

Basic Principles of Recycling Waste Plastic Lubricants into Boiler Oils and Marine Fuels

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Abstract

The article presents the results of a study aimed at confirming the possibility of processing waste plastic lubricants - various types of boiler and motor fuels. This approach will allow for the disposal of hazardous industrial waste while simultaneously generating additional thermal and electrical energy and minimizing the negative impact on the environment. The direct use of waste plastic lubricants as boiler fuel, as well as the products of its thermal and thermocatalytic processing into compounded boiler and marine fuels, was investigated. It has been established that when burning used oils, compared to fuel oil of brand 100, a smaller amount of carbon (by 0.215-0.715 %), sulfur dioxide (by 17.9-20.24 %), nitrogen dioxide (by 1.43-5.39 %), carbon monoxide (by 1.41-5.77 %) and benzene (by 0.39×10^{-5} to 0.46×10^{-5}) is formed. When compounding fuel oil of brand 100, 25-40 % of the 200-350°C fraction obtained by thermal cracking of used plastic lubricants, it is possible to obtain a composite boiler fuel with a kinematic viscosity at 80°C of 50-85 mm²/s and a pour point of 10-25°C. By subjecting used greases to thermocatalytic cracking, it is possible to obtain a fraction with boiling points of 180(200)-360(380)°C, which, in accordance with ISO 8217:2017, is promising for the production of distillate marine fuels of grades DMA, DFA, DMZ, DFZ.

Keywords: Waste lubricants; Preparation; processing; Thermal cracking; Thermocatalytic cracking; Boiler fuel, fractions; Marine fuel; Combustion products; Energy carriers; Environmental friendliness.

1. Introduction

The development of principles and technologies for utilization of the used end product, together with minimization of the negative environmental impact from emissions arising from their implementation, is an essential component of solving the problem of recycling of used lubricants. Creating a closed cycle from the production of greases to their disposal after the loss of consumer properties is a priority task for the industry. Such an approach will ensure the sustainable functioning of the country's circular economy, which is aimed at the efficient use of resources, minimizing waste and keeping products and materials in circulation as long as possible. The implementation of the specified economic model will partially solve the problem of raw material shortage through a more complete use of secondary raw materials.

2. The objective of the research

Considering the regeneration of used greases directly, it should be noted that this area is very complex and requires significant production costs for its implementation due to contamination of greases during their operation and deep chemical transformations in their chemical composition. In addition, after regeneration, additional amounts of thickener, filler and additives must be added to the resulting product to achieve a certain level of performance, which in turn increases the cost of the final grease product.

In view of this, recycling of used greases into other products, including energy, which involves a whole range of technological processes and requires the use of special equipment, is nevertheless a more progressive approach to disposal compared to regeneration and disposal at special landfills.

The strategy for the disposal of waste lubricants is based on a number of waste management directives [1-4], which have been adopted over the years and are being applied quite successfully in EU countries.

Therefore, considering the utilization of waste greases, taking into account the current global realities, we have proposed an integrated approach aimed at obtaining additional energy resources, which will contribute to the energy and resource independence of the state, as well as saving natural material and energy resource.

3. Materials and methods of the research

Materials. The main material of the study was used antifriction (analogues of greases) and preservation (analogues of greases) greases obtained from materials and according to the method described in [5-7] and the properties presented in [8-10]. These greases were studied after 2 years of operation in rolling bearings and 5 years of conservation of agricultural machinery stored in open areas, respectively.

Methods of the research. The research methods used in the laboratory to determine the feasibility of the chosen direction of utilisation of used greases included density at 15 °C (ISO 3675); kinematic viscosity at 40°C (ISO 3104); pour point (ISO 3016); cloud point (ASTM D2500); cetane index (ISO 4264); sulphur content (ISO 14596); ash content (ISO 6245); fractional composition (ASTM D86); determination of Al+Si content (ASTM D 5184-01); calorific value (ASTM D240); identification of components in combustion products (ASTM D240-19, ASTM D5863-22, Method TO-13A); determination of C, H, N (ASTM D5291).

4. Results and discussion

Taking into account all of the above, we propose a comprehensive approach to the disposal of used greases after their use by recycling them into energy carriers, which can be represented in the form of a flowchart (see Fig. 1).

