CONFERENCE PROCEEDINGS
HUNGARIAN JOURNAL
OF INDUSTRIAL CHEMISTRY
VESZPRÉM
Vol. 2. pp. 59 - 64 (2000)

DESCRIPTION OF A PILOT PLANT FOR THE CO-COMPOSTING OF THE SOLID RESIDUE AND WASTEWATERS FROM THE OLIVE OIL INDUSTRY

A.G. VLYSSIDES, A.A ZORPAS*, P.K. KARLIS and G.A. ZORPAS

(National Technical University of Athens, Department of Chemical Engineering,
9 Heroon Polytechniou St., Zographou Athens, G-15700, GREECE)

This paper was presented at the Second International Conference on Environmental Engineering,
University of Veszprém, Veszprém, Hungary, May 29 – June 5, 1999

The co-composting of the solid residue and wastewater from the olive oil production process have been studied as a new method for the treatment of wastewater containing high organic and toxic pollutants. The experimental results for a demonstration plant using solid residue from olive extraction as bulking material and olive oil processing effluents as continuously fed wastewater are reported. Composting temperature was controlled between 45 and 65 °C by air supply and the wastewater addition was fed mainly in order to keep the moisture in the range of 45 to 60% and secondary to replace the carbon substrate. During twenty three days of operation in the thermophilic region, the system was fed with 263 m^3 wastewater in total, which means an average rate of 11.4 m^3 day^{-1} wastewater or 2.9 kg wastewater per kg solid residue. Then followed a three months stabilisation period in the mesophilic region until the final product reached ambient temperature.

Keywords: composting; solid waste residue; oil olive industry

Introduction

Olive oil extraction is among the most traditional agricultural industries in Greece and it has always been, and is still of primary importance for the national economy, as Greece has a share of 15% of world production [1]. The annual olive oil production is in the range of 350.000 - 400.000 tons per year resulting in the generation of about 1.500.000 tons of olive mill wastewater, which causes serious environmental problems, mainly due to its high organic content.

The quantity and the physico-chemical characteristics of olive mills wastewater, commonly called 'vegetation water', depends on the place, age of growth, harvesting season, yearly changes, olive variety, extraction method, etc.

The organic matter of vegetation water contains mainly polyphenols, carbohydrates, polysaccharides, sugars, nitrocompounds, polyalcohols, fats and oil, substances generally worth recovering.

A number of vegetation water treatment methods have recently been employed, especially in the Mediterranean area, and these can be divided into physico-chemical and biological methods.

The physico-chemical methods have the disadvantages of high cost and low efficiency: lime precipitation results in 40% reduction of the organic matter but production of large quantities of sludges. Moreover, the effluents after precipitation as well as the chemical-organic sludges that are produced, have all the toxicity of the initial vegetation water leading to serious disposal problems [2]; reverse osmosis has over 90% efficiency in removing organic matter, but on the other hand high operating cost and sludge disposal problems [2]; incineration (with or without concentration) is reliable but expensive, and complicated by high energy demand and emission of air pollutants; lagooning as a physical method for water evaporation, since a very limited biological degradation takes place [3] has significant cost disadvantages due to land requirements and the necessity for taking special measures to protect public health [4].

Biological methods have certain clear benefits due to their potential for the utilisation of by-products. (compost for fertilising, biogas for energy production, natural colouring substances, proteins for cattle feed enrichment): protein production has low fixed costs but requires additional treatment methods due to the low

---

* Author to whom correspondence should be addressed.

Table 1 Composition of the solid residue

CHARACTERISTICS	VALUE
Total Solids (TS), %	86.00 ± 3.33
Total Carbon content, % of TS	55.45 ± 4.48
Total Kjeldahl Nitrogen, % of TS	1.06 ± 0.015
Total Phosphorous as P_2O_5, % of TS	0.11 ± 0.008
Fats and oils, % of TS	1.8 ± 0.69
Total sugars, % of TS	2.07 ± 0.025
Cellulose, % of TS	37.27 ± 0.438
Hemicellulose, % of TS	16.57 ± 0.942
Ash, % of TS	3.65 ± 0.225
Other extraction substances, % of TS	8.38 ±0.035
Lignin, % of TS	21.9 ± 0.45
Potassium as K2O, % of TS	0.83 ± 0.07
Calcium content, % of TS	0.82 ±0.092
C/N ratio	52.14 ± 5.2
C/P ratio	1123.79 ± 147
Specific weight, g cm^{-3}	1.09 ± 0.02
porosity, %	52.4 ± 5.5

