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LIQUID WASTE MANAGEMENT METHODOLOGY. A WASTE-TO-ENERGY APPROACH

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Abstract

The purpose of this paper was to sum up the most appropriate pretreatment methods for destabilizing the oil waste emulsions coming from metal surface processing operations. A three steps oil waste management pretreatment methodology was proposed considering the application of the waste hierarchy and end-of waste criteria in the spirit of circular economic concept. Our main objective was to valorize the high energy content of oil waste flows using low cost pretreatment methods. The obtained phase can be used as a fuel substitute decreasing this way the waste volume to be disposed knowing that according to the waste hierarchy recycling is better than burning and burning is better than landfilling. The obtained results showed for the recovered oil phases the following values for the determined relevant indicators: carbon content 50÷70%, humidity 20÷65%, ash content 4÷5% and superior heating value 6800÷8800 Kcal/kg. The obtained results for the separated water phase were also encouraging: turbidity 20÷30 NTU (Nephelometric Turbidity Units) and COD (Chemical Oxygen Demand) 5000÷7000 mg/L. The low costs physical-chemical pretreatment proposed technologies brought the obtained results in line with other more expensive hybrid technologies presented in recent literature in the field making them more attractive for the implementation within a circular economic model.

Key words: circular economy, emulsions, waste, waste-to-energy

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1. Introduction

In this paper we focused our experimental tests on finding and summing up the most appropriate methods for destabilizing the oil waste emulsions coming from metal surface processing operations within an oil waste pretreatment methodology in order to draw up relevant conclusions for a waste-to-energy technologic approach critical for the Life Cycle Assessment (LCA) studies (Astrup et al., 2015). Applying waste hierarchy (Arama and Kim, 2016) with emphasis on the implementation of end-of-waste criteria (Arama et al. 2018a; 2018b) in the spirit of circular economic model (Kim et al., 2018c) means actually avoiding both pollution of our environment with high volumes of wastes and the unsustainable use of non-generable resources. It is actually a very challenging approach for all stakeholders interested in the topic that essential means a high degree of harmonized implementation of their good waste management practices. Although pervaded with imprecisions at the practical implementation directions, the concept shows its merits by trying to achieve in long term a high degree of harmonization in relation with for best waste management practices. Although intensely promoted in the latest years at the European level by drafting a legal framework for its implementation, a visible managerial response from industries is still lacking despite that a lot of organizations have already in place certified Environmental Management Systems according to the environmental management ISO 14001 (2015) standards that means meaning they have in place functional waste management programs. However, at

