical characteristics and the elemental chemical composition of the tree samples of activated sludge are listed in Table 1. As it can be seen, sludges 1 and 2 have the same pH (~8) and relatively the same amount of carbon (28.22% and 28.74%), sulfur (0.89% and 0.95%) and ash (44.23% and 42.7%). But they have unlike C/N ratio (14.62 and 6.7) because their different nitrogen content (1.93% and 4.29%). The physico-chemical characteristics of sludge 3 are generally different than those of sludges 1 and 2. Therefore, the characteristics of sludge are strongly dependent on the initial characteristics of raw wastewaters and the treatment performance of wastewater treatment plant (WWTP). On the other hand, the chemical composition of sawdust was: C: 49.4%, H: 6.3% and N: 0.3%. The amount of ash in sawdust was about 2%, which is very low as compared with activated sludge (44.23%, 42.7% and 51.23%). Analysis shows also that sawdust is more acidic than waste activated sludge. From the aforementioned data, it can be seen that addition of sawdust to sludge from wastewater treatment plants can decreases the pH and increases the C/N ratio of the mixture. So, sawdust can be considered as a suitable material for adjusting the C/N ratio of sludge. On the other hand, sawdust has noticeably a lower density than that of sludge. Density of the mixture will then decrease when sawdust is added (Table 1).

Table 1: Physico-chemical characterization of activated sludges and sawdust.

Parameter	Sludge 1	Sludge 2	Sludge 3	Sawdust
Moisture (%)	48	28.2	54.1	15
pH	8.0	7.9	6.5	5.0
C (%)	28.22	28.74	18.87	48.70
N (%)	1.93	4.29	3.06	0.24
H (%)	3.31	4.19	3.42	6.10
S (%)	0.89	0.95	0.66	*n.d.*
C/N ratio	14.62	6.70	6.17	203
Ash (%)	44.23	42.7	51.23	2
Density (g/cm^3)	0.88	0.85	1.29	0.33

n.d.: not-detected

The scanning electron microscopic method is a good technique for showing the structure and morphology of solids. Figure 2a and Figure 2b present the images obtained by SEM of sludge 1 and sawdust, respectively. As the three sludges revealed the same morphology, only the SEM micrograph of sludge 1 was presented. The resulting micrographs show that sludge presents an unordered structure with heterogeneous distribution of particles. However, SEM micrograph of sawdust shows the highly ordered structure being this material a multilayer composite.

In order to identify the mineral composition of raw materials tested in this work, Energy Dispersive X-Ray Analysis (EDAX) was used. As it can be seen, this semi-quantitative analysis shows the presence of C and O as major elements in the case of sawdust. However, in the case of sludge, EDAX analysis shows the presence of the following elements: C, O, N, Fe, K, Ca, Mg, N, Al, Si, S and P (Figure 3).

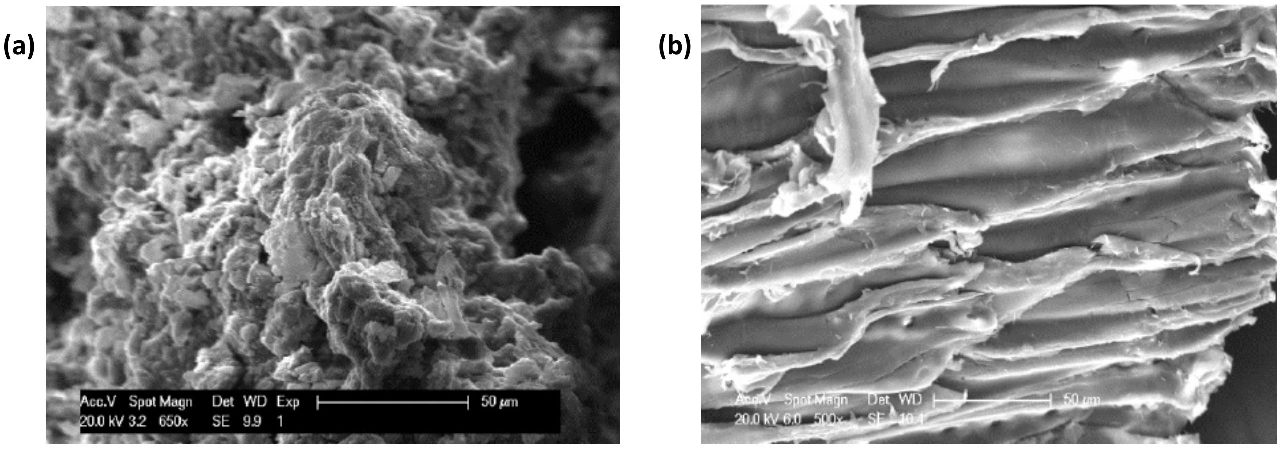

Figure 2: SEM Micrographs of sludge 1 (a) and sawdust (b).

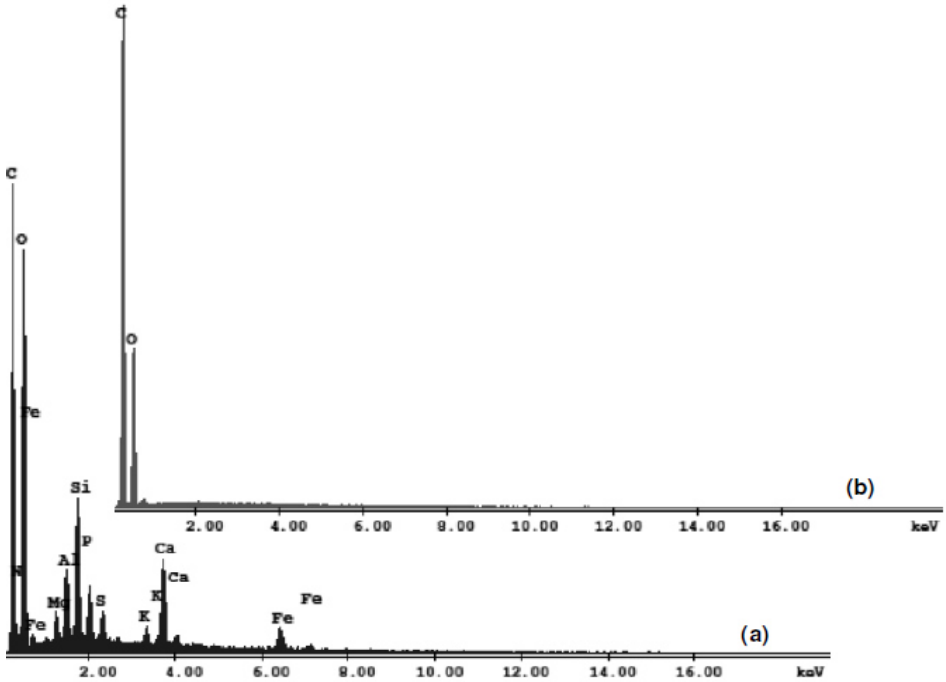

Figure 3: Microanalysis done with EDAX for raw materials: sludge (a) and sawdust (b).

