Multi-Criteria Evaluation of Waste Oil & Petroleum Residues Processing Technologies

C.P. Mihalopoulos[1], An. Dalamanga[1], Ath. Dimou[1], K. Makrinika[1], D. Chomatidis[1] and Ph. Kirkitsos[1]

[1]Ecological Recycling Society (ECOREC), Non Profit Environmental Organization, Athens, Greece
Keywords: waste oil, petroleum residues, technologies, evaluation, Likert scale
Presenting author email: cmihalo75@gmail.com

INTRODUCTION

This content of this study refers to the findings of the 3rd Work Package of a CIP Eco-innovation Pilot and market replication project titled '*Market Promotion and Development of Eco-Processes for Waste Oils and Petroleum Residues – MARE*'. The beneficiaries of the Project are CYCLON HELLAS S.A. and the Ecological Recycling Society. The main scope of MARE Project is the development of an innovative technology for the treatment of Waste Oils & Petroleum Residues (WO&PR) through the design, construction and demonstrative operation of a thin film evaporator. Given the fact that, this technology is currently applied only for the regeneration of Waste Lube Oils (WLO), as fraction of WO&PR, MARE Project aims at the development of a thin film evaporator that can also process other WO&PR streams such as liquid state petroleum residues from ships and to investigate the possibility of processing petroleum residues from industrial applications.

In this framework, it is presented a multi-criteria evaluation of the currently applied processing technologies regarding the exploitation of WO&PR by using methods and techniques that can divert this hazardous waste stream into final products of high added value. The evaluation procedure was the core of the 3rd Work Package titled '*Study for the technical requirements for the development of sustainable and environmentally sound management of waste oils and petroleum residues in Greece*'. The objective of the evaluation procedure was the assessment of the technologies regarding the processing of all WO&PR fractions, namely, WLO, WO&PR from Ships and WO&PR from Industries. The evaluation procedure was conducted by using a five-degree Likert Scale. By using this evaluation technique, both quantitative and qualitative characteristics can be scored in order to express supremacy levels among the examined technologies. Each scoring level indicates the presence of a certain feature that differentiates one technique from another as for a discrete Likert Item. Summarizing the scores for all Likert Items will depict the total score as for a certain criterion. During the evaluation of the WO&PR processing based on technological, environmental, techno-economic, legal and social criteria, the respective technologies were divided into three discrete groups according to their basic operational fundamentals. These groups are referred to physico-thermochemical, biological and thermal treatment of WO&PR.

The summarized results of the evaluation of WO&PR processing technologies are available in full detail as content of the Deliverable D3.2 titled '*Evaluation of new practices, processes, products, technologies and services required and/or created*'. The content of this Deliverable is available at the official MARE website (http://mare.org.gr/el/) and in ECOWEB (www.ecoweb.info), the first European website platform for EU-funded eco-innovations[1].

WASTE OILS & PETROLEUM RESIDUES PROCESSING TECHNOLOGIES

The evaluation results that are presented here are limited to the technologies that are applied worldwide for the processing and not for the entire management of WO&PR. It is noted that the content of the aforementioned Work Package of MARE Project, was the extended mapping, analysis and evaluation in order to integrate the whole 'managerial chain' regarding the collection, temporary storage, pre-treatment, transportation and processing of WO&PR from the main sources of origin (WLO, WO&PR from ships and WO&PR from industries). In this framework, managerial methods for WLO, WO&PR from ships and WO&PR from industries were evaluated independently in correlation with the techniques and practices that are followed in international level regarding their logistics' chain, processing and disposal of the processing by-products. To this end, the evaluation of the practices that are applied for the collection, pre-treatment and temporary storage of WO&PR from ships cannot be unified and therefore, compared with those that are applied for WO&PR from industries because of their different originating sources. That is the main reason why the processing of WO&PR is the only stage of the managerial chain that can be comparatively evaluated for all three WO&PR waste streams.

[1] ECOWEB is an initiative by the European Commission to increase the uptake of eco-innovative research results from FP, CIP and LIFE+ projects. The ECOWEB platform features several functionalities that ensure an optimal exploitation, dissemination and visibility of your research results for you and a large community of eco-innovative SME's, networks and researchers.

As mentioned before, the identification of WO&PR processing technologies is strongly connected with exact types of WO&PR streams. In particular, a common and widely applied technique for the utilization of WLO is the regeneration. Through regeneration, WLO can be reused as marketable lube oils with quality standards that are differentiated according to the applied regeneration technique. These technologies are rather sensitive to impurities regarding the mixing of WLO with other petroleum containing liquid state waste streams, especially for those techniques that are not using vacuum conditions for the fractionation of hydrocarbons in light, medium and heavy weight streams. During the past decade, regeneration techniques were evolved in order to utilize separately and/or as a mix, WLO that are characterized by low quantities of aqueous phase having the advantage of minimizing energy consumption during their de-watering phase. These WLO may be collected from different sources including mixtures of hydraulic, insulating, lube and heat transmission oils.