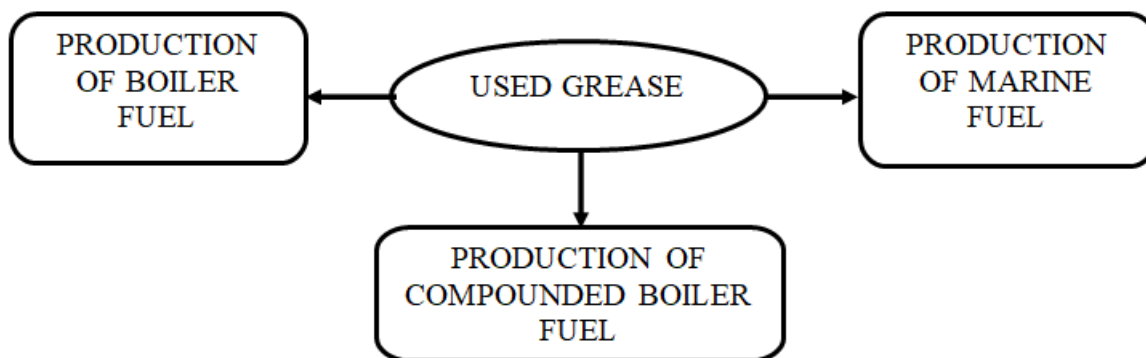


Figure 1. Flowchart of utilization of waste greases by recycling them into energy carriers.

The above flowchart shows the main areas of waste oil recycling, and the choice of a specific area will depend on the current need for a particular product and economic calculations for a particular enterprise where the technology will be implemented.

Production of boiler fuel. One of the easiest ways to recycle used oil products, in particular greases, is to use them as boiler fuel, i.e. to burn them in boilers [11-12].

This area is implemented after preliminary purification of used greases from external contaminants (water, coarse mechanical impurities, etc.) by heating, settling, filtering, centrifugation, etc. It should be noted that according to our laboratory studies, the average value of the calorific value of greases containing polymeric thickeners and various fillers is in the range of 42.5 to 44.5 MJ/kg, which in turn is higher than that of fuel oil - 40.0-42.0 MJ/kg [13].

In this regard, used greases from recycled materials can be considered as a valuable raw material for heat energy production.

All systems that use waste greases as a fuel can be divided into systems for heating industrial premises or systems for converting thermal energy into electricity.

The principle of operation of the first installations (see Fig. 2 a) is based on the combustion of greases (flow I) in the furnaces of specially designed furnaces (1) [14-15], the heat generated is used to heat the coolant (flow IV), which, in turn, is fed by a pump (5) to the heat exchanger (3), which releases the heat to the environment.

The second units (see Fig. 2 b) operate on the principle of supplying cold water (flow IV) instead of the coolant, which evaporates due to the heat generated by the combustion of greases, and the resulting water vapour (flow VI) is fed to the turbine (3) to generate electricity (flow VII).

