Final Report

The Application of Reedbed Treatment Technology to the Treatment of Effluents from Olive Oil Mills

Country/Project Number Tunisia 066599003ZH010

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1. Introduction

This three year project has centred upon the application of reed bed treatment systems to the treatment of olive oil mill effluent (OME). OME is a highly polluting wastewater generated during the extraction of oil from the fruit. Olives have been cultivated in the countries surrounding the Mediterranean Sea for thousands of years, and the wastewaters produced during oil extraction generate a significant amount of organic pollution. Tunisia is the fourth largest producer of oil after Spain, Italy and Greece. Olive oil can be extracted either simply by pressure or by centrifugation, using either a 2-phase or 3-phase system. In all cases, the olives are firstly washed, and then crushed and ground. The 3-phase extraction method was developed in the '70's in order to reduce labour costs and increase processing capacity and yield Whilst classical methods can process around 8-10 tonnes of olives per day, 3-phase continuous systems can process 30-32 tonnes per day with a fraction of the labour requirement. Unfortunately, this technology also uses around 50% more water than the simple pressing method (around 80-100 lts. of water per 100 kg. of fruit processed) and generates around 50% more wastewater per unit mass of fruit processed (~1.7 kg wastewater per kg. olives processed compared to 0.9 in the classical method). As a consequence, more recently, the 2-phase process (which uses much less water than the 3-phase) was developed. This also has inherent environmental problems associated with it, in that although it produces no wastewater (margine) as such, it combines that wastewater that *is* generated with the solid waste (grignon) to produce a single effluent stream of semi-solid (~30% solid by mass). This doubles the amount of 'solid' waste requiring disposal, and it is not able to be composted or burned without some form of (expensive) pretreatment. It is also unsuitable for solvent extraction to produce more oil for soap manufacture.

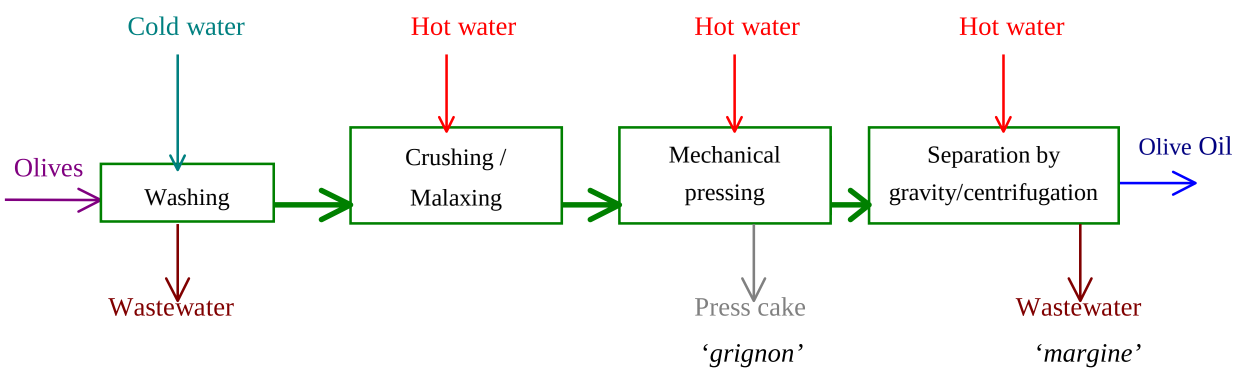

Fig. 1 The Pressure 'Classical' Extraction of Olive Oil

Press-extraction (Fig. 1) is a mechanical process, involving the application of pressure to a stack of mats smeared with olive paste which are alternated with metal discs and placed on a frame that is fitted with a central spike. In oil mills which use the single pressing method or the super-presses, the oil yield depends upon the pressure that is applied to extract the oil. In the continuous (centrifugation) processes (Figs. 2 and 3 below), the olive paste has to be diluted with warm water before separation. In

Tunisia, the classical method of oil extraction accounts for around 40 % of oil production, super-pressing systems around 22%, mixed mills 8% and continuous presses 30%.