3.2 Thermal behavior of sludge during combustion

Because all of the sludges (1, 2 and 3) showed the same behavior on increasing the temperature, only sludge 2 was chosen in this work to show the thermal evolution of sludge from wastewater treatment plants during incineration. The thermal treatment of sludge decreases its amorphous structure. Normally, during combustion, the amount of organic matter decreases and the percentage of total mineral salts increases. This can be clearly obtained from the EDAX analysis which shows a drastic reduction of some elements such as nitogen and carbon and consequently an increase of the mineral content (data not shown). The SEM micrographs of raw and thermally treated sludge shown in Figure 4 indicated that the material do not has a given structure. Formation of aggregates was noticed at high temperatures.

Figure 5 shows the average of four IR spectra obtained for the same sample treated at different temperatures (105°C, 550°C, 750°C and 1000°C). As it can be seen, the intensity of the broad absorption peak centered at 3300 cm^{-1}, which may be assigned to the presence of –O-H and –N-H groups, decreases by increasing temperature and disappears completely for samples heated beyond 550°C. The bands located between 1500cm^{-1} and 1700 cm^{-1}, attributed to functional groups of organic matter such as humic substances, disappear completely at high temperature.

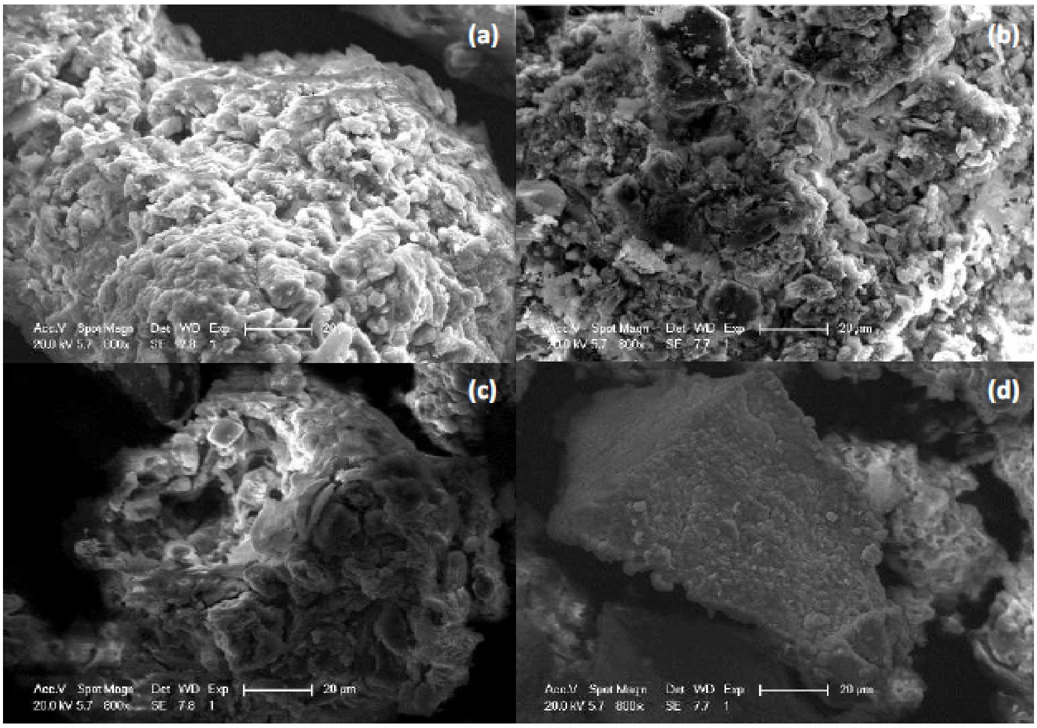

Figure 4: SEM photography of sludge 2 treated at (a) 105°C, (b) 550°C, (c) 750°C and (d) 1000°C.

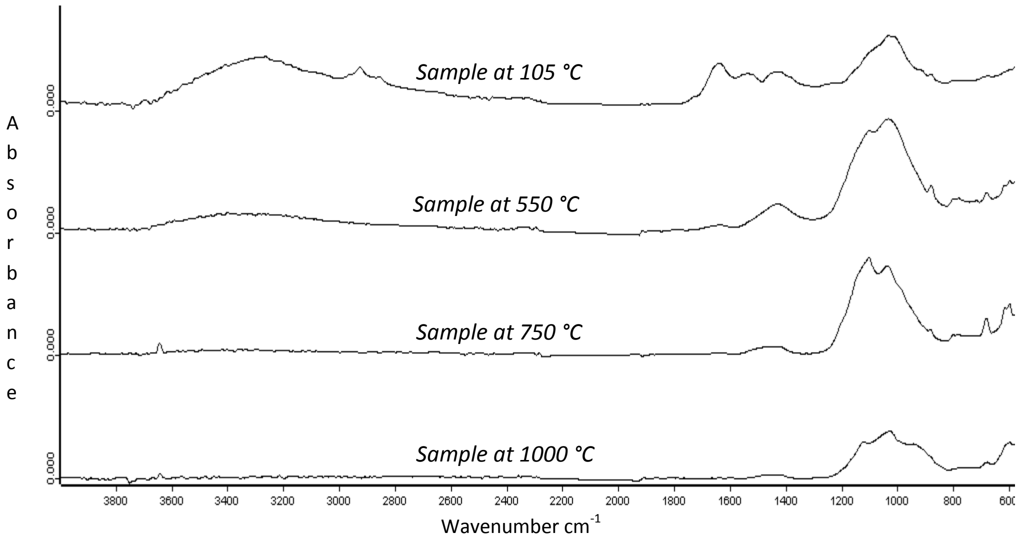

Figure 5: ATR-FTIR spectra obtained for sludge 2 treated at different temperatures.

The bands located in the wave number region 2800-3000 cm^{-1}, attributed to aliphatic methylene, also disappear. This is mainly due to the removal of organic matter by combustion. Indeed, the temperature from which samples can be considered completely mineralised is about 550 °C. The large band centred at 1000 cm^{-1} can be attributed to asymmetric stretching vibration of Si-O and Al-O bonds. On the other hand, the band located at 1450 cm^{-1} can be attributed to the presence of carbonates. This band decreases by increasing temperature.