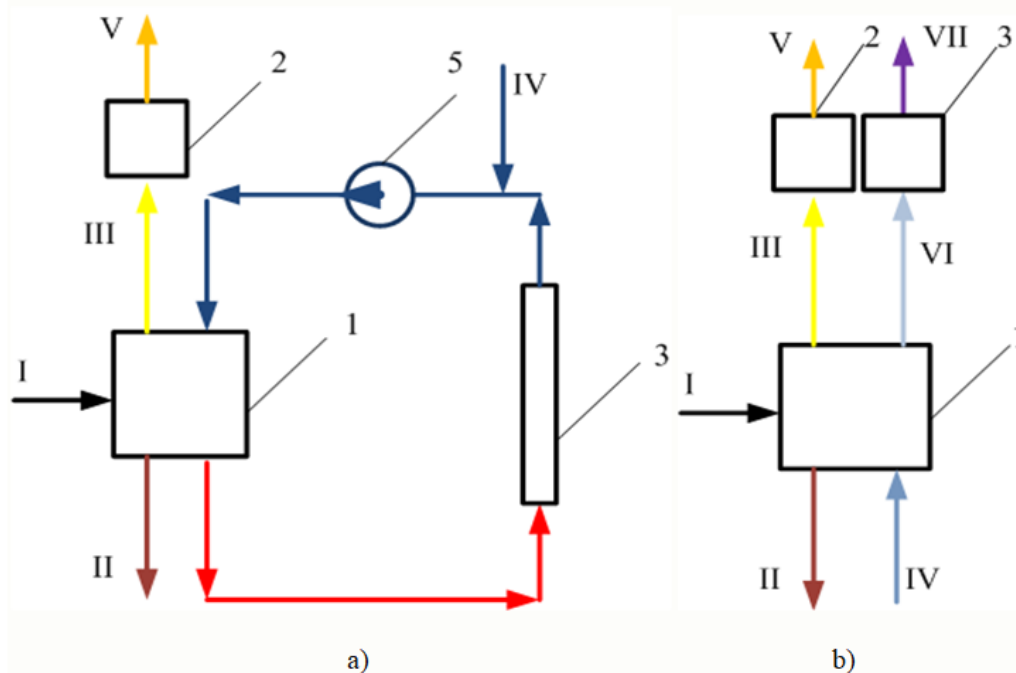


Figure 2. General schemes of utilization of used oils from secondary raw materials: a) to generate heat; b) to generate electricity

The implementation of these schemes, as shown in Table 1, produces by-products – ash (flow II), which is represented by the mineral components MeO and SiO₂, and gases (flow III).

Ash can be used as a filler to increase the strength of various types of construction materials, and the gases include benzopyrene (hazard class 1) and nitrogen dioxide (hazard class 2), which must be neutralized. In view of this, the above scheme provides for their supply to the purification/destruction unit (2), after which the disinfected flue gases are released into the atmosphere (flow V).

Table 1. Average characteristics of boiler fuel combustion products derived from waste grease

Name of the indicator	Numerical values of the indicator		
	Two-component used grease	Two-component used grease with filler	Fuel oil M-100
C, %	0.7-1.2	1.515	1.415
SO ₂ , %	18.58-20.92	40.11	38.82
CO, %	1.53-4.57	5.89	7.301
NO ₂ , %	0.86-3.49	4.82	6.250
C ₂₀ H ₁₂ , %	0.07×10 ⁻⁵ -0.10×10 ⁻⁵	0.14×10 ⁻⁵	0.53×10 ⁻⁵
V ₂ O ₅ , %	-	-	0.29869

Analyzing the data presented in Table 1, we note that along with a higher calorific value waste oils from secondary raw materials are characterized by rather high kinematic viscosity values, which make it difficult to feed them into the combustion zone and require the use of a raw material preheating unit in the above schemes.

The combustion of used two-component greases produces less harmful emissions than the use of fuel oil of the M-100 grade. If the grease contains 5.0 % filler in the form of secondary vulcanized rubber, which contains sulphur, there is a slight deterioration in the composition of flue gases, but it still remains close to the composition of flue gases of M-100 fuel oil. That is, the same methods used for fuel oil combustion can be used to clean flue gases, namely, additional flue gas combustion with the addition of a certain amount of fuel or with the use of filters [16-18], catalysts [19-21] and chemicals [22-23].

Production of compounded boiler fuel. Waste greases can be recycled into boiler fuel components using thermal cracking technology at a final temperature of 400-420 °C and atmospheric pressure in a batch reactor.

Thermal cracking of used greases in the laboratory resulted in products whose characteristics are shown in Table 2.

Table 2. Characteristics of thermal cracking products

Name of the indicator	Numerical value	Boiling point temperature limits, °C
Gases, % (vol.)	8-10	< -0.5
Fuel fraction, % (vol.)	83-87	34-378
Vacuum residue, % (vol.)	5-7	>420

The fuel oil fraction obtained in the laboratory, due to its low sulphur content (0.2-1.5 % by weight) compared to commercial boiler fuels (for example, for sulphurous and high-sulphur fuel oil M-100, the sulphur content ranges from 2.0 to 3.5 % by weight) [24] after preliminary distillation of the low-boiling fraction at a b.p. - 200°C, can be used to improve the properties of fuel oil.

Preliminary removal of light fractions is associated with a low boiling point of the fuel fraction (up to 200°C), which, when combined with fuel oil, will adversely affect the quality of the resulting boiler fuel, in particular, its flash point [25].