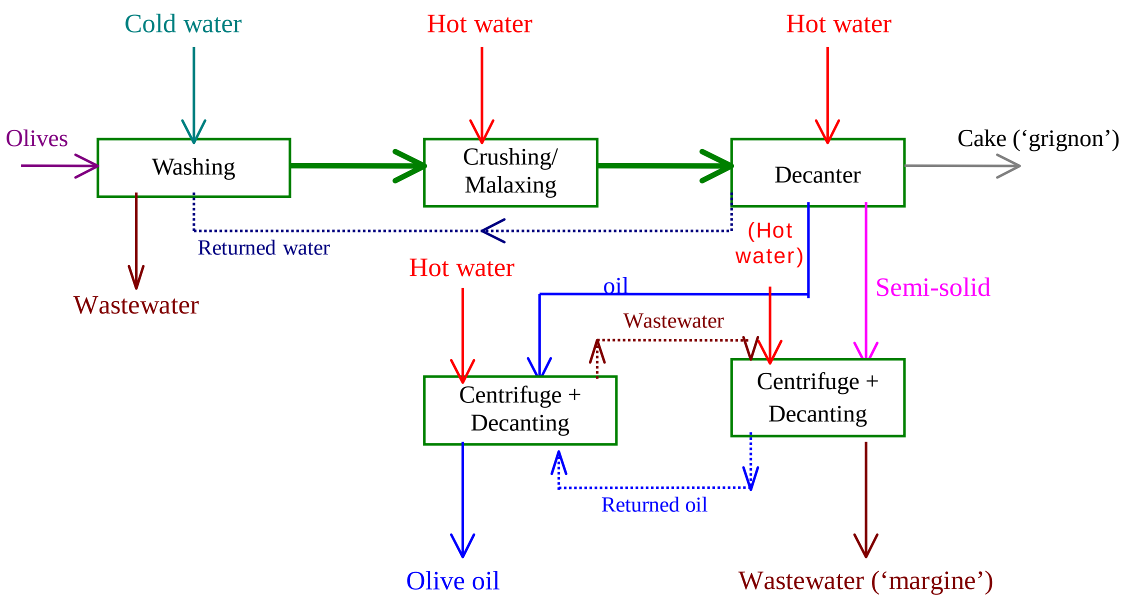

Fig. 2 The 3-Phase Centrifugal Extraction of Olive Oil

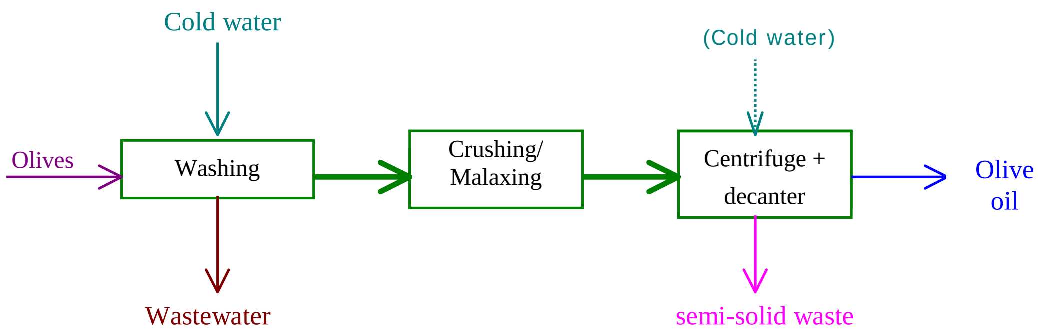

Fig. 3 The 2-Phase Centrifugal Extraction of Olive Oil

The total amount of wastewater generated by the production of olive oil in the olive growing countries of the Mediterranean is in excess of 30 x 10^6 m^3 per year. This olive oil mill effluent (OME) is extremely polluting with a very high chemical oxygen demand (COD) concentration (up to 200g l^{-1}),

Figure 1. Received olives awaiting crushing

Figure 2. Crushing

Figure 3. 'Classical' pressing of olives

Figure 4. Separation of oil

Figure 5. 3-Phase extraction of olive oil

and constitutes a major source of organic pollution in the Mediterranean region, posing a threat to both surface and groundwater quality, and creating a smell nuisance. A typical analysis of the organic fraction of Tunisian OME is given in Table 1.

OME is produced during those months of the year when the olives are pressed (usually November to March). In Tunisia, OME is referred to as 'margine', and the solid waste resulting from the oil extraction process is called 'grignon'.

OME has a complex composition and contains a large number of organic compounds - many of which are toxic and difficult to fully degrade in microbiological systems. This is particularly true for the long-chain fatty acids (such as octa- and hexadecanoic acid) and the polyphenolic compounds that are present. The exact composition of the mill wastewater emulsion depends upon the type of oil extraction process used. Oil extraction by the classical method generally produces a more polluting effluent than that generated by the continuous method.

Figure 6. Grignon formed during olive oil production

pH	4.5 - 6.0
Water Content	83 - 92
Organic and Volatile Material	7 - 15
Mineral Solids	1 - 2
Residual Oil	0.3 - 10.0
Total Sugars	2 - 8
Reducing Sugars	1 - 8
Polyalcohols	1.0 - 1.5
Protein	0.5 - 7.5
Pectins and Tannins	1.0 - 1.5
Phenols	17
Suspended Solids	5 - 35 g/l
BOD_5	65 - 70 g/l
COD	40 - 200 g/l

Table 1. Typical Composition of the Organic Fraction of Tunisian Margine (OME)

(% unless otherwise stated)

The exact composition of the mill wastewater emulsion depends upon the type of oil extraction process used. As already noted, the classical method for removing oil is still used extensively throughout Tunisia, and this procedure can produce a more polluting effluent than that generated by the continuous method, although it may be a smaller overall volume. Processing 100 kg of olives by the continuous method leads to the production of about 20 litres of oil and between 70 and 150 litres of wastewater for treatment/disposal. A comparison of the characteristics of the different margines produced by each of the principal oil extraction methods is given in Table 2.

Parameter	**Pressure extraction**	**3 -phase centrifugation extraction**
pH	4.7 - 5.7	4.5 - 5.9
Dry matter (g/l)	15 - 266	10 - 161
COD (g/l)	42 - 389	15 - 199
BOD_5 (g/l)	90-100	30-50
Suspended solids (g/l)	1-2	6-9
Oil (g/l)	0.2 - 11.5	0.4 - 29.8
Reducing sugars (g/l)	9.7 - 67.1	1.6 - 34.7
Total polyphenols (g/l)	1.4 - 14.3	0.4 - 7.1
o-Diphenols (g/l)	0.9 - 13.3	0.3 - 6.0
Hydroxytyrosol (mg/l)	71 - 937	43 - 426
Ash (g/l)	4.0 - 42.6	0.4 - 12.5
Organic nitrogen (g/l)	0.15 - 1.10	0.14 - 0.97
Total phosphorus (mg/l)	157 - 915	42 - 495
Sodium (mg/l)	38 - 285	18 - 124
Potassium (mg/l)	1500 - 5000	630 - 2500
Calcium (mg/l)	58 - 408	47 - 200
Magnesium (mg/l)	90 - 336	60 - 180
Iron (mg/l)	16.4 - 86.4	8.8 - 31.5
Copper (mg/l)	1.1 - 4.7	1.1 - 3.4
Zinc (mg/l)	1.6 - 6.5	1.4 - 4.5
Manganese (mg/l)	2.2 - 8.9	0.9 - 5.2
Nickel (mg/l)	0.5 - 1.6	0.3 - 1.5
Cobalt (mg/l)	0.2 - 0.9	0.1 - 0.5
Lead (mg/l)	0.4 - 1.8	0.4 - 0.7

Table 2. Typical composition of Tunisian margine (OME) according to oil extracting system used.

(Units as specified)

Satisfactory containment or treatment of strong wastewaters (such as OME) is important in order to minimise the impact of these point sources of pollution, and also to help protect groundwater and surfacewater quality. Treatment of industrial wastewaters can be carried out physically, chemically or biologically. Industrial effluents are often dealt with by a combination of chemical and physical actions, although particularly strong effluents (such as OME) may be amenable to biological treatment. Conventionally, anaerobic digestion is the preferred treatment process for OME, since aerobic processes tend to be inhibited by the presence of certain organic compounds such as caffeic acid, tyrosol, hydroxyltyrosol and *p*-coumaric acid which are known to be present in OME. More recently, combinations of anaerobic and aerobic processes have been employed for treatment of OME.

