Adding value to olive oil production through waste and wastewater treatment and valorisation: the case of Greece

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Abstract

Nowadays, an increasing trend towards olive oil production is observed globally. The extraction of olive oil is mostly implemented through three-phase or two-phase centrifuge systems. Olive pomace derived as a by-product of olive oil processing, constitutes raw material for olive-pomace oil production. The operation of olive oil mills and olive-pomace industries has been connected with the production of heavily polluted wastewater and generation of solid waste. The present study aims at investigating the current treatment methods and techniques applied for the management of olive oil (including olive-pomace oil) wastewater and solid waste in Greece. Aiming at adding value to the Greek olive production process, international practices applied for solid waste and wastewater treatment as well as potential valorisation options are reviewed within this paper. Results revealed that there is room for improvement in wastewater treatment in Greece since the currently applied method i.e. oil removal, neutralization, sedimentation and evaporation, comprises a basic - level technique. Concerning solid waste management, attention must be paid to the use of sludge produced from evaporation ponds since application without appropriate treatment as soil improver may entail diverse toxic effects to soils. Regarding solid waste valorisation, pomace handling is thoroughly exploited since it is utilized for the production of olive-pomace oil and pomace wood. Other valorisation options include production of biomolecules as well as cosmetic products, dyes, construction materials and water decontamination sorbents. However, more work needs to be done in order to maximize the economic feasibility of such practices.

Keywords

Olive oil; olive pomace oil; pomace wood; pomace; centrifuge; waste; wastewater; Greece.

1. Introduction

Globally, olive oil production is characterized by a continuous upward trend that peaked during the last decade, reaching 3.3 millions of tons for the 2011/2012 olive crop year [1]. In 2011/2012, approximately 72% of the world's production came from European countries, 96% of which was produced from three countries: Spain (49%), Italy (12%) and Greece (9%) [1]. During the last decade, Spain has greatly intensified cultivation of olive trees, thus achieving a rapid increase of production to approximately 1.3 millions of tons in 2010, twice the level compared to 1990 [2]. The raw material used for the production of *olive oil* is olives, while *olive-pomace oil* is produced from a by-product from olive production process known as pomace. Olive oil is the main fatty component of the Mediterranean diet [3] while olive-pomace oil can be used for: soap manufacturing, dietary purposes (after refining and mixing with olive oil), biodiesel production and cosmetics.

Overall, Greece has an annual production ranging from 300 up to 400 thousands of tons of oil depending on the olive crop year [4]. During the period 2007-2009, approximately 300 thousands of tons were produced, 75% of which was produced in Crete and Peloponnese [2]. In general, the olive oil sector includes olive oil mills (OOMs), olive-pomace oil production facilities, packaging of oil facilities as well as refinement facilities. Olive oil mills can be categorized, according to the quantity of olives processed in two years period (sum of maximum and minimum year production) to three basic categories: (i) small sized companies where processing capacity is less than 1,500 t olives/ two year period, (ii) medium sized companies where processing capacity is between 1,500 t up to 3,000 t olives in two year period and (iii) large sized companies where processing capacity is greater than 3,000 t olives in two year period [5]. In 2009, 2,369 OOMs were recorded in Greece, 37% of which operated in Peloponnese and 23% in Crete [2]. Furthermore, according to 2011 data, 260 approved packaging facilities were identified without considering the small units operating without approval [2]. Finally, 47 companies producing olive-pomace oil operated in Greece (2012 data) [2]. These facilities were annually supplied with around 200 thousands of tons of pomace [2].

In general, olive oil production process is accomplished through a sequence of activities including: reception of olives, cleaning of impurities, washing with water, crushing of olives, malaxation of paste, olive oil extraction, final centrifugation, storage, filtration and bottling [3]. For the production of olive oil, the basic process is the olive oil extraction which was traditionally carried out through pressing. Nowadays, the extraction in most olive oil mills is performed with the centrifugal process through three-phase or two-phase decanters. Three-phase decanters were the first applied centrifugal systems for olive oil extraction, resulting to the production of three streams i.e. (i) olive oil mixed with water for further centrifugation, (ii) wastewater (known as *vegetable or fruit water* in English, *alpechin* in Spanish, *acque di vegetazione* in Italian and *katsigaros* in Greek) and (iii) solid waste (known as *pomace* in English, *orujo* in Spanish, *sansa vergine* in Italian and *trifasikos elaiopirinas* in Greek). The two-phase decanters turned up later as a more environmental friendly method for olive oil centrifugation. Two-phase decanters produce two streams i.e. (i) olive oil for further centrifugation and (ii) solid waste (known as *pomace* in English, *alperujo* in Spanish, *sansa vergine* in Italian and *difasikos elaiopirinas* in Greek). Pomace produced from 2-phase systems is characterised by higher humidity (~62%) comparing to that of 3-phase (~55%). Pomace from both 3-phase and 2-phase systems is transported to olive-pomace oil facilities. Pomace oil plants process the pomace produced from the two or three phase olive oil mills for the production of olive-pomace oil. In summary, the method includes: reception and storage of fresh pomace, drying of pomace, extraction of dry pomace, distillation, concentration of hexane-water, separation of hexane-water and storage of olive-pomace oil. In addition to the oil produced, exhausted pomace or pomace wood (*orujillo* in Spanish, *sansa esausta* in Italian and *pirinoxilo* in Greek) is also produced.