For example, studies have shown that when 25-40 % is added to 200-350°C fuel oil, the viscosity of the mixture decreases to 50-85 mm²/s and the pour point to 10-25 °C, which greatly simplifies the procedure for its use, especially in winter.

The fuel oil compounding unit with thermal cracking fuel fractions is located directly in front of the furnace as part of a single technological scheme (see Fig. 3) to provide heat energy to the oil refinery.

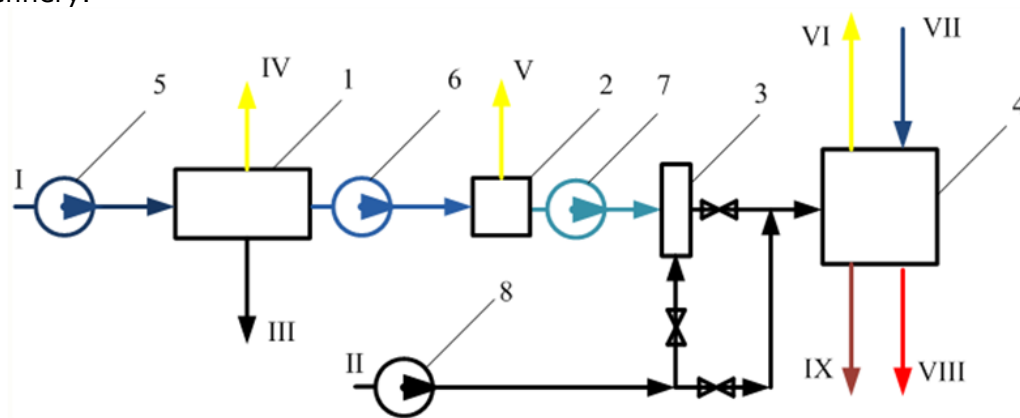


Figure3. Schematic diagram of boiler fuel production: 1 - reactor; 2 - rectification unit; 3 - emulsifier; 4 - furnace; 5, 6, 7, 8 - pumps; I - used oil; II - fuel oil; III - remainder; IV - cracking gases; V - low-boiling fractions; VI - flue gases; VII - cold coolant; VIII - hot coolant; IX - ash

The used grease (flow I) is fed by pump (5) to the thermal cracking reactor, where at atmospheric pressure the grease is slowly cracked to form gases (flow IV), coke (flow III) and fuel fraction, which is fed by pump (6) to the rectification unit (2). In block (2), the lightly boiling fraction (flow V) is separated from the fuel fraction. The boiling point of the lightly boiling fraction will be adjusted depending on the requirements of regulatory documents for the flash point of the compounded fuel. Then the fraction is fed by pump (7) to the emulsifier (homogenizer) (3), where it is mixed with fuel oil (flow II), which is fed by pump (8). Then, the compounded fuel from (8) is fed to the furnace (4).

The scheme also provides for the direct supply of fuel oil to the furnace (4) by means of a pump (8) and shut-off valves. In the furnace (4), the compounded fuel is combusted, which results in the heating of the cold coolant (flow VII). The furnace (4) also produces by-products in the form of flue gases (flow VIII) and ash (IX).

In some cases, compounded boiler fuel can be collected in separate tanks and reservoirs and transported to the consumer when the necessity arises.

For the processing of used oils from secondary raw materials, given their projected accumulation volumes (up to 200 thousand tons), it is rational to use batch plants, but if necessary, in order to increase production capacity, the production process can be combined with continuous-type units.

The addition of thermal cracking fraction to fuel oil will not only reduce the mass fraction of sulphur in it, lower the pour point from +35°C (for M-100 fuel oil), depending on the content of fractions and their boiling point ranges, to an average of +15°C, but also significantly reduce the concentration of harmful substances in flue gases (see Table 1).

Production of marine fuel. The production of marine fuels used in shipping and highly demanded is based on the structure shown in Fig. 4. According to this scheme, the feedstock - used grease (stream I), heated to a temperature of 150-170°C, and is loaded by a pump (4) into a reactor (1), where, in fact, thermal cracking of the feedstock takes place at a temperature of 420-450°C and a pressure of 0.3-0.5 MPa.