In Tunisia, a common way of dealing with the margine that is produced during the pressing season is to convey it from the mills to a central point and discharge it into a purpose built lagoon. Here, the volume reduces by evaporation, and providing that the lagoon base has been sealed (thereby preventing possible groundwater contamination), this can be a perfectly reasonable way of containing the problem. Recently, in the Sfax area of Tunisia, a new facility has been built to receive margine. Four lagoons have been constructed with a combined surface area of 50 ha. and a total storage capacity of 40,000 m^3. A charge of around 7 Tunisian Dinar per tonne of margine is levied for reception at these lagoons. Figures suggest an estimated annual margine production figure of 60,000 m^3 and 350,000 m^3 over the last two years respectively.

Figure 7. Collection of 'margine' by tanker

Figure 8. Margine lagoons outside Sfax

2. Background to Reed Bed Treatment Technology

Artificial wetlands have been used for many years as a cheap and effective way of treating (or pre-treating) wastewaters. The original technology was developed in Germany during the 1970's and has now been applied in areas such as Europe, Scandinavia, South Africa, Australia, USA and Egypt. Often known as reed bed treatment systems (RBTS) or gravel bed hydroponics (GBH), the basis of this simple technology lies in treating wastewater by passing it through an artificially constructed wetland containing (usually) common reeds (*Phragmites australis)* planted in gravel. The flow through the bed is usually in a horizontal direction. The reeds act as both assimilators and reservoirs for contaminants in the wastewater, they transport oxygen into the root zone of the plant and they act as a substrate for microbial activity. Other macrophyte such as cattail (*Typha latifolia*) and bulrush (*Scirpus lacustris*) have also been used. In the U.K. at least one major water company uses reed beds for solids capture on some of their storm water discharges, and tertiary treatment of effluents from some sewage works serving small communities.

Over time, the rhizomes tend to increase the hydraulic conductivity of the growing medium which promotes flow within the bed. The polluting matter in the wastewater is degraded by biological activity within the rhizosphere - both aerobically (with oxygen provided through the leaves and stems of the macrophytes in the vicinity of the rhizomes), and anaerobically elsewhere in the bed. A degree of physical capture of suspended solids also occurs within the growing/support medium. The cited advantages of this type of treatment system include a low initial capital (and subsequent maintenance) cost together with simplicity of construction. They also provide a robust treatment system which is able to accommodate a degree of fluctuation in flow and pollution load. Overall, the process is environmentally acceptable - helping to provide habitats for a variety of flora and fauna. These advantages need to be reconciled with possible problems of public acceptance (although publicity for this type of treatment is almost invariably positive) and the need for a reasonably large land area.

Although there is a good deal of published literature relating to application of reedbed technology to domestic wastewaters, less is available covering its application in treatment of industrial wastewaters. Often this is because the nutrient balance within the wastewater is outside acceptable limits or too high a concentration of biological inhibitor(s) is/are present. Constructed wetlands have been reported as having been used to effectively treat wastewaters from food processing industries, from woollen mills, and from explosives factories.

One group of biological inhibitors that are present in OME at relatively high concentrations are polyphenols. It has long been recognised that phenol-bearing wastes can be successfully treated by wetland treatment systems. More recently, wastewaters containing phenol and *m*-cresol at concentrations of around 100 mg l^{-1} have been effectively treated within a 24 hour period with 60-93% removal and 70-90% removal after 24 hours. Aqueous concentrations of phenol in the range 25-100 mg l^{-1} have been successfully treated by water hyacinth, and trace concentrations of phenanthrene (0.385 mg l^{-1}) have been effectively treated using *Typha* and *Scirpus*. More recently, it has been reported that chlorophenolic wastewaters from a large U.K. chemical manufacturing facility have been successfully treated (>95% removal) in a constructed wetland.

In order to better understand the applicability of reedbed treatment systems to the treatment of OME - either alone or (more probably) as a downstream process in combination with other aerobic/anaerobic processes - a pilot scale reedbed was constructed to investigate removal efficiency of organic pollution and colour from margine. Since the classical production method continues to be prevalent in Tunisia, and since this tends to produce the most polluting margine, this process effluent was chosen for the study - both as the basis of the diluted feed to the large bed and also the raw material for the physiochemical treatment procedures prior to generating the feedstock for the small bed.

3. Outline Technical Aspects of the Project

3.1 Construction of Reedbeds

3.1.1 Large Bed

A reed bed was constructed from sheet steel with overall dimensions of 9m x 1.5mx 0.60m depth of support medium for the reed plants (see schematic diagram in Appendix A). 0.5m wide feed and outlet troughs at either end of the bed reduced its effective length to 8m. Due to the unavailability of siliceous pea gravel, crushed dolomite (2-4 cm) was used as the support medium for the reeds. Mature reed plants (*Phragmites australis)* were harvested locally from sites around Sfax and planted during the period February - May 1997 at a density of $4m^{-2}$ in the constructed wetland. A $1m^{3}$ feed tank has been used to deliver the influent, and a variable position outlet pipe was installed in order to maintain a water depth of 0.55m (although this could be altered if necessary by changing its position).

The sizing of this bed was such that the total internal volume of growing medium was designed to be 8.0m long x 1.5m wide x 1.6m deep. This produces an internal volume of 6.6 m^{3}. If the projected 250 lts of liquid were then fed to the bed each day, assuming a 50% voidage in the growing medium and ignoring evaporation losses, this would give an hydraulic retention time in the bed of 13 - 14 days. In fact, it is likely that there will be less than 50% voidage in the growing medium when the reeds become established, and there will also be some losses through transpiration/evaporation. The full breakdown of projected retention times are as follows:

A feed of 200 lts per day equates to a retention time of approximately 18 days
A feed of 250 lts per day equates to a retention time of approximately 14 days
A feed of 300 lts per day equates to a retention time of approximately 12 days
A feed of 400 lts per day equates to a retention time of approximately 9 days
A feed of 500 lts per day equates to a retention time of approximately 7 days

Town water was used to make up a dilute general fertiliser solution (1kg m^{-3}) and this was fed to the bed during the initial stage of the project at a rate of 250l d^{-1}. In view of the very high COD of margine, and also the presence of biological inhibitors, classically produced margine diluted with town water (4l m^{-3}) was applied to the bed in the first instance - at a volumetric loading of 250 l d^{-1}.