Regarding WO&PR from ships, their management was diverted to those WO&PR that were emerged from the ship's operational functions (e.g. bilge waters) and those that were considered as sediments during the cargo transportation of liquid state fossil fuels (petroleum sludges). As for the quantities of bilge water, they must be subjected to oil-water separation techniques for the sea discharge of the aqueous phase and for the temporary storage of the oily phase above the ship before its deliverance to port reception facilities. Furthermore, the sludgeous sediments of liquid state fossil fuels are delivered also to port reception facilities. From these facilities, the WO&PR from ships are transported mainly to thermal cracking units for refining (removal of water and solid state impurities) and distillation. It must be mentioned that these units, although they have operational similarities with regeneration facilities, they are tailored to process crude oil and not WLO or WO&PR from industries.

WO&PR from industries are those quantities of liquid state waste water that are produced due to certain procedures regarding forming, plating and other manufacturing techniques of industrialized end products. Furthermore, in this category are included those WO&PR that are referred to cooling and/or heating mediums of the respective infrastructures as well as the residual fractions of the organic solvents' industries. These WO&PR are mostly dominated by the aqueous phase. They have a wide range of hydrocarbons' quantitative and qualitative characteristics in accordance with the industrialized process from which they produced. Mostly, they contain other hazardous substances such as PCDs, PCTs and heavy metal traces in various proportions.

Generally, WO&PR from industries according to their physical characteristics can be divided in three discrete categories which are the oily fraction, emulsions and waste water with dissolved hydrocarbon compounds. In several cases, these waste streams are subjected to pre-processing at their sources of origin (industry). The pre-processing procedure is based on techniques for the condensation of the oily phase or the extraction of the dominant aqueous phase. At a later phase, the remaining and condensed WO&PR are subjected to physical and/or chemical treatment for the neautralization – stabilization of hazardous substances, hydrocarbons included.

In this framework, the development of a system that can process several types of WO&PR is the challenge of MARE project.

EVALUATION PROCEDURE

Likert Scale

Likert Scale is a wide spread evaluation technique used by researchers in surveys based on questionnaires. The content of these surveys includes itemization of public opinions in matters related to sociological and/or psychological thematic fields (Wuensch, 2005). The basic fundamental in Likert Scale evaluation is the selection of Likert Items. A Likert Item refers to a trend or a certain feature/characteristic that a respondent is asked to evaluate according to predefined objective or subjective criteria. The evaluated options are expressed by a scale that indicates the level of agreement or disagreement for a Likert Item regarding a certain criterion. Each level is scored with integer values ranged from one (1) to 'D', where 'D' defines the degree of the Likert Scale (Likert, 1932). As for their degree, they are several Likert Scales but the most commonly used is the one with a 5-degree level scoring. According to this scoring a Likert Item is evaluated as for a predefined criterion in the following levels (Trochim, 2006):

- Absolute Disagreement: 1
- Disagreement: 2
- Neutrality: 3
- Agreement: 4
- Absolute Agreement: 5

The evaluation results as for a certain criterion will came up from the summary of scores for each one of the Likert Items. These results are usually presented in column diagrams.

The purpose of selecting a 5-degree Likert Scale is based on the quantification of the technological maturation regarding WO&PR processing technologies. By using this evaluation technique, both quantitative and qualitative characteristics can be scored in order to express supremacy levels among them. Each scoring level indicates the presence of a certain feature that differentiates one processing technology from another as for a discrete Likert Item. Summarizing the scores for all Likert Items will depict the total score as for a certain criterion.

Evaluation Criteria & Likert Items

The comparative evaluation will be based upon five (5) basic criteria. The first one will reflect the level of technological evolution as for the ability of producing end products of high added value and as for the flexibility in processing WO&PR with different characteristics regarding their organic carbon molecules. The second is related with the impacts that arise on the environment and the human health due to systems operation and in relation with the accumulation and disposal of their by-products and/or residues. The third will deal with technical and financial sustainability in terms of investment cost and needed effort in issues regarding the operation and maintenance of the respective systems. The fourth criterion deals with the level of compliance with the current European and national legislative framework. Finally, the fifth criterion is attempting to quantify the social acceptance of WO&PR processing technologies their harmonization with residential environment and their employment potential.

