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ORIGINAL PAPER

Physical characteristics of olive stone wooden residues: possible bulking material for composting process

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Abstract The present work focuses on the study of the physical characteristics of olive stone wooden residues at the prospect of its use as a bulking material in compost process. The physical characteristics that were studied according to particle mesh classification, were the apparent density, porosity, water holding capacity, air free space and air pressure drop. From the experimental results, it was proved that only the fraction of 6.8–12.5 mesh, which is 29.40% of the substrate, could maintain the moisture in the optimum range 40–60%. The fraction of the particles of 2.6–23.6 mesh, which was 74.68% of the substrate, had appropriate porosity for composting. It was also proved that for dried substrate and air velocity 300 m h^{-1}, acceptable pressure drop (10 cm H_2O m^{-1}) was observed for the fraction of the particles of 2.6–27.5 mesh, which was 80.08% of the substrate, while for dried substrate and air velocity 150 m h^{-1}, the respective fraction was particles of 2.6–37.9 mesh which accounted for the 89.48% of the substrate. Conclusively, olive oil processing solid residues have the physical characteristics, so as to be used for composting or as a substrate for co-composting with high strength wastewater.

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Introduction

The solid waste which is produced after the pressing of olives and the oil production in the olive mills is subjected to further treatment in the seed oil mills. It is usually air-dried at 60°C in rotary-drum driers and then it is leached with hexane in order to extract the seed oil. The final by-product is the olive stone wooden residue (OSWR).

The production of solid residue in Greece is about 250,000 tons/year. The calorific value of OSWR is about 4,500 kcal/kg and it is usually used as a fuel in greenhouses, ceramic and lime production plants, bakeries as well as in the olive mills and seed oil mills themselves (Taralas and Kontominas 2006). Recently, the demand of OSWR is decreasing despite the fact that it is cheaper compared to fuel oil (5.5 times cheaper for equivalent calorific value). This can be attributed to the fact that OSWR is more difficult to handle, transport, store and burn. Moreover, unpleasant odors are emitted during its storage due to possible anaerobic conditions, thus restricting its use. Consequently, 25% of the produced solid residues remain unused and hence new uses of this biomass are sought.

The use of solid residues as organic soil conditioner was studied by Tsikalas (1985). Furthermore, the OSWR can be used for the production of organohumic fertilizer either after its conversion to humus (Manios 1979), or after co-composting with high strength wastewater effluents (Vlyssides et al. 1996; Bouranis et al. 1995).

Regarding the characteristics of the solid residues, very limited information exists (Manios 1979). The physical and chemical properties of the solid residues are strongly dependant on the particle size. Knowing the influence of particle size on the physical and chemical properties of OSWR, a suitable particle size range could be chosen in order to optimize the composting process and the final product's properties. As far as the chemical characteristics are concerned, an extent research has been published from our research team (Vlyssides et al. 1999).

Hence, it would be beneficial to investigate the physical characteristics of the solid residues. This study provides such information.

Materials and methods

For the characterization of the OSRW, samples of 50 kg were taken every week for 16 weeks from a plant in Crete. It is worth mentioning that the solid residues composition varies from area to area and from year to year depending on the climatological conditions, cultivation etc. The main physical and chemical characteristics of the OSWR are presented in Table 1.

The samples of the solid residues were classified by sieving through standard-sieve numbers and mesh sizes. Table 2 presents the standard sieve numbers and mesh sizes used. Each fraction was weighed, homogenized and the apparent specific weight, porosity, water holding capacity and air pressure drop were determined. Each measurement was repeated three times and results presented are the mean values.

The determination of water holding capacity and the apparent density of the matter was performed as described by Bouranis et al. (1995). The porosity and free air space of the matter were calculated according to the following expressions (Schulze 1962).

$$\text{porosity, \%} = 100 \cdot \left(1 - \frac{\text{apparent density}}{\text{specific gravity}}\right) \quad (1)$$

$$\text{free air space, \%} = \text{porosity}\ (1 - \text{moisture}) \quad (2)$$

The measurements of the air pressure drop were performed using the apparatus of Fig. 1, consisting of a cylindrical column of 150 cm height and 10 cm diameter. An amount of organic matter was placed in the column up to a height of 100 cm. The air compressor F had a capacity of 5 $m^3\ h^{-1}$ at a pressure of 1 bar and the air flow was controlled by the valve V. There was a Pressure Indicator of U type in the bottom of the column and the air velocity was measured in the top of the column by a digital Vane anemometer (Testo 440). The moisture of the organic feed was set to the desired level.