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sectoral industrial level is still need for a harmonized way to share information about their produced specific waste so that waste from one industry to be used by another one. within the framework of the innovative waste recovery solutions founded or to be searched in closed cooperation between academic, industrial and regulatory sectors at both national and European levels (Korhonen et al 2018a, 2018b). The challenges arising with the implementation process of such this virtuous endeavor point towards the use of more precise defined connected concepts that will can facilitate the demonstration of its functionality at first for small industrial units and afterwards for larger ones. scale for the circular model units with specific waste - and oil waste seems to be such an example - and afterwards, the gained experience will be shared and extended to larger integrated units making a smooth and efficient transition from national towards regional implementation of circular economy. For the moment we have in current waste legislation some helpful explanatory notes in relation to different concepts. The most important in the view of circular economy is actually the concept of End of Waste status. In the article 6(1) and (2) Waste Directive 2008/98/EC (EC Directive, 2008) states that "certain specified waste as is the case of waste oil shall cease to be waste within the meaning of point (1) of article 3 when it has undergone a recovery, including recycling operation, and complies with specific criteria to be developed in accordance with the following conditions: the substance or object is commonly used for specific purposes; a market or demand exists for such a substance or object; the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and the use of substance or object will not lead to overall adverse environmental or human health impacts" (EC Directive, 2008). End-of-waste criteria (Arama et al., 2018b) can be easy fulfilled by the oil wastes coming from metal surface mechanical processing from automotive and generally from industrial sectors because they are suitable for recovery, including recycling operations and, in the context of sustainable economic development a market demand for such products is expected to increase. As has recently been showed in the literature (Madanhire and Mbohwa, 2016), industrial sectors, due to the high consumption of lube oil are generators of large amounts of lubricating oil waste that represent a serious pollution problem. Improving the oil waste management with good management environmental regulations and plans can create the frame of better control of possible environmental impacts brought by them as recently has been shown by Di Vaio et al., 2019 in relation to the prevention of negative environmental effects from seaports and their shipping activities. They mention that "in last decades the main international institutions, like the International Maritime Organization (IMO) and the Marine Environment Protection Committee (MEPC) carried out continuous and deep interventions, consisting of amendments, regulations, standards and proposals of guidelines related to MARPOL 73/78/97. (….) The convention known as MARPOL 73/78 deals with the prevention of pollution of the marine environment by ships from operational or accidental causes, regulating the draining standards for used oil, sewage and waste materials (…) Specifically the Annex I deals with prevention of pollution by oil and oily water." The authors show that methodologies to evaluate the oil spill impacts of shipping activities or methodologies able to monitor, control, quantify and measure the environmental impacts of shipping activities in economic and monetary terms, especially related to the waste management process, are still missing. However, they mention an evaluation model propose by Liu and Wirst who introduce the concept of "service recovery function" mentioning that "all opportunity costs are summarized from natural damages and economic losses." In European countries for example, where ports handle significant traffic flows, the environmental protection awareness and a marked corresponding behavior for sustainability is present in countries such Spain, United Kingdom, France, Netherlands and Germany as the literature reports mentioning that "in many cases, compared to bans and standards, managerial instruments can provide more flexibility for polluters to find low-cost opportunities to reduce negative environmental impacts" (Di Vaio and Varriale, 2018). Such an example is given by good environmental management plans that including key environmental performance indicators for monitoring, controlling assessing and measuring the processes in relation to environmental sustainability and energy efficiency performance in seaports activities (Di Vaio et al., 2018). In the same idea some other countries started to design their own management systems which include their own recycling, developing this way an entire re-refining industry such is the case of Germany. This is not an easy endeavor because "the ability to recycle waste oils is very closely linked to the oil's composition, level, type of contamination and of course economic aspects.(…) As a consequence about 35 % of the collected oil is re-refined into base oil the remaining of 65 % is burnt replacing coal (10%) or used as heavy fuel oil (45 %) and unknown other products (10%). It is also suspected that a substantial amount of used oil is lost or illegally burnt or dumped in the environment." (Madanhire and Mbohwa, 2016).