Overall, the selected basic criteria are:

- Technological evolution,
- Environmental impacts,
- Economical-Technical sustainability,
- Compliance with EU and national legislative framework and
- Social acceptance.

The selection of the Likert Items that composes each criterion was cohesive regardless of the exact technological approaches and/or operational fundamentals of processing technologies. Thus, the evaluation procedure will be expanded not only in systems of the same type (e.g. among thermal treatment technologies) but also, among different types reflecting the relative advantages and disadvantages.

Due to the incapability of testing operationally and experimentally all WO&PR processing technologies, the selection of Likert Items was made in the base of analyzing the respective information that where gained through the internet and bibliographic survey. As for the technological evolution, the respective information refers to the development of techniques for controlling and adjusting parameters that affecting the quality levels of the end products, as well as the energy consumption and the management of the produced residual fractions. As for the environmental impacts, the study was focused on the applied techniques for minimizing impacts on human health and generally, on the residential and physical environment. As for the economical-technical sustainability, the study was based on direct and indirect costs related to investment, usage and sustainable operation of WO&PR processing technologies. The compliance with the legislative framework takes under consideration the waste management principles while the social acceptance deals with the jobs that are creating through the implementation of each WO&PR processing technology. Table 1 summarizes all Likert Items that are composing each one of the five basic criteria.

Table 1: Likert Items for the evaluation of WO&PR processing technologies (ECOREC 2013)

Comparative Evaluation Criteria & Likert Items				
Technological Evolution	**Environmental Impacts**	**Techno-Economic Sustainability**	**Legislative Framework Compliance**	**Social Acceptance**
Implementing Experience	Green House Gas Emissions	Investment Cost	Compliance with Current EU & National Legislative Framework	Social Reactions
Operational Complexity	Air Pollutant Emissions	Operational & Maintenance Cost	Compliance with Waste Management Basic Principles (Hierarchy Pyramid)	Working Conditions

Comparative Evaluation Criteria & Likert Items				
Technological Evolution	**Environmental Impacts**	**Techno-Economic Sustainability**	**Legislative Framework Compliance**	**Social Acceptance**
WO&PR Processing Compatibility	Fossil Fuels Consumption	Pollutant Emissions Trading Cost	-	Employment Potential
WO&PR Processing Flexibility	Water Consumption	Additives Procurement Cost	-	Visual Disturbances
Adaptability to Replace Existing WO&PR Processing Technology	Accidental Consistencies	Safety Measures Cost	-	-
Energy Consumption	Noise Disturbances	Operating Lifetime	-	-
Energy Production	-	Income from Final Product Sales	-	-
Operational Accidental Risk	-	End Product Purchasing Potential	-	-
-	-	Landscape Requirements	-	-

Evaluation Levels, Capacity Factors & Scoring

Likert Items are divided in evaluation levels that are scored with discrete integer numerical values from one (1) to five (5) according to the 5-degree Likert Scale. Each scoring level reflects a certain feature of the system in relation to the Likert Item it belongs. The level scoring will express clearly the supremacy among the compared features. According to the preference and/or supremacy the Likert Scale may be ascending (from 1 to 5) or descending (from 5 to 1).

For example, for the group of criteria named as 'Technological Evolution' and for the Likert Item 'Energy Consumption', the evaluation levels of supremacy are descending regarding their relative preference and are expressed as follows:

- Very Low, scored as '5'.
- Low, scored as '4'.
- Moderate, scored as '3'.
- High, scored as '2'.
- Very High scored as '1'.

On the contrary, for the group of criteria named as 'Social Acceptance' and for the Likert Item 'Employment Potential', the evaluation levels of supremacy are ascending regarding their relative preference and are expressed as follows:

- Very Low, scored as '1'.
- Low, scored as '2'.
- Moderate, scored as '3'.
- High, scored as '4'.
- Very High scored as '5'.

As for a certain group of criteria, the importance of a Likert Item is shown with a capacity factor whose decimal value ranges between 0 and 1. The capacity factor expresses the significance of a Likert Item as part of the respective criterion. Table 2 summarizes the weighting factors (capacity factors) among Likert Items and overall, among the comparative evaluation criteria.

It must be noted that the capacity factors for each group of criteria and their respective Likert Items are independent from the type of WO&PR processing technology (physico-thermochemical, biological and/or thermal) and thus, enabling the comparative evaluation among technologies of different types.