Results and discussion

Generally the composting process will commence spontaneously when the following conditions are met; substrate and water content (40–60%) of the material are supportive of metabolic heat generation, the composting system has a low heat transfer coefficient so the accumulative heat in the bulking material will increase the temperature up to the thermophilic region, the bulking material of the composting system has a high porosity (20–30%) for gas exchange, rendering oxygen available for heat generation through aerobic respiration (Finstein et al. 1985; Grabbe 1988; Hamoda et al. 1998; Haug 1980; Madejón et al. 2002; Mohee and Mudhoo 2005; Molla et al. 2004).

Figure 2 presents the distribution of weight for the various particle sizes of the substrate. The results indicate that there is about equal distribution when the particle size is in the range of 5.0–37.9 mesh.

Figure 3 presents the apparent density of the dry bulking material in relation to the particle diameter. It is obvious that it increases linearly from 0.18 g cm^{-3} (2.6 mesh) to 0.98 g cm^{-3} (61.7 mesh).

Figure 4 presents the water holding capacity of the bulking material with respect to the particle size where it is clear that for particle size over 10.8 mesh, the moisture content cannot exceed 48%.

Table 1 Physical and chemical characteristics of OSWR

Parameter	
Moisture, %	13.50 ± 0.52
Fats and oils, % of TS (Total Solids)	1.85 ± 0.69
Nitrogen content substances, % of TS	7.39 ± 0.037
Total sugars, % of TS	2.13 ± 0.025
Cellulose, % of TS	37.39 ± 0.438
Hemicellulose, % of TS	17.04 ± 0.942
Ash, % of TS	3.66 ± 0.225
Ether extraction substances, % of TS	8.61 ± 0.035
Lignin, % of TS	21.97 ± 0.45
Kjendahl nitrogen content, % of TS	1.093 ± 0.015
Phosphorous content as P_2O_5, % of TS	0.113 ± 0.008
Potassium content as K_2O, % of TS	0.83 ± 0.07
Calcium content as CaO, % of TS	0.95 ± 0.092
Total Carbon content, % of TS	56.13 ± 4.48
C/N ratio	51.34 ± 4.52
C/P ratio	1137 ± 99.11

Table 2 Sieve numbers and mesh sizes that were used in size classification of OSWR

Sieve no.	Sieve	Opening	Mesh	
	(mm)	(in)	(per cm)	(per in)
2 ½	8.00	0.315	1	2.6
3	6.72	0.265	1.2	3.0
3 ½	5.66	0.223	1.4	3.6
4	4.76	0.187	1.7	4.2
5	4.00	0.157	2	5.0
6	3.36	0.132	2.3	5.8
7	2.83	0.111	2.7	6.8
8	2.38	0.094	3	7.9
10	2.00	0.079	3.5	9.2
12	1.68	0.066	4	10.8
14	1.41	0.0557	5	12.5
16	1.19	0.0468	6	14.7
18	1.00	0.0394	7	17.2
20	0.84	0.0331	8	20.2
25	0.71	0.278	9	23.6
30	0.59	0.0234	11	27.5
35	0.50	0.0197	13	32.3
40	0.42	0.0166	15	37.9
45	0.35	0.0139	18	44.7
50	0.30	0.0117	20	52.4
60	0.25	0.0098	24	61.7

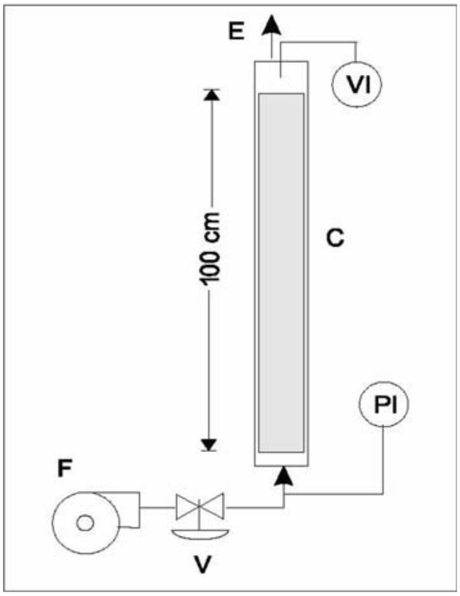

Fig. 1 Experimental apparatus for air pressure drop measurement. C: Bulking material column, E: Exhausting air, F: Air compressor, V: Valve for air flow regulation, PI: Air pressure indicator, VI: Air velocity indicator

