# FUNDAMENTALS AND TECHNO-ECONOMICAL ANALYSIS OF EXPLOITATION OF OLIVE MILL WASTEWATER TO HIGH-ADDED VALUE BY-PRODUCTS

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**ABSTRACT**

The olive oil industry is very important in many Mediterranean countries, both in terms of wealth and tradition. The extraction of olive oil generates huge quantities of high organic wastewaters with toxic constituents that may have a great impact on land and water environments. Series of laboratory experiments, based on the technology of membrane filtration (Ultrafiltration and Nanofiltration and/or Reverse Osmosis), have been carried out for the fractionation of olive mill wastewaters into fractions with nutritive value, phytotoxic action and pure water. Based on these results, a pilot plant of membranes installed in an olive oil mill enterprise for an entire harvesting period and appropriate experiments were performed. The study showed that a fraction of pure water up to 75% can recovered and fractions that contained concentrate nutritious and polyphenol content can be isolated and further exploited in order to reduce the, indeed, high cost of the suggested treatment process.

In this study, a techno-economic analysis for the implementation of the suggested method for the Region of Western Greece is presented. The present study took into account the fixed and the operational costs of the equipment, the costs for the infrastructure and land, the costs for the maintenance, etc., considering the treatment of 50,000 tones per harvesting period in the Region of Western Greece. The study showed that the establishment of one central treatment manufacture could reduce the uncontrolled disposal of OMW and their final discharging in the aqueous receptors. The exploitation of the nutritious content of the fractions as manure in fertilizers together with the polyphenol content that can be used as components of ecological herbicides can depreciate the total cost in a very short period of 1.5 years.

**KEYWORDS**

Olive mill wastewater; Ultrafiltration; Nanofiltration, Reverse osmosis; Membrane processes; Techno-economical analysis

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## 1 INTRODUCTION

Olive oil production has roughly increased worldwide in the last decades. Mediterranean countries produce 95% of the total world production of olive oil estimated to reach 2.4 million tons per year. The largest producers of olive oil are Spain, Italy, Greece, Portugal and Turkey. This makes olive oil extraction, an agro-industrial activity of vital economic significance to many Mediterranean countries.

Despite the vital economic significance to many Mediterranean countries, olive oil production is unfortunately associated with the generation of large quantities of wastewater (olive mill wastewater—OMW) [1] and solid wastes, whose management, treatment and safe disposal raise serious environmental concerns. The characteristic properties of OMW include its dark color, characteristic odor, acidic pH and high organic content mainly composed of classes of pollutants such as polyphenols that may exhibit antimicrobial, ecotoxic and phytotoxic properties [2, 3]. Due to the high organic load of OMW, it may contribute significantly to eutrophication of recipients in which fluid exchange rates are low (closed gulfs, estuaries, lakes etc) [4, 5, 6]. An additional adverse impact of OMW on the environment is the aesthetic degradation caused by its strong odour and dark coloration. Problems arise also from the fact that olive oil production is seasonal and so the treatment process should be flexible enough to operate in a non-continuous mode, otherwise storage of the wastewater will be required [7]. Moreover, the olive mills are small enterprises, mostly family businesses, scattered around the olive production areas, making individual on-site treatment options unaffordable. Therefore, it is not surprising that OMW treatment has received enormous attention over the past several years and various decontamination technologies based on biological, advanced oxidation, chemical and separation processes have been proposed by several research groups as summarized in a recent review article [8].

Coping with the environmental pollution problem, created by wastes from olive mills, presents large difficulties, mainly due to the high cost of the treatment of residual waters using the various systems proposed so far. In recent years, only in Italy more than 100 companies have proposed relevant systems, but none of them constitutes a practical and low-priced solution to the problem. Thus, the present situation is more or less the same as in the past: these wastes are led to large pits or discharged into the sea, lakes, rivers, etc., causing destructive environmental implications. As the fixed cost for installing such systems seems not decreasing, a profit from possible useful by-products could contribute significantly to the problem solution. The present work is oriented to this direction.

The management of OMW has been extensively investigated and some extensive and detailed reviews, which focus mainly on its management, have been recently published [8, 9]. Provided that the fixed cost for the installation of OMW treatment systems seems to be in-elastic, operational cost reduction may be attained through the exploitation of the waste by-products. The proposed separation techniques (prefiltration, ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO)) of the OMW treatment using membranes filtration have already presented in a previous work by the authors [10, 11].

The idea of using membrane technology is revisited in the present work in which a new cost-effective system for complete exploitation of OMW is suggested, offering a viable solution to the problem of OMW disposal. Use of the proposed separation techniques produces by-products that might have high additional benefits. A pilot plant was developed in an olive mill operating in Achaia region (Patras, Greece) during an olive harvesting season [10, 11]. A feasibility-exploitation study was performed to estimate if the depreciation of the expensive investment may be done in a short period.