Table 2: Capacity Factors for Likert Items and Criteria Groups (ECOREC 2013)

Criteria Groups	Likert Items	Capacity Factors
Technological Evolution	Implementing Experience	0,02
	Operational Complexity	0,02
	WO&PR Processing Compatibility	0,02
	WO&PR Processing Flexibility	0,06
	Adaptability to Replace Existing WO&PR Processing Technology	0,01
	Energy Consumption	0,05
	Energy Production	0,05
	Operational Accidental Risk	0,02
	SUB-TOTAL	**0,25**
Environmental Impacts	Green House Gas Emissions	0,06
	Air Pollutant Emissions	0,06
	Fossil Fuels Consumption	0,05
	Water Consumption	0,03
	Accidental Consistencies	0,03
	Noise Disturbances	0,02
	SUB-TOTAL	**0,25**
Techno-Economic Sustainability	Investment Cost	0,07
	Operational & Maintenance Cost	0,07
	Pollutant Emissions Trading Cost	0,02
	Additives Procurement Cost	0,02
	Safety Measures Cost	0,01
	Operating Lifetime	0,02
	Income from Final Product Sales	0,05
	End Product Purchasing Potential	0,03
	Landscape Requirements	0,01
	SUB-TOTAL	**0,30**
Legislative Framework Compliance	Compliance with Current EU & National Legislative Framework	0,05
	Compliance with Waste Management Basic Principles (Hierarchy Pyramid)	0,05
	SUB-TOTAL	**0,10**
Social Acceptance	Social Reactions	0,04
	Working Conditions	0,03
	Employment Potential	0,02
	Visual Disturbances	0,01
	SUB-TOTAL	**0,10**
	TOTAL	**1,00**

For each criterion, the total score emerges from the summary of scores for each evaluation level multiplied with the capacity factor of Likert Item it belongs. The total score expressed as:

$$R_{G,xx,c} = \sum_{i=1}^{j} f_i \cdot L_i \text{ , where}$$

G - WO&PR processing technology type ('CTT' for Physico-Thermochemical Treatment Technologies, 'BTT' for Biological Treatment Technologies and 'TTT' for Thermal Treatment Technologies,).

xx - WO&PR processing technology number per type.

c - Marking of criteria groups ('T' for Technological Evolution, 'E' for Environmental Impacts, 'S' for Techno-Economic Sustainability, 'F' for Legislative Framework Compliance and 'A' for Social Acceptance).

i - Likert item note number per criterion.

j - Total of Likert Items per criterion.

f - Capacity factor per Likert Item.

L - Evaluation level’s score per Likert Item.

RESULTS & DISCUSSION

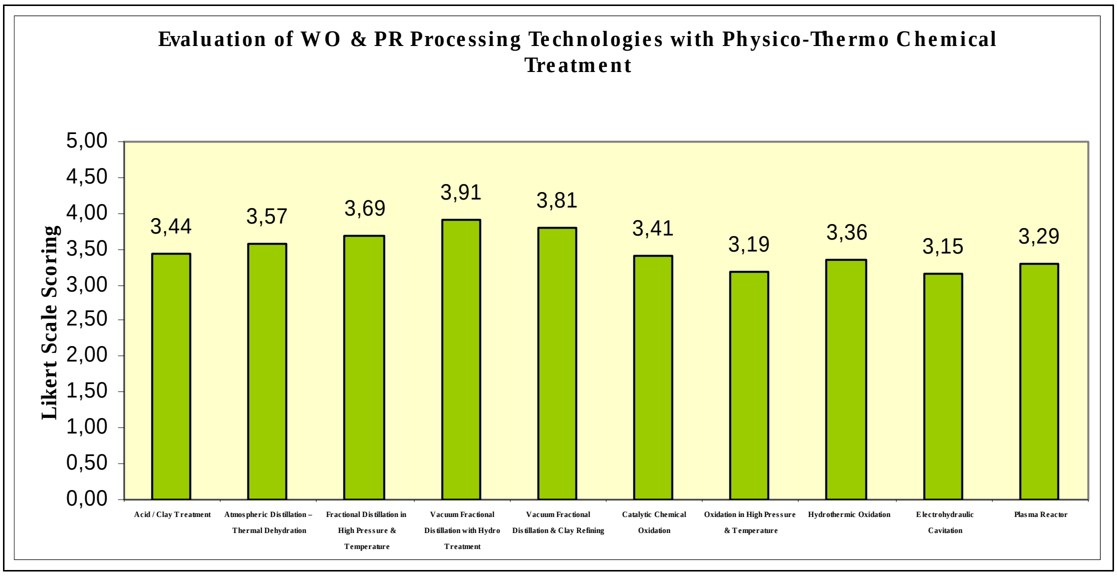
At first, the evaluation procedure took place separately for each type of WO&PR processing technology in order to indicate the most recommended system per type of technological approach. Then, the evaluation expanded among all WO&PR processing technologies in order to point out the most dominant systems as for the five aforementioned groups of criteria.

