REVIEW ON ENVIRONMENTAL IMPACT AND VALOURIZATION OF WASTE COOKING OIL

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ABSTRACT

There is a large volume of waste cooking oil (WCO) in the world, which has made waste management extremely difficult. The main purpose of the large-scale organized collection of WCO is the synthesis of biodiesel. Although alternative applications are equally important and necessitate attention, the majority of studies focus primarily on the synthesis of biodiesel from WCO. The major objective of this review paper is to draw attention to the potential environmental implications of used cooking oil as well as its potential for reuse in products other than biodiesel. It can be transformed into direct-burn energy, biodiesel, hydrogen gas, pyrolytic oil, or hydrogen. Applications like combined heat and power generation (CHP) are where WCO is most useful. Additionally, it can be chemically processed to create biodegradable polyurethane sheets, soaps, alkyd resins, greases, and lubricants. WCO is a carbon source that can be used in fermentation processes to create polyhydroxybutyrate and rhamnolipid biosurfactant after being completely cleaned and sterilized. Therefore, waste cooking oil can be viewed as a waste that can be converted into energy or used as a catalyst for biological or chemical processes.

Keywords: *Biodiesel, Energy, Environmental implication, CPH, WCO*

INTRODUCTION

Cooking oil is a liquid fat made of plant, animal, or synthetic material that is used in baking, frying, and other cooking processes. It is sometimes referred to as edible oil and is used for flavoring and food preparation that doesn't need heat, like salad dressings and bread dips. Although some oils with saturated fat, such as coconut oil, palm oil, and palm kernel oil, are solid at room temperature, most cooking oils are normally liquid. Nuts and vegetables with high-fat content are used to make cooking oil. Edible vegetable oils come in many forms, but three stand out: palm, corn, and sunflower. In particular, the frying process is crucial for the preparation of food. According to [1], it enhances the flavor, color, and presentation of our meals. In the modern world, cooking oil is used as a heat-transfer medium as well as an additive or ingredient.

Waste Cooking Oil

Waste cooking oil is the byproduct of frying food in cooking oil made from processed plant or animal fats. Fat and grease-shaped waste are classified as liquid at room temperature. This kind of waste is created by kitchens, the food industry, and households as a result of food preparation. The fact that it is not soluble in water, however, makes it a contaminant of the environment. In particular, handling this kind of waste presents a difficulty for the collection and transportation systems for waste cooking oil. This is so because used cooking oil usually comes in liquid form. If handled improperly, it will eventually end up in the sewage system and water, further harming the environment.

When food products are fried in homes, hotels, restaurants, and other catering establishments, various edible vegetable oils are used, which results in the production of WCO. Vegetable oils, which in the majority of industrialized nations account for between 15% and 20% of total caloric consumption, are primarily triacylglycerols (88–98%) and are a crucial part of a healthy diet [2]. The consumption of vegetable oil grew globally, rising from 150 million metric tons (MMT) in 2013/14 to more than 200 MMT in 2020/21. According to estimates, the $5.50 billion worldwide WCO market will grow to $8.48 billion by 2027 [2].

Sources of WCO

The majority of waste cooking oil comes from restaurants and food producers. Deep fryers require large vats of oil to create many of our favorite treats. This oil must be replaced regularly to keep food sanitary and tasting fresh. With constant replenishment, businesses are left with large volumes of waste oil. Most people think of restaurants, diners, and fast-food eateries as the biggest sources of commercial grease waste. Yet while Sequential sources plenty of used cooking oil from establishments like these, you might be surprised at other common oil recyclers. Universities, schools, and workplace cafeterias all use oil for deep fryers and other food production. Behind the scenes, huge amounts of waste cooking oil are also produced by the food industry. Oil is also necessary to make your potato chips, corn dogs at the zoo, funnel cake at amusement parks, and more.

More so, when thinking about sources of grease, one does not need to look much further than one's own home. Home kitchens might not individually produce as much used cooking oil as commercial settings, but avid home chefs often create more than they may realize. Even this morning's eggs and bacon can contribute to growing amounts of waste cooking oil. Though it might seem small, the cooking oil from a home kitchen can still make an impact. Your home's drainage and sewer connections are not built to handle large amounts of fats, oils, and grease (FOG). In addition to causing fat build-up to clog your pipes, it can also cause backwash and flooding. If you and your neighbors wash FOGs down the drain, it can lead to municipal sewer damage caused by massive clogs that form over time.

World Distribution of WCO

The market for waste cooking oil is anticipated to increase from $5.97 billion in 2021 to $10.08 billion in 2028 at a CAGR of 7.76%. The increased awareness of renewable energy sources and environmental preservation will cause a significant increase in the global market for used cooking oil. Recent developments in the technology that transforms spent cooking oil into high-quality refined oil will favor the expansion of the market as a whole. Growing government measures to promote WCO usage for industrial purposes are predicted to fuel the used cooking oil market's expansion in the next few years due to the food and foodservice industries' quick evolution and the use of unique preparations in this sector.

WCOs are useful byproducts of the food chain that can be used as environmentally friendly raw materials to make chemicals. There are a staggering number of WCOs in use today, which have major negative effects on the environment, the economy, and society. According to estimates, the world produces more than 15 million tonnes of waste vegetable oil each year, with the European Union (EU) producing close to 1 million tonnes [3]. WCOs are frequently discharged through public sewers, necessitating special upkeep and raising the cost of water treatment. Vegetable oil causes several mass transfers issues because of the adsorption of lipids onto the biomass, which encourages the production of foams and the floating of sludge [4].

Triglycerides, monoglycerides, and diglycerides make up the majority of WCOs, along with varying amounts of free fatty acids (5%–20% w/w) produced during the frying process. Saturated and unsaturated fatty acids, which make up the majority of triglycerides, can be utilized as platform chemicals for the production of goods with added value across a variety of industrial sectors [5]. For example, WCOs are used more frequently in the industry for the synthesis of biofuels or direct-burn energy production [6] [7]. The manufacturing of animal feed [8] and biolubricants [9] are two other non-negligible market areas for recovered WCOs.

Due to recent legal reforms that support the use of used cooking oil for sustainable fuel generation, North America holds the biggest market share. The EU is making significant efforts to expand biodiesel production throughout Europe. According to the European Commission, a significant portion of diesel usage will switch to biodiesel by 2020. Governments in this region are developing regulations to encourage the collection and processing of used cooking oil from cafés, restaurants, lodging facilities, catering companies, and hotels. The regional market is expanding as a result of advertising activities that raise awareness about the recycling of used cooking oil.

The market in the Asia-Pacific is anticipated to experience a substantial CAGR because of the region's growing consciousness of the importance of sustainable energy sources and environmental welfare. Growth will be aided by the rising number of businesses engaged in the region's waste cooking oil collection, processing, and refinement. To meet their demand for raw materials for the manufacturing of biodiesel, businesses with operations in North America and Europe invest in UCO purchases from Asian nations. Market expansion is also aided by how the food and services sectors have changed throughout the region.

Brazil is one of the largest producers of biodiesel, and hence the demand for using alternative sources as feedstock is also increasing. As more countries are using used cooking oil to manufacture biodiesel, Brazil is also promoting its use in biodiesel production. Moreover, in 2016, the Brazilian President signed the biofuels initiative into law which will help increase the production of biodiesel in Brazil in the coming years. On the other hand, to help it achieve its objective of reducing greenhouse gas emissions, Argentina is also increasing its use of renewable energy. The Biofuels Law 26,093 of 2006 required a 5% bioethanol blend in gasoline and a 5% biodiesel blend in diesel beginning in 2010. Since 2016, the blend market has demanded a 12% mix of ethanol and a 10% mix of biodiesel. Such initiatives are expected to increase biodiesel production in Argentina, which will increase the demand for waste cooking oil.