3.1.2 Small Bed

In addition, a second small-scale RBTS was constructed ($1m^{2}$ x 0.6m deep), filled with crushed brick as the inert support medium, and planted with clumps of reeds (similar to those in the large bed) on 6^{th}

Jan. 1998, in order to investigate the possibility of applying RBTS technology to the effluent from either anaerobically digested or physiochemically treated margine. The support medium used for this bed was crushed brick.

3.2 Feeding Regime

3.2.1 Large Reedbed

In order to establish the reeds, prior to dosing them with margine, it was necessary to apply a feed to the beds that would enable the reeds to establish themselves. In the first instance, a daily feed of 250 lts. of a solution of general fertiliser was used for this purpose. After a suitable period, a proportion of margine was then added to the fertiliser solution, and the plan was to gradually increase the proportion of margine in the feed on order to allow the reeds to acclimatise to the presence of OME. It was necessary to reach a compromise in respect of providing a sufficiently large daily feed in order to achieve a bed effluent, whilst not adding too great a volume of margine (which would put too great an organic load onto the bed and overload it.) In practice, the following regime was adopted:

Date	**Feed**
21/2/97 - 8/3/97	fertiliser solution only
9/3/97 - 12/3/97	trial dosing of 2 lts margine d^{-1} plus 98 lts d^{-1} of water
13/3/97 - 26/3/97	fertiliser solution only
27/3/97 - 5/4/97	trial dosing of 4 lts margine d^{-1} plus 96 lts d^{-1} of water
6/4/97 - 27/4/97	fertiliser solution only

During the period May 1998 to April 1999 the large bed was allowed to establish itself through a feeding regime of fertiliser solution plus an added carbon source - as well as occasional feeding with treated municipal wastewater from the local ONAS-operated sewage treatment works in Sfax.

Effective monitoring was resumed in mid-March 1998 coupled with the following feeding regime:

Date	**Feed**
16/5/98 - 22/6/88	fertiliser solution plus carbon source only
25/6/98 - 13/7/98	2 lts margine d^{-1} plus 198 lts. d^{-1} ONAS purified wastewater- *total feed 200 lts d^{-1} with a margine concentration of 1.0%*
16/7/98 - 30/7/98	3 lts margine d^{-1} plus 297 lts. d^{-1} ONAS purified wastewater- *total feed 300 lts d^{-1} with a margine concentration of 1.0%*
3/8/98 - 6/8/98	4 lts margine d^{-1} plus 296 lts. d^{-1} ONAS purified wastewater- *total feed 3001 lts d^{-1} with a margine concentration of 1.3%*
10/8/98 - 31/8/98	4 lts margine d^{-1} plus 246 lts. d^{-1} mains water plus 50 lts. d^{-1} ONAS purified wastewater - *total feed 300 lts d^{-1} with a margine concentration of 1.3%*

2/9/98 - 20/10/98	5 lts margine d^{-1} plus 245 lts. d^{-1} mains water plus 50 lts. d^{-1} ONAS purified wastewater - *total feed 300 lts d^{-1} with a margine concentration of 1.7%*

3.2.2 Small Reedbed

This bed was constructed with the intention of investigating treatment of effluents generated from the laboratory scale physiochemical treatment equipment being operated by ENIS:LARSEN as part of a separate project with JICA.

Date	**Feed**
16/5/98 - 18/5/98	0.5 lts of pretreated margine d^{-1} plus 19.5 lts. d^{-1} ONAS purified wastewater - *total feed 20 lts d^{-1} with a pretreated margine concentration of 2.5%*
21/5/98 - 27/6/98	1.0 lts of pretreated margine d^{-1} plus 19 lts. d^{-1} ONAS purified wastewater- *total feed 20 lts d^{-1} with a pretreated margine concentration of 5.0%*
27/6/98 - 13/7/98	2.0 lts of pretreated margine d^{-1} plus 18 lts. d^{-1} ONAS purified wastewater- *total feed 20 lts d^{-1} with a pretreated margine concentration of 10.0%*
16/7/98 - 30/7/98	2.5 lts of pretreated margine d^{-1} plus 17.5 lts. d^{-1} ONAS purified wastewater- *total feed 20 lts d^{-1} with a pretreated margine concentration of 12.5%*
3/8/98 - 31/8/98	3.0 lts of pretreated margine d^{-1} plus 17 lts. d^{-1} ONAS purified wastewater- *total feed 20 lts d^{-1} with a pretreated margine concentration of 15.0%*
2/9/98 - 20/10/98	4.0 lts of pretreated margine d^{-1} plus 16 lts. d^{-1} ONAS purified wastewater- *total feed 20 lts d^{-1} with a pretreated margine concentration of 20.0%*

3.3 Establishment of Reeds

3.3.1 Large Reedbed

Figure 9. Construction of large reedbed

Figure 10. Large reedbed in place

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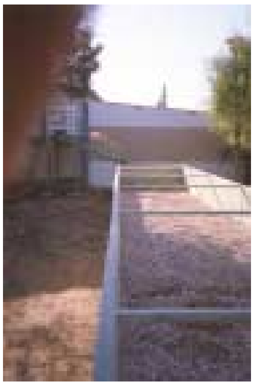

Figure 11. Inert support medium in large bed

Figure 12. Small reedbed showing crushed brick support medium

Figure 13. Reed growth March 1998

Figure 14. Reed growth July 1998

Figure 15. Reed growth December 1998

4. Summary of Technical Results

4.1 General

Charts showing the salient analytical parameters for both of the reedbeds are given in Appendix A. These results need to looked at in conjunction with the respective feeding regimes given in the proceeding section.

