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

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(ECOREC)

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Eco – Innovation

MARE (ECO/10/277237)

MARE Project: Scope

- The content of this paper 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'**
- MARE project proposes significant environmental benefits through the:
  - **First time application in Europe of an eco-innovate technique**
  - **Implementation** of **a source separation system** for **used waste oils and petroleum residues**
  - **Development of a unit for processing the waste oils and petroleum residues** (WO & PR) through evaporation in vacuum conditions
- The beneficiaries of MARE Project are:
  - CYCLON S.A. (as coordinator)
  - Ecological Recycling Society (as co-beneficiary)

MARE Project: Environmental Problem Targeted

- Waste oils and petroleum residues (WO&PR) are representing a significant portion of non-municipal liquid state waste volumes generated in Europe and worldwide.
- In Greece, the estimated 200.000 tons/year. Generally,WO&PR are managed by:
  1. Processing through regeneration at CYCLON Refineries (mainly) for Lube Oil Production
  2. Collection, possible pre-processing (eg. in ports or off shore, separation of aqueous phase and temporary storage of oily phase) and disposal at the crude oil refinery for re-refining.
  3. Mixing with wood-chips for the production of stable secondary fuels with a relatively low heat capacity for disposal in cement kilns, brick and lime industry.
- WO&PR are often mixed with WLO affecting negatively the sustainable management of both waste streams

Waste Oil & Petroleum Residues

Three (3) Main Fractions, all Hazardous (*):

- Waste Lubricant Oils (EWC encoding 12 & 13)
  - From internal combustion engines' lubricating circuits and gear boxes (vehicles e.t.c.)
  - Medium weight petroleum fractions insoluble at aqueous phase
  - Low moisture content
- Petroleum Residual Waste from Ships (EWC encoding 13 & 16)
  - Contaminated Ballast Water, Cargo Residual Sludge and Bilge Oils
  - Heavy weight petroleum fractions
- Industrial Petroleum Residues & Waste Oils (EWC encoding 01, 05, 07, 08, 10, 12, 13, 16, 17 & 17)
  - Soluble at predominant aqueous phase
  - Light weight petroleum fractions (e.g. organic solvents)
  - Water removal as a pre-processing phase is required

Mapping & Analysis of WO&PR Management in 3 Discrete Phases

- Logistics' Chain
  - Generation Sources & Separation at Source
  - Temporary Storage
  - Collection & Pre-Processing (mainly water removal)
  - Transportation
- Processing Technologies and/or Practices
  - Physico-Thermo Chemical (medium & light weight fractions)
  - Biological (light weight fractions)
  - Thermal (all dewatered fractions)
  - Disposal at Petroleum Refineries (heavy weight fractions)
- Management of the Processing Technologies Residual Fraction

Comparative Evaluation: Likert Scale

- Application of a 5-degree Likert Scale
  - Quantification of non-quantified and/or qualified characteristics
  - Ability to assess technologies with different operational fundamentals
- Three level evaluation:
  - Sub-criteria as ‘Likert Items’
  - Basic criteria (weighting factors for each ‘Likert Item’)
  - Overall performance evaluation
- Quantification of supremacy levels (as for a certain Likert Item) in performance evaluation:
  - Very Low, scored as ‘1’.
  - Low, scored as ‘2’.
  - Moderate, scored as ‘3’.
  - High, scored as ‘4’.
  - Very High scored as ‘5’.

Comparative Evaluation: 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
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	-	-

Comparative Evaluation: Scoring Procedure

Total ranking score expressed as:

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

where:

- G: WO&PR processing technology type (Physico-Thermochemical, Biological and Thermal Treatment Technologies).
- xx: WO&PR processing technology number per type.
- c: Marking of criteria groups (Technological Evolution, Environmental Impacts, Techno-Economic Sustainability, Legislative Framework Compliance and Social Acceptance).
- i: Likert item note number per criterion.
- j: Total of Likert Items per criterion.
- f: Capacity factor per Likert Item.
  - Defines evaluator's view

Evaluation Results for WO&PR Processing through Physico-Thermo Chemical Treatment (1)

