CHEDS: Journal of Chemistry, Education, and Science
Vol. 10, No. 1, June 2026
ISSN: 2654-637X (Online) | ISSN: 2614-1817 (Print) | Homepage: https://jurnal.uisu.ac.id/index.php/CHEDS/index

A Comprehensive Review of Petroleum-Derived Products, Refining Procedures, and Crude Oil Fractions

Hussein Hatem Meteab*, *University of Anbar, Iraq*
Ola Abdulhay Ali, *University of Anbar, Iraq*
Ayaat Khamess Ftekan, *University of Anbar, Iraq*

ABSTRACT

This study offers an extensive analysis of petroleum-derived products, refining methodologies, and crude oil fractionation techniques. The study centers on essential refining techniques, including catalytic cracking, hydrocracking, and reforming, emphasizing their contributions to enhancing fuel quality and product yield. A comparison of these processes is given, taking into account their cost, efficiency, and effects on the environment. The article also talks about recent improvements in refining technologies to show how the industry is moving toward more sustainable and energy-efficient methods. The study seeks to furnish significant insights for enhancing refining operations and delineating future research trajectories in petroleum processing.

ARTICLE HISTORY

Submitted 19/01/2026
Revised 28/04/2026
Accepted 02/05/2026

KEYWORDS

Coking, Hydro-Processing, Isomerization, Petroleum, Reforming

***CORRESPONDENCE AUTHOR**

husenhatam86@uoanbar.edu.iq

DOI: https://doi.org/10.30743/cheds.v10i1.12873

1. INTRODUCTION

By transforming crude oil into a variety of fuels, petrochemical feedstocks, and value-added products that support industry, transportation, and contemporary society, petroleum refining plays a crucial role in the global energy system. Due to their high energy density, well-established infrastructure, and economic viability, petroleum-derived products are predicted to remain essential for decades despite growing interest in renewable energy sources. As a result, ongoing refining technology development and optimization are still essential to satisfying the world's expanding energy needs while tackling sustainability and environmental issues (Nurlybayeva et al., 2025). Individual refining processes, including vacuum and atmospheric distillation, thermal and catalytic cracking, hydrotreating, and reforming, have been the subject of much research over the past few decades. Nevertheless, a large portion of the current literature is still disjointed, frequently concentrating on discrete process units or particular products without offering an integrated viewpoint that connects the characteristics of crude oil feedstock, process choice, product quality, and environmental performance. The operational and technological landscape of contemporary refineries has also been drastically altered by recent changes toward cleaner fuels, more stringent environmental regulations, the use of hydrogen, and carbon capture, utilization, and storage (CCUS). A comprehensive and critically synthesized review that captures these interconnected developments is still limited. The processing of heavier and more complex crude oils, rising sulfur and metal content in feedstocks, growing demand for ultra-low sulfur fuels, and the integration of refineries with petrochemical complexes are just a few of the new trends and difficulties in petroleum refining that have been highlighted by recent studies. Refineries are under increasing pressure to lower greenhouse gas emissions, increase energy efficiency, and implement carbon mitigation and hydrogen-based processes. A comprehensive grasp of refining technologies and their changing role in a low-carbon energy transition is required to address these issues (Tanimu et al., 2026). With a focus on the connections between crude oil properties, refining process technologies, product distribution, and environmental considerations, this review aims to critically analyze and synthesize recent advancements in petroleum refining and petroleum-derived products

After distillation, crude oil becomes plastics and such and fuel for cars and heaters an whatnot. The oil industry is extremely powerful and the global economy depends on it. Some of the largest producers and refiners of oil are also among the biggest companies in the world, yet others make products like plastics, fertilizers, cars and airplanes that either come from petroleum or run on hydrocarbons. The price of petrol had a clear connection with the output and was demand dependent (Arezki et al., 2017).

Petroleum that is crude gets drilled in the ground, and it's not necessarily smooth or pristine. The colour of the liquid may be dark brown or black but could also be relatively transparent. Darker colors are often present in the heavier oils (Sengupta et al., 2025). Natural gas, which under may be removed and re-treated to satisfy the requirements of power generation/industrial/domestic uses is commonly found dissolved in the liquid in significant quantities also together with various hydrocarbon types (Alhassan et al., 2025). This review stands out because it compares different petroleum refining processes and talks about new technologies that have been developed in the field. This study differs from traditional reviews by combining both classical and modern methods and focusing on making refining operations more sustainable and efficient.

This work also finds gaps in current research and suggests new areas to explore, especially in the creation of eco-friendly refining methods and the improvement of process conditions to cut down on emissions and energy use. Recent studies have focused on improving refining efficiency through advanced catalytic materials and environmentally friendly technologies (2020–2024). These developments aim to reduce sulfur content, enhance fuel quality, and minimize environmental impact (Akhtar et al., 2024; A. Hussain et al., 2024).