The theoretical COD of the bed effluents was calculated using the following formula:

$$A = \frac{Q_d \,(\ln Co - \ln C_t)}{k}$$

where
- A = Surface area of the bed (m^3)
- Q_d = Flow rate through bed ($m^3\ d^{-1}$)
- Co = Inlet COD ($mg\ l^{-1}$)
- C_t = Outlet COD ($mg\ l^{-1}$)
- k = constant (nominal value of 0.1 for a system of this type)

An examination of the data yields the following general conclusions:

4.2 Large Bed

- Once feeding with margine commenced, BOD, COD and suspended solids removal rates were almost identical, and steadily reduced before levelling out at around 40% at the maximum practical level of margine addition of 1.7% margine.
- A comparison of actual outlet COD with theoretical (ignoring retention time within the system) shows that there is a significantly lower removal of COD than would be expected were the bed treating only municipal wastewater. From an environmental point of view, outlet COD concentrations of >1500 mg/l are unacceptable (although one might argue that a ‘sacrificial’ reedbed removing almost half of the residual COD is worthwhile), and arise as a consequence of removal of <40% of the COD present in the feed. These figures demonstrate the intractable nature of the organic pollution constituents of margine, and the relative non-biodegradability of many components within the margine.
- During the period when the reeds were establishing themselves, there is a gradual reduction in the efficiency of both phosphorus and potassium removal within the system.
- Removal of bacteria reduced dramatically once the feed was raised from 1.0% to 1.3% (accounting for retention time within the bed) but then made a substantial recovery during the following 20 days.

4.3 Small Bed

- COD, BOD and suspended solids removal for this bed show a similar pattern (proportionately) as that for the large bed - although the solids removal is marginally better. Again, residual COD concentrations of >800 mg/l constitute an unsatisfactory discharge from an environmental point of view. The poor COD removal efficiency again reinforces the low treatability even of the pretreated margine.
- Generally speaking, bacteria removal within the small reedbed system is similar to that in the large bed (~ 2 log).

4.4 Sequencing Batch Reactor

- In order to investigate the application of aerobic biological treatment on margine, a series of experiments were carried out on a diluted margine solution to measure COD removal using sequencing batch reactor (SBR) technology. Increasingly concentrated solutions of margine were added to the lab-scale SBR system – the results are charted in Appendix A
- The SBR was able to maintain treatment capability despite increasing inlet feed concentration up to a COD >2500 mg l^{-1}. This indicates that SBR technology could well have application as an end-stage treatment option for margine – perhaps following an anaerobic or physiochemical treatment step.

5. Project Timetable

Total Budget for Project £22180

5.1 Financial 1996 - 1997

2 x S/U representatives visited Sfax for facilitation of design and development of pilot reed-bed, review of construction and reed placement, development of feeding/sampling regime and chemical monitoring parameters. *August 1996*

2 x S/U representatives visited Sfax to progress and realign project. *February 1997*

2 x Tunisian representatives visited Staffordshire University to view operational reed-beds in UK and further develop analytical protocols. *March 1997.*

5.2 Financial 1997 - 1998

2 x S/U representatives visited Sfax to progress/refocus project. *May 1997.*

2 x S/U representatives visited Sfax to facilitate implementation of quality control framework. *December 1997*

2 x S/U representatives visited Sfax to decide whether project should continue to run through to final year or cease at the end of the second year. *March 1998*

2 x Tunisian representatives visited Staffordshire University to spend time working in analytical laboratories developing quality control mechanisms for analysis being carried out by ENIS:LARSEN. *April/May 1998.*

5.3 Financial Year 1998 - 1999

2 x S/U representatives visited Sfax to monitor progress against agreed targets (set in March), and refocus project. *July 1998*

2 x S/U representatives to visited Sfax to review project and participate in the Olive Oil Wastes Symposium organised at ENIS:LARSEN. *January 1999.*

A visit by Staffordshire University colleagues to Sfax, planned for September 1998 was cancelled, as it was not deemed to be necessary for the continued smooth running of the project. A final visit by Tunisian colleagues to Staffordshire University, planned for Spring 1999, was also cancelled (following discussions with British Council), since no further analytical data had been generated since *the January meeting, and the outline framework of the paper emanating from the project had already been agreed and drafted.*

Meeting notes and interim reports on key visits/meetings are included in Appendix B

All visits by Staffordshire University representatives were nominally of 5-6 days duration (including travel), visits by Tunisian representatives were nominally of 10-14 days duration (including travel). ENIS generously paid for Tunisian accommodation for Staffordshire University representatives during their stays in Tunisia, and organised a number of technical visits as well as carrying out all of the support analysis for both reed beds.

6. Summary of Outcomes of Project

The project has proved an excellent vehicle for S/U colleagues to acquaint themselves with key researchers at ENIS, enabling them to meet a number of key Tunisian researchers and industrialists in various fields allied to the area of the project.

Key deliverables for the project include:

- Design and construction of a large and a small reedbed together with associates feeding equipment
- Investigation of the effects of feeding the large reedbed with diluted margine
- Investigation of the effects of feeding the small bed with physiochemically pretreated margine.
- A substantial amount of analytical data resulting from monitoring the performance of both reedbeds
- Drafting of a research paper (jointly authored by the Tunisian/UK Project Coordinators) for submission to and publication in a professional journal
- Construction of a laboratory-scale physiochemical treatment apparatus for use by ENIS
- A limited investigation into the possibility of using sequencing batch reactor technology for treating margine.

Generally, the planning and construction of both beds progressed well, but the reeds in the larger bed took rather longer to establish than hoped. This was identified (by Tunisian colleagues) as being a consequence of lack of carbon in the feed, and when this was rectified, the reeds began to look far more healthy. It is a shame that dolomite (rather than pea gravel) had to be used as a fill for the larger bed, and crushed brick for the small bed, but we had to use those materials that were readily available

As can be seen from the visit reports in Appendix B, a number of our planned feeding regimes had to be modified to accommodate both the sporadic availability of treated municipal wastewater that could be delivered to ENIS, and the practical quantities that could be handled on-site.