In Middle East & Africa regions, many countries are transitioning from conventional energy resources to more efficient energy resources. In African countries, there is a significant opportunity for entrepreneurs, particularly those in informal and rural settlements, to use cooking oil or edible oils to produce and resell biodiesel. In Zambia, a young entrepreneur has grown his business from 200 liters of biodiesel produced from used cooking oil to 3,000 liters per month, selling it to local customers for use in vehicles and machinery. More such initiatives are expected to boost the use of this oil in the production of biodiesel.

Various Vegetable Oils used in Cooking

i. Canola oil

This widely used oil comes from the rapeseed plant. Its neutral flavor and high smoke point make it a great option for frying, sautéing, and baking. It is also used to make margarine. Although canola oil has one of the lowest levels of saturated fats, it doesn't have as much omega-3, which lowers blood pressure as extra-virgin olive oil does. Because of this, encouraging heart health might be a smart move. There is also alpha-linolenic acid (ALA), which the body converts into vital fatty acids.

ii. Olive oil

Olive fruit and pits are crushed to create this fragrant, fruity-tasting oil, which has a green or yellow color. The least refined type of olive oil, extra virgin olive oil, has the lowest smoke point. It also has positive effects on the heart. Bottles marked simply "olive oil" include refined and extra virgin olive oils.

iii. Coconut oil

The rumor about this delectable, popular oil is that it might have disease-preventing qualities, but those who are concerned about their blood pressure should beware: the most saturated fat is found in this oil. It's easy to give in to temptation when something tastes delicious, but excessive saturated fat is bad for your health. Use conventional, non-tropical vegetable oils only. Canola and olive oil are preferable choices.

iv. Vegetable oil

Usually, this oil has a mixed flavor and is unremarkable. Depending on the specific blend, it has a different nutritional value. It frequently consists of a blend of canola, soybean, palm, sunflower, and safflower oils. It is extremely adaptable and often has a medium-high smoke point.

v. Avocado oil

This oil has a beautiful aroma and is good for the body. Monounsaturated fatty acids, which make up the majority of their composition, can help to reduce inflammation. It is also good for frying and searing because of its high smoke point.

vi. Sunflower oil

These are made of sunflower seeds. This refined oil contains a lot of omega-6 fatty acids. It can reduce inflammation and is excellent for your heart. It mostly contains monounsaturated fats and has a high smoke point.

vii. Peanut oil

It tastes bland but is good for the heart. Refined peanut oil is frequently used for frying because of its medium-high smoke point. Although it's relatively uncommon, you can also find unrefined peanut oil.

viii. Almond oil

Almond oil is pleasant and often low in saturated fat if you're looking to add a distinctive, nutty taste to a recipe. Recent research suggests that eating a lot of almonds may help lower blood pressure. Almond oil has a high smoke point, making it suitable for both salad dressing and frying.

Characteristics of Waste Cooking Oil

The quality of used cooking oil is crucial in determining the caliber and appropriateness of the resulting biodiesel. Waste cooking oil has a range of properties based on several variables, such as the type of oil source, how long it was used, the contents of the fried meal, and the temperature at which it was cooked. Usual cooking oil's predominant properties include relatively high quantities of free fatty acids, density, and viscosity.

DISPOSAL AND ENVIRONMENTAL IMPACT OF WASTE COOKING OIL

Disposal of WCO

Various disposal methods of WCO include:

A. Industrial means of Disposing Waste Cooking Oil

There are three standard methods for disposing of drilling waste cooking oil in industrial settings. These are hauling to an onshore plant, offshore discharge, and cuttings reinjection. As it depends on other elements, including ecological circumstances, environmental regulations, and cost, choosing a disposal method to use is typically a highly difficult issue. For example, it is less expensive to dump waste into the ocean than to transport it to an onshore waste disposal facility, but environmental regulations for waste release are highly strict and demand that waste be processed to an acceptable level before being discharged, which adds to the expense. As a result, it is strongly advised that thorough economic and environmental analyses be carried out to weigh the choices before choosing any waste disposal strategy. If the offshore discharge is the preferred way to get rid of waste, there will be no need for storage facilities.

Offshore Discharge

The most practical and operationally secure method of disposal for drilling waste is probably to discharge it into the ocean. This is because it does not require any additional machinery (storage facility) than what is typically present on the rig [10]. Aqueous-based cuttings can be disposed of using this method because they hardly ever need to be treated before disposal. However, before being released into the sea, non-aqueous-based fluids must be treated to a standard that is acceptable to the environment. The concentration of potentially dangerous components in the waste, the volume of the discharge stream, and the sensitivity and capacity of the possible receiving environment are all things to take into account when choosing this choice.

Cuttings Reinjection

Direct disposal of polluted material into the ocean is prohibited by recent severe legislation. This has led to a rise in the practice of reinjecting drilling wastes, particularly drill cuttings, where practical. The slurry is then injected into an underground space at a pressure high enough to fracture the rock. The slurry injection method involves grinding materials into minute particles, combining them with water or another liquid to form a slurry, and injecting the slurry into the earth. The annulus of the well or designated disposal is the two methods used most frequently to inject slurries into the formations. Disposal wells are created to give people a way to move fluid waste without harming the environment into an underground geologic formation.

B. Domestic Disposal Methods

Operations both onshore and offshore frequently cut reinjection. But because there is room for an onshore business, there are many more management options accessible. Onsite burial is possibly the most popular onshore disposal technique. Other techniques include building a waste reserve pit and using thermal processes like incineration, kilns, open burning, etc. Composting, land spreading, landfarming, and other biological techniques are also available. In an onshore setting, trash can be processed and put to use for various advantageous purposes, like road spreading, building materials, etc. In this section, we look at the different ways that trash can be treated and thrown away on land.

Onsite Burial

The act of burying involves putting debris in a man-made or natural excavation, such as a landfill or a pit. It has remained the most popular onshore disposal method for drilling waste due to its simplicity. The low cost, low technology, and lack of waste transfer from the well site are further benefits of this approach. Given our present understanding of the paths by which pollutants migrate, the dangers associated with burying trash need to be carefully evaluated [11]. Onsite burial may not be a good option for garbage that contains large amounts of oil, salt, biologically accessible metals, industrial chemicals, and other materials with hazardous components that can contaminate useful water supplies. For wastes that have been stabilized, burial makes sense since the stabilization procedure will prevent the waste's contents from migrating too quickly [11].

Waste Pits

Any activity involving the management of drilling waste onshore necessitates the use of waste pits, whether lined or made of earth. One of the main purposes, among many others, is to gather and store all drilling-related wastes produced during the drilling operation [12]. Other applications include the management of work-over/completion fluids, the storage and evaporation of produced water, and the emergency containment of produced fluids. To avoid waste materials spilling onto the drilling or manufacturing site, onto neighboring bodies of water, or into residential areas, waste pits must be properly placed. The pits are typically coated with natural or synthetic liners to minimize seepage into groundwater bodies and contamination of the soil.

Landfills

This alternative is the placement of treated or untreated cuttings in a containment unit with a liner and cover designed to keep garbage inside and a cover over it to keep out the elements. The ability of the landfill to hold waste will be determined by the caliber of the design and materials utilized, as well as the underlying geological units [10]. A critical aspect of running a landfill is ensuring long-term containment because wastes disposed of there are not eliminated but rather stored for an extended period. In the case that waste is gathered at various drilling sites, landfills are frequently managed by off-site business entities. On the other hand, some oil companies that do a lot of drilling might build and take care of their landfills.

Environmental Impact of Waste Cooking Oil

1. Impacts on Soil and Plants

Waste cooking oil contains hydrocarbons that can make the land more poisonous and less fertile and productive [13]. The change in color and texture of the polluted soil is a classic indicator of how significantly the aesthetic value of the soil is impacted. According to [14], waste engine oil pollution causes the soil's microbial population and organic matter to decline. Cooking oil waste left on the soil might result in the inactivity of microorganisms, which can cause poor aeration and make the impacted soil more like dust [15]. Waste engine oil contains heavy metals that can be retained in soils as oxides, hydroxides, carbonates, and exchangeable cations. These could bind to organic materials in the soil and cause the microbial life there to die off [16]. Even though some of these metals are vital micronutrients for plants in low quantities, most plant species can experience growth inhibition and metabolic problems when these metals are present in large amounts [17].