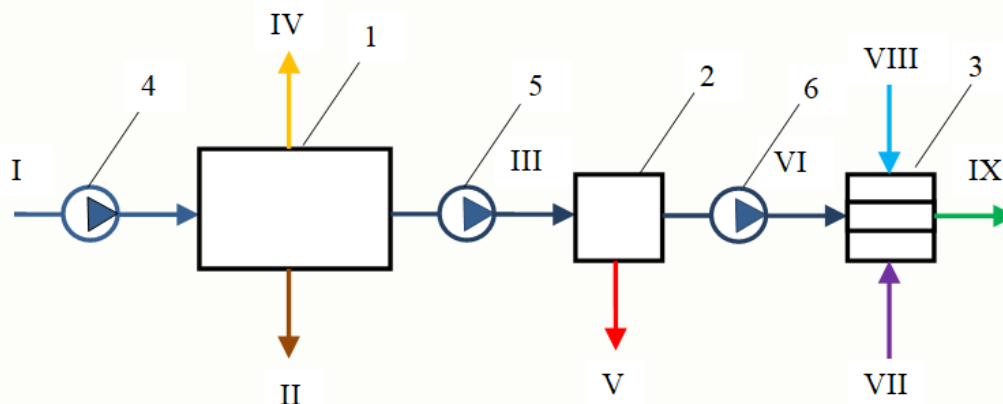


Figure 4. Schematic diagram of marine fuel production: 1 - reactor; 2 - rectification unit; 3 - compounding unit; 4, 5, 6 - pumps; I - used grease; II - carbon residue; III - mixture of fractions; IV - cracking gases; V - low-boiling fractions; VI - main fuel fraction; VII, VIII - additives; IX - commercial marine fuel

In the upper section of the reactor there is a space for the nozzle, which is filled with Me-H-ZSM-5 catalyst or a mixture of catalysts. Feedstock cracking gases formed during heating flow from the lower section of the reactor to the upper section, where they pass through the catalyst nozzle. Reactions occur on the surface of the catalysts that lead to modification of the cracking products. The modification products are then cooled in heat exchangers (not shown in the diagram) and pumped to the rectification unit (2) by a pump (5). Carbon residue (flow II) and cracking gases (flow IV) are removed from the reactor (1) as by-products. The rectification unit (2) separates the broad fuel fraction into the target fraction with a boiling point of 180(200)-360(380)°C and the low-boiling by-product fraction (b.p.- 180(200)°C). Then the

target fraction of marine fuel (flow VI) is fed by a pump (6) to the compounding unit (3), where the final formation of commercial marine fuel (flow IX) is achieved by adding the additives (flows VII, VIII).

The material balance of the process of thermocatalytic cracking of used greases in the laboratory is shown in Table 3. The results of the study of quality indicators in accordance with ISO 8217:2017 of the obtained fraction with a boiling point of 180(200)-360(380)°C are presented in Table 4.

Table 3. Characteristics of thermal cracking products.

Fractions from cracking	Value	Place formation	Application area
Cracker gases, % (vol.)	9-11	Cracker reactor	Energy targets for process support
Fuel fraction, % (vol.)	65-73	Distillation unit	Marine fuel production
Volatile by-product fractions, % (vol.)	10-14	Rectification unit	Production of solvents and motor fuels
Carbon residue, % (vol.)	5-10	Cracking reactor	Energy targets for process support

Table 4. Average characteristics of marine fuels derived from used greases.

Parameter	Value
Kinematic viscosity at 40°C, mm ² /s	2.4-3.5
Density at 15 °C, kg/m ³	825-840
Ash content, %	0.005-0.006
Sulphur content, ppm	Up to 400
Al+Si content, ppm	Up to 60
Cloud point, °C	-9÷-13
Solidification point, °C	-15÷-20
Cetane index, units	44-51
Working heat of combustion, MJ/kg	44.0-44.5
H:C ratio	1.65-1.69

Experimental studies to determine the physicochemical and operational quality indicators of fractions 180(200)-360(380)°C, according to ISO 8217:2017, allowed them to be classified as distillate marine fuels DMA, DFA, DMZ, DFZ.

