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Balanced Waste Management of 2- and 3-Phase Olive Oil Mills in Relation to the Seed Oil Extraction Plant

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ABSTRACT

Olive oil extraction process produces a considerable amount of olive oil mill wastes (OMW) and wastewaters (OMWW) which have a high pollutant load. There are several OMWW treating methods but in most of the cases they are expensive and complex processes and thus they are prevented from being applied in the small-to-medium size olive oil mills (OM), which in the case of Greece are the majority. The 2-phase OMW due to their high moisture content are not accepted from seed oil extraction plants (SOEP) and as a result a waste management problem emerges. Consequently, the 3-phase OM owners refrain from applying the 2-phase olive oil extraction process, but inside the residential districts, where land dispose is lacking, the OM have to operate in the 2-phase olive oil extraction mode. In this paper it is shown that mixing 2-phase OMW with deoiled olive seeds (DOS) in a mass ratio of 2: 1 creates a mixture which has a moisture content that makes it suitable for handling in an SOEP and thus it could be easily accepted for seed oil extraction. As a result the existence of 2-phase OM in a wide region should be necessarily accompanied by a certain number of 3-phase OM. According to this suggestion all OM operating inside or near residential districts would operate exclusively in the 2-phase mode, while the accompanying 3-phase OM would operate outside the residential districts. To investigate the required 3-phase OMWW treating process, a pilot-scale sedimentation-evaporation unit has been constructed and operated in Evia, Greece. A linear volume reduction of 0.47% per day was obtained for the sediment.

Keywords: 2-phase olive oil mill wastes (2-phase OMW), 3-phase olive oil mill wastes (3-phase OMW), deoiled olive seed (DOS), olive oil mill wastewater (OMWW), seed oil extraction plant (SOEP)

INTRODUCTION

The worldwide olive oil production for 2007 was 2.843.493 t, of which 2.178.774 t was produced in Europe. The countries with the largest olive tree cultivation in the world are Spain (2.400.000 ha), Italy (1.140.685 ha), Tunisia (1.500.000 ha) and Greece (765.000 ha) (FAO 2007). The olive oil extraction process generates important amounts of wastes which constitute a source of pollution (Rozzi and Malpei 1996; Kapellakis *et al*. 2006) with a negative impact on land and water environments. In fact, there are three types of oil extraction systems, the traditional pressing process (Kapellakis *et al*. 2008); the 3-phase system (Niaounakis and Chalvadakis 2006); and a relative new one, the 2-phase system (Di Giovacchino *et al.* 1994), that tends to replace the other two systems in practice. The physico-chemical properties and the quantity of the generated wastes depend on the oil extraction system (Caputo *et al*. 2003; Paraskeva and Diamadopoulos 2006).

In the 3-phase systems, two types of wastes are generated, the 3-phase olive oil mill solid waste (3-phase OMSW) (or olive cake or olive pomace or olive-husk) with a moisture content of around 40-50%, and a liquid waste, called 3-phase olive oil mill wastewater (3-phase OMWW). The 3-phase olive extraction centrifugation system has been appeared progressively in Greece since the beginning of the 1970s and soon became the predominant OM type operating in the country, substituting almost all pressure type OM. The main pollutant waste from the 3-phase extraction systems is the 3-phase OMWW. To treat this type of wastewater there are several more or less sophisticated biological, physico-chemical and oxidation treatment methods (Chatjipavlidis *et al*. 1996; Georgakakis *et al*. 2002; Matzavinos and Kalogerakis 2005; Sarika *et al*. 2005; Paraskeva and Diamadopoulos 2006).

Since the 3-phase OMSW still contains a small but considerable amount of oil (4.5-9%; Niaounakis and Chalvadakis 2006), it is transported to olive seed extraction plants (SOEP) and is routinely thermally dried and chemical processed with hexane for seed oil extraction. After the oil extracting the deoiled olive seed (DOS) consists primary of lignin and cellulose and is sold either as mulch for olive trees or as solid fuel for heat production (Vlysides *et al*. 2004; Rodríguez *et al.* 2008).

