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DOCTORAL THESIS

CONTRIBUTIONS TO THE HIGHER ENERGY VALORIZATION OF WASTE OILS USING NANOSTRUCTURED MATERIALS

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ABSTRACT

Waste oils result from lubricants of natural or synthetic origin, used in internal combustion engines and in industrial processes.At the same time, waste oils are considered toxic and hazardous waste for both the environment and humans.

Holders of waste oils are obliged to ensure the sorted storage and sealing of containers of different types of waste oils. Sealed containers, in which used oils are collected, require a fairly high resistance to mechanical and thermal shock, as they are stored in spaces specially designed to prevent environmental pollution in the event of unforeseen leaks.

Mixing of used oils with each other or of oils containing polychlorinated biphenyls or other similar compounds, their discharge into the ground and their discharge is strictly prohibited.

Individuals owning used oil have the obligation to hand over the full amount free of charge to legal entities authorized to collect used oils.

The oils used, which come from heat engines, wear out during operation, causing their properties to change, and need to be changed. In general, the common factors that lead to oil wear are the metal particles in the engine left in the oil, dirt and sometimes water. Waste oils contain metal particles and hydrocarbons.

Environmental pollution with waste oils can be reduced if this hazardous waste is recovered by purifying and reusing it in the automotive and industrial fields. This technology of purification of waste oils requires organizational, scientific and economic efforts for an evolution of this branch.

The paper proposes the development of advanced and integrated technologies for materials with adsorbent properties (eg bentonite) and the use of these materials in waste oil recovery processes, with purifying and energy recovery effect. The main objective is to replace diesel fuel, which is an expensive fuel with purified oils for energy production. To achieve this, we must turn our attention to two important sets of laboratory experiments.

The first tests are related to determining the optimal concentration of bentonite to remove metals from used oil. Purification of waste oil leads to the protection of the combustion plant, to increase its life and to reduce pollutant emissions. The second set of experiments concerns the determination of the energy characteristics of waste oil and purified waste oil for energy production. Elemental analysis, lower calorific value, viscosity, density and ash analysis were determined. Experimental testing of the combustion process on a small-scale boiler was performed, and the results showed an improved combustion process and reduction of pollutant emissions for purified waste oil.

Environmental pollution is a topical issue and the attempt to obtain non-polluting fuels or the recovery of waste materials for energy purposes is of concern to many researchers today.

Used engine oils can be contaminated with impurities resulting from unwanted oxidation processes: sediments, water, metal particles and degraded additives [1]. There are several ways to remove these contaminants.

The proposed technology aims at the process of purification of residual oils from internal combustion engines, by treatment with natural or modified nanostructured compounds. In this regard, bentonite was chosen as the nanostructured material. Bentonite powder plays an important role in the purification of waste oils [2].

Finally, this method of purifying used oil was applied to an industrial hall, from a car service.

The application of the research results will contribute to ensuring a sustainable economic development at the level of the analyzed field. This promotes the exploitation and use of deposits of

natural absorbents (bentonites, zeolites) and the use of new energy resources, while saving classical resources. An important benefit of waste oil treatment-purification is the elimination of a complex source of pollution and the return to consumption of a combustible material. As a result of the investments for the exploitation and use in the field of the project of the natural deposits of absorbents, an economic development of the respective geographical area will take place, which will lead to the improvement of the living and health conditions of the local population.

By creating new jobs, so by increasing the employment rate, it also contributes to increasing the living standards of the population. Also, through the works within the topic, jobs are supported for high value specialists in the field of research, while providing conditions for training specialists in the field and enriching the experience by accumulating the latest knowledge in the field.

CHAPTER 1. INTRODUCTION

This first chapter presents the current issue of trying to obtain clean fuels or recovering waste materials for energy purposes, which is currently of concern to many researchers. It is necessary to resolve the issue of used road vehicle oils in accordance with Directive 2008/98 / EC on waste and the national legislation in force: Decision no. 235 of March 7, 2007. This Decision provides for all operations by which waste oils may be transferred from the holder to economic operators who may collect, recover or dispose of such oils or use them as fuel with adequate recovery of the heat generated. Engine oils are used to lubricate the components of the engine assembly, and its essential properties are: grease / lubrication to reduce friction between moving parts, cooling of parts that come into contact, especially the piston, cleaning parts of residues deposited after the process combustion (eg cylinders, segments, piston), protection against chemical corrosion of engine parts.Particulate contamination is due to incomplete combustion of the fuel and increases the viscosity of the oil.

CHAPTER 2. CURRENT STATE OF THE VALORIZATION BY BURNING OF WASTE OILS FROM ROMANIA AND THE PHYSICO-CHEMICAL CHARACTERISTICS OF WASTE OILS

This chapter presents the problems of waste oils from the automotive field, such as the collection, storage, transport and processing by appropriate categories of this residue.

Numerous studies have been conducted worldwide, which have led to the toxicity of waste oils, based on which technologies have been developed to purify them. Currently, among the most well-known and applied technological processes are: the TDA process, the
INTERLINE process and the CEP-Mohawk process. They separate a fuel and a fraction of purified oil which, following processing, is used in the manufacture of lubricating oils. The problems related to the reduction of pollution with waste oils and related to the recovery of this hazardous waste are still numerous and require, at all times, many organizational, scientific and economic efforts to solve. The following is a block diagram of the waste oil purification process.

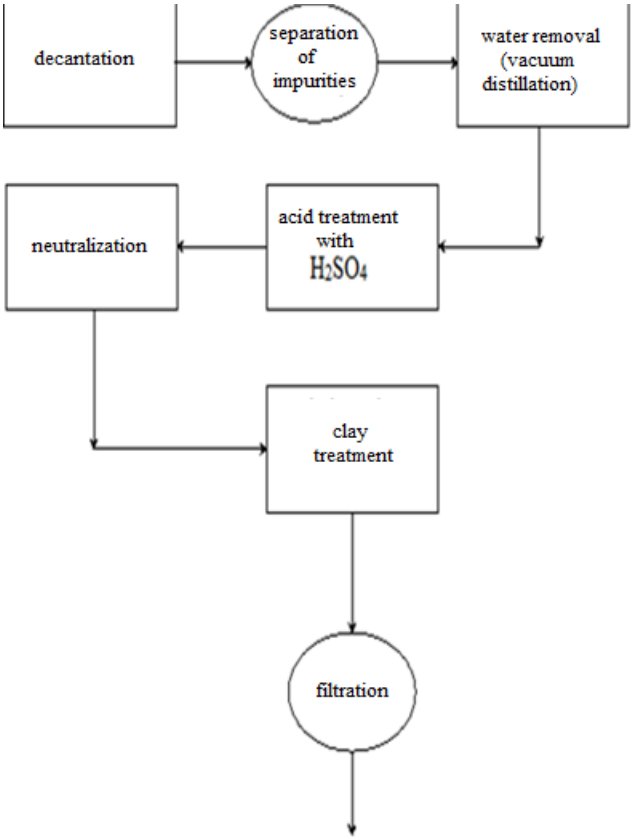


Fig. 2.1 Block diagram of the waste oil purification process. [3]

Starting from this scheme, the aim was to remove impurities from the used oil, without resorting to a chemical process.

Also in this chapter are presented the physical-chemical and energetic characteristics of mineral and used oils. The lubrication of the heat engines is done with the help of mineral oil, which has a complex composition:

- Basic oils, approximately 75-85%
- Additives, approximately 15-25%

Basic oils have the main role of lubricating parts. Depending on the classification, the raw material used and the manufacturing technique, they are:

- mineral base oils, when the raw material is oil;
- synthetic base oils, which are obtained by chemical methods;
- semi-synthetic base oils are mixtures of mineral oils and synthetic oils in a proportion of approximately 20-30%.

Additives are chemicals that, by mixing with the base oil, significantly improve its characteristics in the lubrication system of heat engines.