In addition to the original margine project, the link has enabled other joint work on the inclusion of margine in brickmaking processes to be progressed, and the short-term secondment of a Masters student from ENIS to S/U for technical training

Technically, the project has confirmed the phytotoxicity of margine and indicated that although reedbed treatment systems could have a part to play in the overall treatment of OME, a substantial amount of pretreatment would be necessary (removing some 99% of the organic pollution) prior to using reeds as a final polishing process.

It would also seem that there is a great opportunity for the application of RBTS within Tunisia in municipal wastewater treatment, and it is disappointing that ONAS currently show little indication of building on this work and speedily transferring the technology.

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Appendix A

470

Appendix B

Staffordshire University/ENIS Reed Bed Project

Report on Visit - February 1997

Following discussions with the Director. British Council on 14/2/97, the following were identified as important points for clarification during the visit to ENIS:

1. Dates for March visit by ENIS personnel to UK - personnel to be involved and dates (16.3.97→20 or 21.3.97).

2. Proposed small mobile $1m^2$ bed - decision to build/no build.

3. 1997-98 spending plans/visits timetable.

Current <u>proposed</u> visits for 97-98

S/U → Tunisia	May '97	Discuss/review progress
ENIS → S/U	September '97 (2wk)	Analytical development/QC
S/U → Tunisia	October '97	Implement QC programme
S/U → Tunisia	February '98	Discuss/review progress

4. Agreement on the analysis regime - determinands and frequency

COD, BOD, TSS, Total N, Total P, Total K, Total Phenol - daily at outset and then as agreed

Flow in/Flow out - daily
Air temp. - daily
Water temp. - daily
Sunshine - weekly average
Rainfall - weekly average
Humidity - weekly average
Height of reeds - weekly average

In addition there is a need consider the nature of the growing media, the need to fit/adapt outlet, and plans for recirculation of effluent (collection tank for effluent and pump for recirculation).

<u>AGREED ACTIONS WITH ENIS</u>

S/U and ENIS. Proposed timetable and original budget for 1997-98 accepted and agreed.

Existing bed :

1. Continue with dolomite media despite alkalinity and possible long-term breakdown. May help provide buffering for acidic margine. Plant with reeds as per design using rhizomes from site in city visited on 17/2/97.

2. Contact British Council - Quotation for $1m^3$ tank + pump + pipework + electrical installation
   Quotation provided; cost will not exceed £200

3. Modification to outlet according to design.

4. Purchase of fertiliser - Quotation to British Council. (10kg - 10.5.D - 100 Kg required)
   Quotation provided; cost will not exceed £75.

Proposed start-up regime:

Flush bed through for 3 days with water

Add 1kg of fertiliser to flooded bed at outset to start reeds off.

Add 250 lts of water containing 325 g of fertiliser per day for 14 days to check response of reeds and residual effect (if any) of alkalinity in gravel.

Continue feed on basis of:

14 days	2 lts margine + 248 lts of water + 325 g of fertiliser.
14 days	4 lts margine +246 lts of water + 325 g of fertiliser.
14 days	6 lts margine + 244 lts of water + 325 g of fertiliser.
14 days	8 lts margine + 242 lts of water + 325 g of fertiliser.
14 days	10 lts margine + 240 lts of water + 325 g of fertiliser.

Commence feed week commencing 24.2.97. Margine to be used will derive from traditional pressing process.

NEW mobile bed :

Small 1 m^2 cost estimated at $\sim \frac{1}{9}$ of existing pilot plant. Decision taken to build providing unit can be built to quotation budget, delivered and paid for before 31/3/97.
Quotation provided; cost will not exceed £250.

OTHER ACTIONS DURING VISIT

In addition to discussions at ENIS we had the opportunity to visit three olive oil producing factories (one traditional, one continuous, and one new environmentally system using about one third as much water). This enabled us to obtain a sound grasp of process and the nature and characteristics margine/grignon production using each method.
We also visited the Institut de l'Olivier and secured their backing for both this project and a future possible E.U. bid in conjunction with ENIS.

G. Skerratt
Director
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Report on Visit to ENIS

25-27 May 1997.

By Dr. Glynn Skerratt and Dr. Mike Anderson.

Discussions took place at ENIS on 26th May.

Performance of full scale reed bed

- Original reeds planted 21st February
- Further reeds added 19th May.
- Feeding of margine commenced on 9th March at a flow rate of 250 lts/d and containing fertiliser at a concentration of 1 kg/m^3
- Feeding was suspended on 6th April because of observed yellowing of reeds.

EA stated that the recirculation pump would be installed within the reed bed feed tank during June.

Following review of the results, it was agreed to continue with the current irrigation regime and not feed with margine. During this period the following analysis will be carried out:

pH, NH_4^+, suspended solids, nitrogen, phosphorus and potassium.

GS undertook to investigate availability of polyphenol standard(s) and glass comparator system. GS also took a sample of margine and agreed to carry out some solvent (chloroform) extraction experiments and total phenol analysis in UK.

EA agreed that she and the Olive Oil Institute would investigate Folin method for polyphenol analysis and report on its suitability.

Small-scale reed bed

EA and KM agreed that Mr Ueno would run some flocculation experiments on both margine produced by the classical method AND margine produced by the ecological method (containing more water) and we could review the results in November. This would enable a realistic time scale to be developed for the planting of the smaller mobile unit and its subsequent feeding with the supernatant from any physical treatment process.

Visit by Tunisian personnel in September.

GS stated that the purpose would be to develop appropriate quality control procedures and analytical methods for pH, NH_4^+-N, SS, COD, BOD, N, P and K.

EA agreed - and it was also agreed that Tunisian colleagues would bring samples of margine and bed influent and effluent with them for comparative work.

EA agreed to provide both British Council and GS with CVs for prospective colleagues who would wish to visit UK in September, to enable a final decision to be made.

<u>Meeting with Prof. Ben Kheder Mohammed on 27th May.</u>

(Le Counseil Regional de Recherché Developement Agricole de Centre-Est)

The purpose of the meeting was to investigate the possibility of developing a proposal to assess the application of reed bed treatment systems for aqueous agricultural effluents.