In the mid-1990s, in an attempt to reduce the amount of 3-phase OMWW, a new centrifugation oil extraction system was developed, namely the 2-phase system, which reduces the oil mill wastes (OMW) by 75% (Alburquerque *et al.* 2004; Roig *et al*. 2006; Tsagaraki *et al.* 2007). The only waste generated in the two-phase system is the 2-phase OMW (or wet olive cake or wet pomace) with a moisture content of around 55-75%, a material with transportation, storing and handling difficulties (Arjona *et al*. 1999). In general the 2-phase OMW are characterized as materials with peculiar physico-chemical properties (Roig *et al*. 2006) due to which they cannot be directly composted or burned without some form of pre-treatment that increases the overall management costs. An additional problem associated with the 2-phase OMW is that the existing SOEP cannot handle it and thus they do not accept it (Niaounakis and Chalvadakis 2006). As a result the 3-phase OM owners are not willing to convert and operate their OM at the 2-phase mode, although in certain cases the 2-phase operation mode seems to be the only alternative process available.

Greek OM are usually small-to-medium size and extremely dispersed enterprises, which cannot afford the cost of any sophisticated *in situ* or centralized OMW treatment process, but only the very simple and inexpensive ones

Received: 8 April, 2010. Accepted: 1 May, 2010.

Original Research Paper

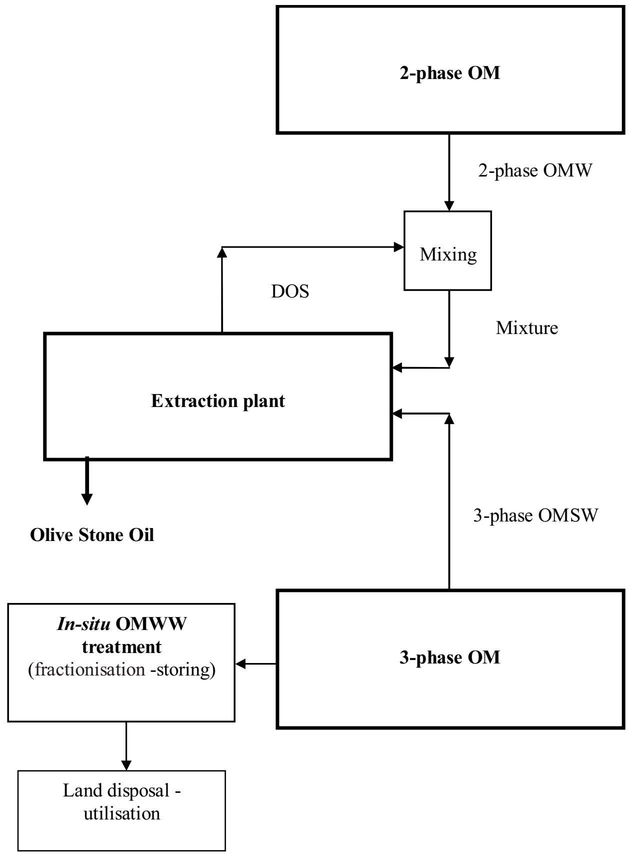

Fig. 1 Flow diagram of the suggested balanced management of 2- and 3-phase OMW.

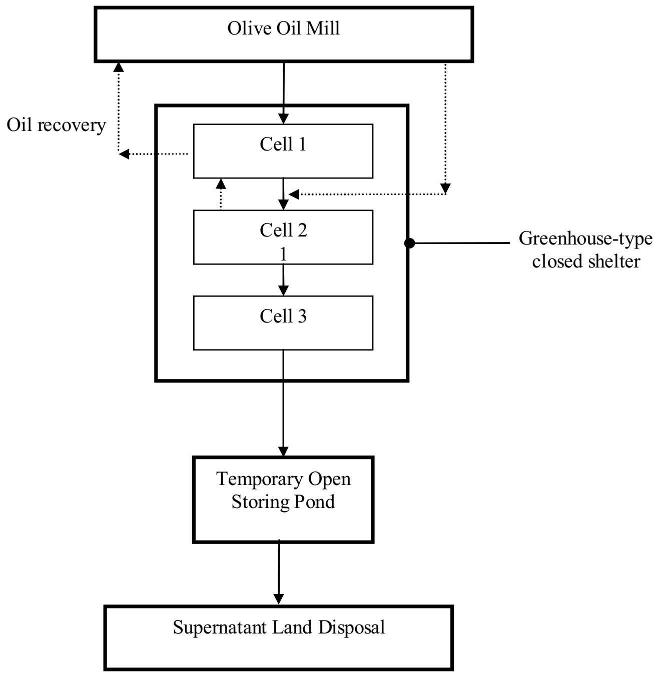

Fig. 2 Flow diagram of the suggested GSB_{10}.

(Kapellakis *et al*. 2006; Tsagaraki *et al*. 2007).