Trying to avoid the disposal of such toxic flows, keeping in mind the waste hierarchy principle that recycling is better than incineration and incineration is better than landfilling, the "waste to energy" technological approach became within the circular economy concept an alternative to be followed provided that environmental standards are met. Intensely promoted by the EU in the last years, The concept of Circular Economy (CE) has been adopted not only by EU countries but also around the world by national governments including China, Japan, UK, France Canada, the Netherlands, Sweden and Finland (Korhonen, 2018 a) as "an approach to combat environmental challenges and promote sustainable development and, (….) at the global level some have even suggested that once CE is fully implemented it would result in economic gains exceeding 1000 billion US dollars annually (FICF and Mckinsey, 2014)" (Korhonen et al., 2018b). To be able to implement this concept, waste should be characterized (Arama and Kim, 2016; Kim et al. 2018a; 2018c; Kim and Arama, 2018), considering waste source/origin, waste producing process, waste composition determined with reliable and special dedicated analytical methods (Kim et al., 2017, Kim et al., 2018b). This endeavor becomes even more important when hazardous substances/compounds that might impart hazardous properties HP1÷HP15 - listed in Annex III of WFD (EC, Directive 2008) replaced with the Annex of EU Regulation 1357/2014 (EC Regulation, 2014) - are involved. In this respect, risk evaluations of the environmental and health due to the pollution became a necessity. In the spirit of precautionary principle, the used assessment methods should be reliable ones and should always involve all interested stake holders including the general public (Arama, 2007a, 2007b; Arama and Nicolau, 2009a, 2009b, 2009c; Arama et al. 2010a, 2010b; 2010c; Arama et al. 2011; Arama et al., 2015; Arama et al., 2017a, 2017b; Comăniţa et al., 2018; Darbra et al. 2008; Das et al.; 2012; Musee et al., 2006; Reichert et al. 2015; Xu and Liu, 2009; Zhang et al, 2010). Stake holders including general public. They should be documented about pros and cons of different proposed waste management alternatives in each specific context. "Energy recovery from waste is an essential part of modern waste management. Within the last decades, waste management has changed from being a sector primarily focusing on treatment and final disposal of residual streams from society to now being a sector that contributes significantly to energy provision and secondary resource recovery. In the transition towards more sustainable energy supply, energy recovery from waste is gaining increasing interest as an option for reducing dependence on imported fossil fuel. Waste-to-energy approach is not as good as recycling for oil waste but is better than landfilling. (Astrup et al. 2015) mention that most studies (25 out of 29 scientific articles) clearly indicate that Waste-to-energy is preferable over landfilling" (Astrup et al., 2015). This is become more evident not only for the municipal waste that are already well known for their potential to participate to a circular economy implementation but also for the oil waste. (Guta et al., 2017, Jamasb and Nepal, 2010; Jeswani and Azapagic, 2016; Malinauskaite et al,.2017). Generally speaking, the use of oil waste as a substitute for fuel with similar characteristics obtained from virgin oil or submit it, where the case, to the recycling process, represent the basic instruments in the endeavor to implement a circular economic model. In this particular case, the model promises to minimize the oil waste amounts. Depending on local and global market for similar products obtained from virgin materials, the opportunity for oil waste recovery, specifically for used oil (lubricating oils) through recycling can be affected. This fact should be taken into account because the market value of lubricating oils obtained from secondary materials, i.e. from waste oils, should be always under the cost of lubricating oils having similar technical and ecological characteristics obtained from virgin materials in order to be sold, regardless if those costs are established following the lack or abundance of the virgin materials/products obtained from those materials on the market. This aspect should be easy to be understood taken into account that, generally speaking, the oil recycling necessitates costly operating processing similar to those applied to the virgin materials. In those conditions, if the applied process is too costly, then those oils, for example lubricating oils, from secondary materials will be impossible to be sold and the secondary market material of this type will be in recession. Literature in the field (Schreck and Wagner, 2017) mentions that "there is an emerging consensus that a sustainable approach to waste management requires further development of secondary raw material markets". In those conditions, the recovery of waste oils as fuel substitute involving minimum treatment costs is a solution less sensitive to the price fluctuation of the virgin materials /products obtained from them. In addition, this type of fuel substitute, if it is a well-controlled product will have characteristics that can fulfill the environmental protection requirements. The management alternatives that we proposed in this pretreatment methodology gather methods that can contribute to: 1) the reduction of waste volumes to be disposed, 2) the recovery of oil waste energetic content and also to 3) the reclamation of water content from the hazardous waste oil emulsions, having as main advantage the low cost for their implementation. "Waste incineration is a well proven treatment technology for discarded chemicals, industrial and hazardous wastes (LaGrega et al.,1994; Santoleri, 1983; Santoleri et al., 2000; Theodore and Reynolds, 1987, 1989) and municipal waste (Consonnini et al., 2005a; b). It is also an alternative sink technology for no-longer reusable or recyclable end-of-life (EoL) consumer or industrial products and materials (Beck, 2006; Santini et al., 2011; Wager et al., 2011) (Tsiliyannis, 2013)".