As can be seen in Figure 6, X-ray diffraction spectra show the presence of Quartz SiO_2 and various structures of carbonates (Calcite and Dolomite). DRX spectrum of sludge calcinated at 750˚C shows that the calcite identified at low temperatures disappears, mainly by decomposition to CO_2. Likewise it can be seen the presence of Quartz and Dolomite, as in the previous cases. It can be seen also that heat treated sample at 1000°C shows well defined crystalline structures. At this temperature, it can be determined Quartz SiO_2 and Dolomite $CaMg(CO_3)_2$, present in all heat treated samples, Albite (Na, K crystalline aluminosilicates) and the appearance of new crystalline phases as Hematite Fe_2O_3.

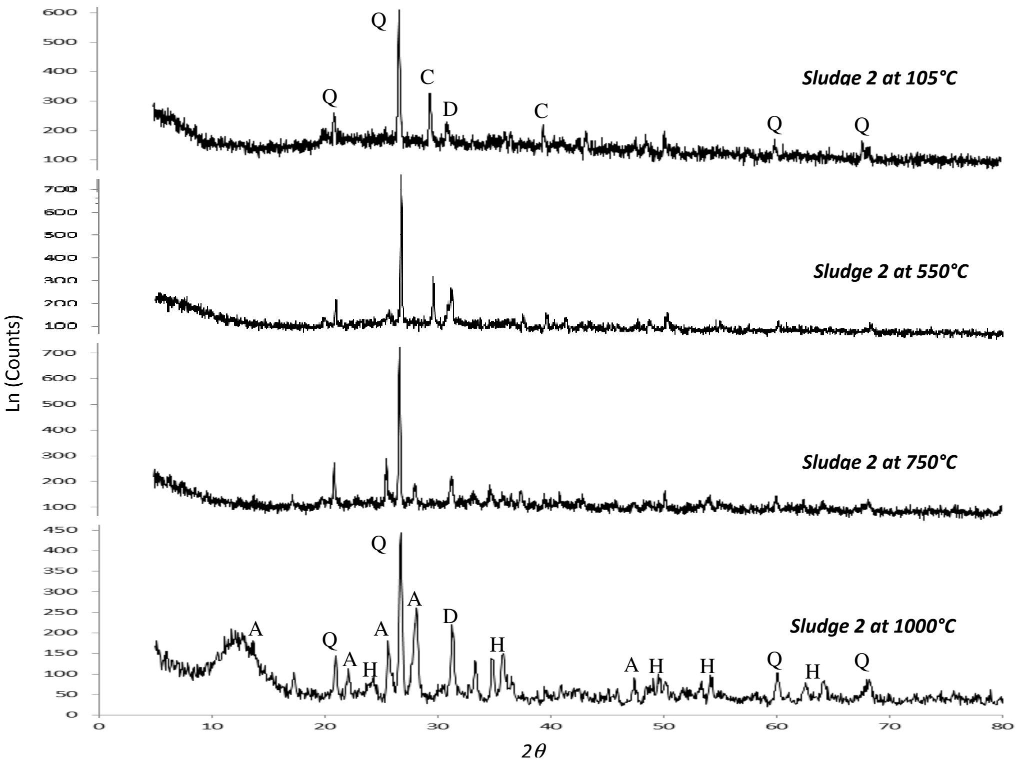

Figure 6: XRD spectra of raw sludge 2 and after its heating at different temperatures (A: Albite ; C: Calcite ; D: Dolomite ; H: Hematite ; Q: Quartz).

3.3 Tests of composting

3.3.1 Evolution of temperature

The evolution of the temperature of each sludge sample for a period of one month in the aerated composting reactors is shown in Figure 7. Temperatures were measured in different parts of each reactor and average value was considered as the temperature of composting material. We found that the three sludges react differently as a function of time. The maximum temperature that can reach sludge 3 was about 32°C. This is probably due to its biological stability caused by a prolonged aeration or to a partial windrow composting that occurs during its residence on the drying beds. However, the temperature of sludges 1 and 2 can reach respectively 40°C and 47°C but the addition of co-substrate is much recommended in order to improve composting process.

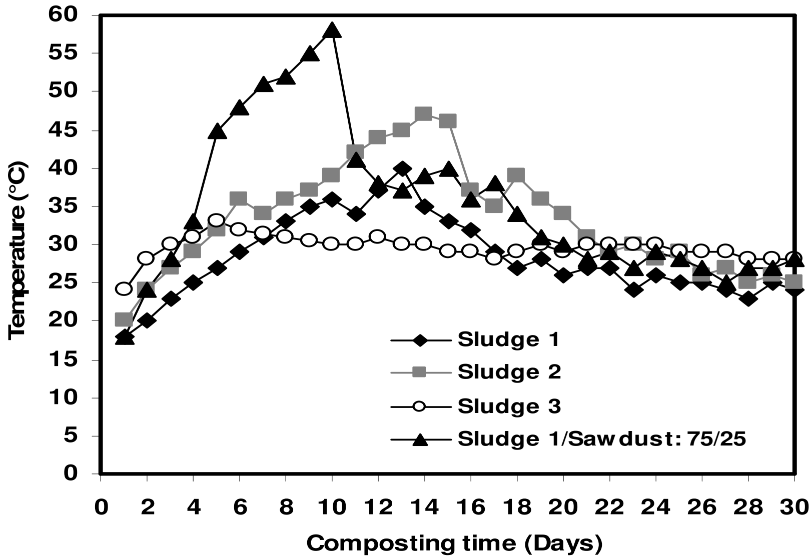

Figure 7: Temperature changes during composting process of sludges 1, 2 and 3 and of sludge 1 mixed with sawdust (75/25).

Results of the evolution of temperature of sludge 1 and its mixture with sawdust (ratio: 75/25), produced during all phases of fermentation are shown also in Figure 7. The analysis of graphs reveals that the temperature, recorded daily during the composting process, increases gradually during the first 10 days to reach a maximum of 58 °C for the mixture (sludge 1 and sawdust), and 40 °C for the sludge alone. This increase is followed by a gradual drop of temperature that tends to stabilize between 24 °C and 28 °C. The remarkable increase in temperature is due to an intense microbial activity developed on a organic material readily biodegradable [16]. Charnay [17] showed that the temperature monitoring is an indirect measure of the intensity of degradation which reaches its maximum in the first month of composting. However, it is important to note that the temperatures reached in the mixture sludge 1/sawdust are higher than those observed for sludge 1, this can mainly be attributed to the good structure of the mixture, which facilitates a good air circulation inside the material and consequently a good biodegradation of organic matter which increases temperature.

3.3.2 Moisture

Water is one of the main elements required for microorganisms activity. If humidity is high, many problems may arise in the process of fermentation. The optimum moisture to be held during composting for optimal microbial activity is generally between 45% and 70% [18]. In our case, the initial moisture content of sludge 1 and its mixture with sawdust was between 46% and 48%. The initial moisture contents were suitable for optimum start up of the composting process. After composting, the moisture of sludge 1 and the mixture decreased significantly to 25% and 23%, respectively (Figure 8). It means that some of the heat generated during composting process causes evaporation of water which leads to a drying of the material [19].