At present, the only cost efficient and the simplest OMW treatment seems to be the OMW storage in earthen, unlined and shallow evaporation ponds, but this treatment presents infiltration, odor emissions and overflowing problems (Roig *et al*. 2006; S'habou *et al*. 2009; Jarboui *et al*. 2010).

To improve the situation, the Laboratory of Agricultural Constructions (LAS) of Agricultural University of Athens (AUA), already since 2002 has constructed and operated, a simple pilot-scale treatment system, based on a 3-cell gravity sedimentation basin (GSB_{10}), made of concrete, and a supernatant deep storage lagoon at Samos island (Georgakakis and Christopoulou 2002). The size of the GSB_{10} was designed for a liquid detention time of at least 10 days.

Following gravity sedimentation, the 3-phase OMWW formed three fractions in the GSB_{10}: 1) The floating oily crust (representing 2.5-3% of total volume), which was manually removed, 2) the light supernatant (68-72% of total volume) which was overflowed to a small earthen lagoon and 3) the thick sediment (25-29% of total volume) stored in the GSB_{10}.

The trapped oil and the thick sediment were stored in the GSB_{10}, while the light supernatant, with reduced COD load by more than 2/3, was overflowing to the storage earthen lagoon. The stored supernatant and rainwater mixture was then disposed off properly to a soil-plant filter absorbed by self-grown vegetation. The disposal of the effluent was completed by the end of May, before odors become a nuisance. The trapped oil was collected from the surface of the 1st and 2nd cell while the thick sediment was left for condensation through evaporation for a two-year period (low and high olive production periods) and then removed and disposed off to the land as a soil-conditioner.

Since 2-phase OM due to their disadvantages should be kept at a minimum and only for specific cases, they cannot replace all 3-phase ones, as it has been attempted in many cases, because more problems would be created than be solved. Today it becomes more and more obvious that the number of 2-phase OM should practically be kept always in balance with the 3-phase OM in a region. In such a scheme, SOEP can play a key role, as they are the only ones capable to mix 2-phase OMW with DOS to reduce the moisture content and then handle the mixture properly. The problem is that SOEP have a limited capacity. To cope with this problem a certain number of 3-phase OM should be excluded from sending 3-phase OMSW to SOEP, depending on the quantity of 2-phase OMW brought in. Thus, SOEP can actually be considered as potential local centralized 3-phase OMSW and 2-phase OMW handling stations (**Fig. 1**).

The excluded 3-phase OM in turn should possess the necessary land area for the treatment of their OMWW. If 2-phase OMW and 3-phase OMSW are in excess, then they will inevitably form large piles of wet solid wastes in front of the plant exposed to rain and causing severe odor emission and leakage problems.

To establish the proper balance among 2- and 3-phase OM in relation to the nearest SOEP, attempts have been made to:

a) Define the proper mixing ratio between DOS and 2-phase OMW in order to correct moisture content of the mixture for further handling by SOEP and

b) Investigate the evaporative drying rate of the thick sediment stored in a GSB_{10} covered by a closed greenhouse-type shelter.

MATERIALS AND METHODS

All 2-phase OMW, 3-phase OMSW and DOS quantities used in this study were obtained from an SOEP operating in the region of Messinia in South Greece. The samples taken were transported to the Lab and put in a freezer for less than 24 hrs. The moisture content was determined by drying the samples at 105°C according to APHA (1995) for 24 hrs.

Samples of 2-phase OMW and DOS were mixed at different ratios and the moisture content of the mixtures resulted was determined.

In **Fig. 2** the flow diagram of the GSB_{10} suggested by LAS of AUA is shown. The 3-phase OMWW entered GSB_{10} and remained for 10 days to settle by gravity, mainly in the first and second cells. To investigate the evaporation process in a covered GSB_{10}, a greenhouse-type roofing of 10 m length, 5 m width and 3 m height has been constructed above the GSB_{10} at a 3-phase OM in Evia, Greece. A sediment height of about 30 cm and a supernatant of about 97 cm were obtained during the experiment in the GSB_{10}. The height of the sediment was measured with time (**Table 2**) in order to estimate its daily volume reduction during evaporation. The volume reduction of the sediment reflects the effect of the evaporation inside the covered GSB_{10} by the greenhouse-type shelter and is expressed as the percentage of the height reduction from its initial height level. Also, the temperature of the air inside and outside the covered GSB_{10} was measured by common digital temperature meters.