- Ten (10) different technologies for the processing of WO&PR were compared:
  - 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.
- Valid for low to medium weight WO&PR fractions
- Regeneration technologies

Evaluation Results for WO&PR Processing through Physico-Thermo Chemical Treatment (2)

- R=3,91 for Vacuum Fractional Distillation with Hydro Treatment
  - 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.
  - Light weight fractions are utilized as fuels for covering self energy consumptions.
- R=3,81 for Vacuum Fractional Distillation & Clay Refining
  - Contaminated clay as the main by=product needs further management
- R=3,69 for Fractional Distillation in High Pressure & Temperature
  - Relatively high investment costs & energy consumption

Evaluation Results for WO&PR Processing through Biological Treatment (1)

- Ten (10) different technologies for the processing of WO&PR were compared:
  - 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.
- Valid for light weight petroleum fractions.
- Often mixed with biodegradable waste streams

Evaluation Results for WO&PR Processing through Biological Treatment (2)

- Light weight petroleum fractions can be mixed with biodegradable waste for biogas production.
- All applications are at pilot and/or demonstrative stage of development.
- R=3,63 for Single Stage Anaerobic Digestion
  - Typical biogas plants
  - Liquid state substrate facilitates decomposition
- R=3,42 for Up Flow Anaerobic Blanket Reactor
  - High investment cost
- R=3,24 for Two Stage Anaerobic Digestion
  - High maintenance cost
- R=3,19 for Activated Sludge
  - Applied technique for liquid state industrial waste

Evaluation Results for WO&PR Processing through Thermal Treatment (1)

- Ten (10) different technologies for the processing of WO&PR were compared:
  - Incineration.
    - Small scale furnaces, uncontrolled burning of WLO.
    - WO&PR must be free of PCBs & PCTs
  - Co-Incineration.
    - Widely applied technique at cement kilns, lime and brick industry.
    - WO&PR must be free of PCBs & PCTs
  - Pyrolisis.
    - Demo scale plants
    - Co-processing with RDF and/or waste with high calorific value
  - Gasification.
    - Demo scale plants
  - Plasma Gasification.
    - Only at pilot scale plants

Evaluation Results for WO&PR Processing through Thermal Treatment (2)

- R=3,52 for Pyrolisis and Gasification
  - Pyrolisis and gasification are having better environmental performance than incineration.
  - The relatively low quantities of WO&PR in comparison with the high investment and operational cost for developing such a plant is a disadvantage
- R=3,47 for Incineration
  - Waste lube oil Directive and the New Framework Directive on Waste Management are highlighting the preference of regeneration over energy recovery technologies

Conclusions

- Most highly rated technology: Vacuum Fractional Distillation with Hydro Treatment
  - In compliance with the waste management hierarchy since it contributed to the 'reuse' principle
  - By-products utilization as fuels
  - No solid state residues such as contaminated clay filters
  - 'Best available technique' in compliance with the Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control)
- Regeneration (thermo-chemical) techniques are more preferable in all groups of criteria.
  - 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.).
  - Regeneration units have more employment potential than waste-to-energy facilities.
  - 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.

Next Step in WO&PR Processing

- **Development of a Thin Film Evaporator**
  - Flexibility in processing various WO&PR streams (e.g. WO&PR from ships as well as WLO).
  - The new processing innovative unit intents to recover materials from WO&PR by producing:
    1. Fuel like vacuum gas oil (20%), free of solids and sludge will be supplied to crude oil refinery for further processing. Due to the high quality recovered fuel do not require sewer processing.
    2. Residual heavy fuel oil (60%), free of water and fuel, will be mixed with the residue of used lube oil re-refining process. This residue is utilized as asphalt extender (IPPC, BREF on best available techniques for the waste treatment industries).
    3. Water (20%) will be fed to existing CYCLON Waste Water Treatment Plant. Waste water may contain organic matter (oil, antifreeze, diluters, and emulsions) and more advanced treatment (e.g. biological) than existing practice (centrifuge) is required. Biological treatment is available in CYCLON's facilities.
  - The annual capacity of the new processing pilot unit will be 2.000 tons of WO&PR.

Thank you for your attention