5. Conclusions

The studies confirmed the possibility of rational use of greases after their service life as raw materials for energy production. The used greases can be used as boiler fuel to generate heat or electricity after treatment. Moreover, their combustion produces less carbon (by 0.215-0.715 %), sulphur dioxide (by 17.9-20.24 %), nitrogen dioxide (by 1.43-5.39 %), carbon monoxide (by 1.41-5.77 %) and benzo&pyrene (by $0.39 \times 10^{-5} \div 0.46 \times 10^{-5}$), which is undoubtedly a positive aspect in reducing the environmental impact of the technosphere on the environment.

Adding 25-40 % of the 200-350°C fraction obtained by thermal cracking of waste plastic lubricants to fuel oil grade 100, a composite boiler fuel with a kinematic viscosity at 80°C of 50-85 mm²/s and a pour point of 10-25°C can be obtained, which greatly simplifies the procedure for its use, especially in winter.

By applying thermocatalytic cracking technology to waste greases, a fraction with a boiling point of 180(200)-360(380)°C can be obtained, which, according to certain quality indicators (kinematic viscosity at 40 °C, 2.4-3.5 mm²/s; density at 15°C, 825-840 kg/m³; ash content, 0.005-0.006 %; sulphur content, up to 400 ppm; Al+Si content, up to 60 ppm; cloud point, -9÷13 °C; solidification temperature, -15÷20°C; cetane index, 44-51 units.), as well as by the working heat of combustion (44.0-44.5 MJ/kg) and MJ/kg H:C ratio (1.65-1.69), according to ISO 8217:2017, is promising for the production of distillate marine fuels of the following grades DMA, DFA, DMZ, DFZ.

References

- [1] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. 2008; OJ L 152: 1-44. Latest consolidated version: 18/09/2015. URL: <http://data.europa.eu/eli/dir/2008/50/oj>
- [2] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) Text with EEA relevance. 2010; OJ L 334: 17-119. Latest consolidated version: 06/01/2011. URL: <http://data.europa.eu/eli/dir/2010/75/oj>
- [3] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance). 2008; OJ L 312: 3-30. Latest consolidated version: 05/07/2018. URL: <http://data.europa.eu/eli/dir/2008/98/oj>
- [4] Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste. 1999; OJ L 182: 1-19. Latest consolidated version: 04/07/2018 <http://data.europa.eu/eli/dir/1999/31/oj>
- [5] Grigorov A, Sinkevich I, Ponomarenko N, Matukhno V, Shevchuk O. Recycling of Polymer Waste into Plastic Lubricants. *Petroleum and Coal*. 2022; 64(3): 709–713.
- [6] Grigorov A, Tulska A, Nahliuk M, Karchakova V. The choice of method of dispersion the thickener for the production of the recycling plastic grease. *Petroleum and Coal*, 2019; 61(6): 1389–1394.
- [7] Grigorov A, Zelenskii O. The use of processed polyethylene products in the manufacture of plastic lubricants. *Petroleum and Coal*, 2019; 61(1): 21–24.
- [8] Grigorov A, Bryhada O, Bondarenko S, Yurchenko L, Sharovatova O. Technology for the Production of Preservation Greases Based on Secondary Polymer Raw Materials. *Petroleum and Coal*, 2024; 66(2): 554–559.
- [9] Grigorov A, Tulska A, Bondarenko O, Bryhada O, Nahliuk M. Technological Control of Production of Plastic Lubricants by Rheological Properties. *Petroleum and Coal*, 2024; 66(1):223–230.
- [10] Grigorov A, Tulska A, Bondarenko O, Yurchenko L, Gornostal S. Determination of the Optimal Concentration of Polymer Thickener for Production of Plastic Lubricants Based on Secondary Raw Materials. *Petroleum and Coal*, 2023; 65(4): 1118–1122.
- [11] Pribadi A, Setiyani TPA, Tjendro, Setyahandana B, Martanto. Utilization of used oil waste for boiler energy source. *E3S Web of Conferences*, 2024; 475: 05003. <https://doi.org/10.1051/e3sconf/202447505003>
- [12] Zhao N, Li B, Chen D, Ahmad R, Zhu Y, Li G, Yu Z, Li J, Wang E, Yun S, Yoon H, Yoon I, Zhou Y, Dong R, Wang H, Cao J, He J, Ju X. Direct combustion of waste oil in domestic stove by an internal heat re-circulation atomization technology: Emission and performance analysis. *Waste Management*, 2020; 104: 20-32.
- [13] Tariq AI, Saleh AM. An experimental investigation into the combustion properties, performance, emissions, and cost reduction of using heavy and light fuel oils. *Case Studies in Thermal Engineering*, 2023; 44: 102832. <https://doi.org/10.1016/j.csite.2023.102832>
- [14] Navaneeth Kashyap KV, Yashas MS, Yogesh Kumar KJ. Design and Fabrication of Waste Oil Fired Furnace. *International Journal of Engineering and Advanced Technology*, 2019; 9(2):1075-1080. <https://doi.org/10.35940/ijeat.B3334.129219>
- [15] Anaidhuno UP, Ologe SO. Design and Fabrication of a Mobile Furnace Fueled by Waste Motor Oil. *International Journal of Scientific Research & Engineering Trends*, 2024; 10(2): 655-658.
- [16] Gregorovičová E, Pospíšil J. Ceramic filters for high-temperature flue gas filtration and their regeneration: A review of the current state of knowledge. *Process Safety and Environmental Protection*, 2024; 190, Part A: 688-703. <https://doi.org/10.1016/j.psep.2024.07.088>
- [17] Yu Y, Tao Y, Wang F-L, Chen X, He Y-L. Separation and Purification Technology, 2020; 251: 117318. <https://doi.org/10.1016/j.seppur.2020.117318>
- [18] H Li-M, Zhang N, Guo X, Dou M-Y, Feng Q, Zou S, and Huang F-Ch. Summary of Flue Gas Purification and Treatment Technology for Domestic Waste Incineration. *IOP Conf. Ser.: Earth Environ*, 2020; Sci. 508: 012016. <https://doi.org/10.1088/1755-1315/508/1/012016>
- [19] Wang H-T, Xiao T-C, Su J-X, Liu W-X, Lu Y-L. Catalytic purification of flue gas from civil-used stove. *Catalysis Today*, 1999; 53(4): 661-667. [https://doi.org/10.1016/S0920-5861\(99\)00153-4](https://doi.org/10.1016/S0920-5861(99)00153-4)
- [20] Stoll M, Furrer J, Seifert H, Schaub G, Unruh D. Effects of flue gas composition on the catalytic destruction of chlorinated aromatic compounds with a V-oxide catalyst. *Waste Management*, 2021; 21(5): 457-463. [https://doi.org/10.1016/S0956-053X\(00\)00129-X](https://doi.org/10.1016/S0956-053X(00)00129-X)