RESULTS AND DISCUSSION

The initial moisture content of 2-phase OMW according to the SOEP data base was calculated to 53.4-77.2% (average 64.3%, 76 measurements) with an oil content of 2.02-5.06% (average 3.64%, 76 measurements) and the moisture content of 3-phase OMSW was 37.8-63.7% (average 48.1%, 302 measurements) with an oil content of 2.3-8.3% (average 6.1%, 302 measurements). To confirm the moisture content of the 2-phase OMW and 3-phase OMSW, samples of these were taken. The results were very close with those given by the SOEP data base; 2-phase OMW had a moisture content of 61.7-63.8% (average 62.4%, 6 measurements), 3-phase OMSW of 45.9-47.5% (average 46.6%, 6 measurements). In addition samples of DOS were taken and their moisture content was found to be 8.1-10.2% (average 9.4%, 6 measurements).

2-phase OMW was found to be about 70% and DOS about 21% by weight of olives treated. This means that one ton of 2-phase OMW is generated from about 1.3-1.5 t of olives treated in a 2-phase OM and the latter generates about 0.3 t DOS. This would correspond to 0.7-0.8 t of 3-phase OMSW, in case that the 1.3-1.5 t of olives were treated in a 3-phase OM. Consequently, the operation of a 3-phase OM as a 2-phase one will result in an increase of 2-phase OMW by about 20-30% and of moisture content by about 20% compared to 3-phase OM.

Different mixing ratios of 2-phase OMW and DOS were tested and the results are shown in **Table 1**. According to **Table 1** the appropriate mixing ratio of 2-phase OMW with DOS in order to reach the desired for handling in the SOEP moisture content was found to be 2: 1 by weight. This means that half a ton of DOS should be available at SOEP for mixing with each ton of 2-phase OMW brought in.

If the quantity of DOS required for moisture correction is taken into account, the quantity of the mixture to be handled by SOEP further increases by about 50% (0.5 t of DOS to 1.0 t of 2-phase OMW).

Hence, each ton of olives treated in a 2-phase OM generates 0.7-0.8 t of 2-phase OMW plus 0.35-0.4 t of DOS for moisture correction which equals to 1.05-1.2 t for handling in SOEP, while each ton of olives treated in a 3-phase OM generates just 0.55 t of 3-phase OMSW. That means that SOEP have to handle the double quantity of OMW to treat 2-phase OMW than that of 3-phase OMSW.

So, for a certain 3-phase OMSW capacity of a SOEP, the operation of 2-phase OM will cause an overloading and an increase in the transportation cost. To avoid this, the selection of the 2-phase mode operation should be done cautiously and only for those OM located in or near residential areas that have no 2-phase OMW alternative handling system.

The SOEP in turn should examine very carefully whether to increase their capacity to receive the 2-phase OMW of the converted 2-phase OM, probably at the expense of the OM, or to reduce accordingly the 3-phase OMSW coming in the plant. Each 3-phase OM converted in 2-phase OM would result in an exclusion of one more 3-phase OM from the SOEP's treatment capacity.

In such a case, the question is what would the excluded 3-phase OM do with their OMW? First of all, the excluded 3-phase OM should be selected in priority among those which already have or can easily find the required land area for the treatment and disposal of their OMW. These mills could then apply the aforementioned OMW management system suggested by the LAS of AUA. In addition, they could install a composting system of their 3-phase OMSW preferably mixed with DOS and sell the resulting compost as a soil conditioner and fertilizer.

Table 1 Moisture content of the mixture of 2-phase OMW and DOS at different mass ratios.

2-phase OMW DOS	Moisture content (%)
10:1	56.55
5:1	52.62
3.33:1	50.19
2.5:1	47.25
2:1	44.49
1.67:1	42.81

Table 2 Height reduction of the 3-phase OMWW sediment inside the greenhouse-type pilot shelter.

Time (days)	Sediment level reduction (cm)	Temperature inside/outside (°C)
0	0.0	17.5/-
25	2.0	24/-
32	2.5	28/28.0
40	3.5	28/19.9
45	5.2	28/22.8
54	7.5	28.5/21.9
61	8.0	28.2/21.5
69	8.5	27.7/20.9
76	10.2	32.1/25.7
81	11.5	36.2/29.8
90	12.5	31.6/25.7
96	14.0	34.3/27.0
102	15.0	38.4/31.2
109	15.5	40.8/32.7
116	17.0	39.1/31.6
123	17.5	39/33.9
130	18.0	39.3/31.8
137	19.0	38.3/33.0
143	20.0	37.7/30.3
150	20.0	38.1/30.8
175	20.0	38.2/-

An experiment was set in the aforementioned pilot installation of GSB_{10} by the LAS of AUA in order to investigate the efficiency of drying by evaporation of the thick sediment remaining on the bottom of the GSB_{10} prior to its direct disposal to land as soil conditioner.

