

Harnessing Used Engine Oil for Power Generation: A Case Study of Kuwait's East Doha Power Station

J. Alrajhi ^{1*}, K. Alkhulaifi ², J. Alazemi ¹ and M. Alardhi ¹

¹ *Automotive and Marine Dept., College of Technological Studies, PAAET, Kuwait*

² *Mechanical Power and Refrigeration Dept., College of Technological Studies, PAAET, Kuwait*

**Correspondence: Correspondence author*

Abstract

Kuwait faces significant challenges in managing the growing volumes of used engine oil while addressing rising energy demands. This study investigates the feasibility of utilizing used engine oil as an alternative fuel for electricity generation in Kuwait's power stations. The analysis compares used engine oil energy potential, emissions profile, and economic viability with conventional fuels such as crude oil, heavy fuel oil, and gas oil. The results indicate that using used engine oil can achieve substantial annual cost savings of over 18 million Kuwaiti dinars. Additionally, environmental benefits include a 19% reduction in CO₂ emissions and a 45% reduction in NO_x emissions compared to traditional fuels. These findings position used engine oil as a viable alternative that supports Kuwait's strategic goals for sustainable energy and environmental responsible management.

Keywords: Used Engine Oil; Power Generation; Kuwait; Environmental Impact

Introduction

As a major oil producer, Kuwait relies heavily on oil for electricity generation. The country's increasing population and extended summer heat place substantial pressure on power stations. Kuwait's first power station, built in 1958, had a capacity of 15 MW [1]. Today, the national electricity generation capacity has grown to 19,673 MW across nine power stations [2], all powered by fossil fuels like crude oil, gas oil, heavy oil, and natural gas. Approximately 22% of the fossil fuel produced locally is consumed in power generation [2]. Over the last decade, the demand for electric energy has surged, as shown in Figure 1.

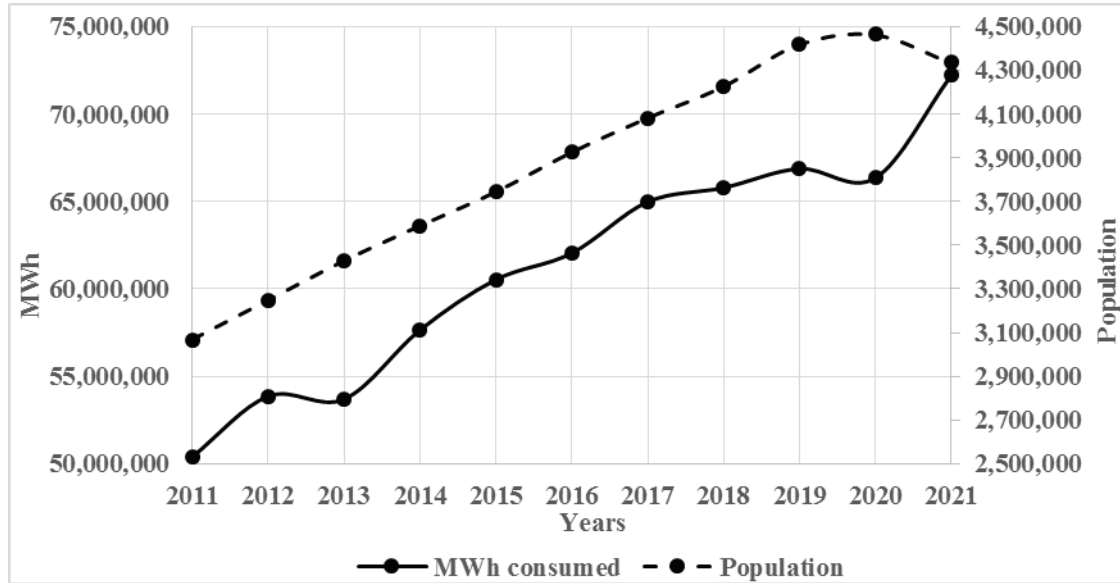


Figure 1. Electricity consumption in Kuwait during the past decade [2].

Kuwait's per capita electricity consumption stands at about 16 MWh annually, driven by a population growth rate of 3.6% and ongoing development. To meet future energy demands, additional power stations will be required, further increasing the need for fuel to power these stations. Figure 2 illustrates the total fuel consumption by power stations in 2021.

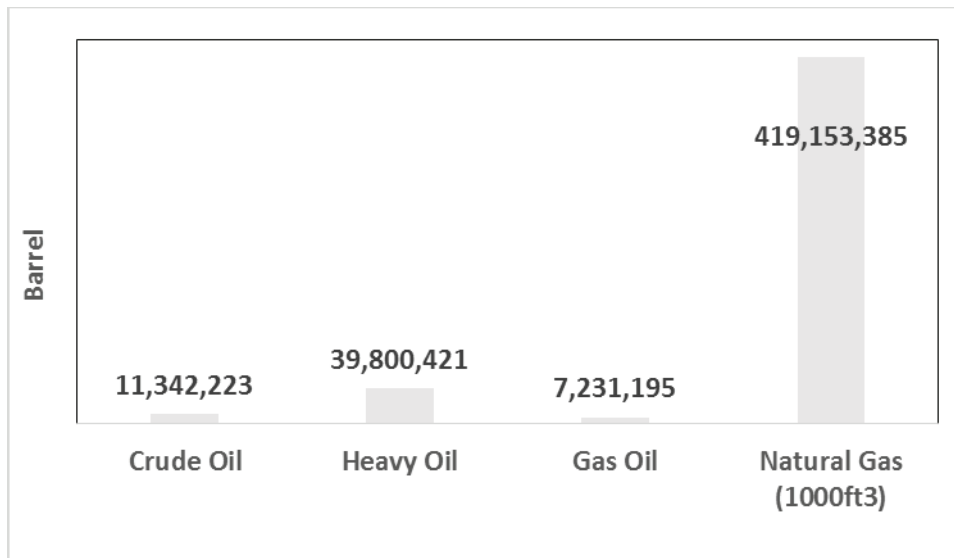


Figure 2. Total fuel consumption in all power stations in 2021 [2].

Over the next five years, electricity consumption is projected to rise by 10%, driving a corresponding increase in fuel demand.

In parallel, Kuwait’s hot desert climate and high per capita income contribute to the country’s large vehicle fleet. In 2021, there were approximately 2.3 million registered vehicles, with an annual growth rate of 2.2% as shown in Figure 3.