Table 2 Composition of the vegetation water

CHARACTERISTICS	VALUE
Total Solids (TS), %	6.33 ± 1.81
Total Volatile Solids, % of TS	90.36 ±3.31
Total Carbon content, % of TS	62.71 ± 16.27
Total Kjeldahl Nitrogen, % of TS	1.2 ± 0.173
Total Phosphorous as P_2O_5, % of TS	0.84 ± 0.158
pH	5.00 ± 1
BOD5, g dm^{-3}	55 ± 35
COD, g dm^{-3}	130 ± 40
Ash, % of TS	9.64 ± 3.31
C/N ratio	53.57 ± 5.4
C/P ratio	75 ± 9.8
Specific weight, g cm$^{=3}$	1.048 ± 0.033

initial removal of organic matter (about 50%); anaerobic digestion has the benefit of energy production but also relatively low efficiency (80%) compared to the high capital cost of the high- technology installations and equipment [5,6]; co-composting is the optimum method from the environmental point of view as the organic matter is totally recovered. Furthermore it has low fixed cost and the final product could be marketable as a high-quality soil conditioner [7].

For the present work a co-composting demonstration plant was designed and constructed in order to treat the wastewater from an olive oil extraction factory. The design of this plant was based on laboratory scale results obtained previously [7]. The results from the operation of this plant are presented in this work.

The fundamental principle of a co-composting system is the biodegradation of the organic matter through exothermic aerobic bioreactions which take place in the thermophilic region with the simultaneous evaporation of the moisture of the wastewater due to the release of thermal energy [8].

In application to wastes from olive oil extraction plants, the critical parameters for the growth of microorganisms and bioreactions are the oxygen demand, the moisture (which must be in the range of 40 to 60%) the temperature (which must be retained between 45 and 65°C; optimum 60°C) and the Carbon/Nitrogen (C/N) ratio (which must be kept below 30/1). The solid residue from the olive oil extraction process is used as substrate (bulking material), the vegetation water as supplier of moisture, carbon and nutrients. Air is supplied for cooling and oxygen needs. In addition, excess nitrogen, in form of urea, is provided for the system.

Methods

Plant Description and Operation

Based on the above mentioned principles a wastewater treatment plant was constructed in Koutsouras, Crete, Greece, in order to handle the effluents from an olive oil factory with 250-300 t annual oil production and 1000-1200 t wastewater. The plant was operated simultaneously with the olive oil factory for 120 days, the common olive oil extraction period in Greece, between September 1992 and January 1993.

Figs.1 and *2* illustrate the flow diagram of the plant, which consisted of: an aerobic bioreactor of 18m length, 6m width and 2.2m height (195 m^3 active volume) with an agitation system of a travelling bridge with a helical type agitator of 0.90m blade diameter. An aeration system of three fans and nine diffusion pipes installed over the bottom of the bioreactor. A wastewater storage tank of 80 m^3 active volume and two dosing pumps. A nutrient preparation and dosing unit, including a preparation tank equipped with a mechanical agitator and two dosing pumps. A Programmable logical controller (PLC) for the control of the plant operation and data collection.

The steps followed in the successive periods are described below.

Start-up Period

At the start-up of the plant, a quantity of about 91.5 t solid residue, 119 t vegetation water and 1600kg urea (as nutrient source) were fed into the bioreactor. The solid residue was agitated and sprinkled with the vegetation water and urea in order to achieve a homogenous mixture in the bioreactor. The compositions of the solid residue and vegetation water are reported in *Tables 1* and *2* respectively. These values were obtained from the analysis of five samples of solid residue and vegetation water and average concentrations are reported. From the analysis, it was indicated that vegetation water did not contain enough nitrogen and so urea was added to cover the needs for this particular nutrient.