## 2 EXPERIMENTAL

Ultrafiltration (UF), nanofiltration (NF) and/or reverse osmosis (RO) (*see Figure 1*) can be used for partial separation of OMW fractions. These methods were investigated in previous work [10, 11] through a systematic parametric study changing accordingly the operational parameters, such as temperature, pressure, ionic strength and initial pH of different source of OMW, size of membranes (pore diameter), etc., in order to lead to a higher separation of toxic fraction from the nutritious one. Different fractions were derived from the whole process: a nutritious fraction as pre- or after- UF concentrate containing the larger components of the solution in terms of molecule size, a toxic fraction as RO concentrate containing the main part of phenols (ecological herbicide), a plant nutritious fraction as RO permeate containing the inorganic salts (fertilizer), and almost pure water for recycling/or irrigation or for free disposal to aqueous acceptors (lakes, rivers or sea).
One thing that is of primary importance, it is that UF provides a "clean" solution appropriate to feed next treatment processes (NF and RO). UF alone cannot isolate individual fractions (in terms of only toxic or only nutrient solutions) but without UF we cannot proceed for further purification with the NF and/or RO. Physicochemical analysis of the collected compounds in pre-treatment procedure, ultrafiltration, nanofiltration and reverse osmosis is shown in the Table 1. The permeate stream from each unit is used as feed stream for the next membrane unit. Treatment can terminated after the implication of NF or RO1 since the permeate stream of NF (*see Table 1*) shows that the produced water can be safely used as irrigation water or to be disposed safely to aqueous receptors.

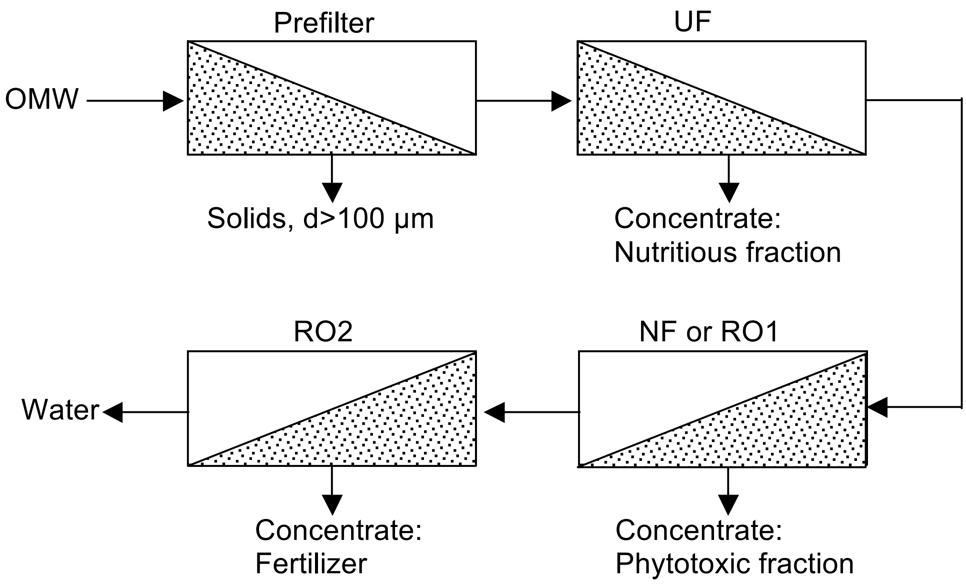


*Figure 1. Separation structure of the flowsheet using ultrafiltration (UF), nanofiltration (NF) and/or reverse osmosis (RO) techniques.*

| *Parameter* | *Raw* | *Perm prefilter* | *Ultrafiltration* | *Nanofiltration* | *Reverse Osmosis 2* |
|---|---|---|---|---|---|

| | | | *Conc* | *Perm= feed NF* | *Conc* | *Perm= feed RO2* | *Conc* | *Perm* |
|---|---|---|---|---|---|---|---|---|
| *Salinity, %* | 0.66 | 0.66 | 0.67 | 0.59 | 1.11 | 0.01 | 0.02 | 0.0 |
| *TSS, g/l* | 21.5 | 18.56 | 46.98 | 2.36 | 5.32 | 0 | 0.0 | 0.0 |
| *t-COD, g/l* | 97.32 | 92.9 | 127.19 | 94.88 | 156.44 | 1 | 9.1 | 0.2 |
| *d-COD, g/l* | 85.68 | 72.24 | 61.92 | 77.64 | 131.32 | 1 | 7.56 | 0.16 |
| *Carbohydrates, g/l* | 28.75 | 20.51 | 18.8 | 24.1 | 51.827 | 0.310 | 3.2 | 0.1 |
| *Phenolics, g/l* | 5.91 | 5.08 | 4.16 | 5.04 | 10.6 | 0.1 | 0..9 | 0.01 |