The main target of this research is the recording and evaluation of current practices which are applied for wastewater and solid waste treatment derived from the olive oil processing industry in Greece in order to uncover opportunities for adding value to the olive oil process through waste and wastewater treatment and potential valorisation of waste streams. To this end, the existing solid waste and wastewater management status in Greece as well as the worldwide practices and exploitation opportunities were studied. Data concerning mapping of Greek treatment methods were collected based on a methodology specifically developed for the needs of this study. Following, the methodology developed and the results obtained are discussed.

2. Methodology

Research was carried out towards two directions: (a) recording the existing management of waste and wastewater produced during olive oil processing in Greece and (b) reviewing waste and wastewater treatment methods and valorisation options proposed through various publications and presentations worldwide.

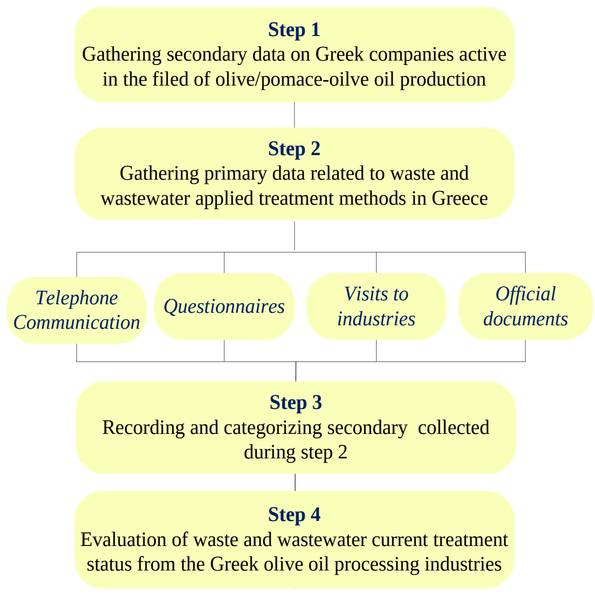

Figure 1: Methodology for recording management methods for treatng wastewater & waste from olive oil production in Greece

In order to assess currently implemented practices in Greece, a four step methodology was developed and adopted. **Figure 1** illustrates the developed methodology. During the ***first step*** of the methodology, an extensive desk research for the collection of secondary data related to Greek companies involved in the olive/pomace-oil production and packaging was carried out. Such information was collected through companies' websites created to promote their products or websites related to olive oil production at national level such as the Hellenic Ministry of Rural Development and Food, regional chambers of commerce and industry, published online catalogues of related industries etc. The research concluded in gathering information regarding the name of the industry, the location, contact details, revenues and the specific industrial activity to which it belongs. The industries were categorised based on their activity as related to: Olive Oil Production (OO-PR), Olive Oil Packaging (OO-PA), Olive – Pomace Oil Production (OPO-PR), Olive – Pomace Oil Packaging (OPO-PA) and Soap Production (SP). The ***second step*** aimed at the collection of information on the current situation related to the generation and treatment of wastewater and solid waste from the production process of the oil industries recorded in the framework of Step1. The above mentioned data were collected through telephone contacts, questionnaires, visits to industries and finally through available official information (i.e. Approval of Environmental Impact Assessment) from the Greek Ministry of Environment and Climate Change (YPEKA). The ***third step*** involved the recording and grouping of the primary data, collected during the implementation of the second step, in order to facilitate the evaluation. More specifically, the following data were recorded: categorization in group/ subgroup/category, capacity, type of oil extraction, information on wastewater generated during production process (type and quantity, management methods, valorization /disposal) and information on solid waste generated during production process (type and quantity, management methods, valorization /disposal). Categorization in group, subgroup and environmental category was given according to the Ministerial Decision (MD) 1958/12 *on the classification of projects and activities into categories/subcategories on the basis of their potential impact on the environment* (Government Gazette B/21/2012) [6]. The ***fourth step*** involved the interpretation and evaluation of the collected information so as to depict current status of wastewater and waste treatment from olive oils in Greece. Projects related to the sector under investigation, belong either to *Category A2* or to *Category B*. Category A2 projects may cause significant adverse environmental impacts and thus the conduction of an Environmental Impact Assessment (EIA) is obligatory. In such projects (B2), the Approval of Environmental Impact Assessment is issued from the regional environmental authority. Category B includes projects that can only cause local and non-significant effects on the environment, and thus they are only subject to Standard Environmental Commitments (SEC).