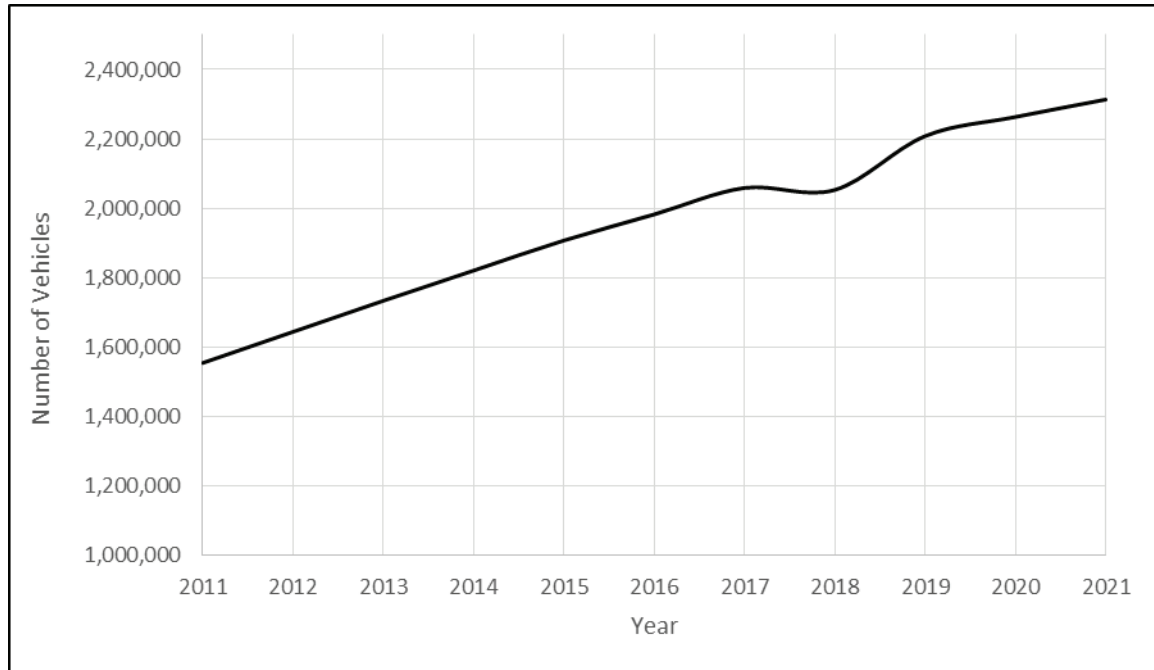


Figure 3. Total number of private registered vehicles over the last decade [2].

This equates to roughly 70 vehicles per 100 people, the majority being passenger cars [2]. The growing number of vehicles has resulted in a significant increase in UEO production, posing both a waste management challenge and an opportunity. Research into using waste products such as UEO for power generation is ongoing [3-5]. UEO, collected from workshops, garages, and sea vessels, presents a way to repurpose waste for energy production [6]. However, UEO becomes contaminated with fuel, combustion byproducts, exhaust gases, and metal particles.

While using UEO as boiler fuel can be cost-effective, it also presents health and environmental risks [7]. Improper disposal of UEO can lead to soil and water contamination. Kuwait’s government is pursuing strategies to reduce pollution while lowering power generation costs. One approach is replacing crude oil and heavy oil with UEO. This method offers a sustainable and environmentally friendly solution, reducing harmful emissions and dependency on expensive fossil fuels. The simplest way to use UEO for electricity generation is by burning it in boilers to produce steam. Alternatively, UEO can serve as a feedstock for biodiesel production through transesterification, which results in fewer pollutants compared to conventional petroleum diesel [8]. The Kuwait Institute for Scientific Research (KISR) has been researching UEO’s use for power generation [9]. They have developed methods to convert UEO into biodiesel, suitable for diesel engines. Similarly, a new experimental method is proposed for producing a diesel-like fuel from the waste engine oil [10]. They proposed new physical and chemical treatment methods to produce diesel-like

fuel from the used engine oil. While UEO's use in Kuwait's power stations remains in its early stages, it holds considerable potential for enhancing the country's energy security and sustainability. However, challenges remain, including inadequate infrastructure for UEO collection and transport and limited public awareness of its benefits. Beyond environmental advantages, replacing crude and heavy oil with UEO in power stations can reduce operational costs significantly. This study aims to investigate the economic and environmental impact of using UEO in power generation, with a specific focus on Kuwait's East Doha Power Station.

Literature Review

Global Energy and Waste Challenges

The global demand for energy continues to grow, fueled by population expansion, industrialization, and technological advancements. The International Energy Agency (IEA) reports that global energy consumption has risen by nearly 2% annually over the past decade, with fossil fuels still making up over 80% of the energy mix [11].

This rising demand underscores the urgent need for sustainable energy sources that can meet consumption requirements while minimizing environmental harm. At the same time, the world faces increasing challenges related to waste generation, particularly hazardous waste such as UEO. Millions of vehicles and machinery worldwide produce UEO, posing significant environmental risks when improperly managed. In the United States alone, around 1.3 billion gallons of UEO are generated annually, with a substantial portion still being disposed of improperly, leading to soil and water contamination [12]. As global vehicle ownership and industrial activities continue to rise, so does the generation of UEO. According to the International Journal of Environmental Science and Development, the global production of waste engine oil exceeds 45 million tons annually but so far 40% of the waste is only adequately disposed or collected, of which only 8% is recycled for reuse [13-14]. Improper disposal methods such as dumping, burning, or landfilling not only result in environmental pollution but also represent a missed opportunity to recover valuable energy. The increasing generation of UEO, driven by the expanding number of vehicles and the challenges of its safe disposal, highlights the need for innovative waste management solutions. Utilizing UEO as an alternative fuel for power generation presents a dual advantage: it helps mitigate the environmental impact of hazardous waste while also contributing to the global energy supply [15].

2.2. UEO as an Alternative Fuel

Several studies have examined the feasibility of utilizing UEO as an alternative fuel in various applications, including power generation [16-18]. UEO, consisting of a complex mixture of hydrocarbons, additives, and contaminants, is often incinerated or disposed of in landfills, both of which pose environmental risks. However, its high calorific value ranging between 38-42 MJ/kg makes it a viable candidate for combustion-based applications such as power generation [15-19].

An experimental study on co-firing UEO with a gaseous fuel such as LPG in a small furnace was conducted [20]. It was found that when a small amount of UEO is co-fired with the gaseous fuel it significantly enhances thermal radiation capabilities

of the gaseous fuel flame by about 80% which makes it a renewable energy source with an attractive potential. Similarly, research by Chatziaras et al. [21] demonstrated that UEO could be utilized in cement kilns, where the high temperatures ensure complete combustion, minimizing the release of harmful pollutants.