The performance of all WO&PR processing technologies was expressed by their total score ($R_{G,xx,c}$), where $1 \leq R_{G,xx,c} \leq 5$. Thus, according to the 5-degree Likert Scale, each WO&PR processing technology was evaluated as having:

- Excellent performance when $4 \leq R_{G,xx,c} \leq 5$,
- High performance when $3 \leq R_{G,xx,c} < 4$,
- Moderate performance when $2 \leq R_{G,xx,c} < 3$ and
- Poor performance when $1 \leq R_{G,xx,c} < 2$.

The results of the evaluation are expressed as column diagrams in Figures 1, 2 and 3 indicating the most dominant systems for each type of WO&PR processing technologies, namely, physico-thermochemical treatment, biological treatment and thermal treatment technologies for direct recovery of energy (electric and thermal).

Figure 1: Comparative Evaluation Results for WO&PR Processing through Physico-Thermo Chemical Treatment



The comparative evaluation of physico-thermochemical treatment technologies was conducted to ten (10) different technologies for the processing of WO&PR, namely (ECOREC 2013):

- Acid clay treatment.
- Atmospheric Distillation – Thermal Dehydration.
- Fractional Distillation in High Pressure & Temperature.
- Vacuum Fractional Distillation with Hydro Treatment.
- Vacuum Fractional Distillation & Clay Refining.
- Catalytic Chemical Oxidation.
- Oxidation in High Pressure & Temperature.
- Hydrothermic Oxidation.
- Electrohydraulic Cavitation.
- Plasma Reactor.

The technologies which gathered the highest scores were:

- Vacuum Fractional Distillation with Hydro Treatment which has an overall score of $R_{CTT,04} = 3{,}91$.
- Vacuum Fractional Distillation & Clay Refining which has an overall score of $R_{CTT,05} = 3{,}81$.
- Fractional Distillation in High Pressure & Temperature which has an overall score of $R_{CTT,03} = 3{,}69$.
- Atmospheric Distillation – Thermal Dehydration which has an overall score of $R_{CTT,02} = 3{,}57$.

Generally, physico-thermo chemical treatment technologies are characterized as 'high performance' techniques for reasons that are related with the production of high added value end products and in particular, due to the fact that their main output (lube oil) can be directly reused in the respective markets. Among them, the most dominant technologies are those that are implementing fractional distillation techniques which are regenerating WO&PR by recovering the desired petroleum fractions. More specifically, fractional distillation is ideal for the recovery of light, medium and heavy weight petroleum fractions. Those fractions can be utilized as intermediate and/or final products in accordance with the self energy consumption demands and/or market demands. Partially, the techniques that are applied from fractional distillation units are correlated with the removal of undesired impurities which are mostly chemical substances (mineral traces) and aqueous phase quantities. Furthermore, the operation of fractional distillation units has minimum environmental impacts concerning green house gas and air pollutant emissions compared to the thermal treatment units.

Based on the evaluation results, the most preferable physico-thermochemical treatment technology is the vacuum fractional distillation with hydro treatment. This technique, in comparison with other vacuum fractional distillation technologies has the advantage that, no solid state filters are used (e.g. clay filters) for polishing of the regenerated lube oil. Additionally, during the distillation procedure the vacuum conditions are ensuring effective and efficient fractionation in lower temperatures in comparison with conventional distillation techniques where fractionation occur in atmospheric and/or high pressure conditions (e.g. atmospheric distillation – thermal dehydration and fractional distillation in high pressure & temperature). Furthermore, the by-products that are consisted by the residual fraction of the whole process can be utilized for the coverage of the unit's energy self-consumptions (light petroleum fractions) and/or, through the hydro process, they can be utilized as intermediate products (e.g. asphalt additives). Among the different techniques of subsequent phases regarding vacuum fractional distillation with hydro treatment, the most dominant are the KTI and REVIVOL (using a thin film evaporator) and PROP (Philipps Petroleum Company) technologies. These units are characterized by their relatively high ratio in regenerating waste lube oils with the subsequent production of high added value by-products. In particular, the KTI and REVIVOL processes are based on:

- Vacuum striping and chemical treatment for de-watering.
- De-asphalting and fractionation through a thin film evaporator.
- Hydro treatment for finishing (polishing) of the end product.