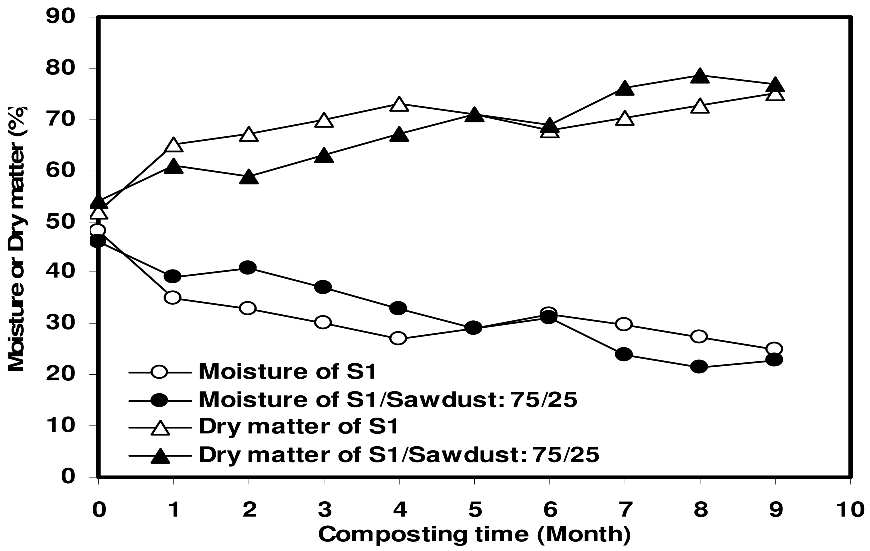

Figure 8: Moisture and dry matter contents of sludge 1 and its mixture with sawdust during composting time.

3.3.3 pH

Overall, the initial waste has a slightly stronger acidity than the finished compost. pH control is often useful in fermentation and allows us to follow the process in order to orientate it favorably. Monitoring pH value is an indicator of the degree of biological and biochemical decomposition. Figure 9a shows the pH change curves on the basis of composting time. As it can be seen, the pH increased gradually in both reactors during composting process. pH of sludge 1 and its mixture increases from 8 to 8.4 and from 7.7 to 8.8, respectively. This behavior is related to the release of NH_3 [20]. Several studies have shown that composts subjected to good oxygenation conditions reach quickly pH values of about 8 [21].

3.3.4 C/N ratio

Carbon is the main element of the waste material; it is divided into total organic carbon (TOC) and inorganic carbon, the last one being in the form of carbonate and bicarbonate. Nitrogen is the second most abundant element in organic waste. During composting, organic nitrogen substrate is mineralized to ammonium (NH_4^+) and nitrate (NO_3^-) when nitrification goes to completion. Mineral nitrogen is thus reincorporated in the microbial metabolism during composting and also in the final compost at their humification. Biodegradability of organic waste is dependent on its C/N ratio. A wide range of C/N ratio ranging from 10 to 80 [22-24] has been reported in the literature. The aforementioned ratio decreases during composting fill to reach values generally between 8 and 25 which can be explained by the fact that micro-organisms consume more carbon than nitrogen [22,25]. Figure 9b shows the C/N ratio changes during nine months of composting. The addition of sawdust increases the C/N ratio from around 15 to 22. Thus, sawdust allows enrichment in organic carbon. Regarding C/N ratio, its evolution is in good agreement with that of the total organic carbon and total nitrogen (Figure 9c and Figure 9d). The C/N ratio of sludge 1 decreases during composting from 15 to 8.41 and that of mixture sludge-sawdust from about 19 to 10. According to Mustin [11], the decrease of C/N ratio is the result of loss of carbon as CO_2 by mineralization during the composting process. At the end of the process, we noticed that the C/N ratio of the sludge and of the mixture reached a value of about 8 and 10, respectively. This is a good result because according to Mustin [11] the optimal range C/N ratio is between 8 and 15.