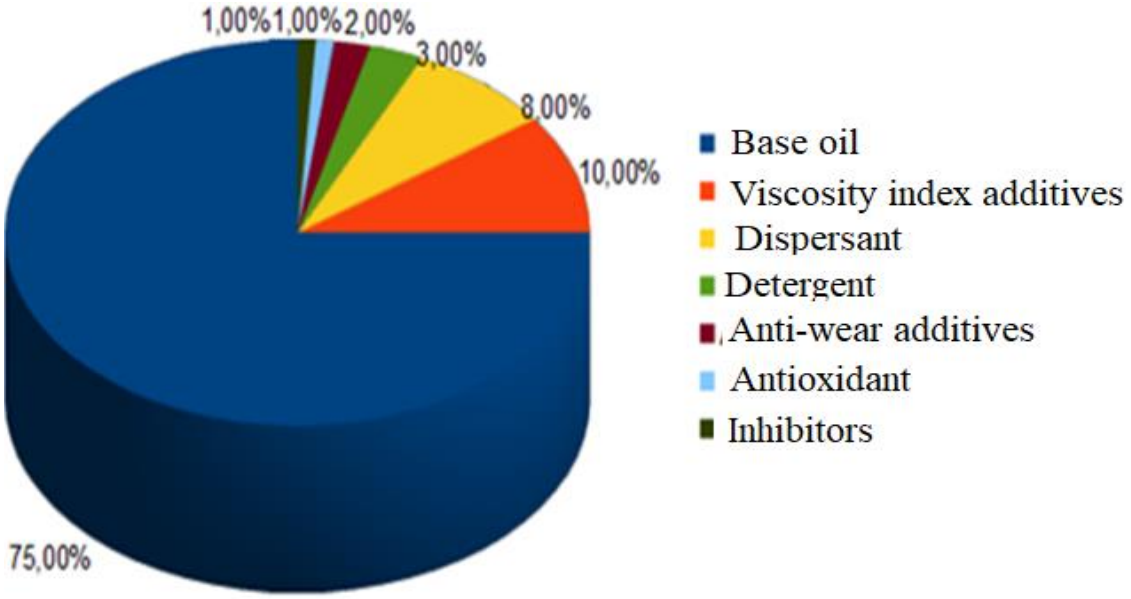


Fig.2.2 Composition of additives in an engine oil (SAE 5W-30) [6]

The physico-chemical properties of engine oils depend to a large extent on the type of base oil, the technology applied in manufacturing, as well as the nature of the additives implemented in the base oil. Unctuousness and viscosity are the main lubrication and flow characteristics of oils. The density of the oils varies between 0.88 and 0.99 g / cm3.

The flash point is the minimum temperature at which oil vapors ignite in the presence of a flame, which is between 200-250 ° C for oil.

The methods of analysis are the same for both the characteristics of waste oils and the characteristics of mineral oils (lubricants). Following the analysis of some waste oil samples, resulting from different categories, an average composition of the used oil was established.

Table 2.2 Average composition of waste oils [7]

Component	% masă
Gasoline (final boiling point 177ºC)	1-6
Diesel (final boiling point 177-343ºC)	10-15
Oil (boiling range 343-429ºC)	60-70
Heavy oil (bright stook)	0-10
Water	0-10
Additives	7-15
Oxidation products	5-8
Solid particles (dust, coal)	1-3

Characteristics of waste oils:

a) TIN oils

Table 2.3 Characteristics of TIN oils [7]

Characteristics	TIN 82/EP/90	TIN 125/EP/100
Density at 20ºC max., g/cm^3	0,919	0,924
Freezing point, 0ºC max.	-20	-15
Viscosity at 50ºC, cSt	82….90	130….140
Corrosion on copper blade, max.	2	2
Corrosion on steel	-	-
Organic acidity KOH/g, min.	-	-
Water (distillation method) %	lipsă	lipsă
Mechanical impurities, %	lipsă	lipsă

b) Oils L

Table 2.4 Characteristics of L oils [7]

Characteristics	L235
Relative density at 20ºC, g/cm^3	0,910
Viscosity at 50ºC, cSt	228….244
Engler viscosity ºE, la 50ºC	30….32
Viscosity at 100ºC, cSt	26
Viscosity at 100ºC, ºE	3,6
Freezing point, 0ºC max.	-4
Mechanical impurities	lipsă
Ash, %, max.	0,01
Coke figure, % max.	1,4
Mineral acidity and alkalinitY	lipsă
Organic acidity, KOH /g, max.	0,04
Water (distillation method)	Lipsă

c) Oils H

Table 2.5 Characteristics of H oils [7]

Characteristics	H100	H46A
Relative density at 15ºC max., g/cm^3	0,910	0,905
Kinematic viscosity at 40ºC, cSt	90….110	44….49
Organic acidity KOH /g, max.	0,05	0,2
Pour Point , ºC	-8	-35
Corrosive action on copper	16	16
the tendency to foam 5 'blowing air	15	9
Ash , % max.	0,01	0,01

The following is a comparison between the characteristics of mineral and used oils, as follows:

Mineral oils are obtained by vacuum distillation of fuel oil. The distillation process results in oils, vaseline and asphalt. Oils are mixtures of alkanes, alkenes, cycloalkanes, aromatic hydrocarbons, cyclic compounds with nitrogen and sulfur with a molecular weight of between 300 and 1,000 atomic units of mass. The presence of alkanes (paraffins) is desirable in the composition of oils, while olefins (alkenes) and sulfur compounds greatly diminish the qualities of a lubricant.

Waste oils are obtained from the wear of lubricating mineral oils, this process requiring adequate collection and sorting, in airtight containers, resistant to mechanical and thermal shock.

The water content has undetectable values in mineral oils compared to used oils and has a share of 0 - 10% of the density of mineral oils, as well as used ones, which is temperature dependent, but differs slightly (880 ÷ 990) kg / m3 at mineral oils compared to (950 ÷ 990) kg / m3 for waste oils.

The density of diesel is about 830 kg / m3. Due to the close density of diesel and oils, they are easily miscible and do not separate after mixing.

The flash point is the minimum temperature at which vapors released in admixture with air ignite from an incandescent source at normal atmospheric pressure. Mineral oils have a flash point between (200 ÷ 250) ° C , compared to used oils, which have a flash point between (160 ÷ 190) ° C . These values are much higher than that of diesel (81° C). However, mixtures with light liquid fuel have a flash point close to that of diesel. [9]

The viscosity of the mineral oil is temperature dependent. At a temperature of 20° C , it will have a viscosity between the values (13,2 ÷ 14,5) °E.

The viscosity of used oil is also temperature dependent. At a temperature of 50° C, it will have a viscosity between (16,6 ÷ 14,7) °E.

The percentage of sulfur in mineral and used oil is almost non-existent, this being a positive aspect, because, following the burning of sulfur, sulfur dioxide SO3 is formed, which, by hydration with water from the flue gases, forms sulfuric acid H2SO3. The advantage of low amounts of sulfur in oils is that it reduces the corrosion process of the cold surfaces of the boilers. [9]

Law no. 22/2011 of July 28, 2011 is particularly important for the topic of this thesis, on establishing limit values, threshold values and criteria and methods for evaluating the metal content of waste oil. The purpose of this law is to prevent, eliminate, limit damage and improve air quality in order to avoid adverse effects on human health and the environment. [11]

Following the combustion process of the used oil, a considerable amount of ash remains, which contains metal residue, which is largely eliminated by the flue gases. Following the experiments, 1 liter of used oil contains about 200 mg of metal impurities, at 10 m3 N flue gases, resulting in a heavy metal concentration of 20 $\frac{mg}{m^3N}$, being a fairly large amount, which is removed into the air and then infiltrates the soil.

Metals with a fairly high percentage, which are found in the composition of used oil and which affect humans are: iron (Fe), zinc (Zn), Lead (Pb), Cadmium (Cd), Copper (Cu), Nickel (Ni) .

Iron, although the proper functioning of the immune system is dependent on this element, inhaled and ingested in excessive amounts, it becomes toxic to humans because it reacts with peroxides in the body, producing free radicals and triggering diseases such as Alzheimer's, cancer, Parkinson's, arthritis, cardiovascular disease and more. [12]

Acute exposure to zinc oxides causes irritation of the respiratory tract and has symptoms such as chest pain, cough, fever, headache, nausea and muscle aches. [11]

The effect on health associated with lead pollution and its compounds leads to decreased hearing, developmental delays (in newborns), hypertension, neurotoxicity, increased infertility, especially in men, and hemoglobin synthesis. Reducing the synthesis of hemoglobin in the blood increases the chances of severe anemia and, at the same time, can cause inability to concentrate and decreased memory, which are consequences of central nervous system disorders. Children are most affected by this element, as the probability of ingesting lead-contaminated soil is higher in children under 5 years of age. [11]

The organs most affected by cadmium exposure are the lungs and kidneys, due to ingestion or inhalation. Another effect of cadmium exposure is that it increases the appearance of impotence in men.Atherosclerosis can also occur, depending on the amount of cadmium in the blood. In the kidneys, the most common diseases are the accumulation of minerals. [11]

Nickel allergies are frequently noticed in those who come into frequent contact with it, more precisely in the dermal level, thus causing allergic contact dermatitis. The most important health problem when exposed to nickel is lung cancer, cancer of the nostrils and sinuses of the paranasal sinuses,

even if this residue is inhaled in small amounts. Other ailments recorded on nickel exposure are the sensation of metallic taste and decreased vitality, both physical and mental. [11]

CHAPTER 3.TECHNOLOGIES FOR THE PURIFICATION OF WASTE OILS. FILTERED NANOSTRUCTURED MATERIALS

This chapter is intended for the presentation of adsorbent materials and especially bentonite. This clay will be used in the experiments performed. In this chapter we will present and compare other methods of purification of waste oils.

Bentonites are mainly made of montmorillonite, they have a low hardness, are light, have a white color with shades of green-blue, pink, yellow, brown. The granulation varies between 1-500 millimicrons. The crack is typically conchoidal. The specific weight is between 2.7 - 2.8 g/cm^3, 1,6 – 1,8 g/cm^3.. They have a compact or porous appearance. [13]

The chemical formula of montmorillonite is: $(Na, Ca)_{0,3}(Al, Mg)_2[Si_4O_{10}(OH)_2]nH_2O$.