Chemicals included in used mineral-based crankcase oil migrate and behave differently in the environment depending on the circumstances. The majority of the oil's high molecular weight hydrocarbon components often adhere to the soil's surface. Waste engine oil contamination of soils causes a considerable decrease in soil moisture [18]. According to [19], spent oil severely inhibits the activities of soil catalase and dehydrogenase, delays the germination of seeds, and reduces plant growth [20]. According to research by [21] and impacts on microorganisms like mycorrhizal fungi, PAHs in waste oil have been proven to cause indirect downstream effects like alteration of the interaction between plants, water, and the air [22]. Waste engine oil always makes the soil darker than it would otherwise be. Due to this, polluted soil can absorb and hold onto heat longer than uncontaminated soil. According to [23], waste cooking-contaminated soils can achieve temperatures of around 65 to 70 °C, which are fatal to many plants that would otherwise thrive there at ideal temperatures of 24 to 32 °C [24].

According to [25], tomato plants were more negatively impacted than pepper plants when the soil was contaminated with leftover cooking oil. Additionally, in waste motor oil-polluted soil, [26] reported that Amaranthus hybridus (spinach) seeds did not germinate well. The seedlings' protein, chlorophyll, and growth were all negatively impacted [27]. In soils polluted with old motor oils, [28] demonstrated that noticeable changes in physical, chemical, and microbiological properties took place. Metals accumulate in soil due to oil pollution and eventually move into plant tissues [29]. According to [30], in spent motor oil-polluted soils, both oxygen intake and seedling growth were reportedly impacted. All of these things threaten the balance of the soil ecosystem, and the amounts of PAHs, heavy metals, and other waste products from engine combustion in the soil are what cause the overall effects on the environment and people's health.

2. Impacts on Aquatic System and Air

After being dumped on soil surfaces, waste engine oil can move and eventually seep into bodies of water [31]. When oil seeps through the soil and into bodies of water like lakes, streams, and rivers, groundwater becomes contaminated. Its effects on aquatic systems include the formation of microscopic films or sheens on the water's surface, which lowers the amount of oxygen penetration needed for fish and other aquatic lifeforms that make up the food chain. Aquatic biota will inevitably suffocate and perish as oxygen penetration into the water decreases. Depending on how contaminated the water is, this form of pollution may also make it impossible to drink. The risks of drinking water contaminated with waste oil range from minor signs of toxic chemical buildup in the liver to whole body function impairment and even the extinction of aquatic life [32]. The very slow groundwater flow pattern lengthens the residence time of metals present in waste oil that is left lying around in the environment.

While an engine is running or when crankcase oil is burned or utilized as a fuel in boilers, incinerators, and cement kilns, contaminants from crankcase oil also enter the air through the exhaust system. Metals like lead, zinc, chromium, aluminum, nickel, copper, and iron can be found in the combustion products of spent crankcase oil. Others include nitrogen oxides, phosphate, calcium, hydrochloric acid, nitro compounds, sulfur dioxide, and sulfur [33]. The air can become contaminated with PAHs produced by oil combustion as they escape the engine through the exhaust [34]. Additionally, the volatile organic components of used engine oil tend to evaporate from the cluttered soil surface into the atmosphere. All of these are released into the air, which results in pollution and a decline in air quality.

3. Health Impacts of Waste Cooking Oil

Exposure to it is hazardous due to the used cooking oil. Due to the physicochemical properties of used oil, the cutaneous route of exposure is the most sensitive [35]. Other exposure routes, including oral and inhalation, become more common when sufferers eat water that has been tainted by used oil or work as artists who frequently come into contact with the forbidden oils. Roadside dust, car exhaust, and indirect inhalation of generator exhaust can all have an impact on the degree of exposure. In addition to individual characteristics like age, gender, nutritional status, family traits, way of life, and state of health, factors like dose, duration, and exposure route can also have an impact on the likelihood of adverse health effects occurring and the severity of such effects after exposure.

The body can be negatively affected by using cooking oil in several ways, including genotoxic, carcinogenic, immune system, neurological, reproductive, and developmental effects. Acute exposure is defined as lasting 14 days or less, intermediate exposure as lasting 15–364 days, and chronic exposure as lasting 365 days or more [36]. Among the hazardous organic substances identified in the combustion products of spent cooking oil are the very toxic polychlorinated biphenyls (PCBs), chlorodibenzodioxins (CDDs), and chlorodibenzofurans (CDFs). High amounts of the metal particles and PAHs may be inhaled by people who live or work close to a recycling facility where used mineral-based crankcase oil is burned as fuel for the home's heating system. Spraying used motor oil carelessly around homes and in landfills to ward off snakes or scorpions, as some people think, is another way to expose people.

The following health impacts of used cooking oil depend on the properties of the compounds in the oil as well as how they are absorbed, retained, or ejected by the host body after exposure. Studies on cattle that consumed spent cooking oil revealed that lead and other metals were distributed and absorbed, among other organs, in the liver and kidney. Studies have shown that when old cooking oil was applied to mice's skin, the PAHs that collected in the oil were absorbed [37].

Different health effects could happen depending on the properties of the oil's constituent constituents. Each brand of oil uses a different blend of oil and additives. The characteristics of the engine in which the oil is used may also have an impact on the oil's final composition. As a result, responses to one batch of used cooking oil could be different from those to a different batch. Parts-fitters (mechanics) and other vehicle mechanics experienced skin rashes, anemia, and nervous system disturbances (headaches, tremors), among other symptoms, when working with a lot of used cooking oil [38]. But while at work, these people also had contact with a wide range of other drugs. Breathing in used cooking oil mist for a short while may cause moderate eye, nose, and throat irritation. Diarrhea could be brought on by large amounts of mineral-based old crankcase oil [36]. Although [34] listed used motor oil as a human carcinogen, the International Agency for Research on Cancer (IARC) did not in 1984.

ECONOMIC POTENTIAL OF WASTE COOKING OIL

Utilizing waste cooking oil as an energy source

More research is being done on environmentally friendly ways to produce new generation fuels like hydrogen and biofuels to lower greenhouse gas emissions. Due to the quick depletion of crude oil, the concept of waste-to-energy is currently booming. Agricultural waste or other used oils like waste cooking oil, used transformer oil, waste gear or engine oil, and waste lubricating oil, are typically utilized as raw materials in the production of alternative fuels, which are primarily based on the waste-to-energy idea [39]. WCO is a possible raw material for energy generation because it produces products including biodiesel, biomethanol, H_2, H_2/CO, and low molecular weight hydrocarbons like CH_4. These items can also be used to generate electricity or power machinery or vehicles. As a result, energy production from WCO can be seen as both a useful method of energy recovery and an efficient waste management strategy.

Vegetable oils were initially used as a fuel to power engines by Rudolph Diesel [40]. However, some WCO characteristics, such as poor volatility, unsaturated molecule reactivity, excessive acid value, contamination caused by food debris, and excessive viscosity, lead to issues such as carbon accumulations and injector blockages [41]. Micro-emulsification, transesterification, and pyrolysis are some of the procedures used to advance the properties of used cooking oil so that it can be used as an energy source in the future. Dilution with solvents or diesel fuel is another method [42]. The traditional technique of using WCO entails gathering WCO and burning it along with burnable waste to create a heat stream that can be used to drive a steam turbine to produce power. The creation of residual ash, handling of residual ash, and emission of hazardous gases are disadvantages of this process.

WCO can be burned on a small scale to produce a flame, which can also be used for heating. This characteristic can be used for applications with large market potential, such as burners. This could include a feature that allows WCO to be put into the burner at various flow rates while being partially segregated from its impurities. Additionally, there is marketable small equipment like lawnmowers and boilers that operates solely on WCO [43].