Beg et al. [22] investigated the production of diesel fuel from UEO by taking samples of from shipyard and light vehicles (bus and truck) at different percentage of blending of pre-treated UEO. Results show that pre-treated UEO of shipyard and 35% blending into fresh diesel are suitable to use as a diesel fuel considering Caterpillar Specific Limit and comparing with the fresh diesel. Their conclusion was that production of diesel fuel from UEO is technically suitable, economically viable and less responsible for polluting the environment.

2.3. Economic and Environmental Impact

The conversion of UEO into usable fuel presents a promising solution to mitigate the environmental risks associated with the improper disposal of used oil, such as soil and water contamination [23]. By using UEO as fuel, greenhouse gas emissions can be reduced by offsetting the need for new fossil fuel extraction and consumption, aligning with circular economy principles that advocate for the transformation of waste into resources. Studies have shown that UEO can result in lower CO₂ emissions compared to crude oil, although it may produce higher levels of NO_x due to contaminants [24-26]. However, with the integration of proper emission control technologies, the environmental footprint of UEO can be significantly reduced, making it a cleaner alternative to conventional fossil fuels.

Prabakaran and Zachariah [27] studied experimentally the treatment of UEO using acetic acid and clay on the performance, combustion and emission characteristics of blends of recycled UEO in a diesel engine. The recycled UEO was blended with diesel at various proportions. Their results showed better engine performance with a decrease in emissions of NO_x and HC.

Hossain [28] studied Waste Cooking Oil (WCO) in a diesel engine either neat or blended separately with diesel, butanol and gasoline, with an additive concentration between 10% and 30% by volume. He noticed that using WCO–butanol fuel gave the lowest NO_x emission and a slight decrease in CO₂ emission than diesel. Combustion characteristics results showed stable engine operation for all blends. The combustion duration was maximal with WCO–butanol blends. The study concluded that the WCO with 10–20% butanol or fossil diesel exhibited similar performance and emission characteristics observed for neat fossil diesel. In this regard, Sharma [29] experimentally investigated the performance and emission characteristics of DI diesel engine using Distillation of Used Lubricating Oil (DULO). This DULO was blended in different proportions with Jatropha biodiesel (JB) and their results compared with base fuel diesel. The test result revealed that the behavior of the engine run on 80% JB and 20% DULO blend was better than other blends considered in the study. The CO, HC and smoke emissions were reduced by 8.7%, 7.3% and 12.4% respectively for this blend, compared to diesel while the NO emission was recorded extra by about 15.3%.

Gabina et al. [30] assessed the technical suitability of recycled UEO in marine engine test bench in comparison with traditional fuels. They simulated real operating

conditions for the engine and electric diesel generators in steady loads. The UEO exhibits lower NO_x and CO₂ emission levels but slightly higher CO emissions and smoke opacity levels than traditional fuel. Hence, UEO as an alternative fuel is acceptable for use in marine diesel engines operated on-board a ship under real conditions and meet the rules applicable to marine environments for burning fuel oils.

On the contrary, Đorđić et al. [31] investigated the potential of obtaining fuel from a mixture of UEO and diesel fuel at different mixtures that can be used as an alternative fuel for internal combustion engines and low power heat generators. They conducted tests to estimate the combustion parameters and emissions at a low heat output. Finally, their results were analyzed and compared with diesel fuel. They noticed higher NO, CO and CO₂ emissions for UEO and its mixtures compared to diesel fuel.

Table 1 compares the CO₂ and NO_x emissions from UEO and other fossil fuels, demonstrating the environmental benefits of utilizing UEO as a fuel.

Table 1. CO₂ and NO_x emissions from UEO and other fossil fuels [32].

Fuel Type	CO₂ Emissions (g/kWh)	NO_x Emissions (g/kWh)
UEO	750 - 950	40 - 80
Crude Oil	800 - 1,000	60 - 120
Heavy Oil	900 - 1,200	70 - 150
Gas Oil	750 - 950	50 - 100
Natural Gas	400 - 550	30 - 60

Economically, Ahmad et al. [33] investigated the recycling and analysis of UEO. Later they compared the physical properties of recycled UEO with fresh engine oil such as flash point, fire point and viscosity. They found that properties between the recycled UEO and fresh engine oil are almost comparable. Moreover, the cost of recycled UEO is relatively low compared to its production from crude oil as the number of purification stage involved is reduced. Katiyar and Husain [34] demonstrated that the process of recycling using 1-butanol is cost-effective and can be efficiently implemented, making it a financially viable option for managing waste oil. The reduced processing costs, combined with the ability to reclaim valuable products, present a strong economic incentive for UEO recycling.

Osman et al. [35] also discussed the economic advantages of using recycled engine oil. Their research on recycling UEO with different solvents demonstrated that the process could produce fuel with properties comparable to fresh oil at a fraction of the cost. By avoiding the expenses associated with crude oil extraction and refining, recycled UEO offers a more affordable alternative, reducing overall operational costs for industries relying on lubricants and fuels.

Using UEO as fuel in diesel engines or generators offers a valuable opportunity for countries to reduce reliance on imported fossil fuels. This approach enhances energy security and bolsters economic resilience by leveraging a domestic resource, thus minimizing the risks of volatile global oil prices and supply chain disruptions.

Furthermore, it contributes to a more sustainable energy framework by lowering greenhouse gas emissions and fostering a circular economy.

2.4. Techniques used in UEO Filtration

Degradation of lubricating oil occurs when different additives or foreign substances (metallic powders, sulfur, water, carbon, ash, etc.) impurify the oil, modifying its chemical composition and affecting its properties [36]. Filtration of UEO depends on the nature of the base oil (mineral or synthetic) as well as the nature and quantity of the contaminating substances. By removing harmful substances, environmental pollution can be reduced, saving resources, and reducing dependence on traditional energy while promoting circular economy and sustainable development [37]. There are a number of methods for treating UEO such as physical Treatment, chemical treatment and biological treatment. Physical treatment may be the least expensive method among all. Its common techniques include [37]:

Sedimentation: by allowing heavier impurities to settle out of the oil due to gravity.

Filtration: by passing UEO through filters with specific pore sizes, trapping solid contaminants while allowing the cleaner oil to pass through.

Centrifugation: this method utilizes high-speed rotation to separate heavier contaminants from the oil based on their differing densities.

The cost of filtering UEO typically cost between \$10,000 and \$50,000, [38] while large-scale industrial systems, more relevant to Kuwait's needs, can range from \$500,000 to \$2 million. Operating costs are influenced by factors such as energy, labor, and maintenance. In Kuwait, where electricity is relatively inexpensive at \$0.03 to \$0.06 per kWh, energy costs for a large filtration plant can range from \$50,000 to \$150,000 annually. For a facility processing 1 million gallons of UEO annually, the total cost of filtration could be around \$200,000 to \$400,000, making it a cost-effective solution compared to disposal UEO in landfills or burning fossil fuels for power generation.