*Table 1. Physicochemical characterization of fractions of the various treatment stages.*

## 3 TECHNO-ECONOMICAL ANALYSIS

### 3.1 Proposed technical solution

Having the appropriate methods that should be followed for the efficient separation of the "nutritious" from the "toxic" fraction, an optimum, technical and economical, design of the process at industrial level was carried out. The target is a technical acceptable solution at the possible lowest fixed and operational cost. This goal was succeeded by applying a conceptual design to find the best process and estimate the optimum design conditions. After definition of the operational parameters, the process flowchart was constructed via a hierarchy of design decisions, namely structure of input-output, recycling, separation and thermal integration [10].

### 3.2 Preliminary design

The techno-economical study for the establishment of OMW treatment plant was done for the Region of Western Greece. The number of all olive mills for three regions (prefectures of Achaia, Ilia, Aitoloakarnania) was recorded. There were three alternative scenarios: a) the establishment of a central operation plant (ex. one per region or a greater area), where OMW will be carried by trucks. Profit will be made by the production of high valued by-products. b) The establishment of more than one lower potential operation plants (one per olive mill). In this case the transport expenses are diminished. c) Mobile OMW treatment unit.

The third case was rejected as olive mills work seasonally in the same period and this constitutes several technical complications. Therefore, the study was concentrated on the other two solutions. Taking into account the location, the distance and the number of olive mills per region, the cost and the time of transportation, the establishment of a central OMW treatment plant per region, judged to be more appropriate from both technical and economical point of view.

The most serious problems that could be faced are: a) the authorities permission for disposal and sale of by-products from the above OMW treatment that may be used as ecological herbicides and fertilizers for agriculture and b) the possible denial of olive mills owners to bear the cost of their OMW storage, despite the fact that they are obliged to perform a kind of treatment.

Four actions took place: a) mapping of the olive mills that are active in Achaia and Ilia regions as first indicative areas. Preliminary study of the cost and transferring time of OMW in a central place per region (e.g. Patras Industrial Area). b) Examination of the legal framework that concerns the approval and sale of ecological herbicides and fertilizers for agriculture in Greek and European market. c) Examination of the market demand for ecological herbicides and fertilizers for agriculture in the trade union and end users. d) Examination the use of OMW components for the production of biodiesel, bio-plastic or other alternative products of high value.

### 3.3 Case study: Region of Western Greece

Region of Western Greece is the suggested area for the establishment of OMW pilot plant. It is an area with a tradition in olive oil production. Furthermore, Achaia is adjoining to several olive oil production areas. There are 50 active olive mills in Achaia and surroundings. Taking into account the distances among olive mills, the transportation costs (fuel and service expenses) are estimated to 0.25 €/km. All the olive mills are gathered close to Patras Industrial Area. There are available areas and the necessary infrastructures for the establishment of an OMW treatment unit. Investments incentives and tax reductions have been given to the Patras Industrial Area for the industrial development in Achaia, which increases depreciation of the investment. Therefore, the establishment of a central plant in the Industrial Area of Patras it is suggested in the present work.

The OMW treatment unit is designed to operate continuously 24h/day, 7 days/week, 7 months/yr (period during oil production from October till April), 210 days/yr. The unit would have a capacity over 50,000 t/yr and will serve a number of about 50 olive mills of the surrounded area (an average production of 1000 t/yr OMW per olive mill will give an average capacity of the unit which arises up to 50,000 t/yr).

The techno-economical study for the establishment of an OMW treatment unit has the following approximate characteristics:

| | |
|---|---|
| Feed to the system | : OMW |
| Feed flowrate | : 10,000 l/h (50,000 t/yr) |
| Permeate flowrate | : 8,000 l/h |
| Working temperature | : 20 - 30 °C |
| Working pressure | : UF: 4 bar, RO: 70 bar max |
| COD removal | : 99.5% |
| Grease substances removal | : 99.99% |
| Dry matter removal | : 99.5% |

UF system: Feed pump, Protective Cartridge Filter, Loop pump, Ceramic elements, Structure, valves and piping, electrical part
RO system: Feed pump, Protective Cartridge Filter, High pressure pump, Filtering elements, Structure, valves and piping, electrical part

Utilities:

| | |
|---|---|
| Air | : 5/6 bar |
| Water for membrane cleaning | : demineralized/soft or osmotized |
| Power supply | : 380 V, 50 Hz, three phases |

Fixed cost:

UF and RO systems, installed on site, feed tanks, any storage or peripheral tanks, pre-filter system, pumps and piping, hydraulic, electrical and pneumatic connections, auxiliary equipment, computers, vehicles, lab and office equipment, security equipment

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Total purchase and installation cost, $C_1$: 1,345,000 €.
*Estimated equipment lifetime: 10 years.*

Buildings cost:
Offices, laboratories, storehouse and auxiliary equipment, land, etc.