In order to uncover potential opportunities for adding value to the olive oil process through waste and wastewater treatment and valorisation, review of the waste and wastewater treatment methods and valorisation options applied worldwide was also conducted in parallel.

3. Results and Discussion

In total, 274 companies related to olive/olive-pomace oil production and packaging were identified during the first step of the methodology, out of which around 64% are olive oil mills and in particular approximately the three quarters (72%) are also engaged in olive oil packaging. Moreover, 3% of all enterprises produce olive-pomace oil out of which about 14% are also packaging olive-pomace oil. Finally, 33% is dedicated to packaging of oils, out of which 96% is engaged to packaging of olive oil. Most of the recorded companies (39%) operate in Peloponnese, in Crete (22%) and in Western Greece (21%).

From the implementation of the second step of the methodology, data for 22 Greek industries related to oil production and packaging were collected through methods discussed in the methodology section. From those, 16 are involved in oil production (olive oil mills), of which 9 have extended their activity to packaging of olive oil. Of the remaining industries, 2 were exclusively active in the packaging of olive oil and 4 in the production of olive-pomace oil and pomace wood, of which 3 are also engaged in packaging of olive-pomace oil while 1 of them also produces soaps.

According to MD 1958/12, industrial activities are classified under the 9th group of Annex IX ("*Industrial Activities and Related Facilities*") with serial number depending on the activity i.e. (a) No. 11 corresponds to *olive oil production*, (b) No. 12 match with the *production of refined oils and fats and of margarine and similar edible fat*, (c) No. 13 related to the *manufacture of other non-processed oils and fats* and (d) No. 14 is relative to *drying of oil seeds, other agricultural products and plant biomass*. Approximately half of the industrial units studied belong to category A2 which is either related to the productive capacity and/or other special issues such as the location of the units etc. Data collected for the production and management of waste from industrial production and processing of oil industries are presented in **Table 1**.

Table 1: Recorded and categorised data for solid waste and wastewater treatment in 22 olive and olive-pomace oil industries in Greece

no	Activity	Capacity	Process of oil extraction	Industrial wastewater type and quantity	Industrial wastewater treatment	Industrial wastewater disposal	Industrial solid waste type and treatment	Sludge treatment and disposal
1	OO-PR[(1)]	**Olive oil mill:** 9 *t olives/ d*	2-phase	0.25 m^3/ *t olive* (3 m^3/d)	Neutralization of acidity Flocculation Precipitation	Transportation to the municipal wastewater treatment plant	**Pomace:** to olive-pomace oil production facilities **Olive leaves:** for animal feed	*n.a.*
2	OO-PR	*n.a.*	3-phase	*n.a.*[65)]	Neutralization of acidity Flocculation Precipitation	Surface water receptor	Pomace: to olive-pomace oil production facilities Olive leaves: animal feed or soil improver or fuel Ash: disposal with MSW or for fertilising	Sludge (precipitation tanks): **T**[(8)] - collection, dehydration, **D** [(9)]- soil improver
3	OO-PR	*n.a.*	3-phase	*n.a.*	Oil collection Neutralization of acidity Precipitation Evaporation in ponds	- (7)	**Pomace**: to olive-pomace oil production facilities **Olive leaves**: animal feed or soil improver or fuel **Ash**: disposal with MSW or for fertilising **Damaged olives**: animal feed or soil improver or for biogas production	**Sludge (evaporation ponds):** **T** - collection, dehydration, **D** - soil improver
4	OO-PR	*n.a.*	3-phase	*n.a.*	Oil collection Neutralization of acidity Precipitation Evaporation in ponds	-	**Pomace:** to olive-pomace oil production facilities **Olive leaves**: animal feed or soil improver or fuel **Ash**: disposal with MSW or for fertilising **Damaged olives**: for animal feed or soil improver or for biogas production	**Sludge (evaporation ponds):** **T** - collection, dehydration, **D** - soil improver
5	OO-PR	**Olive oil mill:** 15 *t olives/ d* **Olive oil production:** 3 *t olive oil /d*	3-phase	*n.a.*	Screening Neutralization of acidity Precipitation Evaporation in ponds	-	**Pomace**: to olive-pomace oil production facilities **Olive leaves**: soil improver	**Sludge (evaporation ponds):** **T** - collection, mixing with olive leaves, **D** - soil improver
6	OO-PR	**Olive oil mill:** 20 *t olives/ d* **Olive oil production:** 5 t /d	3-phase	*n.a.*	Oil collection Neutralization of acidity Precipitation Evaporation in ponds	-	**Pomace**: to olive-pomace oil production facilities **Olive leave**s: animal feed or soil improver or fuel	**Sludge (evaporation ponds):** **T** - collection, dehydration, **D** - soil improver
7	OO-PR & other oils	**Vegetable oils:** 192 *t of processed oil /d*	*n.a.*	25 - 30 m^3/d	Pre-treatment Physicochemical treatment Biological treatment	Surface water receptor	**Gums, waxes and solid waste from the refining process**: added to flour or sold to third parties as a by-product for use **Sediment material (mourga)**: sold to third parties for use (soap)	**Sludges:** **T&D**: by appropriate waste treatment companies
8	OO-PR/ OO-PA [(2)]	50 *t olives/ d*	3-phase	1.2 *t/t olives,* 54 *t/d*	Neutralization of acidity Flocculation Precipitation Evaporation in ponds	-	**Pomace**: to olive-pomace oil production facilities **Olive leaves**: soil improver	**Sludge (evaporation ponds):** **T** - collection, dehydration, **D** - soil improver