2.5. UEO Collection, Transport and Storage

Collecting methods for UEO can be done in various ways that can increase awareness among the public such as creating drop-off centers, commercial collections and offering financial incentives or electric energy subsidies to encourage businesses and individuals to participate in recycling programs. In terms of cost of collection and transport for UEO in Kuwait, these data are not available, therefore, global data is referenced instead. In the U.S., transportation costs for UEO can range from \$0.05 to \$0.20 per gallon, depending on various factors such as the method of transportation, the distance traveled by the truck carrying the oil, the quality of the used oil, and fluctuating fuel prices [12]. Additionally, storage and handling costs typically range between \$0.05 to \$0.10 per gallon. Therefore, the overall cost of handling and transporting UEO is estimated to be between \$0.10 to \$0.30 per gallon, offering potential savings when compared to conventional diesel fuel subsidized prices, which is \$1.44 per gallon [39]. Given that Kuwait is a small country with subsidized fuel prices, the cost of handling and transporting UEO is likely to be significantly lower than in the U.S.

2.6. UEO Physical Properties

The benefits of using UEO as a fuel can be maximized through proper filtration prior to use [40]. Filtration effectively removes contaminants such as metal particles, soot, and other impurities that accumulate during the oil's previous use in engines. This purification process is critical in preventing equipment damage, enhancing combustion efficiency, and ensuring cleaner fuel burning. Properly filtered UEO offers key advantages, including easier handling due to its lower viscosity, more efficient combustion from improved atomization, and a reduced environmental impact by minimizing harmful emissions [7].

When comparing UEO to traditional fuels like crude oil, heavy oil, gas oil, and natural gas for use in the East Doha Power Station, several key factors must be considered. These include calorific value, combustion efficiency, viscosity, and the emission profile of each fuel. Table 2 provides a detailed comparison of the physical properties of UEO and conventional fuels, highlighting UEO's potential as a viable alternative for energy generation.

Table 2. Physical properties of UEO and fossil fuels.

Fuel Type	Viscosity (Pa.s)	Density (kg/m³)	Sulfur Content	Energy Content (MJ/kg)
UEO [41]	<1.0	897	0.2% - 0.5%	38 - 42
Crude Oil [42]	<0.1	<934	0.05% - 5%	42 - 47
Heavy Oil [42]	0.1 - 100	934-1000	1% - 4%	39 - 42
Gas Oil [43]	0.002 – 0.004	820 - 880	<0.0015% (ULSD)	42 - 43
Natural Gas [43]	N/A (gaseous)	700 - 900	<0.0001%	45

UEO lower viscosity simplifies its handling and storage, often eliminating the need for extensive heating, which can be both costly and operationally demanding. This characteristic also enhances combustion efficiency, reducing operational complications and maintenance costs. UEO's high energy content, comparable to that of heavy and crude oils, means it can deliver nearly the same amount of energy per unit of weight or volume, making it a cost-effective and reliable fuel choice for power generation.

2.7. Waste Management and Energy Integration

Using UEO as fuel in waste management offers several environmental and economic advantages. One primary benefit is converting UEO into valuable diesel-like fuels through processes such as catalytic cracking. For example, Gallo-Cordova et al. [44] demonstrated that using metal-doped aluminum silicate catalysts, particularly those doped with nickel, can achieve conversion rates of up to 65%, significantly higher than traditional thermal methods. This approach not only reduces the environmental pollution associated with UEO disposal but also provides a sustainable method to reclaim energy, transforming waste into a reusable resource. In addition, using UEO as fuel helps reduce the environmental impact of oil disposal and the reliance on fossil fuels. Lam et al. [45] explored pyrolysis using microwave

heating as a sustainable process to recycle used engine oil, highlighting the method’s potential in producing reusable products such as gases and oils, which can serve as alternative energy sources. Similarly, Ogbeide [46] investigated the feasibility of recycling spent engine oil as fuel, finding it to be a viable and efficient way to manage waste oil while recovering energy. This method also reduces greenhouse gas emissions and contributes to the circular economy, creating a more sustainable and resilient waste management system.

3. Vehicle Growth in Kuwait

Kuwait has witnessed significant growth in its vehicle population over the past decade, which has directly contributed to an increase in the production of UEO. This rise in vehicle numbers, driven by economic growth and urbanization, has led to higher demand for motor services and, consequently, more UEO generation. Figure 4 illustrates the steady increase in UEO production over this period, highlighting the growing challenge of managing this waste product effectively.

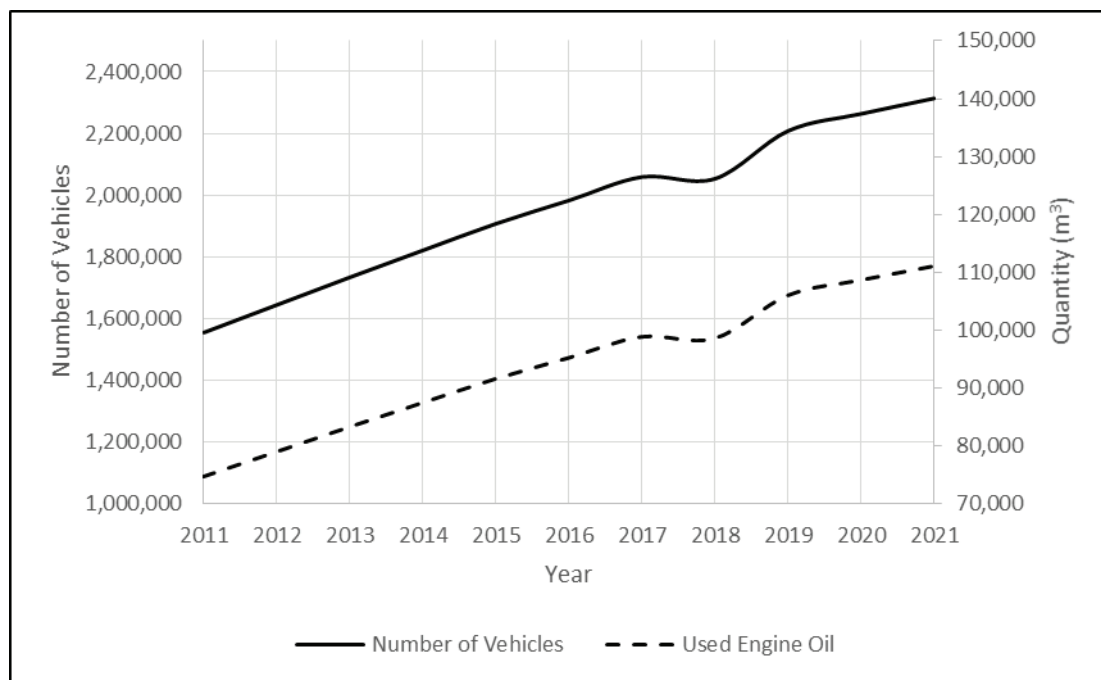


Figure 4. Each vehicle is estimated to consume 6 liters of oil and is replaced approximately eight times per year [2].