Pyrolysis of Waste Cooking Oil

A thermochemical reaction known as pyrolysis occurs when a high temperature and a small amount of oxygen are combined to form a variety of gases, liquids, and solids. [44] examined the pyrolysis of waste cooking oil, which is mostly made of oleic, stearic acids as triglycerides, linoleic, and palmitic, at various temperatures of 400°C-420°C for roughly 180 minutes. In the experiments, fractionating columns measured 0.18m,0.36m and 0.54m in length were used. Condensable hydrocarbons like C5-C17 paraffin and olefins make up the majority of the products produced by pyrolysis. Gases such as H_2, CO, and CO_2 were also produced in minor amounts, as well as aromatics, cycloparaffin, and cycloolefins. [44] also noted that higher temperatures and shorter columns resulted in greater reactant mixture conversion. At higher temperatures, a higher olefin fraction was produced. Due to their high concentration and proximity to the boiling point of gasoline, liquid hydrocarbon products can therefore be utilized as fuel. In the presence of catalysts including Na_2CO_3, silica-alumina, and HZSM-5, [44] examined the pyrolysis of waste sunflower oil. He achieved the maximum conversion rate of 73.17 weight percent using sodium Na_2CO_3 as a catalyst.

Francis et al., [45] described the pyrolysis of used cooking oil (VEGETAMIXOIL®) to create hydrogen gas or H_2/CO, high molecular weight hydrocarbons, coke and low molecular weight gaseous hydrocarbons (C1-C4), which can then be used as an energy source in a fuel cell or assisted in the manufacture of biodiesel through Fischer-Tropsch. The author's procedures are shown in Fig. 1. [45] found out that when water is added to coke, it quickly breaks it down into hydrogen and carbon monoxide.

$$C + 2H_2O \rightleftarrows CO_2 + 2H_2 \quad (1)$$

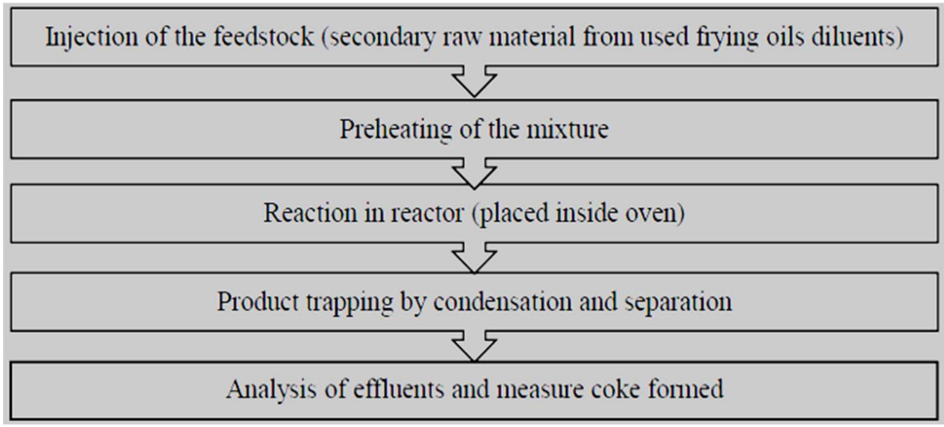

Fig. 1: Procedures for pyrolyzing using cooking oil

Francis et al., [45] also noted that while the creation of CO_2, H_2, and CO is greater at 800 °C than it is at 700 °C, the formation of light hydrocarbons is promoted by the addition of water. The use of pure water steam was shown to be more effective than the author's use of an equimolar mixture of water and nitrogen as a diluent. Additionally, it is reported that altering the flow rate of WCO might cut the residence duration in half. Application of thiophene, a reaction inhibitor, to the mixture of up to 300 ppm will cause a reduction in CO_2 and CO of up to 5.40 and 6.30 percent, respectively.

Research on waste management concerning used cooking oil, waste plastic, and used lubricating oil was conducted by [46]. Used cooking oil and used lubricating oil are typically burned together in Japan as part of routine waste management procedures to create steam heat, which can then be used by a steam turbine to produce electricity. The authors compared this conventional approach to waste management with an alternative system in which pyrolytic oil is produced in conjunction with waste plastic, waste cooking oil, and waste lubricating oil in all four systems. The authors' findings are listed in Table 1. According to [47], the optimum economic and energy-efficient approach may involve combining the use of waste cooking oil, waste lubricating oil and waste plastic for the synthesis of pyrolytic oil. It has been suggested that this pyrolytic oil is a biofuel with low greenhouse gas emissions. It is a cheap fuel with a high hydrocarbon content which can also be used economically as an energy source in engines, turbines, and boilers [47]. Pyrolytic oil can be used instead of either light or heavy fuel oil to power gas heaters, heaters, incinerators, diesel engines, and turbines that make electricity. According to [46], pyrolytic oil has a calorific value of nearly 93 percent that of diesel and a flash point higher than biodiesel (80 °C). Additionally, pyrolytic oil contains nearly no sulphur and reduces nitrogen oxide levels, which results in less smog and no corrosion issues.

Waste Cooking Oil Transesterification

The synthesis of biodiesel, which is made from long-chain fatty acid mono alkyl esters derived by the transesterification process, is the most typical and widely acknowledged industrial application of WCO. Renewability, domestic production, environmental advantages like biodegradability and a decline in most controlled exhaust fumes, harmless usage due to a higher flash point, and spontaneous lubrication are just a few of the advantages of biodiesel [48].

Table 1: Production of pyrolytic oil from waste with cost estimates

Utilized Raw Materials	ultimate Pyrolytic Oil Yield (ML/y) (10^2)	Average Unit Cost of Production (USD/L) (10^2)
WCO +WLO	0.3557	0.0025
WLO +WP	0.3663	0.0024
WCO +WP	0.491	0.0031
WCO + WLO + WP	0.3803	0.0024

Keys: WCO – Waste Cooking Oil, WLO - Waste Lubricating Oil, WP – Waste Plastic

Triglycerides from WCO combine with alcohol in one of the two stages of the process in the presence of a catalyst that may be acidic, basic, or enzymatic to produce fatty acid methyl ester (FAME), which is a by-product that includes biodiesel and glycerol. The acquired biodiesel is typically blended with diesel to power vehicles or generators [49]. Cost analysis for the production of biodiesel reveals that the primary factor increasing the costs of production is the source of the raw materials [50]. Vegetable oils used as a raw ingredient initially make the procedure expensive. Thus, the use of WCO somewhat resolved this issue.

Generation of Hydrogen gas from Waste Cooking oil

It is possible to manufacture hydrogen gas from used cooking oil by employing a steam reforming method with a packed bed column, which is more effective than catalytic reforming, which does not entirely convert the oil [51]. It is also possible to combine unmixed steam reforming with an in-reformer CO_2 adsorbent for sorption [52]. An almost pure stream of hydrogen can be created using these techniques. The essential components of the unmixed reforming combustion process are alternate air inflows, fuel and steam mixtures, and a packed bed of catalyst. It was found that nickel works better when used as a catalyst for the oxidation-reduction process needed to alternately flow air and fuel. The procedure for unmixed reformation can be summarized using Fig. 2.