no	Activity	Capacity	Process of oil extraction	Industrial wastewater type and quantity	Industrial wastewater treatment	Industrial wastewater disposal	Industrial solid waste type and treatment	Sludge treatment and disposal
9	OO-PR/ OO-PA	**Olive oil mill:** 48 *t olives/d* **Packaging:** 320 *t olive oil/d* **Oil refining:** 120 *t of unrefined oils/d*	3-phase	*n.a.*	Oil collection Neutralization of acidity Precipitation Evaporation in ponds	-	**Pomace**: to olive-pomace oil production facilities **Olive leaves**: animal feed or soil improver or fuel **Ash**: disposal with MSW or for fertilising **Damaged olives**: animal feed or soil improver or for biogas production	**Sludge (evaporation ponds):** **T** - collection, dehydration, **D** - soil improver
10	OO-PR/ OO-PA	*n.a.*	*n.a.*	*n.a.*	Oil collection Neutralization of acidity Precipitation Evaporation in ponds	-	**Pomace**: to olive-pomace oil production facilities **Olive leaves**: animal feed or soil improver or fuel **Ash**: disposal with MSW or for fertilising **Damaged olives**: animal feed or soil improver or for biogas production	**Sludge (evaporation ponds):** **T** - collection, dehydration, **D** - soil improver
11	OO-PR/ OO-PA	**Olive oil mill:** *24 t olives/ d* **Packaging:** 4.5 *t olive oil/ d*	2-phase	*n.a.*	Oil collection Neutralization of acidity Precipitation Evaporation in ponds	-	**Pomace**: to olive-pomace oil production facilities **Olive leaves**: animal feed or soil improver or fuel	**Sludge (evaporation ponds):** **T** - collection, dehydration, **D** - soil improver
12	OO-PR/ OO-PA	**Olive oil mill:** 46.4 *t olives/ d* **Packaging:** 4.8 *t olive oil/ d*	2-phase	0.15 *t / t olives* 6.4 *t / d*	Screening Neutralization of acidity Precipitation Evaporation in ponds	-	**Pomace**: to olive-pomace oil production facilities **Olive leaves**: soil improver	n.a.
13	OO-PR/ OO-PA	**Olive oil mill:** 2.4 *t olives/ d* **Packaging:** 3.2 *t olive oil/ d*	2-phase	*n.a.*	Oil collection	Septic and absorption tank	**Pomace:** to olive-pomace oil production facilities **Olive leaves**: *n.a.* **Sediment material (mourga):** for soap production	**Sludge (septic tank):** **T** - collection to the septic tank **D** - appropriate waste companies
14	OO-PR/ OO-PA	**Olive oil mill:** 10 *t olives/ d*	3-phase	*n.a.*	Oil collection Neutralization of acidity Precipitation Evaporation in ponds	-	**Pomace**: to olive-pomace oil production facilities **Olive leaves**: animal feed or as fuel (after drying) to the burner along with the pomace wood **Ash**: disposal with MSW or for fertilising	**Sludge (evaporation ponds):** **T** - collection, dehydration, **D** - soil improver
15	OO-PR/ OO-PA	**Olive oil mill:** 80 *t olives/ d* **Packaging:** 10 *t olive oil/ d*	3-phase	**From olive oil mill:** 0.7 m^3*/t olive,* 53 m^3*/d* **From washing of resins:** 300 m^3*/y*	**From washing of equipment and tanks**: septic tank **From decanter:** Oil collection Neutralization of acidity Precipitation Evaporation in ponds **From washing of resins:** appropriate companies	**From washing of equipment and tanks**: septic tank **From decanter: -** **From washing of resins:** appropriate companies	**Olive leaves:** soil improver **Resins:** appropriate waste treatment companies **Diatomaceous earth:** appropriate waste treatment companies for composting	**Sludge (evaporation ponds):** **T** - collection, dehydration, **D** - soil improver