Co-composting Period

This period got under way when the temperature in the bioreactor came into the thermophilic region due to the

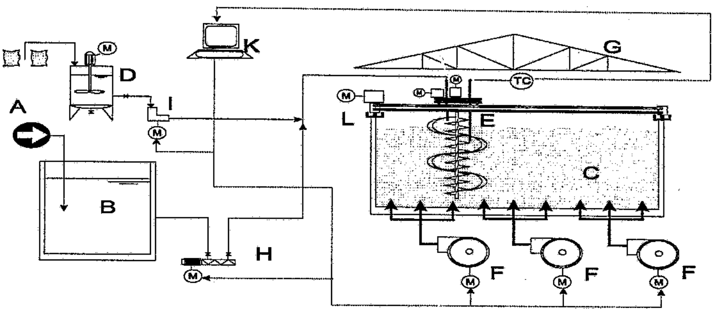

Fig.1 Flow diagram of the plant. A: wastewater feeding; B: feed storage tank; C: co-composting bioreactor; D: urea feeding system; E:agitator; F: air feeding fans; G: roof to prevent access of rainwater; H:mono-pumpfor wastewater dossing; I: proportional pump feeding of urea solution; K:Computer for controlling and data collection; L :Travelling ridge for the agitator; M: Motors; TC: temperature controller

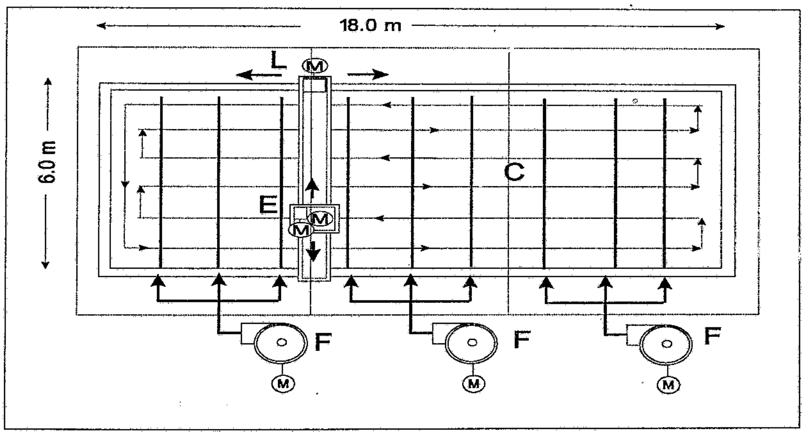

Fig.2 Sectional plan of the bioreactor. C : co-composting bioreactor; E: agitator; F: air feeding fans; L:Travelling bridge for the agitator; M: Motors; ⟶ agitator running; ⟶ air line

increase of the bioreaction rate. During the thermophilic period, oxygen, vegetation water and nutrients were provided for the system.

The compost was mixed by a travelling helical agitator as shown in *Fig.2*. One complete mixing period of total bioreactor content was achieved within two hours. The bioreactor was divided into three areas of 6x6 m. In each area one fan and three diffusing pipes were installed (see *Fig.2*). The travelling bridge, with velocity 1 m min^{-1}, entered each area every 20 min. A temperature control system, fixed on the travelling bridge, controlled the operation of each fan in order to maintain the temperature about 60 °C, according to the following principle: minimum air flow (4.6 m^3 per t of compost) was provided at low temperature (<30 °C) and maximal air flow (56 m^3 per t of compost) was provided at high temperature (>60 °C). The minimum airflow should have corresponded to the minimum oxygen demand for the microorganisms and the maximal airflow to meet the needs of air supply for cooling purposes [9].

The vegetation water was sprinkled on the bioreactor surface in the area of agitation (imaginary cylinder) in quantities inversely proportional to the temperature. The feeding rate was calibrated by the following linear equation according to VLYSSIDES et al. [7]:

$$Q = 2.228 - 0.034\,T \qquad (1)$$

where Q is the vegetation water flow rate, $m^3\ h^{-1}$; T is the temperature, °C with boundary conditions: $Q = 1.2$ for $T \leq 30$ °C and $Q = 0$ for $T \geq 65$ °C.

Urea (15% solution) was fed simultaneously with the vegetation water at a steady rate of 1.34 kg urea per m^3 of vegetation water. The air, vegetation water and urea feeding processes were performed automatically and controlled by the PLC.

Stabilisation Period

After the thermophilic period, in which the organic material was biodegraded, the final product remained in the bioreactor, without any addition of influents. This stabilisation step was necessary in order to assure that the compost could be environmentally safe after its disposal.