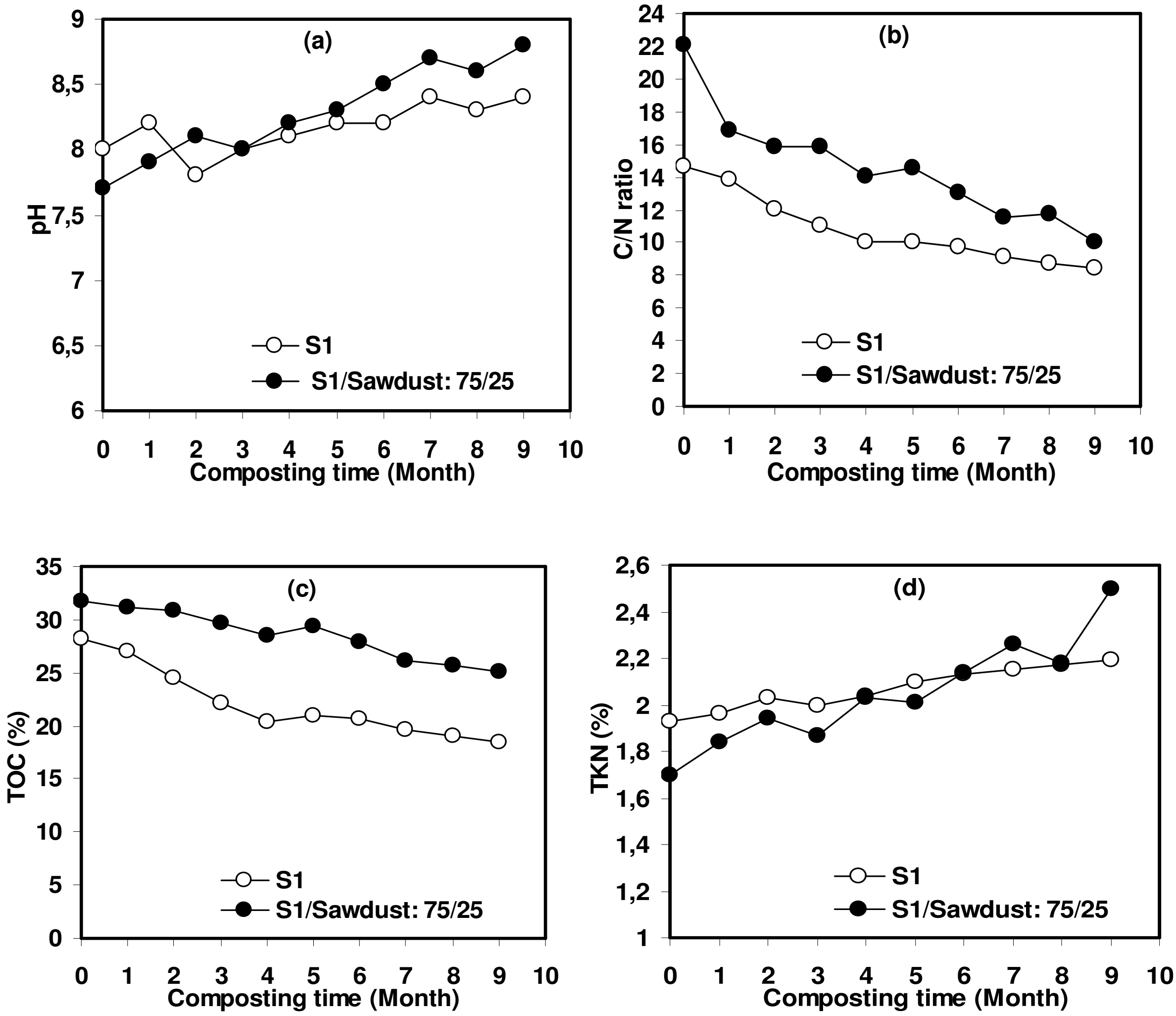

Figure 9: Evolution of pH values (a), C/N ratio (b), TOC content (c) and TKN content (d) of sludge 1 and its mixture with sawdust during composting time.

3.3.5 Decomposition of organic matter Figure 9c shows a decrease in total organic carbon TOC levels throughout the process for the two samples evaluated. TOC decreases from 28.2 to 18.4 in the case of sludge 1 and from 31.7 to 25 in the case of the mixture with sawdust. Decrease in organic carbon is mainly due to the degradation of organic matter by micro-organisms [17]. On the other hand, the percentage of Total Kjeldahl Nitrogen TKN increases slightly. It reaches 2.2% and 2.5% for the sludge 1 and its mixture with sawdust, respectively (Figure 9d). This can be explained by the decomposition of proteins under the effect of heat and the action of microorganisms [11].

ISSN : 2028-2508
CODEN: JMESCN

Generally, the organic matter content and C/N ratio decreases during the maturation of compost between the third and sixth month [26]. After maturation (9 months of composting), the amount of organic matter in sludge 1 and its mixture decreases from 55.77% to 40% and from 59.26% to 43.75%, respectively. It is mainly due to the elimination of carbon as carbon dioxide CO_2, since most of the volatilized organic matter naturally come from carbon-rich substances [26]. The decrease of organic matter after composting of sludge and green agricultural waste, has been related to a microbial mineralization of organic matter in the sludge because lignocellulosic green waste are degraded much more slowly [27-29].

In this work, we calculated the rate of organic matter decomposition by measuring the initial and the final levels of ash obtained by calcination of the samples at 550 °C for 16 hours. The proportion of decomposition of organic matter was calculated according to the following formula:

$$Decomposition\ (\%) = \frac{100\,(C_f - C_i)}{(100 - C_i)\,C_f}100 \qquad \text{(Eq. 2)}$$

Where C_i is the initial amount of ash in the dry matter of raw sample and C_f is the final amount of ash in the dry compost [30].

After composting, the decomposition of organic matter may reach 39.5% and 35.0% for sludge 1 and sludge 1 mixed with sawdust, respectively (Figure 10). After the sixth month, the degradation rate of organic matter is generally slow by comparing it to that corresponding to the previous months. As we can see, the segment of the curve after T6 has a low slope compared to that corresponding to composting time ranging from T0 to T6. This behavior is a sign of maturation. The difference between the two curves is probably due to the ability of each material (sludge and sawdust) to be decomposed.

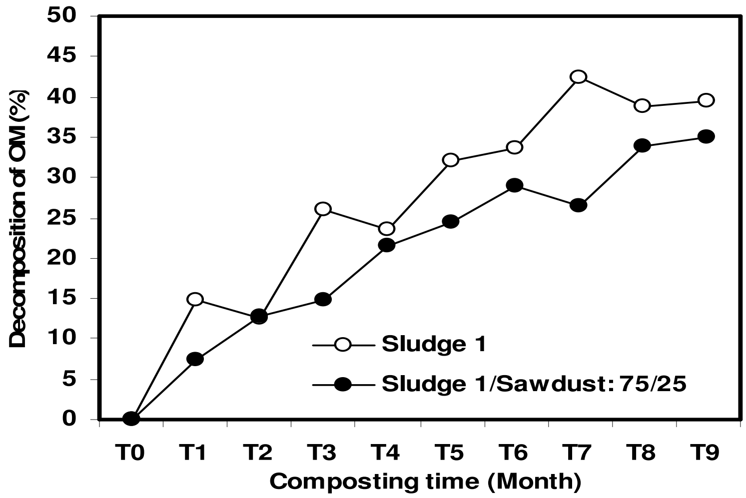

Figure 10: Decomposition of organic matter during composting as a function of time.

3.3.6 Microorganisms activity during the composting process

Microorganisms play an important role in the degradation of organic matter during the composting process. Enumeration of total and faecal coliforms was performed in sludge 1 and in composts obtained after 9 months of composting of sludge 1 and its mixture with sawdust. Results obtained are shown in Table 2. Composting of sludge 1 decreases both, total and fecal coliforms, by about 99.78%-99.82%. As it can be seen, after nine months of composting, the number of total coliforms decreases from 5.4 10^6 to 11.8 10^3 CFU/g and that of fecal coliforms from 12.7 10^5 to 2.22 10^3 CFU/g. In the case of the mixture (75% sludge/ 25% sawdust), the decrease of microorganisms can reach 99.97%-99.99%. As can be seen in Table 2, the number of total and fecal coliforms can be reduced to 0.62 10^3 CFU/g and 0.33 10^3 CFU/g, respectively at the end of the process. According to the Canadian Council of Ministers of the Environment CCME [31], the level of fecal coliforms must not exceeded 1000 MPN per gram of total solid; this is in good agreement with the microbiological analysis of the compost of the mixture of sludge and sawdust which shows a value of about 330 CFU/g. The addition of sawdust to sludge decreases the number of coliforms in compost; this is due mainly to the effect of dilution and to the level of temperature reached (about 58°C) in the case of the mixture. Obtained results are

ISSN : 2028-2508
CODEN: JMESCN

also in agreement with those found by Guene [32] and Charnay [17] who estimated that composting allows elimination of pathogens. Indeed, aerobic composting process allows efficient destruction of pathogens when the temperature reaches about 60°C for several weeks. This can be explained by the fact that microorganisms affect the composition of the substrate, the temperature and pH of the medium. Microorganisms create then the conditions for their own destruction during composting. The U.S. EPA recommends a minimum of 15 days at 55 °C with 5 reversals for windrow composting and 3 days at 55 °C for tunnel or static pile composting [33]. Dumontet et al. [34] reports the results of three other authors and concluded that the hygieinisation of composted sludge is ensured if the product is maintained at 55 °C for 3 days.