no	Activity	Capacity	Process of oil extraction	Industrial wastewater type and quantity	Industrial wastewater treatment	Industrial wastewater disposal	Industrial solid waste type and treatment	Sludge treatment and disposal
16	OO-PR/ OO-PA	**Olive oil mill:** 28 *t olives/ d* **Packaging:** <1 *t olive oil/ d*	3-phase	53 m^3/d	**From washing of equipment and tanks**: septic tank **From decanter:** Oil collection Neutralization of acidity Precipitation	**From washing of equipment and tanks**: septic tank **From decanter:** Surface water receptor	**Pomace**: to olive-pomace oil production facilities **Olive leaves**: animal feed or soil improver or fuel **Dust from steam boiler**: burning	**Sludge (sedimentation tanks):** **T** - collection **D** - soil improver
17	OPO-PR [3]	**Pomace processing:** 400 *t pomace /d*	-	*n.a.*	**Industrial wastewater:** septic tank & absorption system **Leachates from pomace storage**: collection and evaporation in ponds	-	**Olive leaves**: animal feed or soil improver or fuel **Dust from steam boilers**: burning with pomace wood **Dust from dryers**: extraction	**Sludge (evaporation ponds):** **T** - collection, dehydration, **D** - soil improver
18	OPO-PR/ OPO-PA [4]	**Processing:** 400 t pomace /d **Production:** - Olive-Pomace oil: 30 t /d - Exhausted olive pomace 300 t /d	-	*n.a.*	Pre-treatment Physicochemical treatment Biological treatment	Re-use to the biological treatment plant	**Ash**: disposal with MSW	**Sludges:** **T&D**: by appropriate waste treatment companies
19	OPO-PR/ OPO-PA	**Production of olive-pomace oil:** 24 *t /d*	-	**Wastewater from once-through water cooling system**: 1600 m^3/d **Concentrated vapours from the extraction process**: 11 m^3/d **Wastewater from neutralization**: 0.25 m^3/d **From steam boilers:** 1.20 m^3/d **From washing of floors:** 2 m^3/d	**Wastewater from once-through water cooling system**: for disposal **Other industrial wastewater (***concentrated vapours from the extraction process, wastewater from neutralization, from steam boilers, from washing of floors***)**: collection	**Wastewater from once-through water cooling system**: surface water receptor **Other industrial wastewater** (*concentrated vapours from the extraction process, wastewater from neutralization, from steam boilers, from washing of floors*): to municipal wastewater treatment plant	**Ash:** disposal with MSW or as fertiliser **Dust from steam boiler and dryers**: burning to dryer's or boiler's burner **Paste of bleaching earth**: disposal with MSW or as fertiliser **Soap paste:** treatment inside the facility for disintegration and production of oleins sold to various companies for use as biomass fuel in combination with fossil fuels or sold for soap production	-

no	Activity	Capacity	Process of oil extraction	Industrial wastewater type and quantity	Industrial wastewater treatment	Industrial wastewater disposal	Industrial solid waste type and treatment	Sludge treatment and disposal
20	OPO-PR/ OPO-PA/ SP(5)	**Processing:** 500 t pomace /d **Production:** - Olive-Pomace oil: 10 t /d - Exhausted olive pomace 110 *t /d*	-	Wastewater from once-through water cooling system, concentrated vapours from the extraction process, wastewater from neutralization, from steam boilers, from washing of floors and equipment, leachates from pomace storage	**Wastewater from cooling system, concentrated vapours from the extraction process, wastewater from neutralization, from steam boilers:** Reuse as cooling water and feed water to the steam boiler At the end of the operation period, disposal to evaporation ponds **Leachates from pomace storage:** collection and evaporation in ponds	-	**Ash:** disposal with MSW or as fertiliser **Dust from steam boilers:** burning with pomace wood **Dust from dryers:** extraction **Paste of bleaching earth and Diatomaceous earth**: disposal with MSW or sold to other companies e.g. cement industries	**Sludge (evaporation ponds):** **T -** mixing with pomace and lead to dryers, **D** - n.a.
21	OO-PA	**Packaging:** 40 *t/d*	-	*n.a.*	Collection	Septic tank	-	-
22	OO-PA & others	**Packaging:** 0,225 *L/d*	-	*n.a.*	Biological treatment plant	*n.a.*	*n.a.*	n.a.

(1) **OO-PR:** Olive Oil Production

(2) **OO-PA:** Olive Oil Packaging

(3) **OPO-PR:** Olive – Pomace Oil Production

(4) **OPO-PA:** Olive – Pomace Oil Packaging

(5) **SP:** Soap Production

(6) **n.a**: not available information

(7) **-**: not relative information

(8) **T**: Treatment

(9) **D**: Disposal

Based on the study conducted, the main products of the activities under investigation are: olive oil, refined oils, olive-pomace oil and pomace wood. Other intermediate products or by-products that are financially exploited directly or indirectly include: (a) pomace which comprises the raw material for olive-pomace oil production, (b) sediment material from oil storage tanks (in Greek: mourga) which is sold to soap manufacturing industries and (c) olive leaves which are forwarded as animal feed.