Hydrated aluminosilicates are the formations that make up bentonite, which has a high adsorption and ion exchange capacity, due to the fact that it is largely composed of montmorillonite.

Some cations can be replaced due to hydrated aluminosilicates, which make up complex molecules.

Cation exchange and adsorption capacity depend on the crystallinity of the particles, the pore structure, the textural and structural features, the pH and temperature of the solution, the solution-adsorbent contact time, the chemical nature of the sorbent surface and the cation present in the mobile layer.

Waste oil purification technologies are vast, but in this chapter were presented only the closest to the method of purification of waste oil in the thesis, namely: Revivoil technology, Blowdec technology, Dunwell technology, Prop technology.

Technology name: PROP [14]
Licensor: Phillips Petroleum Company
Process description:

In this process, the used oil is treated with diammonium phosphate dissolved in water to separate metals and ash. The next step is that the preheated mixture, consisting of the used oil and the descaling solution, is sent to a container in which the salt water is dispersed in the oil. The metal-phosphate compounds formed as a result of the chemical reaction are removed by filtration. Phosphates do not pose a danger to the environment, so they can be easily removed.

The filtered oil is refreshed by separating light hydrocarbons and water, which can be used for plant needs.

After cooling, the oil is mixed with hydrogen and filtered with diatomaceous earth to remove traces of compounds, which may poison the hydrotreating catalyst. The substances retained by the filter are generally burned and the diatomaceous earth is recycled.

Finally, the oil is passed through the nickel / molybdenum catalyst in the hydrogenation reactor, where the compounds containing oxygen, sulfur, chlorine, nitrogen are removed and the color of the oil is improved.

Conclusions:

This method is quite expensive.Both adsorption and hydrofining treatment are needed.

The advantage is the quality of the oil, which contains less than 10 ppm of metal scrap.So far, the method has been applied in industry. Several plants have been built, but they are not operational due to financial problems.

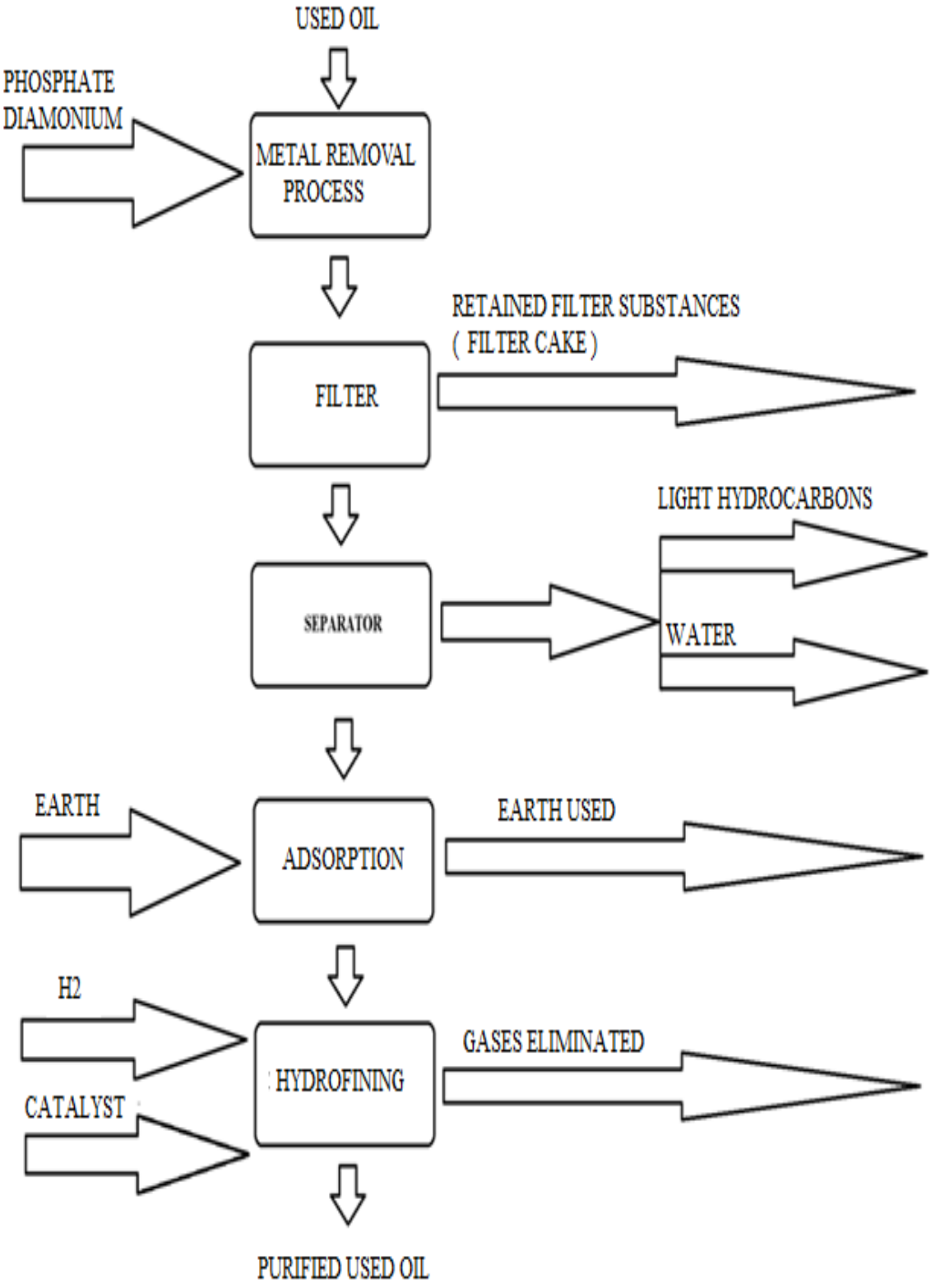


Fig.3.1 Prop technological scheme [14]

CHAPTER 4. ADSORPTION CAPACITY MODELING STUDY FOR THE PURIFICATION OF WASTE OILS

In chapter number 4, the adsorption as a unit operation was deepened from the specialized literature, as well as the thermodynamic equilibrium of adsorption, the equilibrium at adsorption of strong electrolyte ions, activated adsorption, adsorption process kinetics, theories on adsorption process, types of diffusion encountered in adsorption, diffusion coefficients on adsorption, mass transfer on adsorption, mass transfer rate on adsorption, phase contacting methods for mass transfer in adsorption operations, step contacting and fixed layer contacting.

This chapter led to the development of a mathematical model in this thesis and to the choice of the closest calculation relationship that reflects the process of purification of waste oil, using bentonites. The chosen calculation relations are the relations of Freundlich 5.2 and of Kul and Koyuncu [17] 5.3:

$$Q_t = \frac{C_0 - C_t}{m} \cdot V \tag{4.31}$$

$$Q_e = K_F \cdot C_0^{1/n} \tag{4.32}$$

CHAPTER 5. EXPERIMENTAL RESEARCH REGARDING THE PURIFICATION OF WASTE OILS FOR ENERGY RECOVERY

Within this chapter, experimental research activities were carried out with the aim of highlighting the particularities and performances of the process of burning purified waste oil, from the automotive industry. Their role is to confirm the possibility of carrying out an appropriate spray, followed by a proper ignition and combustion, compatible with the requirements of energy installations.

The experiments took place in the Combustion Installations laboratory of the Thermotechnics, Engines, Thermal and Refrigeration Equipment Department of the Faculty of Mechanical and Mechatronics Engineering within the Polytechnic University of Bucharest.

The research carried out up to this stage has highlighted the possibility of capitalizing by burning purified waste oil.

The efficiency of the combustion plant depends on the judicious choice of the constructive and functional parameters of the injectors used. The characteristics of the spray jet for mechanical injectors with vortex chamber (return) are:

- Fuel flow and its adjustment range;
- Jet flaring angle;
- Liquid fuel distribution density;
- Spray fineness (average diameter and droplet distribution);
- Maximum diameter of the fuel drop.

These characteristics must be achieved for the well-defined physical properties of the purified oil used: (viscosity, surface tension and density) and at a preheating temperature necessary for a corresponding fluidity (2-3 ºE). ,

To determine the kinematic viscosity of the used oil, determinations were performed at temperatures of 50 ° C, 80 ° C, 100 , having values of 4,05 ºE, 2.01 ºE, respectively 1,52 ºE.

The flash point of the used oil used is 152° C. All the characteristics of the waste oil analysis bulletin were performed in the I.C.E.M.E.N.E.R.G. and are found in the tables below.

Table 5.1. Waste oil - diesel engine

Nr. crt	Characteristic	U.M.	Value	Method of determination
1.	Lower calorifica value, Q_i	Kcal/kg MJ/Kg	10,110 42,33	ASTM D 240
2.	Carbon content, C	%	84,12	ASTM D 5291-16
3.	Hydrogen content, H	%	14,29	ASTM D 5291-16
4.	Nitrogen content, N	%	0,33	ASTM D 5291-16

Table 5.2. Waste oil - gasoline engine

Nr. crt	Characteristic	U.M.	Value	Method of determination
1.	Lower calorifica value, Q_i	Kcal/kg MJ/Kg	10,023 41,96	ASTM D 240
2.	Carbon content, C	%	83,56	ASTM D 5291-16
3.	Hydrogen content, H	%	13,17	ASTM D 5291-16
4.	Nitrogen content, N	%	0,41	ASTM D 5291-16

Elemental analysis of waste oil for nickel and iron in spark ignition engines (SI engines) and compression ignition engines (CI engines) was performed in UPG laboratories.