As the number of vehicles continues to rise, addressing UEO disposal becomes increasingly important for Kuwait's environmental and energy strategies. By the end of 2021, the vehicles in Kuwait generated over 110,000 m³ of UEO. According to statistical data, this amount is increasing by more than 2,200 m³ annually [2].

In Kuwait, just like any other Gulf country, the frequency of oil changes for vehicles is influenced by several factors, including the type of oil used, the distance driven, and the specific vehicle requirements. Under normal driving conditions, oil

changes are typically recommended every 10,000 kilometers or every 6-12 months. However, due to the harsh climate, frequent stop-and-go traffic, and extensive idling due to traffic jam, oil changes are often required more frequently, approximately every 5,000 kilometers [47]. By the end of 2022, statistics from the Central Statistical Bureau [2] showed that private vehicles traveled over 57,000 kilometers annually, a figure similar to that of 2021. Given this travel distance and the severe environmental conditions, vehicles in Kuwait typically undergo 11 to 12 oil changes each year. This high frequency not only increases engine oil consumption but also leads to a significant production of UEO. These factors underscore the importance of developing effective recycling and reuse strategies for UEO in the country, as the volume of waste oil continues to grow in parallel with the expanding vehicle population.

Utilization of UEO in Power Station Burners

In external combustion devices such as oil burners which are mainly used in power stations, combustion and emission performance of viscous fuels are enhanced with the help of pre-heaters for thinning high oil viscosity and swirlers to promote efficient spray characteristics and mixing characteristics [48-49]. Waste oils, with or without modifications for optimizing combustion can be used as an alternative fuel in boilers. The properties of waste oil can be modified by blending it with fuel oil to achieve the required clean-burning fuel mixture .

Luka et al. [50] experimentally investigated the flame temperature and size as well as emissions of using UEO as a fuel for swirl oil burner. The UEO was pre-treated to remove particulate matter, water and ferromagnetic materials. The UEO samples were then blended with diesel fuel at different volumetric proportions (B0-B50). It was revealed that increasing diesel fuel blend decreases the density and viscosity of the fuel samples. All the blended fuel samples were found to form a homogenous mixture and generated flame temperature higher than the unblended oil sample (B0). It was found that B20 generated the highest flame temperature and size and the lowest carbon monoxide and unburned hydrocarbon while carbon dioxide was the highest compared to B0. They concluded that UEO can be blended with diesel fuel to improve flame temperature and decrease emission levels in swirl waste oil burners.

In a similar study, Madu et al. [51] tested a mixture of UEO and kerosene on atomization and combustion for foundry application to reduce the cost of operation. Their tests were carried out to determine the time taken for some selected materials (copper, aluminum, brass, and lead) to melt using the mixture with a ratio of 1:5 for kerosene and UEO and the ratio of 15:1 for air and fuel respectively. They concluded that a mixture of UEO and kerosene can replace the conventional fuel in the workshop thereby reducing the cost of operation in the foundry operation.

Case Study: East Doha Power Station

The East Doha power station began operations in 1977, serving both as a generator of electricity and a producer of potable water through seawater desalination. In the early 2000, the plant underwent significant modernization to enhance efficiency, reduce

emissions, and increase its power output by integrating gas and steam turbines. Currently, the East Doha power station produces 1,365 MW of electricity and 182,000 m³ of desalinated water per day, making it a vital component of Kuwait's energy infrastructure. The plant is fueled by a mix of crude oil, heavy oil, gas oil, and natural gas to support its dual functions of power generation and water desalination [2]. The selection of the East Doha Power Station as a case study is due to its fuel consumption patterns, which correlate with the volume of UEO produced in the country.

Fuel Consumption at East Doha Power Station and available UEO

Kuwait spends a significant amount on fuel to run its power stations, primarily because its electricity generation heavily relies on natural gas and fuel oil. As a country with abundant hydrocarbon resources, Kuwait utilizes its own oil and natural gas reserves to fuel power generation and water desalination processes. In 2021, Kuwait spends over 2 billion Kuwaiti dinars to fuel its power stations due to its heavy reliance on natural gas and fuel oil for electricity generation and water desalination [2]. Specifically, the East Doha power station consumed over 14 trillion ft³ of natural gas and more than 6 million barrels of fuel oil in 2021 to produce electricity and desalinated water as shown in table 3. In summary, the East Doha Power Station incurs approximately 158 million Kuwaiti dinars annually for its operational fuel costs.

Table 3. Types and quantity of fuel consumed in East Doha Power Station.

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021
Heavy Oil (Barrel)	3,288,258	2,866,951	3,145,653	2,852,384	2,639,757	6,136,383	2,624,869	1,579,356	5,079,153
Crude Oil (Barrel)	3,925,377	3,429,396	4,360,599	3,416,227	3,197,800	114,417	3,193,625	3,544,284	1,153,863
Gas Oil (Barrel)	393	170	307	356	272	225	201	0	0
Total Liquid Fuel (Barrel)	7,214,028	6,296,517	7,506,559	6,268,967	5,837,829	6,251,025	5,818,695	5,123,640	6,233,016
Natural Gas (1000 ft³)	4,342,891	19,421,476	14,121,889	15,345,401	19,723,726	15,364,480	18,523,513	17,076,939	14,223,288

On the other hand, Kuwait's large vehicle fleet generates a significant amount of UEO, which could be harnessed as a fuel source for the East Doha Power Station, providing both economic and environmental benefits as shown in table 4.

Table 4. : Available UEO annually.

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021
Available UEO (Barrel) / year	719,7	755,9	791,8	823,0	854,7	852,3	916,7	939,5	960,4
Available UEO relative to Heavy oil Consumed (%)	21.9%	26.4%	25.2%	28.9%	32.4%	13.9%	34.9%	59.5%	18.9%
Available UEO relative to Crude oil Consumed (%)	16.4%	19.9%	16.5%	22.1%	24.8%	719.4%	26.8%	24.0%	79.4%

The amount of available UEO has generally increased over the years by 33% with an annual increase of around 3.7%. This increase reflects the growing volume of used engine oil, likely due to the rising number of vehicles and engine maintenance activities in Kuwait. The high volume of UEO and its significant proportion relative to heavy oil and crude oil highlight its potential as an alternative fuel source, particularly if integrated effectively into energy production strategies. Using UEO as a partial replacement for heavy oil or crude oil can lead to significant cost savings due to its lower cost. UEO, often priced significantly below heavy oil or crude oil, can reduce fuel expenses for East Doha power station. For example, if UEO replaces 20% of heavy oil used annually, the savings could be over 18 million Kuwaiti Dinar. However, this savings needs to be weighed against additional operational costs related to UEO treatment, maintenance, and environmental compliance. Furthermore, using UEO can utilize a locally sourced resource and advance sustainability goals, aligning with circular economy principles. This approach not only supports environmental sustainability but also helps shift the station's fossil fuel consumption towards export, as the Kuwaiti government aims to enhance its export capacity to 4 million barrels per day.