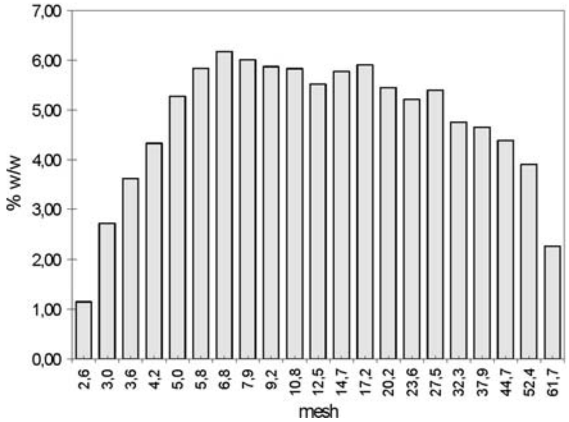

Fig. 2 Percentage (%) weight distribution of fractions with different particle diameters

In the literature, it has been stated that the proper moisture content for composting is 40–60% (Grabbe 1988) with optimum range 50–55% (Schulze 1962). This imposes a restriction if a minimal free air space has to be maintained. Although there is no specific data available showing how much free air space is needed for satisfactory aerobic decomposition, it appears from previous observations that a minimum of 30% should be maintained.

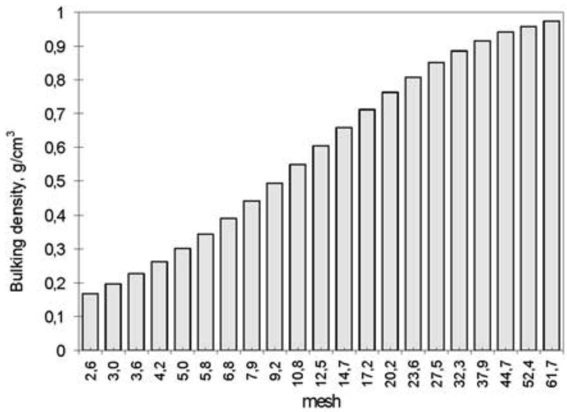

Fig. 3 Apparent density of fractions with different particle diameters

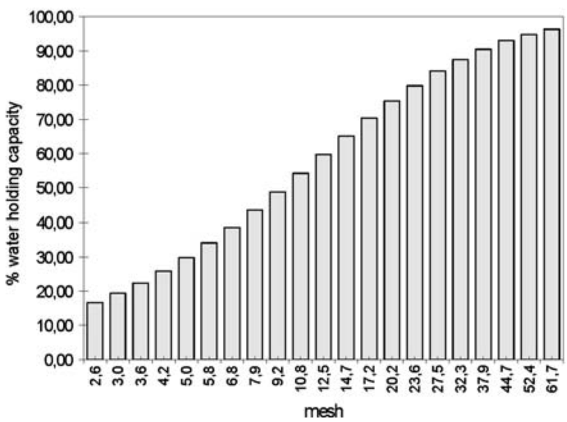

Fig. 4 Percentage (%) water holding capacity of fractions with different particle diameters

An important factor in gas exchange is the moisture content. The diffusion coefficient of oxygen through gas filled space is 10,000 times higher than through water filled space (Griffin 1981). Figure 5 presents the air free space of the bulking material, dried and with maximum moisture content, in relation to particle size diameter.