2. Material and methods

The proposed management methodology for pretreatment of oil waste is made of the following three steps:

1) Selection of representative samples of emulsions of o/w type;

2) Characterization of the selected waste samples - Case study;

3) Preliminary destabilizing tests;

For those systems that are emulsions of o/w type the main technical aspects that should be taken into account when selecting the most appropriate methods for destroying their stability are presented next. An emulsion is by definition a disperse system containing at least two phases: a discontinued phase named dispersed phase and a continuous one named dispersion phase separated by an interface. Due to the high surface that dispersion phase presents because of its high division degree, emulsions are non-equilibrium systems that have a high free superficial energy. That means that they will tend towards an equilibrium state that can be reached when particles of the dispersed phase can adhere one to another (like in coagulation process) lowering the interface until it disappears. In order to recover the valuable energetic component from such oil wastes the general practice in the field is to perform first a set of preliminary tests using appropriate techniques to completely destroy the emulsion stability up to phase separations. As Pintarič et al. (2016) mention, the main issue when trying to pretreat/treat the oil wastes from different industries is related to the fact that they represent mixtures of o/w emulsions presenting significant variations in compositions (different amounts of solids, additives, biocides antifoams etc.), these variations being reflected in the wide range of COD values - general indicator for organic content oxidizable with potassium dichromate - varying from 1000 mg/L to 300000 mg/L. A successful pretreatment/treatment of those kind of emulsions will necessitate different combined cleaning techniques including different level of chemicals consumption (coagulants/flocculants) in order to bring a COD value in the range of 100-125 mg/L required for the discharge of treated waste water into the surface water.

Consequently, we stressed in our proposed pretreatment methodology the importance of selecting groups of o/w emulsions coming from same industry or operations, that can be characterized and pretreated for destroying their stability based on some general common features so that the resulted recovered oil and wastewaters phases to be easier to be used with or without further treatment in an efficient way.We gave as example a case study where the o/w emulsions come from metallic surface processing. The three steps of the proposed methodology are detailed next.

Step 1: Selection of o/w representative emulsions samples from metallic surface processing

The fluids used in the metallic surface processing are called Metal Working Fluids (MWFs) and represent generally a high proportion of the oils that are used in the industry. They "improve performance of machining operations, increasing tool life and yielding better surface finishing. (…) The major limitation of MWFs is that they lose their lubricating properties with time because of their exposure to high temperatures and stresses in mechanical operations and ultimately need to be replaced. As a result, large volumes of oily wastewater are periodically generated which have to be treated before discharge" (Cambiella et al., 2007). "As Pintarič et al. (2016) mentions waste water should fulfil stringent legislations norms for chemical oxygen demand (COD), mineral oils, the total organic carbon (TOC), lipophilic substances, benzene-toluene-xylenes (BTX), absorbable organic halogens (AOX) etc. in the discharged effluent streams" This is due to the fact that they have "great capacity of penetration in the ground representing a threat for ground waters" (Bensadok et al., 2007). Pollution risk evaluation of the water courses is in great attention in the latest years. Organizations are encouraged to enforce the monitoring and the assessment of their pollutants discharges by applying appropriate environmental assessment methodologies using relevant indicators This way they will be able to manage all direct/indirect environmental impacts linked to their activities/products/services as required by ISO 14001 (2015) - environmental management standard recommendations - in order to comply with the environmental pollution requirements. (Arama et al. 2013; Arama et al, 2017b, Arama et al, 2018a). In those conditions "industrial wastewater treatment plants are faced with the need for more efficient and complex technologies on the one hand, and higher profitability requirements on the other hand" (Pintarič et al., 2016) and this can be achieved starting with an appropriate selection of groups of emulsions to be pretreated/treated with certain type of combination of technologies. In this respect we have chosen as case study two samples of waste oil classified according to the harmonized European Waste Catalog (EWC) (EC Commission Decision, 2000; EC Commission Decision, 2014; EC Regulation, 2014;) as dangerous under the code: 12 01 09* machining emulsions and solutions free of halogens - Sample E1 (Emulsion 1) and under the code: 16 10 01* aqueous liquid waste containing hazardous substances. – Sample E2 (Emulsion 2).

Step 2: Characterization of the selected waste samples for the selected case study

Source. Emulsions are coming from an organization producing parts for automotive industry.