The stabilisation period took place in the mesophilic region and it was terminated after three months, when the temperature dropped and reached ambient values.

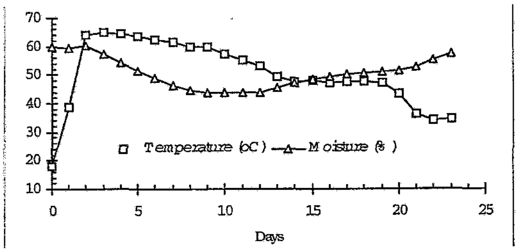

Fig 3 Temperature and moisture changes during composting

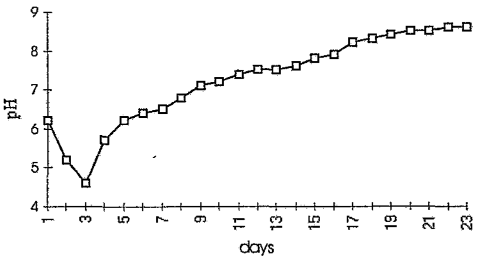

Fig.5 pH during composting

Methods of Analysis

During the plant operation, especially the composting period to which emphasis is given in this work, daily samplings and analyses were performed. Every day 36 different core samples of 100g weight each were taken from various places and depths of the bioreactor. Every sample was homogenised before analysis. The sample moisture was measured according to Standard Methods [10] and the evaporated water was calculated by mass balance. Total Organic Nitrogen was determined by a macro-Kjeldahl method according [11]. Total Phosphorous was determined according to the Chapman method [12]. Total organic carbon was determined according to Higgins et al. [13]. The pH was determined by the method Chang and Hudson [14].

Results and Discussion

Temperature and Moisture

As shown in *Fig.3* the temperature rapidly increased to 63°C after 36 hours from the start-up and remained above 60°C (control set point) for 9 days. It was controlled by the air supply for which the flow rate is shown in *Fig.4*. This indicates an insufficiency of the air supply for cooling the system and the reasons for this are discussed later. Other, uncontrolled, parameters that were affecting the temperature were the periodic mixing (one minute mixing time for each point per two hours) of the bulking material, and the wastewater feeding. After 21 days the temperature dropped to 36°C, which meant that the system was operating in the mesophilic region and the bioreactions rate was reduced as shown by the limiting carbon content. It was decided that the composting period was finished after 23 days, when the temperature dropped below 35°C.

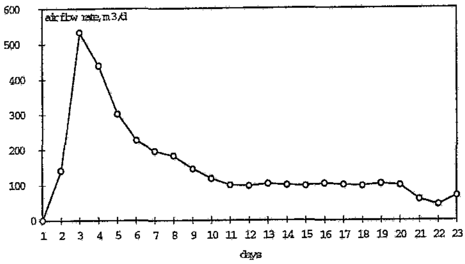

Fig.4 Air flow during the composting

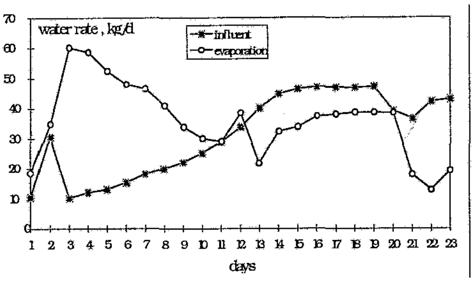

Fig.6 Water balance during composting

As was expected the moisture continuously decreased during the first ten days until it stabilised in the range of 48-52% (*Fig.3*). After the 20th day, the moisture started to increase due to the low energy production related to the low biodegradation rate.

As shown in *Fig.4* the air feeding fluctuated during the first 9 days while the following days, after about 11 days, the air feeding stabilised near to 20000 m^3 day^{-1} due to the temperature drop.

pH

pH is a parameter, which greatly affects the composting process. The optimum pH values are 6-7.5 for bacterial development, while fungi prefer an environment in the range of 5.5-8.0 [15]. Usually during composting the pH values are initially low because of volatile acids production, then the pH increases and in the final stage of composting a decrease in the pH is expected. This pattern was not followed in the present experiments (*Fig.5*) in the final stage when the pH gradually increased because of excess ammonia production from biodegradation of urea.