Table 2: Enumeration of microorganisms in sludge 1 and composts.

	Sludge 1	Compost of sludge 1	Compost of the mixture
TC (CFU/g)*	$5.4\ 10^{6}$	$11.8\ 10^{3}$	$0.62\ 10^{3}$
FC (CFU/g)*	$12.7\ 10^{5}$	$2.22\ 10^{3}$	$0.33\ 10^{3}$

* colony-forming unit

3.3.7 Phytotoxicity test

Phytotoxicity is a toxic effect by a compound on plant growth. It is one of the most important criteria for evaluating the suitability of compost for agricultural purposes. To evaluate phytotoxicity of composts produced in our study, the effects of their aqueous extracts on germination of seed wheat were evaluated by measuring the index of germination IG. The obtained results show that IG is of the order of 58.75% and 71.70% for composts of sludge 1 and its mixture with sawdust, respectively. According to Zucconi et al. [35], compost is considered nontoxic when the IG exceeds 50%. In our case, the index of germination of seed wheat exceeds this limit value and it indicates that the composts produced are stable, mature and nontoxic for crops.

3.3.8 Mineral profile analysis of sludge and composts by ICP-OES

Generally, domestic sources of minerals are mainly associated with leaching from plumbing materials (Cu and Pb), gutters and roofs (Cu and Zn) and galvanized materials, the use of detergents and washing powders containing Cd, Cu and Zn, and the use of body care products containing Zn. Tap water itself also contains considerable amounts of some mineral elements [36-38]. Activated sludge process removes substantial quantities of metals from wastewater during primary and secondary settling. Thus, the concentration of metals in activated sludge waste depends strongly of their content in influent wastewater.

Prior to compost application to the soils, there is a need to determine the trace element concentrations in the final products. Limit of heavy metal levels in organic amendments for agriculture varies widely between countries. There is a variety of tolerance to heavy metals and it reflects differences in the interpretation of the available scientific data on the heavy metal levels that constitute a significant health or environmental risk. The use to which the compost may be put is also another cause of variability of limit levels [39].

Singh and Kalamdhad [40] published a review on the reduction of heavy metals during composting.Heavy metals from the compost can be reduced by addition of some chemicals (natural zeolite, red mud, lime, sodium sulfide, bamboo charcoal and bamboo vinegar, etc.) and biological agents during composting process. In comparison to other chemicals, natural zeolite is a good amendment because it has ability to exchange sodium and potassium with toxic metals [40].

The concentration of chemical elements in the sludge 1 and the biowaste compost samples are given in Table 3. Mineral element levels in the prepared composts are generally quite low. The results of the ICP analysis showed that the concentrations of the most suspected elements like As, Co, Cr, Cu, Mo, Ni, As, Cd and Pb are generally below the limit values established by the Canadian quality standards (for 1st quality compost) and the American directives on the compost quality [31,41,42]. Regarding the element zinc, its content is lower than the limit value set by the American standards for biosolids and that of compost of class B (2nd quality). However, the zinc content in the final compost can be reduced by mixing the maturated material with another compost or by substituting sawdust by other sample of this carpentry waste or other co-substrate (such as straw, manure, palm bark, etc.) having a lower concentration of zinc.

Samples of straw, palm bark and manure were collected in order to determine their mineral composition. The concentration of zinc in the aforementioned dry materials was about 46.7 mg/kg, 58.8 mg/kg and 190.5 mg/kg, respectively. These concentrations are lower than those obtained for sawdust (820.4 mg/kg d.m.) used in this work as a co-substrate. For this reason, we plan to study in our future works the co-composting of sludge with the aforementioned agricultural waste products.

Table 3: Average content of mineral element in sludge 1 and composts, expressed in mg element/ g sample.

Element	Sludge 1	Compost of sludge 1	Compost of the mixture sludge1/sawdust: 75/25	Canadian standards 1st quality*[41]	Canadian standards 2nd quality**[41]	American standards [42]
Al	35.4	36.2	33.7			
As	*n.d.*	*n.d.*	*n.d.*	0.013	0.075	0.075
B	0.21	0.211	0.19			
Ba	0.03	0.0393	0.04			
Be	*n.d.*	*n.d.*	*n.d.*			
Bi	*n.d.*	*n.d.*	*n.d.*			
Cd	0.001	0.00109	0.0012	0.003	0.02	0.085
Co	0.013	0.014	0.012	0.034	0.15	
Cr	0.059	0.061	0.058	0.21	1.06	3
Cu	0.31	0.32	0.288	0.1	0.757	4.3
Fe	25	26	25			
Li	0.029	0.027	0.028			
Mn	0.34	0.35	0.30			
Mo	0.0037	0.00301	0.0029	0.005	0.02	0.075
Ni	0.035	0.036	0.0323	0.062	0.18	0.42
Pb	0.073	0.083	0.081	0.15	0.5	0.84
Se	*n.d.*	*n.d.*	*n.d.*	0.002	0.014	0.1
Sr	0.205	0.231	0.235			
Ti	3.1	3.1	2.87			
Tl	*n.d.*	*n.d.*	*n.d.*			
V	0.059	0.0603	0.0546			
Zn	1.42	1.44	1.27	0.5	1.85	7.5
Ca	51	52	58			
K	5.8	5.7	6			
Mg	10.9	10.1	10.6			
Na	1.7	1.6	1.7			

n.d.: not-detected ; * Type "A" and "AA"; ** Type "B"

3.3.9 SEM micrographs of composts

The scanning electron microscope morphologyof composts (Figure 11a and Figure 11b) obtained after eight months of maturation in perforated bags was examined. As it can be seen, the structure of the compost of pure sludge (Figure 11a) is generally different from that of the maturated compost obtained by composting the mixture of sludge and sawdust (Figure 11b). SEM image of sludge compost reveals generally an irregular and heterogeneous morphology. Whereas, the organized structure of carpentry waste was partially transferred to the product of co-composting. The microanalysis of these samples done with EDAX (Figure 12) revealed the presence of the same elements already detected in the raw sludge.

3.3.10 FTIR Spectroscopy monitoring of composting process

A Fourier transform infrared spectrophotometer (FTIR) was used to evaluate the characteristics of sludge, mixture of 75% sludge and 25% sawdust and their matured composts (Figure 13). As it can be seen, the bands attributed to aliphatic methylene, located in the wave number region 2800-3000 cm^{-1}, decreases when organic matter becomes stabilized. The bands located at 1240 cm^{-1} decrease also, being these bands attributed to C-O and C-N vibrations of carboxylic acids and amides. The band at the wave number of 1650 cm^{-1}, attributed to amide I, carboxylates and C=C from aromatic and alkenes decreases slightly in the compost as compared with the original waste. All that can describe the main changes in the organic matter structure which evolves to enhance their polarity.