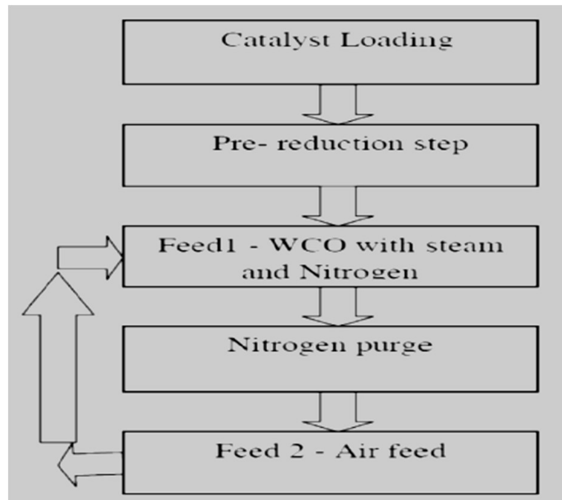

Figure 2: Steps for converting used cooking oil to hydrogen [52]

At a temperature interval of 600–700 ^{0}C at 1 atm, [53] examined chemical loop reforming of used cooking oils with a packed bed reactor. The same author also studied the same system with carbon dioxide sorbent (pre-calcined dolomite) filled at the reactor's center. The first pass of six air and fuel-stem cycles produced hydrogen that was about 100% pure, followed by passes that produced hydrogen that was around 95% pure and cycles that produced carbonation efficiency that was stabilized at around 56%. The following reaction strategy applies to the steam loop reforming of WCO:

1) To feed the steam-WCO

WCO's catalyst reduction

$C_nH_mO_k$ + (2n + 0.5m − k)NiO → nCO_2 + $0.5mH_2O$ + (2n + 0.5m − k)Ni………………….(2)

Water gas shift reaction

$CO + H_2O \rightleftarrows CO_2 + H_2$…………………………(3)

Steam reforming

$C_nH_mO_k + (n - k)H_2O \rightarrow nCO_2 + (2n + 0.5m - k)H_2$…………………………………..………....(4)

2) For Air feed

Oxidation of catalyst

$Ni + 0.5O_2 \rightarrow NiO$……………………………...(5)

Gasification of Carbonaceous deposit

$C + O_2 \rightarrow CO_2$…………………………….……(6)

$C + 0.5O_2 \rightarrow CO$……………………….……(7)

As a result, employing dolomite in a steam loop reforming system can be a successful and environmentally responsible approach to using WCO to produce hydrogen gas

Ozone-treated oil

After preheating WCO and treating it with water and/or ozone, it is possible to obtain WCO treated with ozone. The fuel produced using the patented process and machinery has a higher heating value (approximately 9730 kcal per/kg), a lesser kindling point (around 51.3 °C) and a lower density than biodiesel produced using standard methods. Thus, the fuel produced by the technique has the potential to be a cost-effective replacement for the manufacturing of methyl ester [54]. Scientists have limited opportunities in the areas of used cooking oils ozonation, process intensification, and prospective market.

WCO: Production of electricity by WCO

I. Combined heat and power system (CHP)

The combined heat and power (CHP) system is one of the prospective uses for used cooking oil in which energy is produced from waste cooking oil. Additionally, other uses for the heat produced in the process include water heating. The process, which incorporates both liquid and gaseous phases, is modeled on the Organic Rankine Cycle [55]. The majority of the system's components are the waste cooking oil reservoir tank, filtration sections, combustion units, enlargement units, generator units, pump units, condensation units, and exhaust units. Commercial goods are offered in markets based on this structure. One of Owl Power Company's flagship products, VegawattTM, is a computerized CHP system that won one of the 2009 Popular Sciences Invention Awards [56].

Combined heat and power (CHP) systems and waste cooking oil can use a variety of fuels, including biomass, bio-oil, vegetable oil, and fats, making them a viable substitute for fuel based on petroleum. Due to the accessibility of completely automated CHP equipment at a range of scales, this technology is more adaptable (local to global scale) [57]. The system is extremely effective for restaurants employing deep fryers because it can directly use waste cooking oil as its raw material and produce heated water and energy in return. A refrigerator-sized micro-scale was created specifically for the processing of WCO.

II. Combining external combustion steam engine with electric generators

The use of electric generators connected to external combustion steam engines is another method of producing power from waste cooking oil. The utilization of patented technology allows for the creation of small, high-kilowatt generators with little nitrogen and sulfur oxide emissions. Utilizing technology, heat is produced during the burning of filtered waste cooking oil fuel, which is then used to create steam.

Electricity is then produced by rotating an electric motor connected to an electric panel using steam [58]. Such technology has the potential to bring about a revolutionary change that lessens our dependence on fossil fuels. Given that there is a dearth of literature on the subject, WCO usage in this function can be extended with research.

III. Fuel for internal combustion engines made from waste cooking oil.

Waste cooking oil with no particles can be used as fuel for diesel engines. When used under the same conditions, leftover cooking oil can produce 313kW more power than alternative fuels such as soy oil, rapeseed oil, red diesel, sunflower oil, or biodiesel. Additionally, the power output was found to be rather clean, with lower emissions of particulate matter (0.035 mg/L), carbon monoxide (1.328 mg/L), nitrogen oxide (1.491 mg/L), and sulphur oxide (0.001/L) at standard pressure and temperature [59].

WCO as a raw material for products with added value

Triglycerides and a substantial number of free fatty acids make up the majority of the chemical makeup of WCO. WCO can be successfully used in a variety of chemical or enzymatic procedures to create new chemical entities as value-added products. A substantial amount of glycerol is also produced during the process of creating biodiesel from WCO, and this substance can be used for a variety of additional purposes. The produced glycerol can be utilized directly for the manufacturing of methanol, low-grade animal feed, chemicals (polyethylene glycol), hydrogen gas, and effluent systems. In contrast, the glycerol produced can be refined and supplied as a raw material to other companies, including those in the food, textile, and chemical sectors [60]. Free fatty acids, catalysts, and inorganic salts for transesterification processes are the main pollutants found in the glycerol obtained during the synthesis of biodiesel. Thus, glycerol can be refined by adding strong sulfuric acid [61].

A. Reuse of WCO for the synthesis of bio lubricant

Bio lubricant" (octyl esters) is another value-added product made from used cooking oil. Since most lubricants on the market are petroleum-based, a more affordable and environmentally friendly source is required. From new vegetable oils, including jatropha oil, palm oil, castor oil, soybeans oil, rapeseed oil, etc., scientists have created bio-lubricants. Unused oil used as a raw material account for roughly 80 to 90 percent of the cost of producing bio-lubricants made from these virgin oils. To produce bio-lubricants, researchers are focusing on WCO's affordable, accessible, and environmentally favorable solutions. WCO was converted to bio-lubricants using a two-step process by [62] that involved enzyme-based hydrolysis and esterification with octanol. When the water to oil ratio was kept at 4, hydrolysis catalyzed by 1 g/L of Candida rugosa lipase ensued, resulting in the highest conversion of 92 percent after 30 hours, with the final product being free fatty acids. Hexane-extracted free fatty acids were subsequently subjected to the second step of esterification, which utilized an Amberlyst 15H catalyst (2 g). At an ideal temperature of 80°C, a 3:1 molar ratio of octanol to FFA converts 98 percent of the octanol to FFA in 3 hours.

B. Use of WCO in the manufacture of grease

Grease has several uses in the world of machines since it is used to reduce tension between mechanical components. Although non-biodegradable, grease is often produced from petroleum-based raw materials. In 2011, [63] worked on a green alternative for grease, namely one made from left-over products like waste cooking oil and spent bleaching clay. Cooking oil that has undergone thermal deterioration reacts with water to form polymeric contaminants. As a result, WCO has greater flash and fire points as well as intrinsic viscosity. Additionally, it is a readily available, biodegradable waste material that is utilized as one of the ingredients in the creation of grease. WCO and spent bleaching clay were vigorously mixed by an overhead stirrer at room temperature (about 21 ^{0}C) to create grease from used cooking oil. Different formulations comprising 20 to 50 percent WCO balanced by spent bleaching clay were evaluated, and the results showed that formulations with 70 to 75 percent spent bleaching clay balanced by WCO were preferable. When grease made from this process is kept for a particular time (more than one month), oil migrated out of the thickener, changing the consistency of the grease [63].