Water Balance

As shown in *Fig.6*, the water that entered the composting system by wastewater feeding was not in balance with the evaporated water over the entire period. During the first ten days the water evaporation was much higher than the rate of sprinkling of wastewater and the following ten days the sprinkled water rate was higher than the evaporated one, so the overall water balance was not kept stable during the process. It would be difficult to achieve a stable water balance, since there is a need for moisture control by using an on-line moisture probe, which is generally not available in practice. The stabilisation of the water and carbon balance is the main key for successful continuos

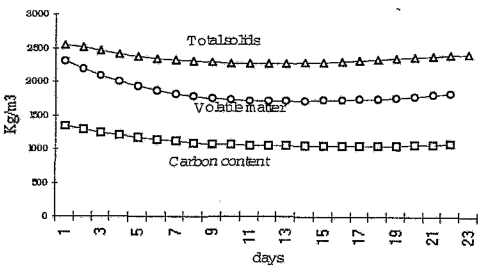

Fig.7 Total Solids, Volatile Matter and Carbon content changes during composting

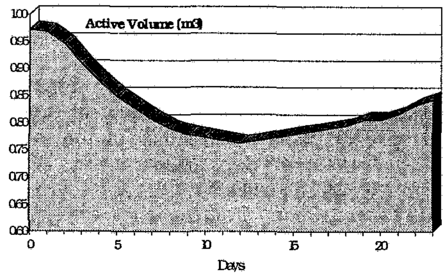

Fig.9 Active bioreactor volume during composting

co-composting process [7], and this was the main target during the present process.

At the end of the composting period, the system had consumed 263 m^3 wastewater, which was equal to an average rate of 11.4 m^3 day^{-1}, corresponding finally to 2.9 kg wastewater per kg solid residue. These figures indicate that in order to treat the total amount of the wastewater that is produced in the plant (about 1200 m^3 annually), four to five similar plants would be required or the plant must be used for successive batches of waste solids.

Carbon Content and Carbon Balance

Fig.7 shows the changes in total carbon content, of solids and liquid, during composting. The daily carbon dioxide that was produced during the composting was calculated by the following relation

$$(C-CO_2)_t = (C)_{t-1} - (C)_t + C_{w.w.} \cdot (F_{w.w.})_t \quad (2)$$

where $(C - CO_2)_t$ is the total carbon content of CO_2 produced at day t, kg; $(C)_{t-1}$ total carbon content of the bioreactor at a day before day *t* kg (data from *Fig.7*) $(C)_t$ total carbon content of the bioreactor at day t, kg (data from *Fig.7*); C_{ww} carbon content of wastewater, kg m^{-3} (*Table 1*); $(F_{ww})_t$ daily flow rate of wastewater at day t, m^3 (data from *Fig.6*).

The carbon balance is shown in *Fig.8* and it was stable only between the 13th and 20th day of composting. A significant amount of the solid residue was consumed during the first ten days of the composting process as was observed by the reduction of the volume of the bulking material as shown in *Fig.9*. The minimisation of residue consumption would be beneficial for the wastewater treatment process.

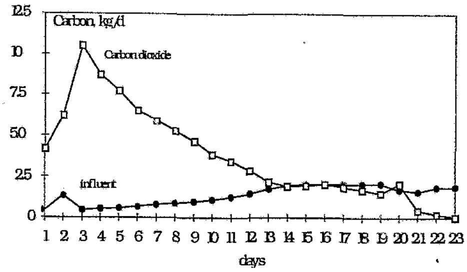

Fig.8 Carbon balance during composting

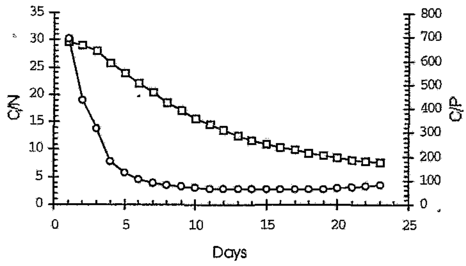

Fig.10 Ratio of carbon/nitrogen and carbon/phosphorous variation during composting

Carbon/Nitrogen and Carbon/Phosphorous

As shown in *Fig.10* the C/N ratio steadily decreased due to the continuous urea inflow as well as wastewater feeding. The excess of nitrogen showed that the urea addition was not necessary. This could not be foreseen because it was not known at the beginning how much wastewater was going to be consumed during the process. The C/P ratio rapidly decreased during the first 10 days, when the vegetation water inflow was maximal and afterwards the ratio stabilised at about 80/1.