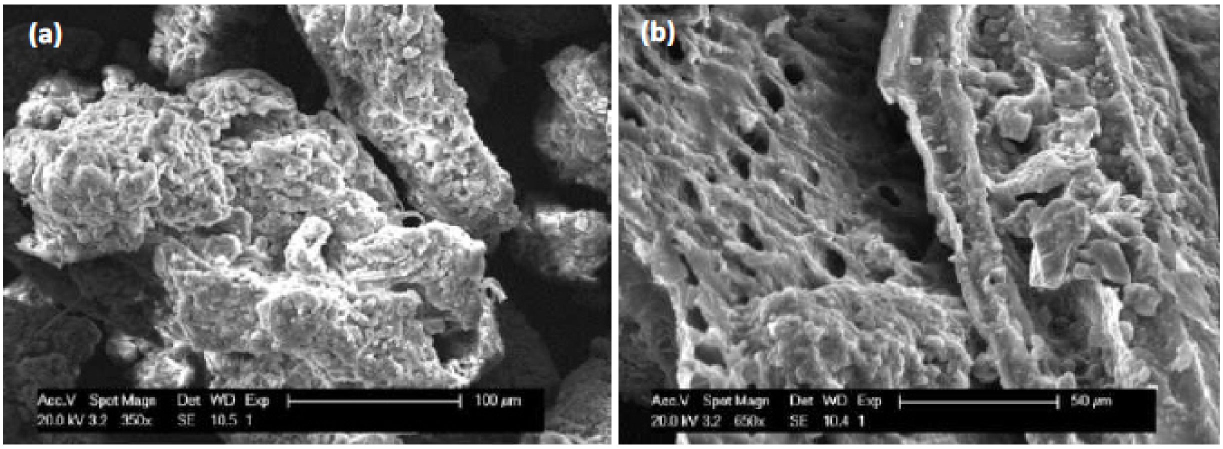

Figure 11: SEM Micrographs of compost obtained from sludge 1 (a), and the mixture of 75% sludge and 25% sawdust (b).

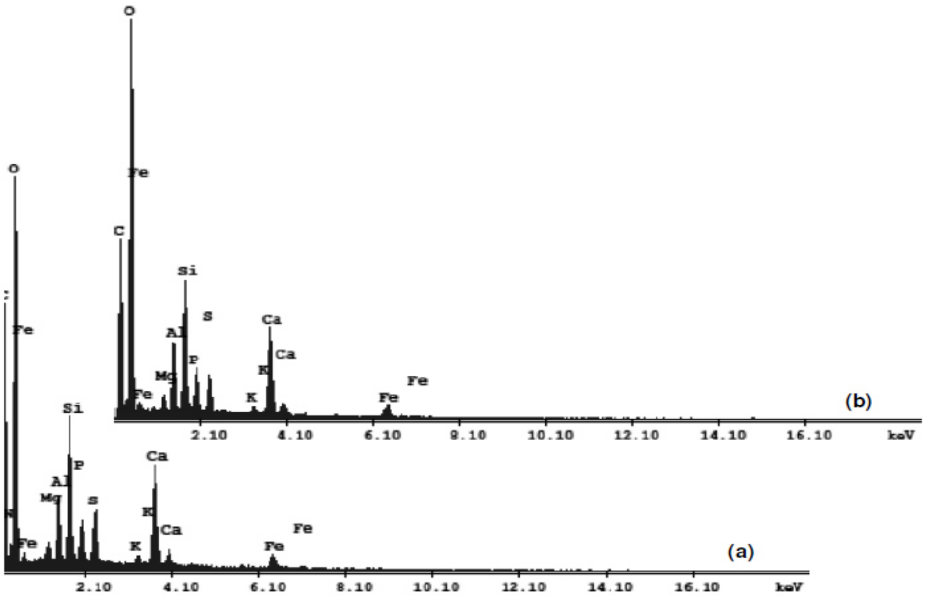

Figure 12: Microanalysis done with EDAX for compost samples after 9 months of composting: compost of sludge (a) and compost of the mixture 75% sludge/ 25% sawdust (b).

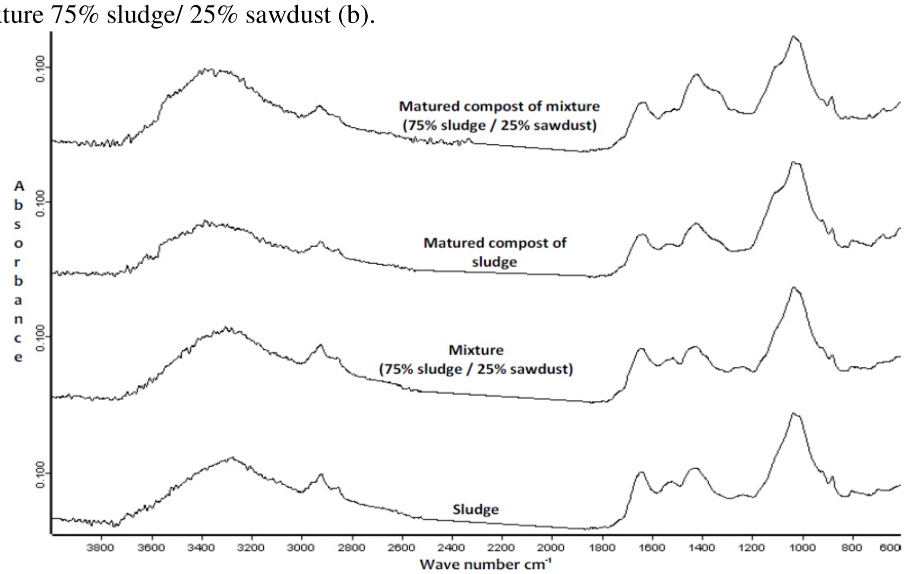

Figure 13: ATR-FTIR spectra obtained for, in decreasing order, matured compost of the mixture (sludge/sawdust: 75/25), matured compost of sludge 1, mixture (sludge/sawdust: 75/25) and sludge 1.