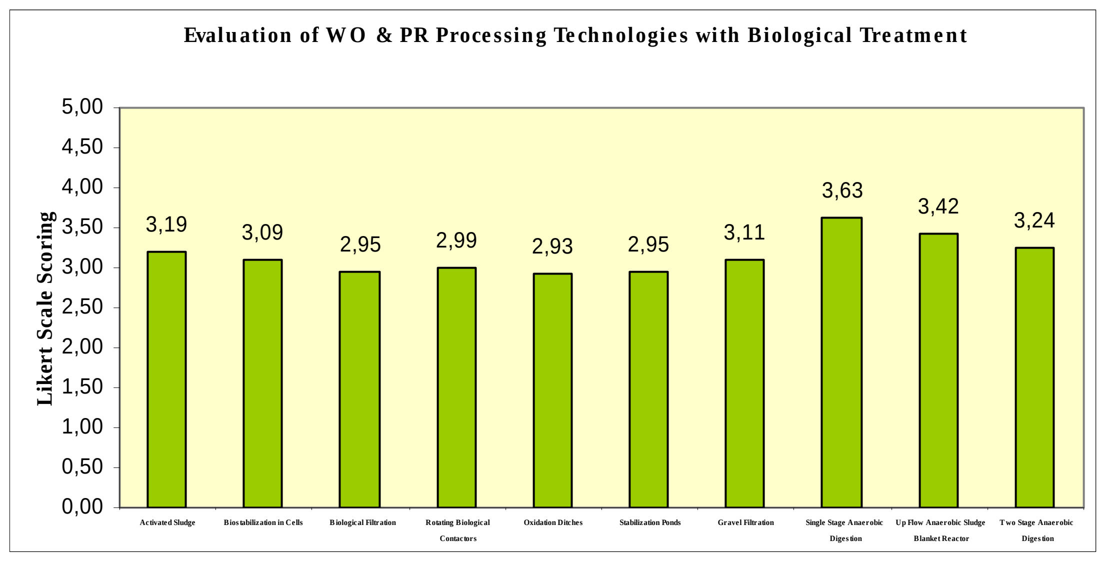
The processing of WO&PR through biological treatment techniques is not a common practice due to the fact that, WO&PR and especially those that are referred to waste lube oils and liquid state petroleum residues from ships, are consisted of high molecular weight compounds with more than 20 atoms of carbon. To this end, WO&PR are characterized generally by low compatibility as for their utilization by biological treatment technologies for their decomposition. Nevertheless, WO&PR from liquid state industrial waste (with low weight carbon molecules) can be co-treated with other organic substrates through aerobic and/or anaerobic techniques.

Overall, the comparative evaluation was conducted to ten (10) different technologies for the processing of WO&PR, namely (ECOREC 2013):

- Activated Sludge.
- Biostabilization in Cells.
- Biological Filtration.
- Rotating Biological Contactors.
- Oxidation Ditches.
- Stabilization Ponds.
- Gravel Filtration.
- Single Stage Anaerobic Digestion.
- Up Flow Anaerobic Sludge Blanket Reactor.

- Two Stage Anaerobic Digestion.

Figure 2: Comparative Evaluation Results for WO&PR Processing through Biological Treatment



The technologies which gathered the highest scores were:

- Single Stage Anaerobic Digestion which has an overall score of $R_{BTT,08} = 3{,}63$.
- Up Flow Anaerobic Blanket Reactor which has an overall score of $R_{BTT,09} = 3{,}42$.
- Two Stage Anaerobic Digestion which has an overall score of $R_{BTT,10} = 3{,}24$.
- Activated Sludge which has an overall score of $R_{BTT,01} = 3{,}19$.