Regarding the production processes of the examined industries, no big differences during the production of the same product were observed. Thus, main stages for olive oil production include reception of olives, cleaning of impurities, washing with water, crushing of olives, malaxation of the paste produced from crushing, centrifugation (*3-phase or 2-phase decanters*), final centrifugation and storage. In this study, the majority of the studied olive oil mills (approximately 70% from those that available data existed) were three-phase olive oil mills. Moreover, it was observed that the method of extracting the oil determines both the capacity and the qualitative and quantitative characteristics of the resulting oil, wastewater and solid waste. For 3-phase olive oil mills, an average ratio of 0.23 kg of oil produced/ kg of olives processed was recorded.

The operation of olive oil mills results in wastewater and waste production. During 3-phase process, besides oil mixed with water, wastewater and solid waste (pomace) are generated while from 2-phase decanters only olive mixed with water and pomace (with higher humidity that pomace from 3-phase mills) are produced. Therefore, in these cases, generated wastewater mainly comes from washing of olive oils, floor and equipment washing and the second centrifugation. Based on the recorded data and as it was expected, the average ratio of produced wastewater (kg) per olives processed (kg) for 3-phase is much higher than that for 2-phase, 1.23 and 0.22 respectively. Vegetable water derived from 3-phase decanters is responsible for the high polluting load and the black colour of wastewater produced from olive oil mills using three-phase centrifugation. In **Figure 2**, key information recorded during the study for 3-phase and 2 phase extraction processes are illustrated.

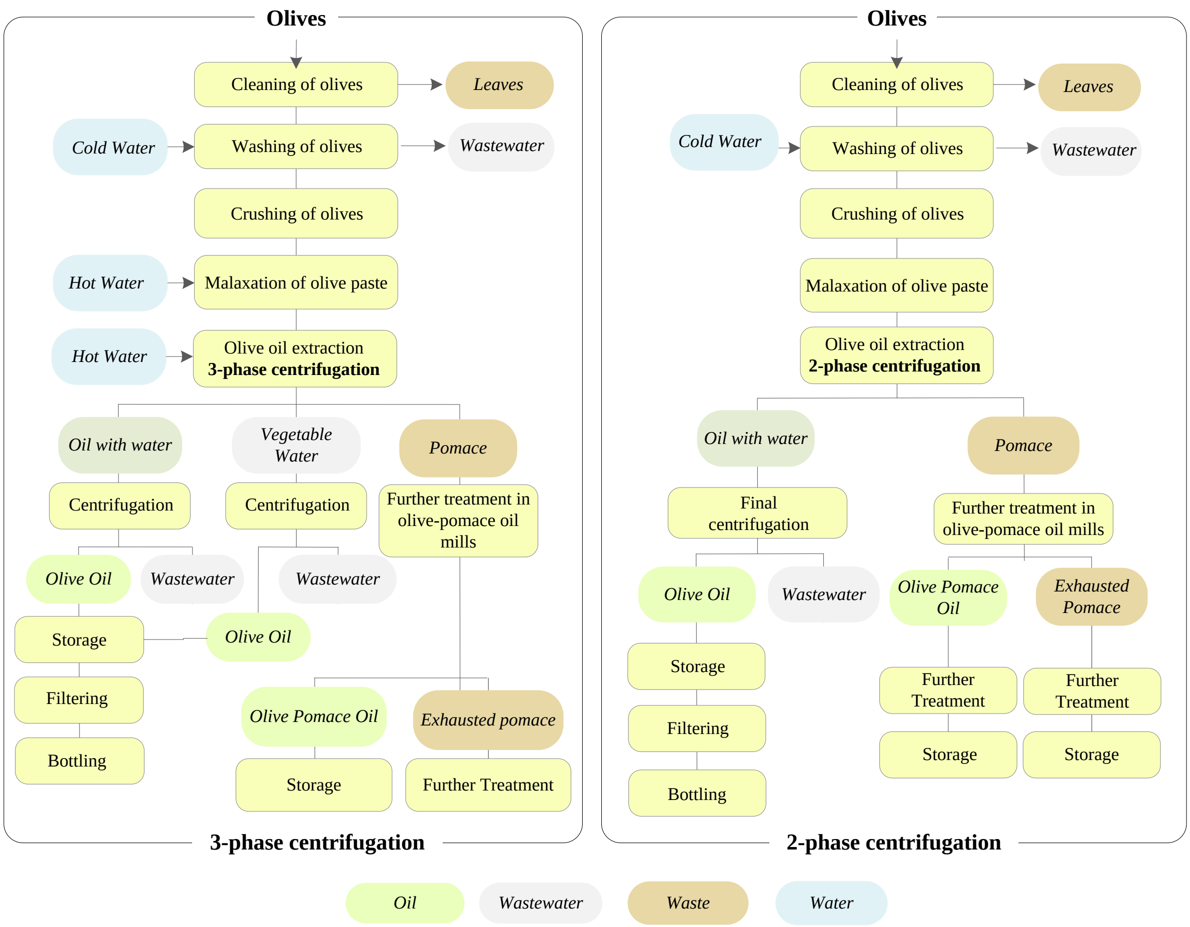

Figure 2: Key information related to 3-phase and 2-phase centrifuge in olive oil mills