The following table presents the results of all the analyzed samples:

Table 5.3. Test results from used oils

	Used oil SI engine B			Used oil CI engine M		
	1	2	3	1	2	3
Quantity g	5,81	5,5	5,75	5,15	5,87	5,75
Nickel concentration (Ni) ml/kg	0	0	0	2,13	0,68	0,52
Iron concentration (Fe) ml/kg	148,88	94,9	101	220,19	127,19	117,56

From the analysis of waste oils (both from SI engines and from CI engines), the initial concentration of metal ions is between 50 and 200 mg / liter. 4 classes are required, namely: 50, 100, 150 and 200 mg / g. The equilibrium adsorption capacity was calculated for these 4 classes and the values in the table below were obtained:

Table 5.4 Initial metal ion capacity and equilibrium adsorption capacity

Cantitatea inițială de ioni de metal, mg/l	50	100	150	200
Capacitatea de adsorbție, mg/l	5	10	15	20

The following experiment was performed at the National Center for Micro and Nanomaterials (C.N.M.N.), the structural analysis laboratory within the U.P.B.

It is mentioned that the bentonite used in the experiment was procured from Romania, more precisely from the calcium bentonite quarry from Orașul-Nou, activated by a specific process, having the following technical data presented in the table below:

Table 5.5 Technical data on bentonite used in the experiment

Colour	Maximum granulation [mm]	Bulk density [kg/m^3]	Moisture	pH	Compression strength(wet) [N/cm^2]	Bentonite number
Cream colored	Ø 0,063 - sort B6SA max. 25 % - sort B5SA max. 15%	800-850	Max. 10 %	Min. 8%	4 - 5	Min. 0,85

After mixing, we took the mixture between adsorbed metal ions and bentonite. Mixing time was not monitored in these experiments. The ash test was performed by burning the mixture for 2 hours at 815 degrees Cesius. Subsequently, elementary ash analysis was performed using Agilent 8800 Inductively Coupled Plasma Mass Spectrometry (ICP-MS) equipment (Agilent Technologies, Japan).

Prior to ICP-MS measurements, the samples were weighed individually and placed in special TFM tubes. After the addition of 2 ml of nitric acid (HNO3), the samples were digested in a microwave system (Milestone Ethos, FKV, Bergamo, Italy) at 200 ºC for 35 minutes at a maximum power of 1800 W. After cooling, the digestion fluids were diluted with ultrapure water to 25 ml. The measurements were performed for the most abundant isotopes of each element and the results presented in the following table were obtained:

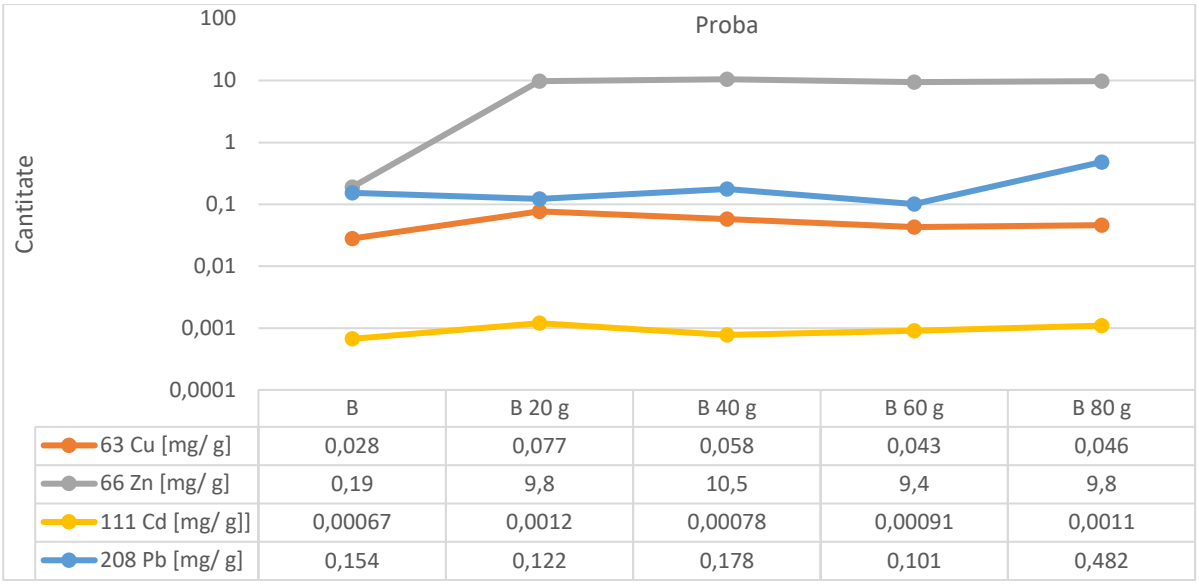


Fig. 5.1. Ash samples of used oil with 20 g, 40 g, 60 g, 80 g, bentonite

Table 5.6. Results after analysis of bentonite ash mixed with used oil

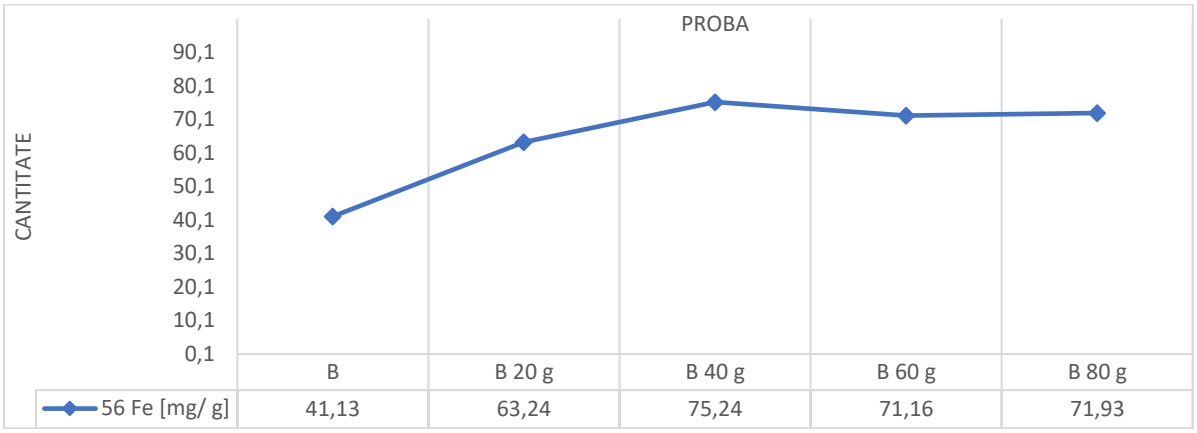
Sample	Quantity [g]	56 Fe [mg/ g]	63 Cu [mg/ g]	66 Zn [mg/ g]	111 Cd [mg/ g]	208 Pb [mg/ g]
B	0,1004	41,13	0,028	0,19	0,00067	0,154
B 20 g	0,1009	63,24	0,077	9,8	0,0012	0,122
B 40 g	0,1005	75,24	0,058	10,5	0,00078	0,178
B 60 g	0,0999	71,16	0,043	9,4	0,00091	0,101
B 80 g	0,1002	71,93	0,046	9,8	0,0011	0,482

From these analyzes it was possible to draw two graphs in order to choose the best sample for the experiment.



	B	B 20 g	B 40 g	B 60 g	B 80 g
63 Cu [mg/ g]	0,028	0,077	0,058	0,043	0,046
66 Zn [mg/ g]	0,19	9,8	10,5	9,4	9,8
111 Cd [mg/ g]]	0,00067	0,0012	0,00078	0,00091	0,0011
208 Pb [mg/ g]	0,154	0,122	0,178	0,101	0,482

Fig.5.2. Graphical determination of Cu, Zn, Cd, Pb impurities, adsorbed by bentonite



	B	B 20 g	B 40 g	B 60 g	B 80 g
56 Fe [mg/ g]	41,13	63,24	75,24	71,16	71,93

Fig.5.3. Graphical determination of Fe impurities, adsorbed by bentonite

From the presented results it was chosen to perform the calculations and experiments, for 20 g and 40 g of bentonite introduced in a liter of used oil. The aim was to make as little bentonite as possible. The optimal mixing time is of the order of minutes (between 10-30 min). Note that the mixture was made with a battery mixer. Obviously, at the combustion plant to be implemented, the mixture in the used oil tank will be coordinated by an automatically operated electrical device.