By gas exchange, oxygen is supplied and carbon dioxide, heat and water vapor is removed (Manios in press). It is of vital importance to supply sufficient oxygen because only by aerobic respiration, and not by fermentation, self-heating can be achieved. Aerobic conditions in composting systems are usually evaluated in terms of interstitial macropore oxygen concentration with minimum oxygen concentrations nearly 5% (Willson et al. 1980). When the aerobic

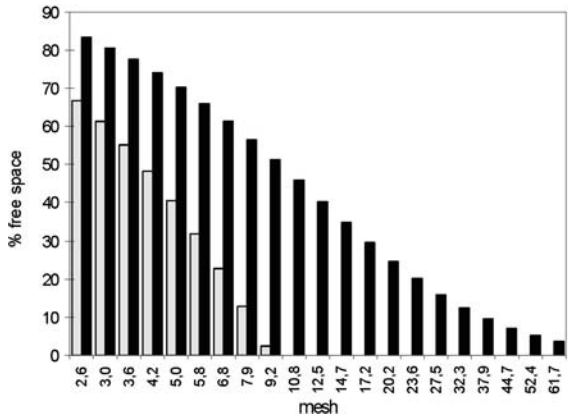

Fig. 5 Percentage (%) free space of fractions with different particle diameters □: substrate with maximum ater content (59%), ■: dried substrate

bioreactions initiate, the temperature increases, because heat production rate exceeds its loss to surroundings. Operating temperature of 60°C has been proposed by many researchers (Finstein et al. 1985; Willson et al. 1980). Air cooling through the compost material is the usual way for the removal of excess heat (Haug 1979, 1980; MacGregor et al. 1981; Suler and Finstein 1977; Thostrup 1988; Willson et al. 1980). It has been proved that air requirement for heat removal is 8.98 times higher than for oxygen supply. Thus, air supply should be 250–300 m^3 per m^3 of bulking material and hour (Finstein et al. 1985). It is worth noticing that energy consumption for air feed is the major component of the total energy consumption. It is strongly related to air pressure drop. For instance, for pressure drop of 10 cm H_2O m^{-1} and air flow rate of 300 m^3 h^{-1}, the horsepower requirement is about 0.17 hp, while for 100 cm H_2O m^{-1} and the same air flow rate, the energy consumption increases up to 1.5 hp (Pollak 1979). This energy consumption increase reflects a considerable operating cost. Thus, from the economic point of view, pressure drop of windraw piles should be up to 20 cm H_2O m^{-1} (Finstein et al. 1985).

Figures 6 and 7 present the pressure drop in relation to the particle size of the material for different air flow rates, while in Figs. 8 and 9 the pressure drop is presented for the bulking material, dried and with maximum moisture content (59%), in relation to the air flow rate.

It is well known that the substrate's moisture plays an essential role in the composting process with

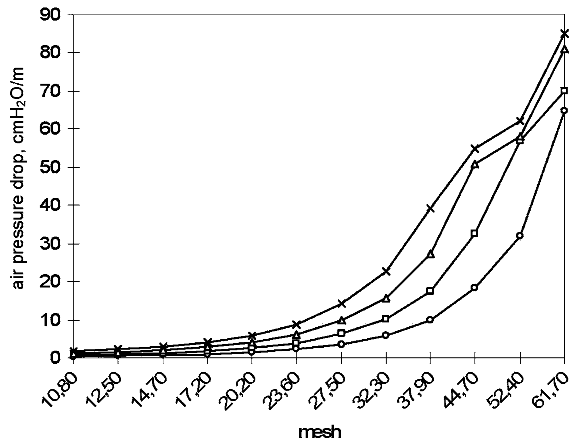

Fig. 6 Air pressure drop of fractions with different particle diameters for dried substrate. x: 300 m/h air velocity, △: 250 m/h air velocity, □: 200 m/h air velocity, ○: 150 m/h air velocity

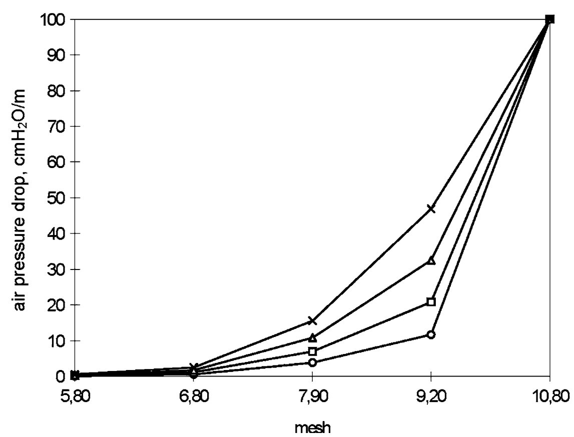

Fig. 7 Air pressure drop of fractions with different particle diameters for substrate with maximum water content (59%). x: 300 m/h air velocity, △: 250 m/h air velocity, □: 200 m/h air velocity, ○: 150 m/h air velocity

optimum range from 40 to 60%. From the experimental results (Fig. 4), it has been proved that only the fraction of 6.8–12.5 mesh, which is 29.4% of the substrate, can maintain the above mentioned moisture level.