Reuse of Waste Cooking Oil as a fermentation media component

WCO disposal has become problematic due to the massive amount of WCO being produced. One of the top options for its effective exploitation is the manufacturing of biodiesel from waste cooking oils. However, the manufacturing of biodiesel from WCO has a high processing cost, which drives up the price of the finished good. So, it's important to look into how used cooking oil can be used to make products with added value in a cost-effective way. By using used cooking oil as a possible carbon basis throughout the fermentation procedure, the majority of studies have successfully screened bacteria that can accumulate surface active chemicals [64]. The cost of producing fermentation products can be reduced because there is a huge supply of WCO available as waste material. As a result, WCO makes biotechnological operations more cost-effective and, in some situations, produces an increased output compared to previously employed carbon basis like glucose [65]. Almost all of the oils supplied to the media for the fermentations were sterilized separately first. Steam autoclaves are capable of sterilization. Most of the time, used cooking oil was added after being filtered, but occasionally it wasn't [66]. Always evaluate the chemical qualities of WCO, such as the proportion of unsaturated and saturated fatty acids, water content level, free acidity, oxidation number, and presence of particulate matter (to determine the filtration stage) [67].

The manufacturing of biosurfactants and bioemulsifiers is a high-cost, low-yield process. Both the number and quality of these biomolecules were regulated by the type of carbon substrate utilized as a substrate. To produce these biomolecules with lower production costs and higher yields, waste cooking oil was employed as the basic media component. Different strains of Pseudomonas aeruginosa, including L2-1, B1-3, 7a, and 6c, were examined for the generation of polyhydroxyalkanoates (PHAs) and rhamnolipids by fermentation using glycerol, used cooking oil, cassava wastewater, and using used cooking oil and cassava wastewater as the substrate [68]. The P. aeruginosa 7a strain produced the most biomass with WCO out of all the strains tested on various substrates (6.8 g per L). Furthermore, all strains produced 43.3 to 50.4 percent of the dry weight of PHA from WCO, the highest results of any substrate. With used cooking oil as the carbon basis, strain L2-1 produced PHA at a rate of 39% of the dry weight of the cells, resulting in 4.2 g of dry cell mass per L.

The length of the produced PHAs' chains ranges from C8 to C16, and the degree to which the monomers are unsaturated varies significantly depending on the type of carbon source utilized. Short-chain monomers (C8:0-37.5%), C10:0–42.1%), and C12:0–13.2%) and unsaturated monomers (4.8 percent) were found to be present in higher concentrations in the same product when used cooking oil was used as the carbon basis. So, compared to hydrophilic substrates like glycerol, WCO, a hydrophobic substrate, produced higher yields of PHA. The identical fermentation technique yielded rhamnolipids, whereas WCO produced a more consistent yield that ranged between 245.6 and 273.1 mg/L. Except for WCO, where monorhamnolipids predominate, the dirhamnolipid RhaRhaC10C10 was prominent. Unsaturated rhamnolipid production is comparable and was unaffected by the carbon supply.

Siddhartha et al., [68] also discovered that sugars were digested more quickly than hydrophobic substrates or oil as a carbon basis. To enable the consumption of oil by microbes in the pattern of readily available glycerol and fatty acids, used cooking oil should be enzymatically broken down. When WCO or CWO, two media components that break down triglycerides, are present, strain L2-1 was discovered to create esterases and lipases. Following the stationary growth phase, the synthesis of rhamnolipids (a biosurfactant) was seen in the same fermentation process. The significant amount of leftover oil that remains after 72 hours is also helped to dissolve by the biosurfactant that is produced. The procedure is more economical when PHAs and rhamnolipids are produced simultaneously.

For several fermentation processes, Cooper and Paddock's medium has received extensive research [69]. In this medium, there are various quantities of WCO, glucose, 0.1 percent KH_2PO_4, 0.5 percent $MgSO_47H_2O$, 0.01 percent $CaCl_2$, 0.01 percent NaCl, and 0.5 percent yeast extract. Technical grade glucose and WCO concentrations range from 1 to 10 percent, and these concentrations require an experimental adjustment that differs depending on the type of fermentation used. Most of the time, 7 to 8 percent technical grade glucose and 5 percent WCO are used. The ability to create biosurfactants was found in several Saccharomyces cerevisiae strains. When these strains were grown on Cooper and Paddock's medium to create biosurfactant, it was discovered that S. coreanus 2023 generates 4.35g/L which is the lowest amount and Y42 yeast generates the maximum amount of biomass, up to 20.01 g/L. In this medium, glucose makes up roughly 8% while WCO makes up 5%. The concentration that generated the highest biomass output and emulsification activity for this specific fermentation method was 5 percent glucose and 5 percent WCP. It was found that S. cerevisiae 2031 used WCO as an extra carbon source for biomass formation, but that the rate of waste cooking oil consumption decreased over time [69]. The author's maximum uptake through day six was 37.58 percent. After ingestion of a soluble competitive metabolite, the presence of a water-immiscible substrate induced the formation of a biosurfactant.

An extensively researched source for the synthesis of polyhydroxybutyrate (PHB) was Cupriavidus necator. [66] used waste frying oil, heated rapeseed oil, and pure rapeseed oil as media components in research fermentation systems. A PHB outcome of 1.2 g/L was produced using WCO, which is comparable to the yield produced by glucose. After 72 hours, pure oil produced 0.62 g per liter and heated oil produced 0.9 g per liter of PHB, respectively. In comparison to saturated fatty acids and unsaturated fatty acids were found to promote the accumulation of more energy-rich PHB. With used cooking oil as the carbon basis and carbamide as the source of the nitrogen, the identical strain of C. necator H16 and its mutant transformation, C. necator PHB4, produced PHA with outstanding results [1].

Reuse of Waste cooking oil to make soap

One of the simplest ways to use WCO is to produce soap or detergent, which may then be used for bathing, cleaning dishes, and clothes, cleaning the house, cleaning animals or vehicles, etc. Low-grade soaps can be made instantly using the saponification process, which involves a reaction with sodium orthosilicate or an alkali metal hydroxide solution (between 1 and 5 percent).

Additionally, these soaps may be combined with different types of organic salts like gluconate, citrate, succinate, and surface-active substances [70]. Because they react so quickly with carbon dioxide and moist air, it is not a good idea to use such strong alkaline compounds. Another patented technique for turning waste cooking oil into hand soap or detergent combines amine derivatives like alkyl amine, alkylene amine and alkanol amine with surface-active ingredients like linear alkylbenzenesulfonate, sarcosine salt, etc. This process can result in gentle, handle-safe liquid soaps. The author claims that in addition to removing peroxides from WCO, the suggested approach is also capable of doing so [71].

Utilizing waste cooking oil in animal feed

Animal diets must include oils and fats because they provide high-energy diets and because some critical fatty acids are required but cannot be synthesized by animals. This requirement is met by vegetable oils, which also serve to hold the other components of animal feed together [72]. WCO from deep fryers is a very cheap source of this oil. Through the food chain, food that is given to animals like pigs and poultry farms indirectly reaches people.

Therefore, it is important to add animal food ingredients purposefully. WCO was initially purified and added directly to animal feed. Later investigations into the animal feed made from waste cooking oil found several dangerous elements, including dioxins [73]. As a result, there are currently some rigorous regulations that prohibit the use of waste cooking oil in animal feed. Waste cooking oil from restaurants and other food service establishments may be used, but not factory oil, according to the European Commission's 2004 statement. United Kingdom government permits the use of waste cooking oil in animal feed when it is collected by a recognized waste transporter, treated safely, and authorized for use in animal feed [74].

Due to the heat processes that take place during frying, WCO differs in composition from vegetable oil. Due to the elevated levels of malondialdehyde and other reactive 2-thiobarbituric acid compounds that were found in it, WCO is unsuitable as an ingredient in animal feed. Animal and human consumption oils may have no more than 6 g of TBARS per g. Therefore, the necessary purification measures should be taken to remove lipid peroxides and TBARSs before using WCO in animal feed. Lipid peroxidases and TBARSs could not be removed using traditional methods including filtering, degumming, bleaching, and deodorizing. As a result, [75] successfully experimented with novel techniques. Activated carbon, Al_2O_3, activated clay, and HZSM-5 zeolite were used in the physical adsorption process. In the chemical adsorption process, carbamide, sodium glutamate, and amino acids were used. The author employed three separate techniques: physical adsorption, chemical adsorption, and water extraction. Out of all the techniques, Chemical adsorption was found to be the most effective in the presence of 0.1 percent H3PO4 and eliminated approximately 80% of both pollutants. He mentioned the use of chemicals as a practical, successful, and effective way for WCO purification [75].