Sample E1 represents spent cutting fluids and coolants containing commercial products like Ecocool Global and Ecocool Ultralife LBF with water in different proportion and commercial additives like Actinia 14/Acticide 14 - biocide for industrial use and Renoclean SMC – detergent.

Sample E2 represents a mixture that comes from different operations such as:1) cleaning and maintenance operations (cleaning the air filter), 2) cleaning operations from waste disposal space contaminated with oils, 3) mechanical processing (cooling fluids) and can contain small amounts of the above-mentioned commercial products and a variety of other oils and detergent products used in organization.

Step 3: Preliminary destabilizing tests

Those tests have been performed considering some of the pretreatment/treatment techniques for o/w emulsions that combine physical and chemical processes like gravitational settling, filtration, flotation, centrifugation, dilution, adsorption, conventional heating coagulation, flocculation, (…) as they are mentioned in the literature (Pintarič et al., 2016; Zolfaghari et al., 2016).

3. Results and discussion

In the Table 1 are summarized the results of the preliminary tests performed on the chosen type of emulsions. We followed in this pretreatment methodology what is generally reported by the literature in the field (Hu et al. 2017; Mihaila et al., 1994) namely that "visual observation is probably the simplest cheapest, and quickest method to assess the gravitational separation of the emulsion without expensive analytical instruments" having as reference the aspect of the initial samples. Sample E1 is liquid with milky aspect; left without shaking at the room temperature after one week tends to separate an oil phase with a volume between 0÷1% of the initial volume. Sample E2 is a liquid with blurry dark grey color; left about one week without shaking at room temperature presents a trend of floating light grey suspensions adherent to the recipient;

We considered generally gravitational and centrifugal separation with the two well-known mechanisms namely creaming and sedimentation. The densities of the two phases are pretty close one to another so one expects that creaming to happen more often within the physical applied techniques while sedimentation one expects to seldom appear and only in chemical or (combined) hybrid techniques.

The results leaded to the three types of conclusions for the purpose of destroying the stability of o/w considered emulsions and for future development of the optimized treatment technologies. ***Conclusions of type W:*** are referring to "***weak towards average results"***; ***Conclusions of type M****:* are referring to "***average towards good results***"; ***Conclusions of type G****:* are referring to "***goods towards very good results***".

Conclusions of type **W** have been generally attributed to tests giving *"weak towards average results"* in the process of destroying stability that was noticed only through visual observations in terms of color or opalescence changes and flotation trend of few fine flocons. The observed changes were generally comparable to those observed usually after 2÷3 weeks of leaving such emulsions in transparent containers, without shaking them at normal temperature. Due to the weak obtained visual results observations, those type of preliminary tests will not be recommended in the proposed methodology for the optimization treatment method to be further followed.

Conclusions of type **M** have been generally attributed to the tests giving *"average towards goods results"* in the process of destroying stability that was noticed only through visual observations in terms of color or opalescence changes for color changes or opalescence with ready visible separation of phases that progresses in very short time either with the formation of a superior oil layer (creaming phenomenon) either with the formation of flocons that float or sediment in 2÷3 hours. Those changes are generally visible in very short time and the good results point toward resuming are selected to resume the further the tests experiments for optimization of phase separation.

Conclusions of type **G** have been generally attributed to the tests giving *"good towards very good results"* in the process of destroying stability visible only through changes in color, opalescence and immediate separation of phases, progressing in time by obtaining very good clarities for the aqueous phase and of very well developed flocons that can float or even settle in a very short period of time. For those tests, some global or specific indicators capable to characterize separation efficiency of phases and the possibility to use the oil phase have been realized. The preliminary tests results are synthetized in the Table 1.