Conclusion

The feasibility of co-composting activated sludge from domestic wastewater treatment plants with sawdust has been evaluated and compared with the process made with the sludge alone. The composting time of 30 days in silos under aerobic conditions followed by maturation in perforated bags for eight months evidenced the mineralization and humification of organic matter. Composts obtained were characterized by determining physico-chemical and microbiological parameters both, at the end and during the composting process in order to monitor it.
Based on results obtained in this study, it can be concluded that composting is a good way to reduce the volume of sludge and to valorize it. The structure of the mixture of sludge and sawdust facilitates further the circulation of air inside the material and consequently provides a good biodegradation of organic matter accompanied with an increase of temperature. The evolution of the parameters analyzed shows a decrease of C/N ratio and moisture due essentially to the loss of carbon as CO_2 by mineralization and the evaporation of water, respectively. Compost of sludge 1 and its mixture with sawdust reached pH values of 8.4 and 8.8, respectively. Fecal and total coliforms decrease significantly after composting. The composts produced were stable, mature and nontoxic to wheat. Index of germination IG being of the order of 58.75% and 71.70% for compost of sludge 1 and that of sludge 1/sawdust mixture, respectively. This evidences again the advantage of the co-composting process as an alternate technology for the management of both sludge from wastewater treatment plants and wood wastes.
The expected parameters for a prospective application in industrial scale are as follow: amount of materials to be treated and their characteristics, additional equipment (grinding, sieving, mechanization and automation, etc.), operating conditions such as fermentation time, air-flow and periods of reversal, reduction and control of the secondary pollution such as odors, optimization of the operating expenses, etc. Like any technical feasibility study of a project, it is necessary to integrate construction and operating costs.

Acknowledgement-Authors gratefully acknowledge all the persons of the International Institute for Water and Sanitation IEA-ONEE (Rabat, Morocco) for their useful discussion and their help during this study, and the other hand, the support of the Generalitat Valenciana (Spain) Project Prometeo II 2014-077.

References

1. Albrecht R., Thèse de Doctorat de l'Université Paul Cezanne Aix-Marseille III (2007).
2. Hung Y.T., Wang L.K., Shammas N.K., Handbook of Environment and Waste Management: Air and Water Pollution Control, World Scientific Publishing Co. Pte. Ltd. (2012).
3. Eckenfelder W.W., Activated Sludge Process Design and Control, Theory and Practice Taylor & Francis Routledge, Lancaster (1998).
4. Xue Y., Yang F., Liu S., Fu Z., *Bioresource Technol.*100 (2009) 1055.
5. Mohammed T.A., Birima A.H., Noor M.J.M.M., Muyibi S.A., Idris A., *Desalination,* 221 (2008) 502.
6. Zhou X., Wang Q., Jiang G., *Bioresour Technol.* 182 (2015) 267.
7. Zhen G., Lu X., Kobayashi T, Li YY., Xu K., Zhao Y., *App. Energ.* 148 (2015) 78.
8. Sanchez-Hernandez E.P., Weiland P., Borja R., 2013. *Int. Biodeterior. Biodegrad.* 83 (2013) 10.
9. Antizar-Ladislao B., Lopez-Real J., Beck A.J., *Chemosphere* 64 (2006) 839.
10. Pagliai M., Vignozzi N., Pellegrini S., *Soil Till. Res.* 79 (2004) 131.
11. Mustin M., Le Compost, Gestion de la Matière Organique, F. Dubusc eds, Paris (1987) pp. 957.
12. Tejada M., Garcia C., Gonzalez J.L., Hernandez M.T., *Soil Biol. Biochem.* 38 (2006) 1413.
13. Amine-Khodja A., Trubetskaya O., Trubetskoj O., Cavani L., Ciavatta C., Guyot G., Richard C., *Chemosphere* 62 (2006) 1021.
14. Semple K.T., Reid B.J., Fermor T.R., *Environ. Pollut.* 112 (2001) 269.
15. Prechthai T., Padmasri M., Visvanathan C., *Resour. Conserv. Recy.* 53 (2008) 70.
16. Waksmen S.A., Cordon T.C., Huloi N., *Soil Sci.* 47 (1939) 83.
17. Charnay F., Thèse de Doctorat, Université de Limoges (2005).
18. Jeris J.S., Regan R.W., *Compost Sci.*14 (1973) 10.
19. Francou, C., Thèse de Doctorat, Institut National Agronomique Paris- Grigon(2003).
20. Tang J.C., Kanamori T., Inoue Y., Yasuta T., Yoshida S., Katayama A., *Process Biochem.*39 (2004)1999.
21. Sanchez-Monedero M.A., Roig A., Paredes C., Bernal M.P., *Bioressour. Technol.* 78 (2001) 301.
22. Bernal M.P., Navarro M.A., Sanchez-Monedero M.A., Roig A., Cegarra J., *Biochem. Soil Biol.* 30 (1998) 305.
23. Gagnon, B., Robitaille R., Simard R.R., *Can. J. Soil. Sci.* 79 (1999) 201.
24. Roletto E., Chiono R., Barberis E., *Agr.Wastes* 12 (1985) 261.
25. Eggen T., Vethe O., *Compost Sci Util.* 9 (2001) 19.

26. Moumeni L., Boutekrabt A., Rev. Energ. Ren. : Production et Valorisation – Biomasse (2001) 79.
27. Hernandez T., Masciandaro G., MorenoJ. I., Garcia C., *Waste Manage.*26 (2006) 1370.
28. Mena E., Garrido A., Hernandez T., Garcia C., *Commun. Soil Sci. Plant Anal.* 34 (2003) 957.
29. Huang G.F., Wong J.W.C., Wu Q.T., Nagar B., *Waste Manage.* 24 (2004) 805.
30. Echab A., Nejmeddine A., Hafidi M., Kaemmerer M., Guiresse M., Revel J.C., *Agrochimica, XLII-N* (1998) 6.
31. CCME (Canadian Council of Ministers of the Environment), Guidelines for Compost Quality (PN 1340) (2005).
32. Guene O., Compostage artisanal intégré à la gestion des ordures ménagères, données de terrain et outils de diffusion, CREPA, Ouagadougou (Burkina Faso)(1995).
33. ADEME. Les boues d'épuration municipales et leur utilisation en agriculture. Dossier documentaire n° 3832 (2000).
34. Dumontet S, Dinel H, Baloda S.B., *Biol. Agric. Hortic.* 16 (1999) 409.
35. ZucconiF., ForteM., MonacA., de BeritodiM.,*Biocycle*22 (1981) 27.
36. Nicholson F.A., Smith S.R., Alloway B.J., Carlton Smith C., Chambers B.J., *Sci. Total Environ.* 311 (2003) 205.
37. Sorme L., Lagerkvist R., *Sci. Total Environ.* 298 (2002) 131.
38. Aonghusa C.N., Gray N.F., *J. Environ. Sci. Health Part A: Toxic/Hazard. Subst. Environ. Eng.* 37 (2002) 1.
39. White P.R., Franke M., Hindle P., Integrated Solid Waste Management: A Lifecycle Inventory. An Aspen Publication (1999).
40. Singh J., Kalamdhad A.S., *International Journal of Environmental Protection* 2 (2012) 36.
41. BNQ : Bureau de Normalisalion du Québec (1995).
42. US-EPA, Composting of municipal wastewater sludges, cincinnati, Ohio Seminar Publication, (1995).

(2015) ; http://www.jmaterenvironsci.com