CONCLUSIONS

Waste cooking oil's origin, features, and global distribution have all been covered in detail. This study demonstrates how inefficient cooking oil waste management results in environmental damage, notably water and land pollution, when used cooking oil is dumped into the environment. A layer of oil that covers the water's surface and blocks oxygen from dissolving results in mass extinction of marine life. In addition, the presence of oil breakdown byproducts leads to the mixing of oil and water to make the water more chemically oxygen-demanding and toxic. Furthermore, the continued use of used cooking oil poses a risk to consumers since it can combine with other substances to produce dangerous byproducts such as peroxides, aldehydes, and polymers. Even though wasted cooking oil is a proven carcinogen, it can still be used to make high-value products like bio-diesel, lubricants, biopolymers, and soap. Numerous local communities are ignorant of the threat. A measure must be considered to overcome the lack of awareness regarding the management of used cooking oil, including the effects it has on the environment and its potential for reuse.

REFERENCES

[1] Hanisah K, Takeharu T, Tajul AY, Kumar S. Waste cooking oil as substrate for biosynthesis of poly(3-hydroxybutyrate) & poly(3-hydroxybutyrate-co-3-hydroxyhexanoate). In: Malays J, Microbiol, Turning waste into a value-added product; 2008. p. 51.

[2] Orsavova J, Misurcova L, Ambrozova JV, Vicha R, Mlcek J. Fatty acids composition of vegetable oils and its contribution to dietary energy intake and dependence of cardiovascular mortality on dietary intake of fatty acids. Int. J. Mol. Sci. 2015;16(6):12871-12890.

[3] Gui MM, Lee K, Bhatia S. Feasibility of edible oil vs. non-edible oil vs. waste edible oil as biodiesel feedstock. Energy 2008;33(11):1646-1653.

[4] Ortner ME, Müller W, Schneider I, Bockreis A. Environmental assessment of three different utilization paths of waste cooking oil from households. Resour Conserv Recycle 2016;106:59–67.

[5] Lin CSK, Pfaltzgraff LA, Herrero-Davila L, Mubofu EB, Abderrahim S, Clark JH, et al. Food waste as a valuable resource for the production of chemicals, materials and fuels. Current situation and global perspective. Energy Environ Sci. 2013;6(2):426–464.

[6] Namoco CS, Cloma JT, Rabago G, Surbano R, Buna CC. Development of a mechanical dry corn picker. J Eng Appl Sci. 2017;12(2):409–413.

[7] Chrysikou LP, Dagonikou V, Dimitriadis A, Bezergianni S. Waste cooking oils exploitation targeting EU 2020 diesel fuel production: environmental and economic benefits. J Clean Prod. 2019;219:566–575.

[8] Tres A, Bou R, Guardiola F, Nuchi CD, Magrinya N, Codony R. Use of recovered frying oils in chicken and rabbit feeds: effect on the fatty acid and tocol composition and on the oxidation levels of meat, liver and plasma. Animal 2012;7(3):505–517.

[9] Karmakar G, Ghosh P, Sharma B. Chemically modifying vegetable oils to prepare green lubricants. Lubricants 2017;5(4):44.

[10] OGP. Environmental aspects of the use and disposal of non-aqueous drilling fluids associated with offshore oil & gas operations. International Association of Oil and Gas Producers. OGP Publications 2003:342

[11] Owens CK, Rycroft DR, Stephenson MT, Norris G, Johnson JA, Crame LW, Inglesfield C, Grieg A. Exploration & Production (E&P) Waste Management Guidelines, E&P Forum, Old Burlington Street, London 1993;2.58(196):25–28.

[12] Flemming C, Ivan C, William AP. Theoretical and Practical Models for Drilling Waste Volume Calculation with Field Case Studies; 2010.

[13] Christesen LH, Argebo A. Determination of sulphur and heavy metals in crude oil and petroleum products by Energy X-ray Fluorescence spectrometry and fundamental parameter approach. Anal Chem. 1981;1788- 1792.

[14] Aina M, Matejka G, Mama D, Yao B, Moudachirou M. Characterization of stabilized waste: evaluation of pollution risk, Int. J. Environ. Sci. Technol. 2009;6(1):159-165.

[15] Snyder C. Risk Assessment Guidance for Superfund, Human Health Evaluation Manual, Office of Emergency and Remedial Response, U.S; 2005.

[16] Yong RN, Mohammed AMO, Warkentin BP. Principles of contaminant transport in soils. Elsevier Science Publishers, Amsterdam 1992:258.

[17] Fernandes JC, Henriques FS. Biochemical, physiological and structural effects of excess copper in plants. The Botanical Review 1991;57:246 -273.

[18] Akoachere JTK, Akenji TN, Yongabi FN, Nkwelang G, Ndip RN. Lubricating oil-degrading bacteria in soils from filling stations and auto-mechanic workshops in Buea, Cameroon: Occurrence and characteristics of isolates. Afr J. Biotechnol. 2008;7(11):1700-1707.

[19] Achuba FI, Peretiemo-Clarke BO. Effect of spent oil on soil catalase and dehydrogenase activities, Inter. Agrophy. 2007;22:1-4.

[20] Adenipekun CO, Oyetunji OJ, Kassin LS. Effect of spent engine oil on the growth parameters and chlorophyll content of Corchorus olitorius Linn. Environ. 2008;28:446- 450.

[21] Renault S, Zwlazek JJ, Fung M, Tuttle S. Germination, growth and gas exchange of selected boreal forest seedlings in soil containing oil sands tailing. Environ. Poll. 2000;107:357-365.

[22] Nicolotti G, Eglis. Soil contamination by crude oil: Impact on the mycorhizosphere and on the revegetation potential of forest trees. Environ. Poll. 1998;99:37-43.

[23] Donahue RL, Miller RW, Shickluna JC. An Introduction to Soils and Plants Growth. Prentice-Hall Inc., U.S.A; 1990. P. 667.

[24] Raven HP, Ray FE, Susan EE. Biology of Plants, 7th Edition. New York: W.H. Freeman and Company Publishers; 2005. P. 504–508.

[25] Anoliefo GO, Vwioko DE. Effects spent lubricating oil on the growth of Capsicum annum L. and Lycopersicon esculentum Miller. Environmental Pollution 1995;88:361-364.

[26] Odjegba VJ, Idowu FS. Effects of spent engine oil on the germination and growth of Amaranthus hybridus. Biosci. Res Comm. 2002;14:101-105.

[27] Odjegba VJ, Sadiq AO. Effects of spent engine oil on the growth parameters, chlorophyll and protein levels of Amaranthus hybridus L. The Environmentalist 2002;22:23-28.

[28] Ekundayo JA, Aisueni N, Benka-Coker MO. The Effects of drilling fluids in some waste and burrow pits in western operational areas of Shell Petroleum Development Company of Nigeria Limited on the soil and water quality of the areas. Environmental Consultancy Service Group, Consultancy Services Unit, University of Benin, Benin City, Nigeria; 1989. p. 2-9.

[29] Vwioko DE, Anoliefo GO, Fashemi SD. Metals concentration in plant tissues of Ricinus communis L. (Castor Oil) grown in soil contaminated with spent lubricating oil. Journal of Applied Science and Environmental Management 2006;10:127-134.

[30] Osunbor CC, Anoliefo GO. Inhibitory effect of spent lubricating oil on growth and respiratory function of Arachis hypogeal L. Official Journal of Faculty Science University of Benin, Nigeria 2003;1:73- 79.

[31] Olugboji OA, Ogunwole OA. Use of spent engine oil. AU J.T. 2008;12(1):67-71.

[32] Noln JJ, Harris C, Cavanaugh PO. Used Oil: Disposal Options, Management Practices, and Potential Liability, Third Edition Rockville, MD: Government Institutes; 1990.