Future Prediction

As illustrated in Figure 1, Kuwait's electricity demand experienced a steady rise from 2011 to 2021, with the exception of a decline in 2020 due to the COVID-19 pandemic, which caused a significant departure of foreign residents. Looking ahead, Kuwait's electricity demand is expected to continue growing, driven by an annual population growth rate of 3.6% and a per capita electricity consumption of 16 MWh per year. In 2022, with an estimated population of 4.5 million, total electricity consumption was around 72 TWh. As the population increases, demand will proportionally rise, reaching approximately 74.6 TWh in 2023 with a population of 4.66 million. This growth is expected to persist, with the population anticipated to reach nearly 6 million by 2030, pushing electricity demand to approximately 92.6 TWh annually as shown in Figure 5.

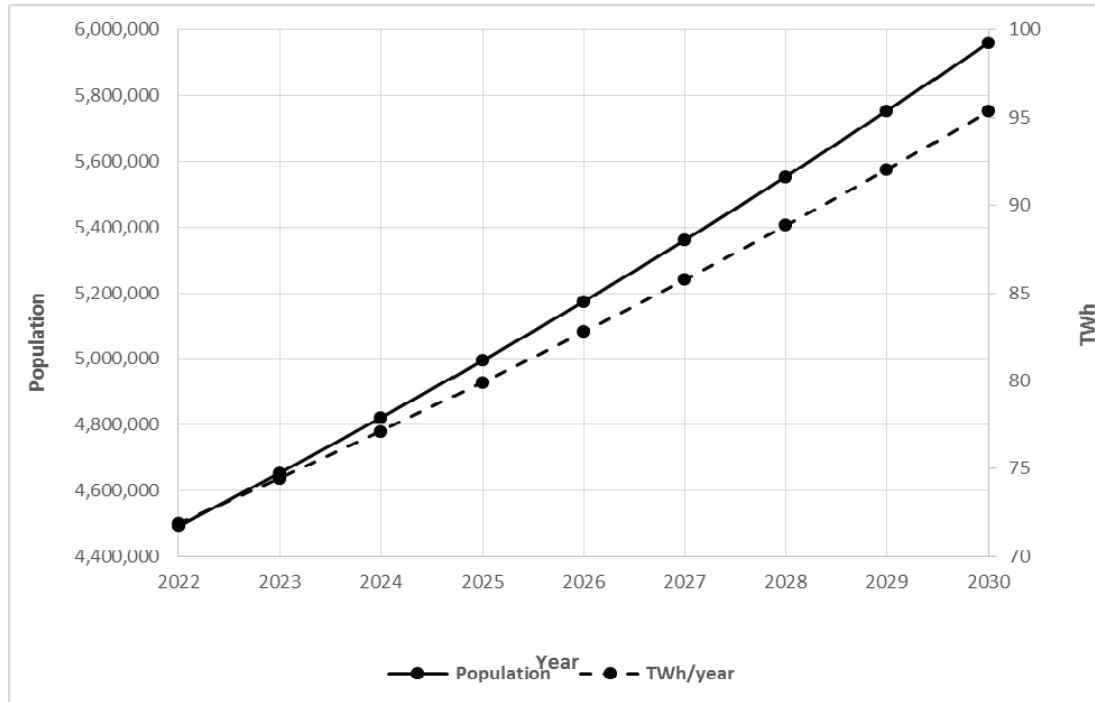


Figure 5. Expected population growth and Electricity.

This escalating demand underscores the mounting pressure on Kuwait's energy infrastructure, necessitating continuous expansion of power generation capacity to avoid shortages. Between 2022 and 2030, Kuwait's electricity needs will increase by more than 23 TWh, signaling a considerable rise in power requirements. Addressing this demand will be crucial, especially given Kuwait's heavy reliance on fossil fuels for electricity generation. Expanding energy production under the current system would result in burning more fossil fuels, leading to increased expenditure on power generation and higher emissions. However, the country's growing stock of vehicles, which increases at an annual rate of 2.22%, is driving a 3.7% yearly rise in UEO. This growth will yield over 287,000 m³ of UEO by 2030, which could be repurposed for power generation, equivalent to saving over 18 million Kuwaiti Dinar annually. If UEO is utilized from 2022 to 2030, Kuwait could save over 162 million Kuwaiti Dinar in total, providing a cost-effective and more sustainable alternative for energy production. Furthermore, incorporating UEO as a substitute of fossil fuel will help in reducing greenhouse gas emissions which will support Kuwait's environmental sustainability goals.

The environmental advantages of using UEO compared to crude oil, heavy oil, and gas oil in terms of CO₂ and NO_x emissions are shown in table 5. UEO emits 19.55 megatons of CO₂, which is 5.6% lower than crude oil and 19% lower than heavy oil, making it a more carbon-efficient fuel. Additionally, UEO's NO_x emissions are significantly lower 33.3% less than crude oil and 45.5% less than heavy oil showing its potential to substantially reduce air pollutants that contribute to smog and respiratory problems. While gas oil matches UEO in terms of CO₂ emissions, UEO still outperforms it by producing 20% less NO_x. These reductions make UEO an

environmentally preferable option, as it not only helps lower greenhouse gas emissions, contributing to climate change mitigation, but also improves air quality by curbing NO_x pollutants. Furthermore, Utilizing UEO encourages the recycling of waste oil, which reduces the demand for fresh oil extraction or allows oil resources to be redirected towards exports.

Table 5. Expected emissions of UEO compared to other fossil fuel from year 2022-2030.

Type of Fuel	CO ₂ (Mega ton)	NO _x (Mega ton)	Reduction in CO ₂ (%)	Reduction in NO _x (%)
UEO	19.55	1.38	0	0
Crude Oil	20.7	2.07	5.6%	33.3%
Heavy Oil	24.15	2.53	19.0%	45.5%
Gas Oil	19.55	1.725	0.0%	20.0%

Implementing UEO on a larger scale in Kuwait requires a coordinated effort across multiple sectors. Establishing a robust infrastructure for the collection, treatment, and distribution of UEO is critical for scaling its use in power generation. This would require investment in refining and filtration technologies to ensure the fuel's quality and minimize operational challenges. Furthermore, public awareness campaigns, which requires a lot of attention could encourage widespread participation from industries and individuals. Integrating UEO into Kuwait's energy strategy not only offers significant economic and environmental advantages but also aligns with the country's long-term sustainability goals, reducing reliance on imported fossil fuels and promoting circular economy principles. By fostering collaboration between government sectors such as Ministry of Electricity and Water, Kuwait Municipality and The Public Authority for Environment can pave the way for a more sustainable energy future.