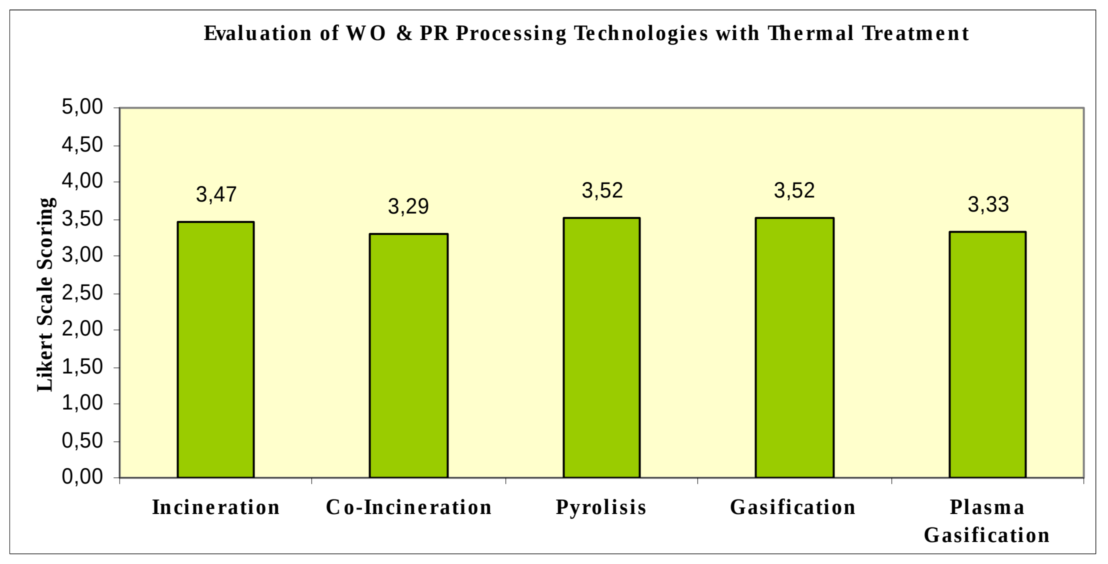
Generally, anaerobic digestion techniques are more preferable than aerobic ones because during their subsequent biological decomposition phases it is producing biogas that can be utilized for energy recovery. Furthermore, anaerobic digestion processes are characterized by a relatively low rate of decomposition of the organic matter and thus, are enhancing the degradation of molecules with more than 20 atoms of carbon. To this end, anaerobic digestion techniques are more compatible than aerobic decomposition in processing light weight fractions of WO&PR waste streams. Besides the biogas production, the biological co-treatment of WO&PR along with other organic substrates can produce as final product soil fertilizer (compost), either directly through composting (aerobic decomposition) or indirectly through anaerobic digestion and aerobic decomposition of the digestate. In any case, the utilization of WO&PR by applying biological treatment techniques is a rather recent approach that has relatively few applications of pilot and research scale implementations. The evaluation of those techniques was conducted in order to integrate the main pillars of organic waste treatment technologies (chemical, biological and thermal) and to provide an alternative pathway for sustainable and environmental friendly management of industrial WO&PR.

Regarding strictly the evaluation procedure, the most highly scored biological treatment technology was the single stage anaerobic digestion. The term ‘single stage’ indicates that all the subsequent phases of decomposition are evolved simultaneously inside a single bioreactor with continuous feeding conditions. Single stage anaerobic digestions has wide implementing experience and for this reason is characterized by relatively low investment, operational and maintenance costs in comparison with other anaerobic digestion techniques.

Thermal treatment technologies are referred to those techniques that are utilizing the calorific value of WO&PR in extremely high temperature condition for the recovery of electric and/or thermal energy. The comparative evaluation was conducted to five (5) different technologies for the processing of WO&PR, namely (ECOREC 2013):

- Incineration.
- Co-Incineration.
- Pyrolisis.
- Gasification.
- Plasma Gasification.

Figure 3: Comparative Evaluation Results for WO&PR Processing through Thermal Treatment



The technologies which gathered the highest scores were:

- Pyrolisis which has an overall score of $R_{TTT,03} = 3{,}52$.
- Gasification which has an overall score of $R_{TTT,04} = 3{,}52$.
- Incineration which has an overall score of $R_{TTT,01} = 3{,}47$.

The main aspects in developing thermal treatment technologies are the minimization of air pollutant's emissions, the stabilization of the inorganic (ashes) solid state residues and the maximization of the produced electric and/or thermal energy. In this framework, the current technological progress is focusing on the design of more 'greener' waste-to-energy techniques. Nevertheless, at present the development of thermal treatment technologies has been inhibited because of negative social reactions and due to the fact that these technologies are characterized by high investment costs.

Based on the evaluation results, the technologies that are referred to pyrolisis and gasification were more attractive than the traditional and more experienced incineration techniques. In particular, pyrolisis and gasification are characterized by high environmental performance compared to incineration because of the production of synthetic gas (syn-gas). The thermal treatment and energy recovery of this intermediate product is minimizing the air pollutant emissions as its aerial compounds are completely oxidized to carbon dioxide and water vapors. Furthermore, the current experience has shown that pyrolisis and gasification units are more flexible in terms of adjusted (customized) capacity. This is an advantage for thermal treating small to medium quantities of liquid state hazardous waste (such as WO&PR) compared to large capacity facilities for incinerating the annually produced large quantities of municipal solid waste.

As for their economic and technical sustainability, pyrolisis and gasification are less preferred compared to incineration due to their relatively low implementing experience. To this end, high investment costs can be compensated by the incomes from the exploitation of the produced energy. In addition, it is crucial for these units to ensure the availability of raw material before their commissioning.