[33] Vazquez -Duhalt R. Environmental impact of used motor oil. Sci Total Environ. 1989;79(1):1-23.

[34] Teresa R, Douglas JH, Zenon P. Determination of heavy metals and volatile aromatic compounds in used engine oils and sludges, fuel 2005;85(4):481-485.

[35] Christopher Y, Van Tongeren M, Urbanus J, Cherrie JW. An assessment of dermal exposure to heavy fuel oil (HFO) in occupational settings. An Occup. Hygn. 2011;55:319-328.

[36] ATSDR (Agency for Toxic Substances and Disease Registry), Toxicology profile for used mineral-based crankcase oil. Department of Health and Human Services, Public Health Service Press, Atlanta, GA, USA; 1997. p. 1-208.

[37] Granella M, Clonfero E. The mutagenic activity and polycyclic aromatic hydrocarbon content of mineral oils. Int Arch Occup Environ Health 1991;63:149-153.

[38] Hazlett JM. Report of the Calumet Air Monitoring Project, Louisiana Department of Environmental Quality, Office of Environmental Assessment; 2005.

[39] Selvia PK, Sharmaa M, Kamyotra JS. Spent oil management and its recycling potential in India inventory and issues, Pro. Environ. Sci. 2013;18:742.

[40] Rudolph D. The Diesel Oil Engine and Its Industrial Importance Particularly for Great Britain, J. Ame. Soc. Nav. Eng. 2012;24(1):653.

[41] Amit, S., Biodiesel: Production and Properties, RSC Publishing; 2012.p. 5.

[42] Julia K, David C, Guillermo Q, Salvador G, Miguel G. Direct determination of polymerised triacylglycerides in deep-frying vegetable oil by near-infrared spectroscopy using Partial Least Squares regression, Food Chemistry 2012;131(1):353.

[43] Wong YW, Andrews S, Wong M, Euro. Pat. 2236022 A2, Yen Wen Wang; 2010.

[44] Dandik L, Aksoy HA. Pyrolysis of used sunflower oil in the presence of sodium carbonate by using fractionating pyrolysis reactor, Fuel Process. Technol. 2018; 57(2):81.

[45] Francis B, Julien G, Lucie C. Pyrolysis of secondary raw material from used frying oils, Recents progress en genie des Procedes, Numero 2007;94(2):1.

[46] Singhabhandhu A, Tezuka T. Prospective framework for collection and exploitation of waste cooking oil as feedstock for energy conversion. Energy,2010;35(4):1839-1847.

[47] Czernik S, Bridgwater AV. Overview of applications of biomass fast pyrolysis oil, Energy Fuels 2014;18(2):590.

[48] Merve C, Filiz K. A new application area for used cooking oil originated biodiesel: generators, Energy Fuels 2005;19(2):645.

[49] Gokhan C, Selim K. Increased yields in biodiesel production from used cooking oils by a two-step process: Comparison with one step process by using TGA, Fuel Process. Technol. 2008;89(2):118.

[50] Nikhil G, Virendra KR. Enzyme catalyzed transesterification of waste cooking oil with dimethyl carbonate, J. Mol. Catal. B: Enz. 2013:88 36.

[51] Richard JF, Stefan C. Hydrogen production by steam reforming of waste vegetable oils, Am. Chem. Soc., Div. Fuel Chem. 2003;48(2):592.

[52] Pimenidoua P, Rickett G, Dupont V, Twigg MV. Chemical looping reforming of waste cooking oil in packed bed reactor, Bioresour. Tech. 2010;101(16):6389.

[53] Pimenidoua P, Rickett G, Dupont G, Twigg MV. High purity H_2 by sorption-enhanced chemical looping reforming of waste cooking oil in a packed bed reactor, Bioresour. Tech. 2010;101(23):9279.

[54] Masatoshi M, Seishiro M, Euro. Pat. 1026224 A1, Markl, Herbert, Prof. Dr. Ing.; (2000).

[55] Bossche VD, Alex H. Euro. Pat. 2014880 A1, Universiteit Gent; 2009.

[56] Trent J. Vegawatt: A Generator that runs on grease, http://www.apartmenttherapy.com/vegawatt - a-generator-that-runs-85216.

[57] Michele B, Andrea DP. Emission calculation methodologies for CHP plants, Energy Procedia 2012;14:1323.

[58] Thomas VT, Cordova TN, US Pat. 0001957 A1, Phoenix Power Group, Llc.; 2013.

[59] Pocknell TM, Venni AK, US Pat. 20100313839 A1, Tony Michael Pocknell, Adrian Kurt Venni; 2010.

[60] Alexandre BL, Valquiria AL, Sonia VWBDO. Glycerol as a by-product of biodiesel production in Brazil: Alternatives for the use of unrefined glycerol, Renew. Energy 2012;45:138.

[61] Banavali RM, Hanlon RT, Schultz AK. Euro. Pat. 2159212 A1, Rohm and Haas Company; 2010.

[62] Chowdhury A, Mitra D, Biswas D. Biolubricant synthesis from waste cooking oil via enzymatic hydrolysis followed by chemical esterification, J. Chem. Technol. Biotechnol., 2013;88(1):139.

[63] Abdulbari HA, Rosli MY, Abdurrahman HN. Nizam MK. Lubricating grease from spent bleaching earth and waste cooking oil: Tribology properties, Int. J. Phys. Sci. 2011;6(20)4695.

[64] Shiping W, Wenjie Z, Sang Z, Zhenglong J, Dongsheng Z. Microbial conversion of waste cooking oil into Riboflavin by Ashbya gossypii, Biosci. J. 2013;29(4):1000.

[65] Saharan BS, Sahu RK, Sharma D. A review on biosurfactants: fermentation, current developments and perspectives, Genetic Eng. Biotechnol. J. 2011;29:1.

[66] Verlinden RAJ, Hill DJ, Kenward MA, Williams CD, Piotrowska SZ, Radecka IK, Production of polyhydroxyalkanoates from waste frying oil by Cupriavidus necator, AMB Express Springer Open J. 2011;1(11):1.

[67] Papanikolaou S, Dimou A, Fakas S, Diamantopoulou P, Philippoussis A, Galiotou-Panayotou1 M, Aggelis G. Biotechnological conversion of waste cooking olive oil into lipid-rich biomass using Aspergillus and Penicillium strains, J. Appl. Microbiol. 2011;110(5):1138.

[68] Siddhartha GVAOC, Francois L, Sylvain M, Eric D, Marcia N, Jonas C. Cassava wastewater as a substrate for the simultaneous production of rhamnolipids and polyhydroxyalkanoates by Pseudomonas aeruginosa, J. Ind. Microbiol. Biotechnol. 2009;36(8):1063.

[69] Virgie AA, Irene GP, Jessica FS, Rubio MLD. Substrate Dependent Production and Isolation of an Extracellular Biosurfactant from Saccharomyces cerevisiae 2031, Philippine J. Sci. 2012;141(1):13.

[70] Kazuo S. Kasukabe J, US Pat. 5000870, Mimasu Oil Chemical Co., Ltd.; 1989.

[71] Kazuo S. US Pat. 4839089, Mimasu Oil Chemical Co., Ltd.; 1989.

[72] Jayce, M., Recycled cooking oils-their use in pig Feed, Primefact, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/315636/Recycled-cooking-oils-their-use-in-pig-feed.pdf, 2013.

[73] Supple B, Howard HR, Esther GG, Leahy JJ. The effect of steam treating waste cooking oil on the yield of methylester, J. Ame. Oil Chem. Soc. 2002;79(2):175.

[74] Food Standard Agency, Waste cooking oil from catering premises, http://food.gov.uk/business-industry/guidancenotes/foodguid/wastecookingoil.Ugsuj5IweO4, 2021.

[75] Zuojun W, Xinghua L, Thushara D, Yingxin L. Determinations and removal of malondialdehyde and other 2- thiobarbituric acid reactive substances in waste cooking oil, J. Food Eng. 2011;107(3):379.