Conclusion

The utilization of UEO as a fuel for East Doha power station can offer significant environmental, economic, and operational advantages. UEO can serve as a viable alternative to conventional fossil fuels used in the power station as crude oil, heavy oil, and gas oil. Its lower viscosity and relatively lower sulfur content contribute to more efficient handling, reduced maintenance costs, and cleaner combustion. The high energy content of UEO, comparable to that of other fuels, ensures that it can reliably meet energy demands while also reducing reliance on more costly and polluting fuel sources. From an environmental perspective, UEO offers several key benefits, including lower emissions of CO₂ and sulfur dioxide compared to crude and heavy oils, as well as a reduction in particulate matter and unburned hydrocarbons. The use of UEO supports broader waste management and sustainability goals by repurposing a waste product, aligning with circular economy principles. Economically, UEO provides a cost-effective fuel option in Kuwait, where energy demand is high, and waste management is a growing concern. Using UEO as a fuel aligns well with Kuwait's 2030 goal of reducing reliance on conventional fossil fuels,

while supporting the nation's broader sustainability objectives. Thus, Kuwait can decrease its dependence on crude oil and heavy oil for power production and reserves its valuable crude oil exports or refining. This approach not only enhances the country's energy security but also contributes to economic diversification by promoting more sustainable and efficient energy practices.

References

- [1] Alotaibi, S. Energy consumption in Kuwait: Prospects and future approaches. *Energy Policy* 2011, 39, 637–643. doi:10.1016/j.enpol.2010.10.036.
- [2] Central Statistical Bureau (CSB). [Online]. Available: https://www.csb.gov.kw/default_en.
- [3] Buchori, L.; Widayat, W.; Muraza, O.; Amali, M.I.; Maulida, R.W.; Prameswari, J. Effect of Temperature and Concentration of Zeolite Catalysts from Geothermal Solid Waste in Biodiesel Production from Used Cooking Oil by Esterification–Transesterification Process. *Processes* 2020, 8, 1629.
- [4] García-Marino, M.; Rivas-Gonzalo, J.C.; Ibáñez, E.; García-Moreno, C. Recovery of catechins and proanthocyanidins from winery by-products using subcritical water extraction. *Anal. Chim. Acta* 2006, 563, 44–50.
- [5] da Silva, A.L.; Luna, C.B.B.; de Farias, A.F.F.; de Medeiros, S.A.S.L.; Meneghetti, S.M.P.; Rodrigues, A.M.; Costa, A.C.F.M. From disposal to reuse: Production of sustainable fatty acid alkyl esters derived from residual oil using a biphasic magnetic catalyst. *Sustainability* 2020, 12, 10159.
- [6] Olugboji, O.; Ogunwole, O. Use of Spent Engine Oil. Technical Report, AU J.T. 2008, 12, 67–71.
- [7] Katiyar, V.; Husain, S. Environmental impacts of used oil. *Material Science Research India* 2010, 7(1), 245–248.
- [8] El-Kassaby, M.; Nemit-Allah, M.A. Studying the effect of compression ratio on an engine fueled with waste oil produced biodiesel/diesel fuel. *Alexandria Engineering Journal* 2013, 52(1), 1–11.
- [9] Ali, N., Sebzali, M., Safar, A., & Al-Khatib, F. (2015, November). A feasibility study of using waste cooking oil as a form of energy in Kuwait. In *2015 International Conference on Sustainable Mobility Applications, Renewables and Technology (SMART)* (pp. 1-5). IEEE.
- [10] Bani-Hani, E., Alkhatib, F., Sedaghat, A., Alkhazzam, A., Al-Dousari, F., & Al-Saad, O. (2020). An Experimental Study on Producing a Sustainable Diesel-like Fuel from Waste Engine Oil. *Renewable Energy Research and Applications*, 1(2), 143-150.
- [11] Newell, R.G.; Raimi, D.; Aldana, G. *Global Energy Outlook 2019: The Next Generation of Energy*. Report 19-06, July 2019.
- [12] U.S. Environmental Protection Agency. [Online]. Available: https://www.epa.gov/sites/default/files/202009/documents/1.11_waste_oil_combustion.pdf.
- [13] Jwaida, Z., Dulaimi, A., Bahrami, A., Mydin, M. A., Özkılıç, Y., Ramadhansyah Jaya, R., & Wang, Y. (2024). Analytical review on potential

- use of waste engine oil in asphalt and pavement engineering. *Case Studies in Construction Materials*.
- [14] Wang, H.; Derewecki, K. Rheological properties of asphalt binder partially substituted with wood lignin. In *Airfield and Highway Pavement 2013: Sustainable and Efficient Pavements*; 2013; pp. 977–986.
- [15] Naima, K.; Liaqid, A. Waste oils as alternative fuel for diesel engine: A review. *Journal of Petroleum Technology and Alternative Fuels* 2013, 4(3), 30–43.
- [16] Hussain, Z.; Santhoshkumar, A.; Ramanathan, A. Assessment of pyrolysis waste engine oil as an alternative fuel source for diesel engine. *Journal of Thermal Analysis and Calorimetry* 2020, 141, 2277–2293.
- [17] Nabi, M.N.; Akhter, M.S.; Rahman, M.A. Waste transformer oil as an alternative fuel for diesel engine. *Procedia Engineering* 2013, 56, 401–406.
- [18] Gabina, G., Martin, L., Basurko, O. C., Clemente, M., Aldekoa, S., & Uriondo, Z. (2019). Performance of marine diesel engine in propulsion mode with a waste oil-based alternative fuel. *Fuel*, 235, 259-268.
- [19] Behera, P. Experimental studies on utilization of used transformer oil as an alternative fuel in a DI diesel engine. Diss. 2013.
- [20] Al-Omari, S.B. Used engine lubrication oil as a renewable supplementary fuel for furnaces. *Energy Conversion and Management* 2008, 49(12), 3648–3653.
- [21] Chatziaras, N.; Psomopoulos, C.S.; Themelis, N.J. Use of waste derived fuels in cement industry: a review. *Management of Environmental Quality: an International Journal* 2016, 27(2), 178–193.
- [22] Beg, R.A.; Sarker, M.R.I.; Pervez, M.R. Production of diesel fuel from used engine oil. *International Journal of Mechanical & Mechatronics Engineering* 2010, 10(2), 1–6.
- [23] Pinheiro, C.T.; Quina, M.J.; Gando-Ferreira, L.M. Management of waste lubricant oil in Europe: A circular economy approach. *Critical Reviews in Environmental Science and Technology* 2021, 51(18), 2015–2050.
- [24] Ishizaki, K.; Nakano, M. Reduction of CO₂ emissions and cost analysis of ultra-low viscosity engine oil. *Lubricants* 2018, 6(4), 102.
- [25] Geo, V.E.; et al. Study of engine performance, emission and combustion characteristics fueled with diesel-like fuel produced from waste engine oil and waste plastics. *Frontiers of Environmental Science & Engineering* 2018, 12, 1–9.
- [26] Qasim, M.; Ansari, T.M.; Hussain, M. Emissions and performance characteristics of a diesel engine operated with fuel blends obtained from a mixture of pretreated waste engine oil and waste vegetable oil methyl esters. *Environmental Progress & Sustainable Energy* 2018, 37(6), 2148–2155.
- [27] Prabakaran, B.; Zachu Thomas Zachariah. Production of Fuel from Waste Engine oil and Study of performance and emission characteristics in a Diesel engine. *International Journal of Chem Tech Research* 2016, 9(5), 474–480.
- [28] Hossain, A.K. Combustion characteristics of waste cooking oil–butanol/diesel/gasoline blends for cleaner emission. *Clean Technologies* 2020, 2(4), 447–461.