CONCLUSIONS

As a result of the evaluation procedure, the most highly rated technology for the processing of WO&PR was the Vacuum Fractional Distillation with Hydro Treatment and in particular, those techniques that are using thin film evaporators for the fractionation procedure and hydro treatment for polishing of the final product. This technological approach is characterized by major advantages of technical, environmental and social nature. First of all, this technology complies with the waste management hierarchy since it contributed to the 'reuse' principle by utilizing waste lube oils for the production of lube oils of the same or better quality. Secondly, it produces by-products that can be utilized as fuels (light weight fractions) and/or structural materials (heavy weight fractions). Thirdly, the use of hydro treatment for the refinement of the end product does not produce solid state residues such as contaminated clay filters that needed to be disposed off and/or further managed. Furthermore, this technique has been mentioned as 'best available technique' in compliance with the Directive

2010/75/EU on industrial emissions (integrated pollution prevention and control) at Annex I, Paragraph 5: Waste Management, topic: oil re-refining).

As for the comparative evaluation among different types of WO&PR processing technologies and in particular, among regeneration and waste-to-energy technologies it is clear that regeneration techniques are more preferable in all groups of criteria. More specifically, regeneration technologies are tailored to process specific WO&PR streams while waste-to-energy plants are co-processing WO&PR along with the primary waste stream (municipal solid waste, RDF e.t.c.). This is leading to the fact that in terms of full time equivalent, regeneration units have more employment potential than waste-to-energy facilities. Secondly, a part of the regeneration processing procedure (vacuum distillation) is widely applied in thermal cracking plants for the processing of crude oil and the subsequent production of liquid state fuels (ECOREC 2013). Furthermore, due to the fact that the vacuum conditions are lowering the mean temperatures inside the processing chamber, regeneration technologies have less energy consumptions and minimized environmental impacts that arise from the aerial emissions.

In this baseline, MARE project aim at the evolution of vacuum fractional distillation with hydro treatment through a thin film evaporator in order to process not only WLO but also WO&PR from other sources and in particular, from ships. The new wiped thin film evaporator is currently erected at CYCLON's regeneration refinery in Aspropyrgos, Greece. Having a treating capacity of 2.000 tons/year (300kg/h) of WO&PR, the thin film evaporator aims at the separation of these streams in petroleum product readily available for further processing at refineries, petroleum sludge as a by-product that can be utilized in asphalt production and water. More specifically, the outputs of the new unit will be (CYCLON 2012):

- 20% water containing traces of light hydrocarbons recovered and condensed at 50°C. This output will be adequate for biological waste water treatment and must be treated biologically as they may contain traces of petroleum oils, antifreezes, diluters and emulsions.
- 20% of petroleum product rich in carbon chain C14 to C20, recovered and condensed at 50°C. This product, free of water, solids and sludge will be supplied to crude oil refinery for further processing. Due to its high quality, no sewer processing is required by crude refiners.
- 60% water-free and petroleum product-free bottom residue (petroleum sludge) at approximately 220°C. The bottom residue will be mixed with the residue of used lube oil re-refining process for the later production of asphalt extender (IPPC, BREF on best available techniques for the waste treatment industries).

REFERENCES

Likert, Rensis (1932). 'A Technique for the Measurement of Attitudes', Archives of Psychology 140: 1–55

Trochim, William M. (October 20, 2006). 'Likert Scaling'. Research Methods Knowledge Base, 2nd Edition. http://www.socialresearchmethods.net/kb/scallik.php. Retrieved on April 30, 2009.

Wuensch, Karl L. (October 4, 2005). 'What is a Likert Scale? and How Do You Pronounce Likert?' East Carolina University. http://core.ecu.edu/psyc/wuenschk/StatHelp/Likert.htm. Retrieved on April 30, 2009

CYCLON HELLAS S.A., (2012), 'Business plan of the new eco-innovative process of waste oils & petroleum residues', CIP Eco-innovation ECO/10/277237 'Market Promotion and Development of Eco-Processes for Waste Oils and Petroleum Residues – MARE', Deliverable 6.1

Ecological Recycling Society, (2013), 'Review, Analysis & Report of Practices at EU & Greece on Petroleum Waste & Residues' Management', CIP Eco-innovation ECO/10/277237 'Market Promotion and Development of Eco-Processes for Waste Oils and Petroleum Residues – MARE', Deliverable 2.1

Ecological Recycling Society, (2013), 'Creation of Jobs by the Implementation of Environmentally Sustainable Management Techniques for Waste Oils and Petroleum Residues', CIP Eco-innovation ECO/10/277237 'Market Promotion and Development of Eco-Processes for Waste Oils and Petroleum Residues – MARE', Deliverable 2.3