From the evaluation of data it was obvious that the prevailing waste treatment method that it is currently applied includes oil collection, neutralization of acidity, sedimentation and disposal to open evaporation ponds (lagoons). Half of the industries studied use the evaporation ponds as the final treatment/disposal step. In general, the evaporation ponds are widely used worldwide despite the fact that in some cases only waste volume is reduced and serious problems might occur due to leakage of wastewater to soil and/or groundwater [9]. Despite that, the specific treatment method is a low cost method and thus widely applied [9]. It must be also noted, that according to the Greek Joint Ministerial Decision (JMD) 15/4187/266/11.04.2012 on *the Standard Environmental Commitments (SEC) of Industrial Activities* (Government Gazette B 1275/B/11.4.2012) [7] and in particular condition E3 (Annex I), oil collection, neutralization, sedimentation and final disposal to open evaporation ponds is proposed as treatment method for wastewater from olive oil production. Based on the same condition, equivalent method can also be applied. Condition E3 has been further explained in *Official Document (12550/744/F15/2.11.2012) on General guidelines for implementation of the condition E3 of JMD 15/4187/266/11.04.2012* issued by the General Secretariat for Industry and the General Secretariat for Environment [8]. Based on this document, neutralisation should be conducted with addition of at least 5 kg of lime per ton of olives processed or 2% per unit volume of wastewater while during precipitation the sediment should be left to settle at least for 3 hours [8]. Moreover, 3 companies are applying (approximately 14% of the studied companies) oil collection, neutralization of acidity, sedimentation and finally either disposal to surface water receptor (2) or to municipal wastewater treatment plant (1). Furthermore, two industries apply a pre-treatment, followed by physicochemical and finally biological treatment while disposal is either conducted to a surface water receptor or it is reused for the needs of biological treatment plant. Wastewater production from the industries involved in the production and packaging of pomace oil mainly comes from: cooling water from refrigerators of hexane, wastewater from the process of separating the mixture of water, oil and hexane, concentrated vapours coming from extraction and wastewater from neutralization. Olive-pomace oil industries studied either apply pre-treatment methods, physicochemical and biological treatment or focus on specific wastewater streams.

Solid waste produced form the oil production includes: pomace, olive leaves, inappropriate (damaged) olives, ash from the operation of burners, dust due to burners operation or due to drying of pomace and sludge derived from the evaporation, the precipitation and / or septic tanks. Pomace handling is 100% undertaken by the olive-pomace facilities, where olive-pomace oil and pomace wood are produced. This is an excellent example of by-product valorisation since waste produced from one company constitutes raw-material for another. Olive-pomace oil producers buy pomace from olive oil producers and as a result olive oil producers are in line with their environmental obligations and have profit at the same time. It is very often that pomace oil producers pay olive oil producers with pomace oil or pomace wood instead of money. The evolution of 2-phase decanters resulted in producing pomace with higher humidity (62% instead of 55% from three-phase decanters) resulting in proportional increase of energy consumption needed for drying of pomace. This caused an increase to pomace wood cost. It must be also noted, that according to *Z8 condition* of JMD 15/4187/266/11.04.2012, pomace should be treated at olive pomace facilities. Most Greek industrial units use olive leaves as animal feed or as fertilizer or as fuel. Inappropriate olives are available as animal feed or soil improver or for biogas production. The ash from pomace wood burners is disposed with municipal waste or to fertilization. Similarly, the sludge resulting from both the production process and the treatment of wastewater are collected, dehydrated and used in most of the times (83%) as a soil improver, alternatively one industry dispose its sludge in landfills and another to authorised companies for further treatment. Despite the fact that according to *Z8 condition* of JMD 15/4187/266/11.04.2012 sludge from the evaporation ponds should be disposed as soil improver after mixing and dehydration or with alternative treatment methods, during study it was not possible to record the exact circumstances that this is conducted in Greece. Nevertheless, sludge from evaporation ponds should not be applied directly to soil since this may entail risks due to toxic effects. Moreover, production of the following types of waste was also noticed: solid residues from oil tanks available for making soap, used resins, bleaching earth and diatomaceous earth used as filtering mediums which are given to appropriate companies and dust. In olive pomace oil industries dust is usually collected in cyclones and comes from the dryers of pomace and from steam boilers. Dust from dryers are initially undergo extraction and then burned along with pomace wood in dryer's burner or steam boiler burner while dust from steam boilers are burned with pomace wood.

In order to determine further valorisation opportunities for solid waste and wastewater produced from the Greek oil industries, literature review was conducted. As mentioned above, the olive oil production process generates two kinds of residues, the liquid residues (wastewater) and the solid residues such as pomace, olive stone, olive leaves and small twigs. The valorisation of these residues after proper treatment has been studied extensively and numerous practices have been proposed. Until now, the exploitation of some streams has been successfully incorporated in industrial scale e.g. pomace valorisation for olive pomace oil production while for others, such practices have not been integrated into the production process mainly due to concerns related to the potential negative effects from the application or/and due to their low economic feasibility.