Another critical parameter for the composting process is the porosity of the substrate with optimum range of 20–30%. For the dried substrate, the fraction of the particles of 12.2–23.6 mesh, which is 16.6% of the substrate, has porosity in the optimum range, while the fraction of the particles of 2.6–23.6 mesh, which is 74.7% of the substrate, has porosity from 20

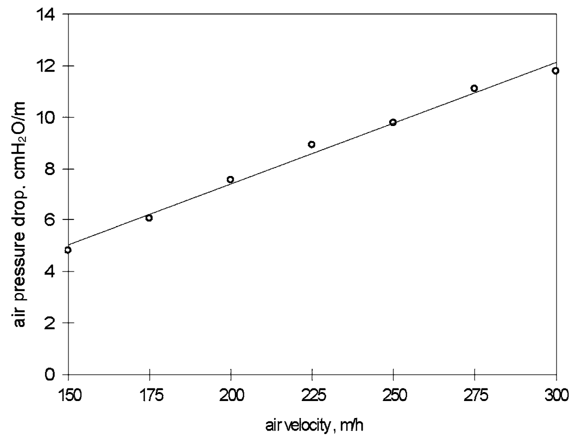

Fig. 8 Influence of air velocity on the air pressure drop in dried substrate

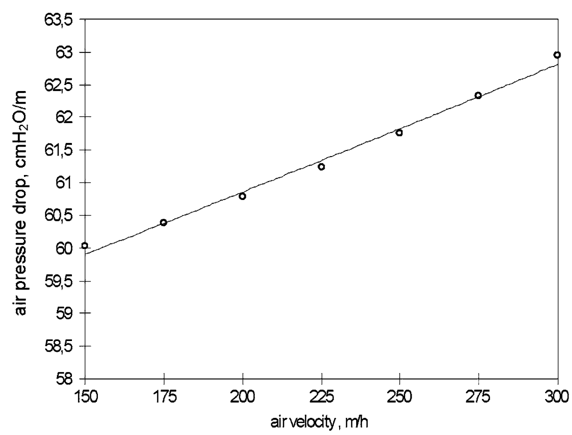

Fig. 9 Influence of air velocity on the air pressure drop in substrate with maximum water content (59%)

to 85% (Fig. 5). The respective results for the substrate with the maximum moisture (59%) is the following: 12.0% of the substrate of 5.8–6.8 mesh has the ideal porosity, while only 29.1% of the substrate of 2.6–6.8 mesh has appropriate porosity for composting (Fig. 5).

From Fig. 6, it has been proved that for dried substrate and air velocity 300 m h^{-1}, acceptable pressure drop (10 cm H_2O m^{-1}) is observed for the fraction of the particles of 2.6–27.5 mesh, which is 80.1% of the substrate, while for dried substrate and air velocity 150 m h^{-1}, the respective fraction of particles of 2.6–37.9 mesh which accounts for the 89.5% of the substrate. For substrate with maximum moisture and air velocity 300 m h^{-1}, only 35.11% of the substrate of 2.6–7.9 mesh has acceptable pressure drop, while for air velocity 150 m h^{-1}, the respective fraction is 41.0% of the substrate of 2.6–9.2 mesh (Fig. 7). From Fig. 8, it is obvious that for an acceptable pressure drop (10 cm H_2O m^{-1}), an air velocity below 260 m h^{-1} can be imposed on the system for dried substrate. On the other hand it is worth noticing (Fig. 9) that for substrate with maximum water content the air pressure drop is much higher that the acceptable level for air velocity ranging from 150 to 300 m h^{-1}.

Conclusively, as far as the physical characteristics of the solid residues (substrate) are concerned, it can be mentioned that they are satisfactory for the compost process. Olive stone wooden residue is a suitable substrate for co-composting with industrial effluents since it has high enough moisture and porosity in order to favor the aerobic process through air supply.

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