In **Table 2** the reduction in volume (expressed as height change) of the sediment due to evaporation at different inside and outside air temperatures is listed. The total reduction of the sediment height was 66.7% (from an initial height of 30 cm the sediment was reduced to 10 cm). This reduction was achieved after 143 days of evaporation and then remained constant until the 175^{th} day. The plot of the sediment height values against time in **Fig. 3** has shown a linear relationship with a daily height reduction of 0.47% (slop of fitting line). After the evaporation of the sediment in cell 2, the residue formed a dark colored dried sludge, which was easily detached from the polyethylene sheet of the bottom.

CONCLUSIONS

SOEP could be considered as potential centralised OMW treatment plants. However, the 2-phase OMW, because of their high moisture content, cannot be handled properly in the SOEP and therefore are not accepted from them. Nevertheless, especially inside residential districts the OM have to be converted in order to operate in the 2-phase extraction mode, which causes a 2-phase OMW treatment problem. To overcome this problem, this paper suggests the mixing of 2-phase OMW with DOS in a ratio of 2: 1 to produce a mixture with a moisture content that is appropriate for being handled in SOEP. According to this suggestion, in order to treat 2-phase OMW, the SOEP would have to handle almost

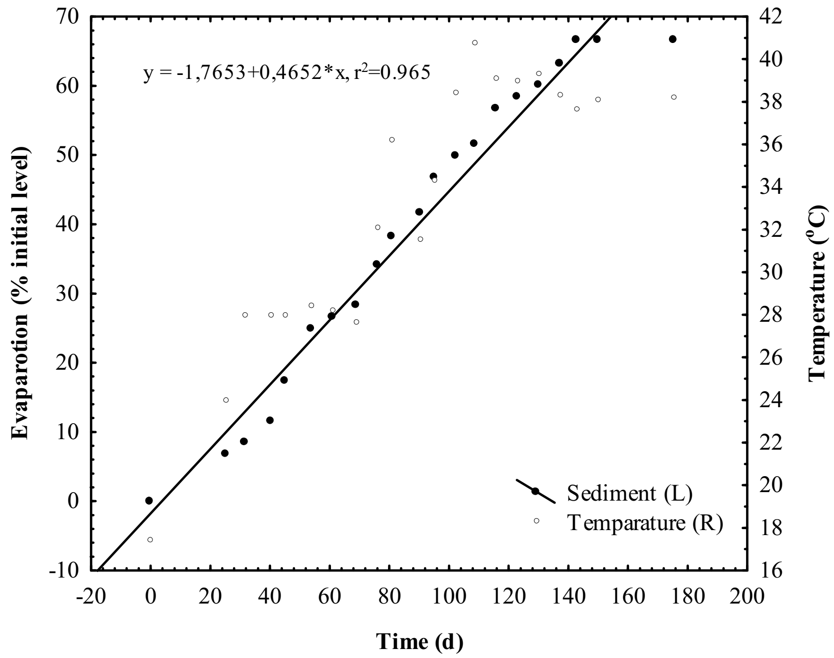

Fig. 3 3-phase OMWW sediment evaporation with time. Percentage associated in an initial sediment level (height) of 30 cm.

the double quantity of OMW than of 3-phase OMSW. To cope with this overloading of the SOEP capacity, either the capacity has to be increased, or a certain number of 3-phase OM have to be excluded from sending their 3-phase OMSW to SOEP. The excluded 3-phase OM should be selected among those that possess the necessary land for OMW treatment.

The excluded 3-phase OM could follow the suggested *in situ* treatment method based on sedimentation-evaporation in a greenhouse-type covered GSB_{10}, in which the sedimentation evaporates with a linear volume reduction of 0.47% per day, and the supernatant overflows to a storage earthen lagoon.

ACKNOWLEDGEMENTS

We thank AGREK- K.SAMANTOUROS Co. for financing the evaporation greenhouse-type shelter and the OSEP of Messinia for giving the data and the material. Also, we thank Dr. Despo Kritsotaki for her help with English.

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