For the tests that gave good results and where marked with G in Table 1 we analyzed some relevant indictors that in the literature are also used to show the efficiency of phase separation and the quality of the separated phases. We have chosen the following indicators: for ***aqueous phase***: *Turbidity, COD (Chemical Oxygen Demand), DOC (Dissolved Organic Carbon) TDS (Total Dissolved Solids) PP (Petroleum Products) and for the* ***oil phase*** were: *Qs (Superior heating value), Qi (Inferior heating value),* (Serbanescu et al, 2018) *Humidity, Total Organic Carbon.*

In the Table 2 and Table 3 are presented the best obtained results with the proposed pretreatment methodology for the sample type "E1" (results G* in Table 1 and for the sample type "E2" (results G** in Table 1).

Table 1. Pretreatment methods of o/w emulsions for recovery of oil phase and for facilitating the further treatment of separated water phases to be discharged in surface waters

Applied Methods for destroying emulsions stability	***Results***	
	Samples Name	
	Sample E1 (12.01.09*)	***Sample E2 (16.10.01*)***
I.1.Through impact in gravitational field		
-Sedimentation	W	M
-Filtration with paper filter (retains 2÷3µ)	N/A	G
-Filtration with combined filter (paper and carbonized wood)	N/A	G
I.2. Through impact in centrifugal field	W	W
I.3. Through variation of temperature	W	W
I.4. Through variation of temperature and centrifugation	M	W
I.5. Through dilution	W	W
II.1. Through pH modification	M	W

II.2. Through introduction of electrolytes (small molecular weight coagulants) followed by sedimentation 2 hours		
-Salts of Me^{2+} soln. 5 % $MeCl_2$. Sedimentation (2 h)	M	G
-Salts of Me^{3+}/Me^{2+}soln. 5 % $MeCl_3$/$MeCl_2$. Sedimentation (2 h)	N/A	N/A
III.1. Through pH change with conc. acids (pH:3÷4) with oil phase separation and sedimentation for 2 hours.	G*	W
III.2. Through pH change with conc. acids(pH:2-3) followed by progressive centrifugation for 10 minutes at 6000 rpm (rotations per minute) and oil phase separation	M	N/A
III.3. Through introduction small molecular weight coagulants, pH:6÷6.5 - for being in the area of acceptance for discharging treated water in the surface waters		
Coagulation with small molecular weight coagulants (soln. 5% $MeCl_3$) and sedimentation for 2 hours.	N/A	G
Coagulation with small molecular weight coagulants (soln. 5% $MeCl_3$) and filtration with paper filter retaining 2÷3 microns and carbonized wood waste.	N/A	G**

Table 2. The best preliminary tests for the obtained water phase after destroying emulsion stability

Samples with results type G	***Aqueous Phase Efficiencies of abatement for the following indicators compared to the initial sample from ecological point of view for water phase reclamation***					
	Turbidity	***SM***	***TDS***	***COD***	***DOC***	***PP***
	Units of Measurements					
	%	%	%	%	%	%
Sample E1(results G*in Table 1)	90 ÷99	-	60÷63	80÷89	80÷91	90÷99
Sample E2 (results G** in Table 1)	90÷93	50÷58	12÷16	40÷50	70÷75	45-50

Table 3. The best preliminary tests for the obtained oil phase after destroying emulsion stability

Samples with results type G at the preliminary tests	***Oil Phase Indicators with relevance for the use of separated oil phase as fuel substitute***					
	Humidity	Q_s	Q_i	C_{total}	***TOC***	***Ash***
	Units of Measurements					
	%	Kcal/kg	Kcal/kg	**%**	**%**	**%**
Sample E1(results G*in Table 1)	20÷22	8000÷8300	7500÷7700	70÷72	-	4 ÷5
Sample E2 (results G** in Table 1)	60÷65	6500÷6800	6300÷6500	-	45÷50	4÷5

For these two types of pretreatment we have tried to keep the costs of pretreatment as low as possible. For the sample type "E1" we used for separation of phases a combined chemical and physical treatment with concentrated acid (HCl) until up to pH=3÷4 and sedimentation for 2 hours. The obtained recovered oil phase has a humidity of 20÷22%, TOC about 72%, Superior Heating Value of 8000÷8300 Kcal/Kg comparable with a diesel fuel (that has the superior heating value of about 10000 Kcal/Kg) and an ash content about 4÷5%. Relative to the initial treated liquid aqueous emulsion sample "E1" composition, the efficiencies for separated *aqueous phase* were considered good towards very good. The range of variation for obtained abatement efficiencies for the considering the relevant indicators for water phase - turbidity, COD, DOC and PP was 80÷99% only with addition of acid up to pH=3÷4 followed by sedimentation for 2 hours.