In order to calculate the minimum mixing time between the used oil and bentonite, so as to reach the adsorption capacity at equilibrium with minimum electricity consumption, the equation Kul and Koyuncu [17] was derived in relation to time, obtaining

$$\frac{dQ_t}{d\tau} = \frac{V}{m}\left(-\frac{dC_t}{d\tau}\right)\Big|_0^{Q_e} \tag{5.4}$$

Next, the Kul and Koyuncu equation wsa solved [17]. In order to solve the mathematical model, an experimental constant determined by tests and validated by experiments was needed.

Adsorption is done from the initial concentration C_0, to the equilibrium concentration C_e.

The adsorption capacity at equilibrium is given by Freundlich's isotherm:

$$Q_e = K_F \cdot C_0^{1/n} \tag{5.5}$$

Where, in addition: Q_e is the adsorption capacity at equilibrium, mg/g; K_F is Freundlich's isothermal constant.

The equation that describes the variation of the concentration in time:

$$\frac{dC_t}{d\tau} = ak_L(C_e - C_t) \tag{5.6}$$

C_t - concentration at a given time;
C_e - equilibrium concentration;
ak_L - volumetric mass transfer coefficient (does not vary over time);
$d\tau$ - period of time;
$C_t = C_e + (C_0 - C_e)\, e^{-ak_L\tau}$ - Variation of concentration over time

$$\frac{dC_t}{C_e - C_t} = ak_L\, d\tau \Rightarrow -\ln|C_e - C_t| = ak_L\, d\tau + \text{constant} \tag{5.7}$$

$$\text{La } \tau = 0 \Rightarrow \text{constant} = -\ln|C_e - C_0| \tag{5.8}$$

$$-\ln|C_e - C_t| = ak_L\, d\tau - \ln|C_e - C_0| \tag{5.9}$$

$$\ln|C_e - C_t| = -ak_L\, d\tau + \ln|C_e - C_0| \tag{5.10}$$

$$\ln|C_e - C_t| = \ln e^{-ak_L\tau} + \ln|C_e - C_0| \tag{5.11}$$

$$\ln|C_e - C_t| = \ln [(C_e - C_0)\, e^{-ak_L\tau}] \tag{5.12}$$

$$(C_e - C_t) = (C_e - C_0)\, e^{-ak_L\tau} \tag{5.13}$$

$$C_t = C_e + (C_0 - C_e)\, e^{-ak_L\tau} \tag{5.14}$$

Where

$$ak_L = k \cdot V \tag{5.15}$$

k= 0 ÷ 0,9

The equation that determines the equilibrium equation. C_e

$$\frac{V_{(C_0 - C_e)}}{m_{bentonită}} = Q_e = K_F \cdot C_0^{\frac{1}{n}} \tag{5.16}$$

V - V solution + V bentonite
C_0 - the initial concentration of metal ions
Q_e - adsorption capacity at equilibrium

K_F- Freundlich isothermal constant
k - experimentally established constant

$$C_0 - C_e = \frac{m_{bentonită} \cdot K_F \cdot C_0^{\frac{1}{n}}}{V} \quad (5.17)$$

In the next step, certain values were introduced to determine which has the highest adsorption capacity of impurities, depending on the amount of bentonite introduced into the solution.

The experimental mathematical calculation was done with the help of a program adapted in Excel, using the equations presented above. The results are presented in table 5.7. From this table will be presented only 2 graphs for P1 and P5:

Table 5.7 Optimal mixing time on adsorption

Initial concentration of metal ions, mg / l	50	100	150	200
Adsorption capacity, mg / liter	5	10	15	20
Sample	P1	P2	P3	P4
Mixing time with 20 g of bentonite, sec	2261	2335	2409	2483
Sample	P5	P6	P7	P8
Mixing time with 40 g of bentonite, sec.	1269	1354	1456	1590



Fig.5.4 Variation of metal concentration Ct in the adsorption process for P1

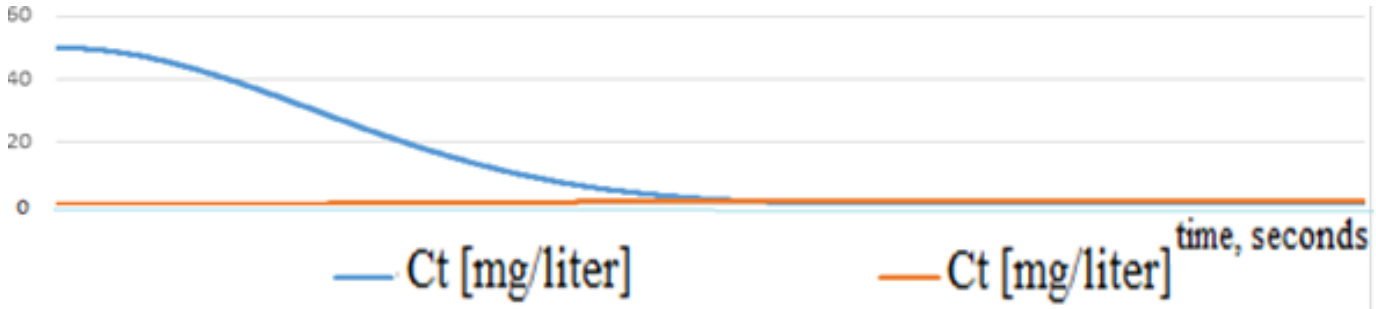


Fig.5.5 Variation of metal concentration Ct in the adsorption process for P5

As can be seen from the experiments and graphs above, at 40 grams of bentonite added to a liter of oil, bentonite has the best adsorption and a shorter time for iron (Fe), and for the metals copper (Cu), zinc (Zn), cadmium (Cd) and lead (Pb), 20 g / l bentonite is optimal. For the experiment, 30 g of bentonite

/ l waste oil was chosen, in order to have a balance in the adsorption of all metals in the waste oil.

In order to obtain a good fineness of the drops formed when using purified oil characterized by kinematic viscosity ν = 12-19 cSt, surface tension σ = 2,4-2,6 N/m and density ρ = 830-870 kg / m^3, the following connections are recommended between the supply pressure and the outlet diameter: p_{al} ≤15 bar, , for debits G_d ≤ 1500 kg/h you can choose the diameter of the vortex chamber, d_e = 6-7 mm and the converging angle of the outlet nozzle γ = 90-120^o.

An important feature of the vortex injector, which largely determines its scope, is the size distribution of the droplets formed. Experimental research has shown that the maximum diameter of the droplets in the sprayed liquid is proportional to the radical of the injector scale and inversely proportional to the square root of the total pressure drop in the injector, according to the relation below:

$$d_{max} = C \cdot \sqrt{M_i/\Delta p} \tag{5.17}$$

where: d_{max} is the maximum droplet size, in μm; M_i - injector scale, in mm^2, Δp- pressure drop through the injector (generally equal to the supply overpressure) in bar; C is a proportionality coefficient, which depends mainly on the physical properties of the liquid to be sprayed and the processing quality of the component parts of the injector. For injectors with superior processing quality C = 1500, and for those with medium quality C = 2000. The first step is to calculate the scale of the injector with the relation:

$$M_i = \frac{G_d}{0{,}77 \cdot \sqrt{\Delta p \cdot \delta}} \tag{5.18}$$

For low and medium thermal powers (Pt ≤ 200 kW) results in an oil flow of approximately 25 kg / h, at a lower calorific value of the oil of 37000 kJ / kg. Under these conditions the injector scale Mi = 0,288 mm^2 (for a Δp = 15 bar).

Finally, the maximum diameter of the drop is calculated:

$$d_{max} = 1500 \cdot \sqrt{\frac{0{,}288}{15}} = 207\ \mu m \tag{5.19}$$

It can be concluded that a spray nozzle diameter of 0.5 mm is optimal for the combustion plant that will equip the car workshop building, presented in Chapter 6.

By removing the metal ions, which are found in the largest proportions in the used oil, increases the life of the injector nozzle, which will no longer be impacted by these metal ions, thus avoiding the phenomenon of corrosion.

Experimental research consists in the analysis of the burning process of used oil from the automotive industry. This experiment can help depollute the environment by burning used and purified oil in ecological conditions.

The experiment was performed on a mixture of waste oil purified with 30 g of bentonite. The tests were performed on automotive waste oil and bentonite purified waste oil, also from the automotive field.