- [29] Sharma, A.; Gupta, G.; Agrawal, A. Utilization of waste lubricating oil as a diesel engine fuel. *IOP Conference Series: Materials Science and Engineering* 2020, 840(1).
- [30] Gabina, G.; Martin, L.; Basurko, O.C.; Clemente, M.; Aldekoa, S.; Uriondo, Z. Performance of marine diesel engine in propulsion mode with a waste oil-based alternative fuel. *Fuel* 2019, 235, 259–268.
- [31] Đorđić, D.; Milotić, M.; Čurguz, Z.; Đurić, S.; Đurić, T. Experimental testing of combustion parameters and emissions of waste motor oil and its diesel mixtures. *Energies* 2021, 14(18), 5950.
- [32] Nazari, S.; Shahhoseini, O.; Sohrabi-Kashani, A.; Davari, S.; Paydar, R.; Delavar-Moghadam, Z. Experimental determination and analysis of CO₂, SO₂ and NO_x emission factors in Iran's thermal power plants. *Energy* 2010, 35(7), 2992–2998.
- [33] Ahamad, M. T., ChadraSekhar, B. P., Mohan, P. N., Joshi, K. S., & Sree, T. D. R. (2015). Recycling and analysis of spent engine oil. *International Journal of Scientific & Engineering Research*, 6(11), 711-715.
- [34] Katiyar, V.; Husain, S. Recycling of used lubricating oil using 1-butanol. *International Journal of Chemical Science* 2010, 8(3), 1999–2012.
- [35] Osman, D.I.; Attia, S.K.; Taman, A.R. Recycling of used engine oil by different solvent. *Egyptian Journal of Petroleum* 2018, 27(2), 221–225.
- [36] Diphare, M.J.; Muzenda, E.; Pilusa, J.; Mollagee, M. A comparison of waste lubricating oil treatment techniques. In *2nd International Conference on Environment, Agriculture and Food Sciences (ICEAFS'2013)*; Kuala Lumpur, Malaysia, August 25-26, 2013; pp. 106–109. Available: <https://ujcontent.uj.ac.za/esploro/outputs/journalArticle/A-comparison-of-waste-lubricating-oil/9911113407691>.
- [37] PurePath Green Technology. Available: <https://www.purepathtech.com/literatures/recycling-of-used-motor-oil>
- [38] U.S. Environmental Protection Agency. Management of Used Oil. [Online]. Available: <https://www.epa.gov/used-oil/management-used-oil>.
- [39] Petroleum data for the State of Kuwait 2019-2022. <https://www.moo.gov.kw/upload/2019-2022.pdf>
- [40] Abu-Elella, R.; Ossman, M.E.; Farouq, R.; Abd-Elfatah, M.J.I.J.C.B.S. Used motor oil treatment: turning waste oil into valuable products. *Int. J. Chem. Biochem. Sci.* 2015, 7, 57-67.
- [41] Bufares, A. M., Abdalla, A. A., Hashem, G. G., Melad, M. S., & Elabeedy, E. A. Physical and Chemical Properties of Virgin and Used Engine Oils.
- [42] AlShammari, A., Alomair, O., Elsharkawy, A., Oil Viscosity Models for Greater Burgan Oilfield-Kuwait, *Int. J. of Petroleum and Petrochemical Eng.*, 2023, 8(2), 13-30, <https://doi.org/10.20431/2454-7980.0802002>.
- [43] Heywood, J. B., author. (1988). *Internal combustion engine fundamentals*. New York :McGraw-Hill Book Company.
- [44] Gallo-Cordova, A.; Hidrobo, A.; Ponce, S. Chemical Recycling of Used Motor Oil by Catalytic Cracking with Metal-Doped Aluminum Silicate Catalysts. *Sustainability* 2023, 15, 10522.

- [45] Lam, S.S.; Russell, A.D.; Chase, H.A. Pyrolysis using microwave heating: a sustainable process for recycling used car engine oil. *Ind. Eng. Chem. Res.* 2010, 49, 10845–10851.
- [46] Ogbeide, S. An investigation to the recycling of spent engine oil. *J. Eng. Sci. Technol. Rev.* 2010, 3(1), 32–35.
- [47] Bommareddi, A. AN ENGINE OIL LIFE ALGORITHM. Master's Thesis, Mechanical Engineering, 2009.
- [48] Daniel, B.J. Waste oil burner pre-heater design. US Patent No. US WO 20130206046 A1, 2012.
- [49] Baukal, E.C. *Industrial combustion testing*. NY, Ohio: CRC Press, Taylor and Francis Group, 2010.
- [50] Luka, B.S.; Robinson, I.E.; Sampson, C.O.; Japhet, J.A.; Ibrahim, T.K.; Udom, P.O. Effect of diesel fuel blend on flame and emission characteristics of used engine oil as heating fuel using swirl waste oil burner. *Rigas Tehniskas Universitates Zinatniskie Raksti* 2020, 24(1), 545-561.
- [51] Madu, M.J.; Aji, I.S.; Martins, B. Design, Construction and Testing of a Burner that uses an admixture of used engine oil and Kerosene for foundry application. *Int. J. Innov. Res. Sci. Eng. Technol.* 2014, 3(9).