It was agreed that Tunisian colleagues would formulate a draft proposal (for a project of 2-3 years duration), and that this would be forwarded to GS for comment ***<u>within six weeks</u>.***

The proposal could involve looking at 2 dairy farms (one large, one small) and would seek to identify the resources needed for construction of the bed(s), monitoring and analysis, administration of the project and access to external expertise. This proposal may form the basis of a future bid to British Council for support, or to the E.U. under their MED-TECHNO scheme (accepting that in the latter case, it would be a much larger overall project and that British Council would take only a passive interest in the work)

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Report on Visit to Tunisia/ENIS

by Dr. Glynn Skerratt and Dr. M. Anderson

between 6-10 December 1997

General

Following a meeting with Mr. J. Mackenzie (Director BC) on Sat. evening, we drove to Sfax on Sun 7th and had meetings (and a site visit) with ENIS staff on Monday and Tuesday. We returned to Tunis on Wednesday morning and again had meetings with BC staff, prior to flying home on Wednesday afternoon.

Outcome of Meetings:

Meetings at ENIS - Dr. Emna Ammar (EA) + GS + MA

Provisional date set for next meeting at ENIS: 9-11 March 1998
Provisional date set for next visit by ENIS personnel to S/U: w/c 27th April 1998

1. The recirculation pump for the large bed has been delivered but not yet installed.
2. **Action:** EA to arrange for installation asap.
3. The Folin method for (poly)phenol analysis has been tested by ENIS and found not to work. At present we are without a usable phenol method.
4. **Action:** GS to review.
5. EA explained that between 27th April and the second week in November, the large bed was only fed with water/fertiliser and that since then it had received dilute margine at a concentration of about $4m^3$ of margine per m^3 at a volume of about 200 litres per day. One analysis had been carried out giving an inlet COD of about 680 mg/l and an outlet COD of around 400 mg/l.
6. **Action:** EA/GS agreed that we would immediately start to feed the bed (at the current rate of about 200 lts/d) with a margine concentration of $5lts/m^3$ and analyse inlet and outlet (weekly) for COD, BOD and pH - this data to be reviewed throughout Dec/Jan/Feb with the intention of reassessing the feeding regime at our next visit in March.
7. EA explained that there had been no action with the small scale reed bed since our last visit.
8. **Action:** EA to fill the small reed bed with pea gravel (if available) or broken brick, plant with reeds and commence feeding with 20 lts/d of standard water/fertiliser solution. The intention is to supply the ultimate feed from a small physiochemical (P/C) treatment plant for classically produced olive oil developed from Mr. Ueno’s work.
9. GS asked what had happened to the proposal that was due to be sent (within 6 weeks) from the Agricultural Research College which we visited on our last trip in May.
10. **Action:** EA agreed to phone and ask later in the week.
11. GS and EA discussed the production of a paper relating to the current project.

12. **Action:** EA/GS agreed to start to draft text. EA to cover olive oil production in the Mediterranean basin, particularly in relation to Tunisia, and the nature and environmental consequences of current aqueous waste disposal practices. GS will cover the general application of reed bed treatment technology, especially with regard to industrial effluents - particularly those containing phenol. We will exchange text, and look to include analytical data as it is generated during the winter. When we next meet in March we will combine our text and aim to produce some draft output.

13. GS explained that BC may be able to include aspects of Mr. Ueno's P/C treatment work in our current project as a 'front-end' process prior to reedbed treatment.

14. **Action:** EA to arrange for a quotation for the (agreed design of) laboratory scale settlement apparatus, and, together with Mr. Ueno, list the flocculants and coagulants that he would need to progress this work (on the new P/C plant) so that we would be in a position to look to feed the small reed bed in the spring with output from the lab scale plant. When GS receives list and approves, S/U can order them and arrange shipment.

15. GS suggested that when ENIS personnel next visit S/U, some time could be spent working on streaming current apparatus - this would help in the P/C work. GS offered to do some preliminary work in advance of this if 40-60 lts of margine could be shipped to S/U.

16. **Action:** EA to investigate possible shipment and difficulties associated with organising this.

17. MA explained possible valorization of sludge produced from upstream P/C treatment.

18. **Action:** MA to investigate further in preparation for receiving 'real' samples after March.

19. MA/EA/GS discussed the possibility of developing a joint 'workshop', probably to be held in Greece - with the working title:

20. "Combined Technologies Currently Under Development for the Disposal of Olive Oil Waste Streams"

21. and to include potential Greek and Turkish partners.

22. **Action:** EA agreed to investigate the possibility of including Portuguese contacts. MA agreed to pursue matter with JM and also Greek/Turkish contacts, produce outline structure for event and send information to EA.

23. GS asked EA to send a summary of all current participants in the reed bed project together with a brief indication of their actual role in our work (at JM's request).

24. **Action:** EA agreed

25. Discussed the possibility of developing a proposal looking at sustainable management of the new Sfaxian margine lagoons (see next section). This could involve identifying factors such as potential for groundwater pollution, evaporation rate, ways of maximising capacity and scoping whether this method of disposal might correspond to 'best current environmental practice' for Sfax/Tunisia

26. **Action:** GS agreed to discuss further with JM (see Sect. 3)

Meeting at C.G.B. Brick sa. - EA + GS + MA

27. Viewed local new margine disposal lagoons (15 km. from factory). Discussed with brick company management about possible utilisation of margine in their production process.

28. **Action:** EA agreed to meet with owner of brick company on his return from abroad w/c 15th Dec., with a view to developing a proposal to investigate aspects of this work.

Meeting at British Council - JM + GS + MA

29. Discussed all of the issues and points raised above. The following extra points were agreed:

30. **Action:** JM to await information from EA about:

  Quotation for lab scale P/C treatment unit as discussed with GS
  Anticipated difficulties associated with shipping margine/clay to S/U.

before deciding upon appropriate course of action.

GS to await information from EA about flocculants that are needed for Mr Ueno to use on the new P/C pilot plant.