The characteristics of the flue gas composition measurements for the fuel waste oil and purified waste oil are summarized in the tables below, using the spray nozzle with a diameter d = 0,5 mm:

Table 5.8 Waste oil flue gas measurements

Sample	O_2	CO	CO_2	NO	NO_2	SO_2	NOx	t gas	λ
	%	ppm	%	ppm	ppm	ppm	ppm	°C	
1	17.3	1628	2.7	11	0	0	11	238	5.68
2	17.3	1722	2.7	14	0	0	14	238	5.68
3	17.2	1813	2.8	15	0	0	15	242	5.53

The temperature values for the experiment flame were determined using the Fluke TiX560 thermal imaging camera. The appearance of the flame jet during the first experiment for waste oil is shown in the following figures:



Fig.5.6. Appearance of the flame outside the hearth

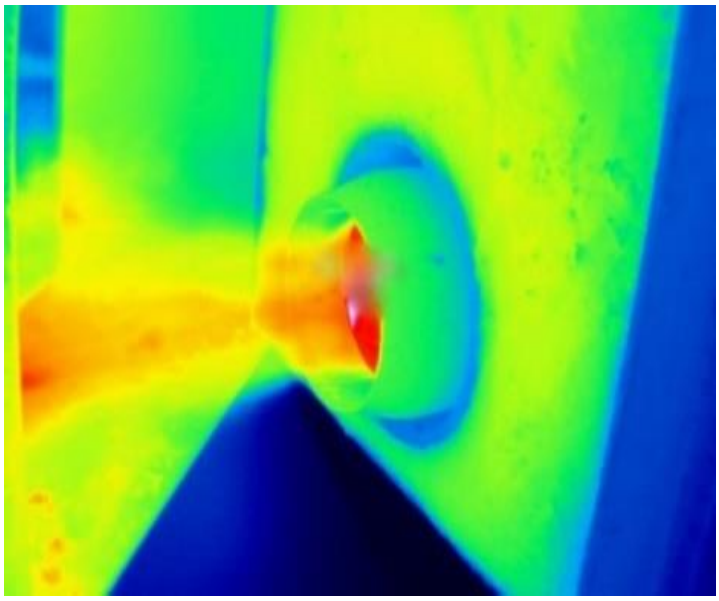


Fig. 5.7. Appearance of the flame with the help of the thermal imaging chamber with used oil fuel, temperature between 860-920 °C

Table 5.9. Flue gas measurements purified waste oil with 30g bentonite

Sample	O_2	CO	CO_2	NO	NO_2	SO_2	NOx	t gas	λ
	%	ppm	%	ppm	ppm	ppm	ppm	°C	
1	16.9	1172	3	28	4	0	32	280	5.12
2	16.9	1293	3	27	4	0	31	278.3	5.12
3	17.4	1277	2,6	20	4	0	24	263.3	5.83

The appearance of the flame jet during the experiment on purified waste oil is shown in the following figures:

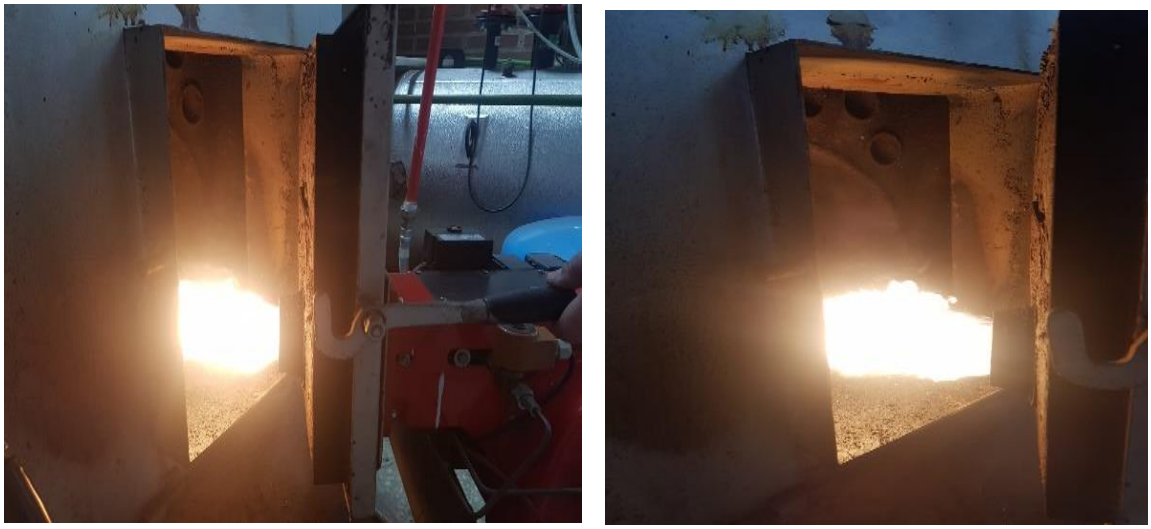


Fig.5.8. Appearance of the flame outside the hearth

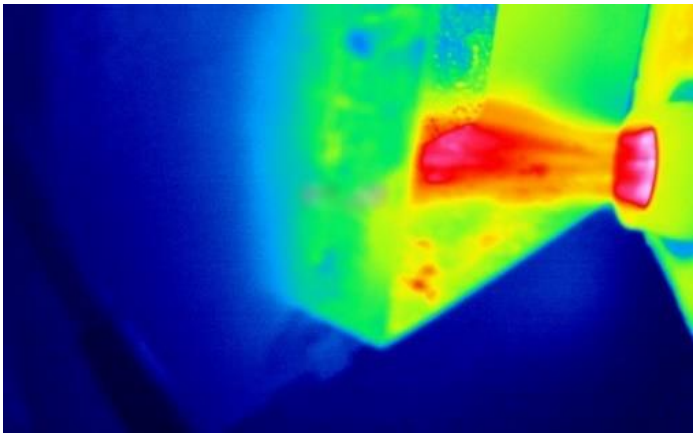


Fig. 5.9. Appearance of the flame with the help of the thermal imaging chamber with purified used fuel oil, temperature between 950-1020 ° C

The reduced width of the flame is also represented by the thickness / length ratio, which had values in the range 0.26 m - 0.29 m. The pollutant emissions were within the accepted limits for a low thermal capacity installation.

CHAPTER 6. TRANSFER OF WASTE OIL PURIFICATION TECHNOLOGY TO AN INDUSTRIAL INSTALLATION

In Chapter 6, on the basis of experimental data obtained in the laboratory, this data is transferred to a real installation, having at its disposal a company dealing with the automotive field (repairs and overhauls of road vehicles). A heating installation will be designed for the two halls of the company, using purified used engine oil. For this purpose, the heat losses of the buildings, the heat demand, the fuel flow were calculated, resulting according to the calorific value.

The hall has a metal frame, plated with 200 mm isopan (walls) and 70 mm (roof), respectively. The construction consists of two annexes, with a total area of 222 m2, having a door framed in the

common wall that separates the 2 annexes.



Fig.6.1 Presentation of the industrial hall on which the transfer of the technology developed in the thesis was analyzed

Below is the calculation of the combustion plant and the consumption of purified waste oil. The fuel used is a waste oil that has the following analysis with reference to the initial state:

C^i=84,5 %; H^i=8,2 %; S_{ci}=0,4 %; N_i=1 %; O_i=3,5 %; A_i=1,9 %; W_{ti}=0,5 %; W_f=0 %;

The following data are also given:

- room temperature: t_0=15 ° C
- absolute air temperature: x=10 $\frac{g}{kg\ aer}$

Calculation of calorific value

$$Q_i = 339 \cdot C^i + 1030 \cdot (S_{ci} - O_i) - 25{,}1 \cdot W_{ti} = 36741.05 \ \frac{m_N^3}{kg} \quad (8)$$

Calculation of air and flue gas volumes

$$V_{0min} = 0{,}01 \cdot \left(1{,}867 \cdot C^i + 5{,}6 \cdot H^i + 0{,}7 \cdot S_{ci} - 0{,}7 \cdot Q_i\right) = 2{,}015 \ \frac{m_N^3}{kg} \quad (9)$$

$$V_{a0} = \frac{100}{21} \cdot V_{0min} = 9{,}596 \ \frac{m_N^3}{kg} \quad (10)$$

$$V_{aum0} = (1 + 0{,}00161 \cdot x) \cdot V_{a0} = 9{,}75 \ \frac{m_N^3}{kg} \quad (11)$$

$$V_{CO_2} = 0{,}01867 \cdot C_i = 1{,}578 \ \frac{m_N^3}{kg} \quad (12)$$

$$V_{SO_2} = 0{,}007 \cdot S_{ci} = 0{,}003 \ \frac{m_N^3}{kg} \quad (13)$$

$$V_{0N_2} = 0{,}79 \cdot V_{a0} + 0{,}008 \cdot N_i = 7{,}589 \ \frac{m_N^3}{kg} \quad (14)$$

$$V_{RO_2} = V_{CO_2} + V_{SO_2} = 1{,}58 \ \frac{m_N^3}{kg} \quad (15)$$

$$V_{0gu} = V_{RO_2} + V_{0N_2} = 9{,}169 \ \frac{m_N^3}{kg} \quad (16)$$

$$V_{0H_2O} = 0{,}112 \cdot H^i + 0{,}01242 \cdot W_{ti} + 1{,}242 \cdot W_f + 0{,}00161 \cdot x \cdot V_{a0} = 1{,}079 \ \frac{m_N^3}{kg} \quad (17)$$

$$V_{0g} = V_{0gu} + V_{0H_2O} = 10{,}248 \ \frac{m_N^3}{kg} \quad (18)$$

$\lambda_{ev} = 1{,}5$
$\lambda_1 = 1{,}5$
$\lambda_0 = 1{,}5$
$t_p^{"} = 15\ ^\circ\text{C}$
$t_0 = 15\ ^\circ\text{C}$
$t_c = 35\ ^\circ\text{C}$