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Total building cost: 345,000 €

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Total fixed cost, *C*: 1,690,000 €

Initial capital cost, *IC*: 304,000 €

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Establishment cost (fixed cost + Initial capital cost): 1,994,000 €

Biodynamic experiments, $C_2$: 1,000,000 €

Operational cost:

| | |
|---|---|
| Raw materials and auxiliary materials: | 30,200 €/yr |
| Power: | 149,700 €/yr |
| Manpower: | 329,000 €/yr |
| Maintenance: | 67,300 €/hr |
| Administrative expenses: | 274,000 €/yr |
| Depreciations: | 144,300 €/yr |

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Total operational cost (taxes exclude), *OC΄*: 1,008,000 €/yr

3.4 Economical potential – Assessment of the investment
Production of an amount of 50,000 t/yr OMW treatment gives [10-11]:
5% nutritious fraction: 2,500 t/yr
15% toxic fraction: 7,500 t/yr
Pure water for recycling or irrigation: 40,000 t/yr

The value of the "nutritious fraction", taking into account its concentration in nutritious components (either as fertilizer or as animal feed integrator) is estimated that has an order of magnitude of 100 €/t UF concentrate, that gives 250,000 €/yr. The value of the "toxic fraction" as herbicide is estimated as much higher, due to the higher value of phytotoxic constituents (herbicides) in the market. Taking into account the concentration of the RO concentrate, a modest value of 500 €/t RO concentrate is estimated, that gives about 3,750,000 €/yr.

Taking into account that taxes are 40%, a net profit, which is the first criterion of the investment, is estimated:

Incomes (toxic & nutritious fraction), *R*: 4,000,000 €/yr

Taxes, [$T$=0.4($R$-$OC'$)]: 1,200,000 €/yr
Profit after taxes and depreciation, ($K$=$R$-$OC'$-$T$): 1,792,000 €/yr

From the above analysis, the rate of return on investment, $i_r$, is estimated:

$$i_r=K/(C+IC) \quad (1)$$

where $K$: the annual net profit, $C$: total fixed cost, and $IC$: the initial capital cost. Between two or more alternative investments the one with the highest $i_r$ will be chosen. When an investment is exanimate separately, the $i_r$ of the investment should be higher than a minimum acceptable rate of return that has been determined by the company (possibly the bank interest). This method does not take into account the time value of money. Thus, $i_r$ = 1,792,000/(2,345,000+304,000)=68%.

The time needed to rebound the establishment capital cost from incomes during the operation period of the OMW treatment unit, i.e., the mean payout period, $\tau$, *is estimated as follows*:

$$\tau = (C+IC)/ K \quad (2)$$

The total cost of the investment can be replaced by the fixed cost and to the net profit the depreciation can be added. Between two or more alternative investments the one with the lowest$\tau$ will be chosen. In Western Greece Region case, the mean payout period for the investment is estimated to $\tau$ = 1.5 years.

**4 CONCLUSIONS**

The management of produced OMW constitutes a long-term and particularly unsolved problem, because of their high organic load, their particular physicochemical composition, the potentially toxic attributes, the intense of short time interval of production and the high cost investment requirements. The present work presents a techno-economic analysis of the OMW treatment using membranes filtration. The idea of using membrane technology is presented by authors [11] in a previous work in which a new cost-effective system for complete exploitation of OMW is suggested, offering a viable solution to the problem of OMW disposal. A pilot plant was designed, constructed and installed in a typical olive mill, where OMW quantities were treated at larger volumes. The efficiency of the proposed method for separation and exploitation of the OMW useful constituents was demonstrated.
In the present work, a feasibility study of the proposed method at a regional level was performed, indicating very positive financial results for a future exploitation. The successful integration of this work establishes the basis for a complete and profitable solution of one of the most important Mediterranean environmental problems, providing as main achievements:
a) The development of a new cost-effective system for complete exploitation of OMW, which offers a viable solution to the problem of OMW disposal. The introduction of the proposed new integrated technology reduces dramatically the environmental damage and provides a profitable alternative to the olive mills due to utilization of all by-products.
b) The development and production of alternative ecological herbicides and other useful by-products. It is expected that these new products will be highly accepted from the farmers and will enhance the agriculture sustainability.
The rate of return on the investment is extremely high, much higher than the current bank interest, which makes the investment vital. Moreover, the mean payout period can be considered as satisfactory, taking into account that the whole equipment of the investment is

new, and the total cost of the investment has been considered, thus in the net profit the depreciations have been added. This is a very encouraging result, taking into account that a rather low value for the toxic fraction was also considered. The above result is characterized as positive and indicates to undertake the investment.

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