Conclusions

The plant operated successfully with respect to the wastewater consumption without any hazardous effects to the environment. Furthermore, the general design of the plant as well as the selection and the quality of equipment were also successful.

The short duration of the co-composting period (23 days) with 263 m^3 vegetation water consumption indicates that the total wastewater effluent from the particular factory (1200 m^3) could be treated in five similar successive phases of operation. For this purpose, the content of the bioreactor, after the end of thermophilic operation, should be transferred out into a static pile for mesophilic stabilisation in order to start a new phase of thermophilic treatment. It should be stressed that the solid waste required to treat the volume of wastewater produced is sufficient due to the fact that the waste production rate from the olive oil mills is about 1 t of solids per 3 m^3 of wastewater.

The main issues, which require more investigation and optimisation, are given below:

- The production of high temperatures (>60°C) during the first 9 days indicates apotential wastewater loading increase, leading to possible efficiency improvement. Thus the modification of *Eq.(1)* might be advisable.

- The air feeding process was rather unsuccessful for cooling the bioreactor content at high temperatures. As previously reported the fans operation was controlled by temperature measurements which were taken at one spot of each bioreactor area every 20 minutes, which did not represent the mean area temperature. The optimum solution for this problem would be the installation of additional temperature probes across the travelling bridge in order to obtain an accurate profile of the real temperature conditions. A possible explanation for the low cooling efficiency could be attributed to the non-homogeneous air distribution in the bioreactor, due to the high solids concentration (formation of air pathway channels).
- The accumulation of nitrogen and the final high pH in the system indicates that an excess urea feed was provided. Therefore, the application of a flexible and dynamic feeding control formula based on daily analyses is required.

REFERENCES

1. Michelakis N. Olive oil processing wastewaters managment. Proceedings of International Conference in Olive oil processing wastewater treatment methods, Hania, Crete, Greece, 1991
2. Fiestas Ros A.J.: Reuse and complete treatment of vegetable water: Current situation and prospects in Spain. Proceedings of International Conference in Olive oil processing wastewater treatment methods, Hania, Crete, Greece, 1991
3. Vlyssides A., Loizidou M., Bouranis D.L., and Karvouni G.: ***Journal***, *1995*, Paper in preparation
4. Marinos E.: Lagooning concentration of olive oil processing wastewaters. Proceedings of International Conference in Olive oil processing wastewater treatment methods, Hania, Crete, Greece, 1991
5. Boari G., Brunetti A., Passino R. and Rozzi A.: Agricultural Wastes, *1984*, 10, 161-175
6. Georgacakis D., Kyritsis S., Manios B. and Vlyssides A.: Economic Optimization of Energy Production from olive oil wastewater. Proceedings of the Int. Conference on Energy from Biomass, Brescia, Italy, 1986
7. Vlyssides A., Parlavantza M. and Balis K.: Co-Composting as a system for handling of liquid wastes from olive oil mills. Proceedings of the International Conference in Composting, Athens, Greece, 1989
8. Jewell J.W. and Kabrick M.R.: J. W.P.C.F, *1980*, 52, 3, 512-523
9. Finstein M.S.: Biocycle, *1980*, 21 25-7
10. American Public Health Association (APHA), Standard Methods for the examination of water and wastewater, 17th Edn, 1989
11. Jackson M.L.: Soil Chemical Analysis. Prentice-Hall Inc., 1962
12. Charman H.D. and Pratt P.F.: Methods of analysis for soils, plants and waters. Univ. of Callifornia, 1961)
13. Higgins A.J., Kaplovsky A.J. and Hunter J.V.: J. W.P.C.F., *1982*, 54, 5, 466-473
14. Chang Y. and Hudson H.J.: Trans.Br.Mycol.Soc., *1967*, 50(4) 649-666
15. Kapetanios G.E., Loizidou M. and Valkanas G. Bioresource Technology, *1993*, 44, 13-16