Determination of yield

The efficiency of the boiler is determined by the relation:

$$\eta_i = 100 - (q_{ev} + q_{ch} + q_m + q_{ex} + q_{rf}) \ \% \quad (19)$$

$q_m = 0{,}8\%$
$q_{ch} = 0\ \%$

For

$\lambda_{ev} = 1{,}5$ and $t_{ev} = 160\ ^\circ\text{C}$

$$I_{g1,5.160} = \frac{(160-100)\cdot(4197{,}491-2075{,}782)}{200-100} + 2075{,}782 = 3348{,}807 \ \frac{kJ}{kg} \quad (20)$$

At $t_0 = 15\ ^\circ\text{C}$

$$I_{0aum\,t_0} = \frac{1291{,}123 \cdot 15}{100} = 193{,}668 \ \frac{kJ}{kg} \quad (21)$$

$$i_{c_0} = c_c \cdot t_0 \quad (22)$$

Q_{ev} is calculated with the relation:

$$Q_{ev} = (1 - 0{,}01 \cdot q_m) \cdot \left(I_{g1,5.160} - \lambda_{ev} \cdot I_{0aum\,t_0} \right) - i_{c_0} = 3006{,}456 \ \frac{kJ}{kg} \quad (23)$$

$$q_{ev} = \frac{Q_{ev}}{Q_i} \cdot 100 \quad (24)$$

$q_{ev} = 8{,}183\ \%$
$a_{antr} = 0{,}90$
Q_{rf}=0 $\frac{kJ}{kg}$
$q_{rf} = 0\ \%$
$q_{ev} = 8{,}183\ \%$

$q_{ex} = 1\ \%$
$\eta_i = 90{,}017\ \%$

Determination of useful heat and fuel consumption

$\eta_i = 90{,}017\ \%$
$\lambda'_p = 1{,}5$
$Q_u = 80$ kW
$I_{0aum\ 15} = 1291{,}193 \cdot 0{,}15 = 193{,}679\ \frac{kJ}{kg}$

$$B = \frac{Q_u}{0{,}01 \cdot Q_i \cdot \eta_i + (1 - 0{,}01 \cdot q_m) \cdot \lambda'_p \cdot (I_{0aum\ 15} - I_{0aum\ t_0})} = 0{,}00238\ \frac{kg}{s} \quad (25)$$

The actual fuel flow is:

$$B_{ef} = (1 - 0{,}01 \cdot q_m) \cdot B = 0{,}002\ \frac{kg}{s} \quad (26)$$

$$B_{ef} = 0{,}002 \cdot 3600 = 7{,}2\ \ \frac{kg}{h}$$

$$B_{ef\ month} = 10{,}8 \cdot 8 \cdot 25 = 1440\ \frac{kg}{month} \quad (27)$$

The above calculations were made in order to find out the heat demand as well as the heat loss. The calculations were made at an ambient temperature of 20, resulting in a heat demand of 80 kW for both halls.

3 heating solutions for the industrial hall are proposed and the most efficient and economical solution is chosen, namely:

- OHA radiant tubing (gas)
- Radiant ceiling panels (electric)
- Boiler on purified used oil

OHA radiant tubing (gas)

The radiation heating system can be used for: industrial halls, warehouses, car services, gyms, high-rise spaces, exhibition pavilions, showrooms, flower and vegetable greenhouses, animal farms, ovens with strictly controlled temperature. The OHA radiation heating system is recommended for heating industrial spaces and spaces with medium and high heights. The flexibility of the system consists in adapting the radiant piping to any requirements regarding its route inside the heated room. The radiant piping can have different configurations, depending on the heat demand and the height of the building, which can be monotubular or bitubular.

The disadvantages of this system are the high installation and maintenance costs due to the fuel consumed (gas). In conclusion, this hall heating system will not be chosen.



Fig.6.2 OHA radiant tubing (gas)

Radiant ceiling panels

Central heating systems that use local heaters transmit heat, mostly through radiation.Heat transfer by convection promotes the formation of air currents. The warm air rises next to the heater to the top of the room and entraines dust particles that largely deposit on the surface of the walls near the heater and the rest is transported to the room. The air circulation is more or less active, depending on the location of the heater. In all cases, the air near the ceiling is warmer than that near the floor.

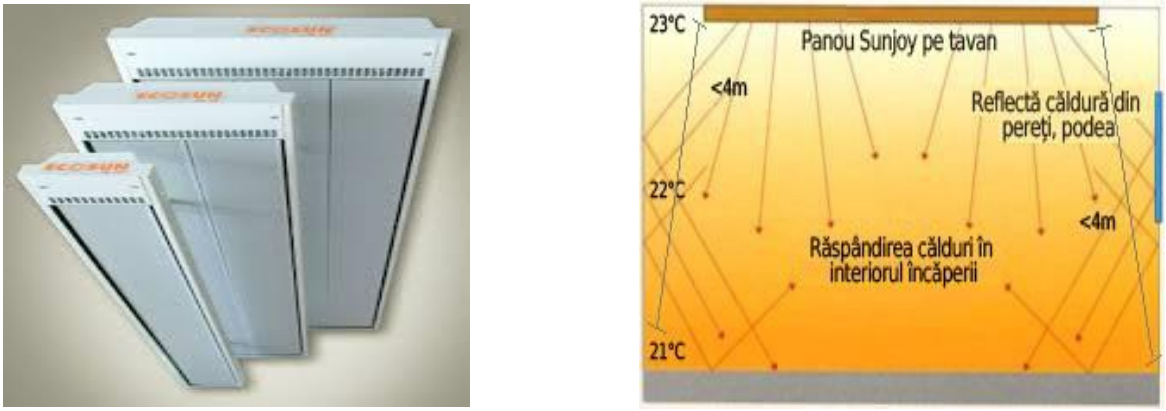


Fig.6.3 Radiant ceiling panels

The disadvantages of this installation are:

- a radiant panel does not heat the air: it only heats solid bodies such as furniture, floor or people in the space, but only the surfaces that the radiant panel "sees".
- no savings on the electricity bill: for 1 kWh of heat, at least 1 kWh of electricity is consumed.
- thermal inertia - practically non-existent. A radiator stays warm for 30-40 minutes, after the boiler is switched off, the heated floor remains warm for 2-4-6 hours, unlike radiant cooling panels.

Boiler for purified waste oil

One of the great advantages of this heating solution is the production of "clean heat", using cheap fuel and high performance.

The boiler uses a separate suction pump, takes the fuel from the tank and pumps it safely to the burner, even over long distances. There, it is filtered to 100 microns and preheated to 35 ° C in the heat filter. Subsequently, the oil enters the combustion chamber and heats to the desired temperature, which

is different depending on the oil used. This is important to have both a good and constant ignition.

The fuel is sprayed with compressed air at a relatively low pressure This allows the use of larger nozzles that do not clog, even if they are dirty or semi-fluid oils are used.

Both used and purified oils can be used as fuel without too many changes to the burner. All that needs to be done is to mount a dial to readjust the preheating temperature and combustion air according to the fuel used.

The used oil boiler is the most economical way to heat commercial or industrial halls, production halls and warehouses. Boilers can be easily equipped with a universal oil burner to be able to use purified waste oil, as it is an economical and environmentally friendly fuel.



Fig.6.4 Waste oil boiler



Fig.6.5 Waste oil boiler burner

Analyzing all three heating systems in an industrial hall, it is admitted that the heating system based on purified waste oils is the most advantageous and, at the same time, economical choice. The boiler is designed to always maintain a constant temperature, thus reducing fuel consumption. The exhaust pipe is kept clean due to its inclination, the ash is collected in the tray, which must be emptied periodically. Normally, cleaning is done in a few minutes. The installation on which the experiment was made is a Hiton HP-145 used oil boiler.

CHAPTER 7. CONCLUSIONS. PERSONAL CONTRIBUTIONS. PERSPECTIVES

CONCLUSION

The paper aimed to develop a scientific idea on the purification of waste oils in a way that is as economical and environmentally friendly as possible.

Following the studies and experiments performed, it was possible to identify a number of advantages deriving from the waste oil purification process. In general, the pollution of the environment with waste oils can be reduced, if this hazardous waste is capitalized by its purification and reuse in the automotive and industrial fields. Although such waste oil purification technology requires organizational, scientific and economic efforts to be implemented, it can be considered a real success, as it contributes to the protection of the environment and the reduction of pollution facing contemporary society.

Another particularly important aspect is that waste oil pollution has a harmful effect on human

health, because, through the process of burning this residue, large amounts of heavy metals (iron particles, cadmium , nickel, zinc, lead) are released into the atmosphere through the ash.These, ingested or inspired by humans, can lead to diseases such as cancer, Alzheimer's, Parkinson's, arthritis, cardiovascular disease and many more.