Report on Visit to Tunisia/ENIS

by Dr. Glynn Skerratt and Dr. M. Anderson

between 4th -11th July 1998

On the 7th July Mike (MA) and I (GS) had a meeting with Dr. Ammar (EA)) and Prof. Benzinza (MB). There has been obvious growth within both of the reedbeds - particularly the large one, although the main growth region in this bed has been at the inlet-end. Clearly the improved feeding regime agreed during the last visit has been successful (200 lts/20 lts per day of ONAS effluent respectively to the large/small bed + appropriate volumes of margine as agreed). EA produced a detailed report from a project student who had been monitoring the performance of both beds for a 5 month period since March.

GS agreed to recommend continuance of the project to BC as long as the current level of attention to the feeding and monitoring of the pilot beds could be guaranteed by ENIS. EA and GS agreed to increase the overall volume of feed to the <u>large bed</u> in an attempt to get improvement of growth along the bed - as follows:

Raise feed to 300 lts. per day - 3 lts. of margine + 297 lts. of ONAS effluent. Maintain for 4 weeks
Raise feed to 400 lts. per day - 4 lts. of margine + 396 lts. of ONAS effluent
Maintain for 4 weeks.
Raise feed to 400 lts. per day - 6 lts. of margine + 394 lts. of ONAS effluent
Maintain for 4 weeks.
Raise feed to 400 lts. per day - 8 lts. of margine + 392 lts. of ONAS effluent
Maintain for 4 weeks.

The analysis on the bed will continue with inlet/outlet analysis of pH, COD, ammonia, suspended solids and BOD

For the <u>small bed</u>, EA and GS agreed to raise the feed volume to 30 lts. per day (i.e. 29 lts. per day of ONAS effluent + 1 ltr. per day of margine) and maintain for 4 weeks. This would then be increased to 2 lts. of margine per day + 28 lts. per day of ONAS effluent - maintained for 4 weeks. At this stage, we agreed to review the situation

EA explained the problem of organizing feeding during the holiday period in August and EA/GS agreed to discuss this with British Council later in the week.

EA and MA then discussed a possible ceramic project at ENIS, and EA explained that there would be a project student working on this at LARSEN in association with CGB Brick. MA produced a written project plan for this work and discussed and agreed it fully with the student and EA.

On Wednesday 8th EA, MA, GS, Prof. Medhioub and M. Kallel Monem (ENIS) had a meeting with a representative from the Ministry of Agriculture and three representatives from ONAS - the Ministry of the Environment. We discussed possible applications of reedbed treatment prior to irrigation with treated wastewater and also for small communities/hotels etc. The overall tenor of the meeting was good, and afterwards EA and GS agreed that ENIS should write a draft outline proposal for ONAS to consider.

Unfortunately, the follow-up meeting scheduled for 9th July with the representative from the Ministry of Agriculture, and the visit to the OTD farm and also the olive grove which receives ONAS wastewater for irrigation, had to be canceled. However we were able to pay a visit to CGB Brick for further information gathering and collection of site plans.

On 10th July we visited the Ceramic Technical Centre in Tunis and met with the Technical Director, as well as having a tour of the equipment and the facilities. This was followed by a meeting with the JM and ML at the British Council (BC).

The main points to emerge from the meeting with BC were:

1. The reedbed project would continue until our next scheduled visit in January. EA will make necessary arrangements for someone to tend and feed the reedbed during August and the first two weeks in September and BC will arrange payment of 300 TD (upon written confirmation/agreement of this from ENIS) to cover the cost. ENIS will also include in the letter that they will then continue to tend/feed both beds until the end of the project. During August - when analytical support may not be available - a photographic record to confirm required/anticipated reed growth will be needed.

2. EA and other ENIS colleagues would produce a written proposal to ONAS (a letter from the Director) within 10 days. Hopefully, a response would be forthcoming before August, but contingency plans for a follow up letter from BC and/or S/U to ONAS were discussed and agreed. The proposal would be as detailed as possible, suggesting perhaps both size and location of a possible reedbed which might be studied in parallel to the one on Sousse for example.

3. EA explained about possible plans for a macrophyte conference in Tunisia during 1999 involving the Centre de l'Eau in Tunis. JM advised EA about seeking EU support from the Tunisia bureau and also indicated that subject to a reasonably detailed proposal being received within the next 4-5 months, then BC may be sufficiently interested themselves to assist in helping make the event happen.

4. MA explained about the success of the Athens olive oil workshop and explained tentative plans to stage a further event in Tunisia during the early part of 1999. JM again felt that EU support may be forthcoming and offered to take a proposal to the Tunisia EU delegation for consideration. JM also indicated a high level of BC support for the idea but explained about likely limits on funding possibilities prior to April '99.

The subsequent meeting at Centre de l'Eau - although not with our original intended contact - was useful. They have a large amount of pilot-scale wastewater treatment plant and the facilities for good experimentation on plant design and technology optimisation.

We also met with Prof. Moncef Haddad in his office at the Institut Preparatiore aux Etudes d'Ingénieurs de Nabeul. He was most helpful in explaining that he had supervised a project student 3 or 4 years ago who had undertaken a comparison of a number of macrophyte wastewater treatment systems on a hotel effluent and produced a thesis documenting all of the results and conclusions. He provided a copy of this for EA - and I feel that the contents will be most helpful in guiding our thinking in the later stages of this project. If the proposed macrophyte event next year becomes reality, thin I hope that Prof. Haddad is able to make a contribution.

In addition to the above, we were able to experience more of Tunisian culture in respect of visits to Chaafar, Younga, El Jem, El Kantaoui harbour, Kerkennah Island (without disembarking!) and Nabeul.

In conclusion, providing that the same degree of attention can be paid to the beds for the remainder of the project, then I feel sure that we can obtain some useful results to enable our proposed publication to proceed, and also place ENIS in a good position to enable them to develop an extension project with ONAS if they so chose. In addition, the opportunity is there to investigate the potential opportunity for energy saving in the brickmaking process through addition of margine. Finally, there is the possibility of a 'macrophyte event' and a 'olive oil workshop-type event' being staged during 1999 - either or both of which may attract EU funding and thereby increasing the profile of ENIS/LARSEN both within Tunisia and also internationally.

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