However, it should be noted that although the efficiencies of abatement were very high (the COD for the initial treated o/w emulsion was about 300 000 mg/L) and the final very good result for the treated sample exhibited a COD of about 37000 mg/L which means over 95% efficiency, in order the waste water to be discharged in the surface water it will be still necessary to apply a further treatment to final reach a COD values around 120÷125 mg/L.

Our obtained results (see Table 2 and Table 3) were similar with those reported by other researchers in terms of abatement efficiencies for relevant water and oil phase indicators (Santo et. al. 2012; Demirbas and Kobya, 2017) by applying more expensive hybrid methods. For example, results reported by Rattanapan et al, 2011; Siles et al., 2012 and cited by Jamally and its coworkers (Jamaly et al., 2015) showed that for reference samples with a similar range of COD (300 000 mg/L) as our used sample E1, the removal efficiencies for the main relevant indicators for water phase were COD: 50÷99 and turbidity 90÷99% using DAF (Dissolved Air Flotation) coupled with acidification and coagulation to treat biodiesel waste water. The same is valid also for the oil phase according to the results presented in Table 3 where we have obtained an oil phase with 20÷22% humidity and a calorific power comparable to a diesel fuel but with a less expensive pretreatment technology. We hope that further optimization of this proposed technology can improve significantly the water phase indicators aiming also for as low as possible treatment costs.

For the sample type "E2" for separation of phases we used coagulation with small molecular weight coagulants (soln. 5% $FeCl_3$) followed by filtration with a combined filter paper retaining 2÷3 microns and carbonized wood waste from food industry in the spirit of circular economy to be able to use the wastes from two types of industries. Relative to the initial sample "E2" the abatement efficiencies for the investigated relevant indicators for aqueous phase were ranging as follows: for turbidity:90÷99%, for COD and DOC about 50÷60%. The initial range of turbidity was about 1700÷2000 NTU and the final value was < 30 NTU. The initial range of COD was about 12000 mg/L and the final obtained COD was about 5000 mg/L.

Those values are still high enough to be discharged in the surface waters, so that the obtained water phase will necessitate further treatment to reach the required legal limits for surface water discharge. The used filter material was composed of carbonized waste wood from food industry and filter paper that retained the sludge from coagulation process. This filter material can be incinerated because it has TOC of more than 50% and Qs about 6800 Kcal/Kg comparable with a solid fuel like a bituminous coal this way it can be easy used as a fuel substitute.

4. Conclusions

With the proposed methodology we hope to help producer/holder, to reduce the volume of waste to be disposed and to be able to recover valuable components from their waste and start to implement the principle of circular economy so that waste from one industry can be used another industry.

The obtained results showed for the recovered oil phases the following values for the determined relevant indicators: carbon content 50÷70%, humidity 20÷65%, ash content 4÷5% and superior heating value 6800÷8800 Kcal/kg which might be a valuable fuel substitute with the condition that ecologic characteristics that can be further investigated dependending on the requirements of incineration facility to be met.

The obtained results for the separated water phases were also encouraging: turbidity 20÷30 NTU (Nephelometric Turbidity Units) and COD (Chemical Oxygen Demand) 5000÷7000 mg/L. The low costs physical-chemical pretreatment proposed technologies brought the obtained results in line with other more expensive hybrid technologies presented in recent literature in the field making them more attractive for the implementation within a circular economic model.

We believe that future waste recovery technologies will make circular economic model an instrument of balancing social, economic and environmental aspects within the frame created by European common market that will offset local and conjuncture differences between different European industries/economies at a certain moment.

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