In other words, used car oil can be considered one of the main sources of pollution today, due to the dramatic increase in the number of vehicles. Through this paper it can be demonstrated that waste oil is an ecological alternative in the field of fuels, also contributing to the reduction of pollutant emissions. From the experiment of burning waste oil and purified waste oil, it was observed, based on data obtained with the MAXILYZER gas analyzer, that carbon monoxide (CO) decreases by about 30% when burning purified waste oil, but at the same time also observed an increase in nitrogen oxides (NOx) by 50% - 60%. Thus, it can be concluded that this increase is due to the fact that in purified oils, combustion is better due to the retention of metal ions, and the increase in temperature has led to an increase in nitrogen oxides (NOx). The results were presented in tables 5.8 and 5.9, respectively. It is important to note that NOx emission values are lower than required by law.

In particular, attention has been paid to used automotive oil to highlight the composition of impurities. Following the analyzes performed on the used oil, heavy metal residues were discovered, as presented in tables 5.3 and 5.4.

Another conclusion from the in-depth study of other waste oil purification technologies currently in use (Revivoil technology, Blowdec technology, Dunwell WFE technology, Prop technology) is that most of them require chemical and physical processes that involve substantial financial costs, thus presenting a major disadvantage. In the scientific approach, we started from Prop technology, the only one that uses clay as an adsorbent, and developed a new technology for purifying used oil.

The innovative element of this paper is the use of bentonite, which, although known as a filter material, has never been used in the automotive field as an adsorbent. Certainly, it could be observed that bentonite is a clay, an accessible material, which is found in quite large quantities in Romania, has remarkable characteristics of adsorption of impurities, ion exchange, plasticity, discoloration power, high degree of dispersion and , which makes it even more attractive, is a relatively inexpensive material.

Following the theoretical studies on the model of the adsorption process, it became necessary to develop a mathematical model in the case studied, starting from the calculation relations of Freundlich, Kul and Koyuncu [17], more precisely relations (1) and (2), because they best reflected the process of purifying used oil using bentonite.

The calculation of the minimum mixing time between waste oil and bentonite, so as to reach the adsorption capacity at equilibrium with minimum electricity consumption, was performed by deriving in relation to time, the equation Kul and Koyuncu [17] (5.2) and of Freundlich's equation (5.3), giving rise to a new mathematical model (5.14, 5.15, 5.16, 5.17), which is another innovative element of the paper.

Another conclusion came from the experiment on the analysis of ash resulting from the burning of the residue resulting from the bentonite adsorption process, where it was observed that the sample with the mixture of 40 grams of bentonite added in a liter of oil has the best adsorption capacity for iron (Fe), and the sample with the mixture of 20 g bentonite / l of oil is optimal for the metals copper (Cu), zinc (Zn), cadmium (Cd) and lead (Pb). In order to have a balance in the adsorption of all metals in the used oil, the sample with the mixture of 30 g bentonite / l used oil was chosen for the continuation of the energy recovery experiments.

Thus, at a theoretical level, the combustion characteristics of the fuel jet were determined and it was concluded that a diameter of the spray nozzle of 0.5 mm is optimal for the combustion plant that will equip the car workshop building. Another aspect found is that by removing metal ions, which are found in large proportions in used oil, it increases the life of the injector nozzle, which will no longer be impacted by these metal ions, thus avoiding the phenomenon of corrosion.

Following the experiments performed in the laboratory on used oil and purified used oil, it was found that the flame intensity of purified used oil is higher compared to that of used oil, these results

being shown in Figures 5.6-5.9.

Theoretically, 3 methods of heating the industrial hall were analyzed, namely: with OHA radiant gas tubes, with radiant ceiling panels and with the boiler on purified used oil. Following this analysis, it was concluded that the most efficient heating method from an economic point of view, as well as ecologically for a car service, is the heating through the boiler on purified used oil.

At a practical level, the experiment initially performed on a pilot boiler was subsequently applied on an industrial scale, in a hall, which show the following conclusions on emissions from the combustion process:

- the CO concentration decreased by an average of 52% when the purified oil was burned
- NOx concentration increased by 57% (from 33 ppm to 52 ppm), due to the increase in the temperature in the hearth when burning the purified oil

It turns out, through these data, that the results obtained from the experiments on the pilot boiler at the Polytechnic University of Bucharest can be found, on another scale, in the industrial installation on the Hiton boiler.

PERSONAL CONTRIBUTIONS

In the case of this doctoral thesis, the author had personal contributions that shaped the content of the entire paper. These include the following:

- Design of the principle scheme of the waste oil purification installation presented in figure 4.12
- Carrying out the analysis of the metal content of the used oil presented in table 5.1
- Designing the logical scheme for determining the experimental results figure 5.23
- Creation of a mathematical model, regarding the adsorption time of metals from used oil purified with bentonite, starting from the equation of Kul and Koyuncu [17] relation 5.2 and Freundlich relation 5.3.
- Presentation of the optimal mixing time from the developed mathematical calculation and making graphs represented in figures 5.33 - 5.40.
- Performing the analysis of adsorbed metals of bentonite mixed with used oil, presented in table 5.5.
- Carrying out experiments on the burning of used oil and purified used oil.
- Presentation of the flame aspect with the help of the thermal imaging camera in figure 5.42 and 5.44.
- Comparison and conclusion of the results obtained from the experiment and from the pilot plant presented in table 5.7 and 5.8.
- Application of experimental results and their transfer to an installation of an industrial hall.
- Calculation of the fuel required for the heating period (November-March).
- Calculation and determination of boiler efficiency.
- Comparison and conclusion of the results obtained from the experiment and from the actual installation presented in tables 6.1 and 6.2.
- During the writing of the thesis, 8 publications [82], [83], [84], [85], [86], [87], [88] were elaborated and published in scientific journals, which present studies / methods presented in this doctoral thesis and one being published in the UPB bulletin [89].

PERSPECTIVES

Given the research undertaken in this paper, the following directions can be mentioned as a perspective:

The mathematical model can also be implemented for other adsorbents, such as zeolites, and for used oils, such as those in restaurants and supermarkets. With the developed mathematical model it is possible to establish the equilibrium concentration in time, depending on the volume of the solution, the volume of the adsorbent, the Freundlich isotherm constant, the initial concentration of impurities and the experimental constant.

The arrangement of an industrial hall whose main source of heating is a boiler on purified waste oil is economically and practically advantageous. This type of heating system is perfect for heating large areas in the following sectors:

- Industry sector: industrial constructions, goods warehouses, production halls;
- Automotive sector: car depots and car workshops;
- Agriculture sector: agricultural buildings, basements, garages, sports and recreation facilities, tents, churches.

An important benefit of waste oil treatment-purification is the elimination of a complex source of pollution and the return to consumption of a combustible material.

The application of the research results will contribute to ensuring a sustainable economic development at the level of the project field. This promotes the exploitation and use of natural absorbent deposits (bentonites, zeolites) and the use of new energy resources, while saving classical resources.

As a result of the investments for the exploitation and use in the field of the project of the natural absorbent deposits, an economic development of the area will take place, which will lead to the improvement of the living and health conditions of the local population.

For the future there are two design options for the installation:

- The first solution would be to purchase the standard installation, then it will be necessary to adapt the mixture between bentonite and used oil, by an automated electric mixer.Also, the bottom of the tank where the amount of metal ions adsorbed by the bentonite, as well as the bentonite itself, will be deposited, must be adapted in such a way that it can be removed.
- The second solution would be for the equipment supplier to implement the changes made from the beginning.
- The purification was done without an automated installation. In the future, an automated purification plant is required, which is shown in Figure 7.1.

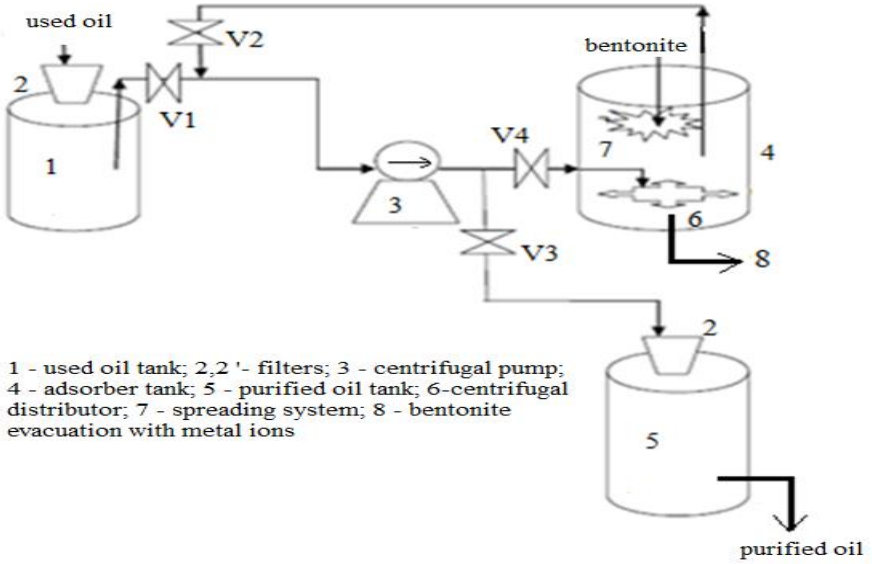


Fig. 7.1 Technological scheme of purified waste oil. Stage I, V1 and V4 open, V2 and

V3 closed; stage II V1 and V4 closed, V2 and V3 open.

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