In particular, as also recorded in Greece, the produced pomace is used for the extraction of olive pomace oil, with the use of solvents, after being subjected to drying. The exhausted olive pomace, given its high calorific value, is used as a fuel in olive mills for the generation of energy through combustion [10, 11]. However, the total energy recovery rate is low considering that most of the energy produced is used in the drying process [12]. Other less common applications of olive pomace include its use as a sorbent material for the treatment of heavy metal contaminated water [13] as well as its application to soils for increasing sorption of pesticides [14, 15].

Other solid residues produced during the olive oil production are the olive leaves and twigs as well as the olive stones. Olive leaves and twigs are widely used as animal feed or for the production of thermal energy [16]. Moreover, olive leaves are used in herbal teas due to their antioxidant properties [16]. Olive stones may be used for the production of energy due to their high calorific value as well as for the production of activated carbon for the removal of dyes [17], heavy metals and other contaminants from water and wastewater [18-25].

Wastewater treatment methods for vegetable water produced during oil production have been reviewed elsewhere [3]. In general, aerobic and anaerobic treatment, including anaerobic co-digestion with other effluents and composting, are predominant while advanced oxidation processes have attracted much attention since they can result in a high degree of treatment and valorization [3, 26]. In specific, olive mill wastewater may be applied to soils as it is rich in nutrients, after being subjected to biological treatment for the reduction of its toxicity and phenolic content [27]. In addition, for the composting process to be achieved, olive mill wastewater must be firstly absorbed in a solid substrate [16]. Olive oil by-products may also be used as a nutrient source for the cultivation of edible fungi [28-30].

The bioconversion of olive mill wastewater and of other olive by-products for the production of biomolecules such as biopolymers, enzymes and phenolic compounds constitutes another valorisation alternative [27]. The production of polysaccharides from the microbiological treatment of olive mill wastewater, such as xanthan which can be used in the food industry as a food thickening agent and stabilizer, has been proposed [27]. Furthermore, pectins may be extracted from olive mill wastewater and olive pomace and subsequently used as gelling agents, stabilizers and emulsifiers in the food industry [16, 31-33]. Olive oil by-products may be used as a substrate for the production of enzymes which have applications in the dairy, pharmaceutical, detergent and other industries [34]. Last but not least, both olive mill wastewater and olive pomace contain substantial amounts of antioxidant phenols which present valuable antioxidant, anti-inflammatory and antimicrobial properties that can be recovered and used in the food and pharmaceutical industry [27, 16].

The valorisation of olive mill wastewater for dyeing textile materials such as wool and acrylic fibers has also been studied [35, 36] based on the fact that they constitute an abundant source of natural dyeing substances. Moreover, olive mill wastewater given its substantial sugar, volatile acid, polyalcohol and fat content may be used as a substrate for biohydrogen, biomethane and bioethanol production [27]. Finally, the use of olive mill wastewater and olive pomace in brick and fired clay masonry units production has been reported to have positive quality and economic results [37-40].

4. Conclusions

In conclusion, main products derived from the Greek olive oil production industries include olive oil, refined oils, olive-pomace oil and pomace wood. Other by-products with economic value include pomace which comprises the raw material for olive-pomace oil production, sediment material from oil storage tanks which is sold to soap manufacturing industries and olive leaves which are forwarded as animal feed. The extraction of olive oil is mainly implemented through three-phase or two-phase centrifuge. The method of extracting the oil determines to a great extent both the capacity and the qualitative and quantitative characteristics of the resulting oil, wastewater and solid waste. Concerning wastewater production, the 3-phase process leads to generation of three streams i.e. oil mixed with water, wastewater and pomace while 2-phase decanters produce only olive mixed with water and pomace. Therefore, 3-phase extraction results in higher volumes of wastewater. Vegetable water derived from 3-phase decanters is responsible for the high polluting load of wastewater. From the evaluation of data it was obvious that the prevailing waste treatment method that it is currently applied in Greece includes oil collection, neutralization of acidity, sedimentation and disposal to open evaporation ponds. This is a basic - level technique and thus alternative more advanced treatment options shall be applied resulting to better environmental protection along with other benefits e.g. bioenergy. In relation to solid waste management and valorisation, an excellent example of by-product valorisation is pomace processing for olive pomace oil and pomace wood production, since waste produced from one industrial unit constitutes raw-material for another. Moreover, sludge produced from evaporation ponds can be used as soil improver only after mixing and co-composting with other substrates. Apart from the above, alternative valorisation options such as production of antioxidants, biopolymers, enzymes and dyeing textile materials, which have recently received a great deal of attention in various publications, needs to be further developed so as to increase feasibility of the processes towards industrial use; thus adding more value to olive oil production process.

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