- [21] Baltrėnas P, Urbanas D, Sukackienė Z, Stalnionienė I, Stalnionis G, Jasulaitienė V, Tamašauskaitė-Tamašiūnaitė L. Flue gas purification from NO using supported Cu–Mn and Cu–Mn–Nb catalysts synthesized by electroless metal deposition method. *International Journal of Environmental Science and Technology*, 2020; 17: 3857-3874. <https://doi.org/10.1007/s13762-020-02745-6>
- [22] Zhu Z, Xu B. Purification Technologies for NO_x Removal from Flue Gas: A Review. *Separations*, 2022; 9(10): 307. <https://doi.org/10.3390/separations9100307>
- [23] Flagiello D, Erto A, Lancia A, Di Natale F. Advanced Flue-Gas cleaning by wet oxidative scrubbing (WOS) using NaClO₂ aqueous solutions. *Chemical Engineering Journal*, 2022; 447:137585. <https://doi.org/10.1016/j.cej.2022.137585>
- [24] Pei X, Jameel AGA, Chen Ch, Al-Ghamdi IA. Swirling Flame Combustion of Heavy Fuel Oil: Effect of Fuel Sulfur Content. *Journal of Energy Resources Technology*, 2021; 143(8): <https://doi.org/10.1115/1.4048942>
- [25] Santos SM, Nascimento DC, Costa MC, Neto AMB, Fregolente LV. Flash point prediction: Reviewing empirical models for hydrocarbons, petroleum fraction, biodiesel, and blends. *Fuel*, 2020; 263: 116375. <https://doi.org/10.1016/j.fuel.2019.116375>

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