2. RESEARCH-METHODOLOGY

To guarantee thorough coverage and academic rigor, this review was carried out using a systematic literature survey. Relevant publications were gathered using major scientific databases, such as Scopus, Web of Science, ScienceDirect, and Google Scholar. In order to capture both fundamental knowledge and recent technological advancements in petroleum refining, the literature search concentrated on studies published between 2000 and 2025. The following keywords and search terms were used: "petroleum refining," "crude oil fractionation," "hydrocracking," "catalytic cracking," "hydrotreating," "clean fuels," "hydrogen in refineries," "refinery–petrochemical integration," and "carbon capture and storage in refineries." To guarantee the dependability and caliber of the sources, peer-reviewed journal articles, reputable review papers, and carefully chosen academic books were included. Excluded were conference papers, reports without peer review, and studies that were redundant or unrelated. The chosen literature underwent critical analysis and classification based on the type of refining process, feedstock properties, product quality, environmental impact, and new sustainability trends. Rather than just descriptive summaries, comparative analysis, the identification of technological challenges, research gaps, and future opportunities were emphasized.

3. RESULTS AND DISCUSSION

3.1 Petroleum's Chemical Composition.

Petroleum is a mixture of various hydrocarbons that can have a range of physical and chemical properties. according to where it is distributed throughout the world. Carbon is without a doubt the primary element, followed by hydrogen, nitrogen, and other elements, as shown in Table 1.

Table 1*:* Composition of Petroleum Elements.

Elements	Percentage range
Carbon	83%–87%
Hydrogen	10%–14%
Nitrogen	0.1%–0.2%
Oxygen	0.1%–1.5%
Sulfur	0.5%–6%
Metals	<0.1%

Petroleum falls into three broad classes of hydrocarbons. The type of carbon-carbon bond defining them. The following are the classes:

- The saturated hydrocarbons have only carbon–carbon single bonds in them. The cyclic are called naphthenes (or cycloalkanes) and the acyclic, paraffins (or alkanes).
- Unsaturated hydrocarbons as weekly they contain multiple CC bonds (double, triple or both). They are less saturated than the paraffins, having fewer hydrogen atoms per carbon and less hydrogen carbon ratios. Olefins are unsaturated hydrocarbons. Alkene refers to a class of compounds that have a carbon-carbon double bond, and alkyne refers to a class of compounds that contain a carbon-carbon triple bond.
- Aromatic hydrocarbons, a particular kind of cyclic chemicals that resemble the structure of benzene.

Density of petroleum is around 800 kg/m33. The specific gravity, which is the weight of a given volume when compared to water (which has a sg. of 1), for petroleum is around 0.8. The denseness actually can make oil less valuable and harder to refine. Light crude is considered the most valuable and easiest to refine, while the viscosity of heavy. Refining crude is more expensive. "Sour" crude containing sulphur and acidic chemicals costs less than low-sulphur "sweet" crude. There are various types of crude oil companies: upstream, midstream and downstream. Crude oil is treated as raw material while dealing downstream, crude oil and more refined products like different light and heavy distillates are stored and transported midstream, then end consumer goods are sold downstream (Coutinho et al., 2022; Feng et al., 2019; Li et al., 2023; J. Liu et al., 2023).

3.2 Crude Oil Properties and Their Influence on Refining Technologies.

The physical and chemical characteristics of crude oil, a highly complex mixture, are crucial in determining refinery configuration, process choice, and product yield. The choice and severity of refining processes, as well as operational difficulties and environmental performance, are directly influenced by important characteristics of crude oil, such as API gravity, sulfur content, metal concentration, acidity, and boiling-point distribution. Through traditional atmospheric and vacuum distillation, light crude oils with high API gravity and low sulfur content are typically easier to process and produce higher proportions of valuable light products like gasoline, kerosene, and diesel. On the other hand, low API gravity, high viscosity, increased sulfur and metal contents, and a higher proportion of high-boiling components are characteristics of heavy and extra-heavy crude oils. In order to upgrade heavy fractions into lighter products, processing such feedstocks necessitates more intricate refinery configurations that include conversion units like thermal cracking, delayed coking, and hydrocracking. One of the most important factors influencing refining techniques is sulfur content. In order to comply with increasingly strict environmental regulations on fuel sulfur levels, high-sulfur crude oils require extensive hydrotreating and hydrodesulfurization processes. Hydrotreating lowers sulfur emissions and enhances product quality, but it also raises operating expenses and hydrogen consumption. Refineries that process sour crudes must therefore make trade-offs between economic efficiency, hydrogen availability, and environmental compliance. Heavy crude oil also contains metal contaminants like nickel and vanadium which are potential catalyst poisons thus leading to increased deactivation and fouling of the catalytic units. In order to counteract these impacts, refineries usually resort to guard beds, feed pretreatment or residue upgrading technologies including for example residue hydrocracking and coking. However, the solutions are capital and operationally complex with the close connection on feedstock quality and refinery design. The acidity of crude oil, usually in the form of total acid number (TAN), also impacts refining processes, as it accelerates corrosion in distillation and post-distillation systems. High-TAN crudes need corrosion resistant materials, chemical inhibitors or blenders for refinery economics and process integration strategy. In general, to meet the global trend of heavier, higher sulfur and more chemically complex crudes petroleum as feedstocks has increased demand for flexible and integrated refining technologies. Today's refineries are required to make changes to process designs in order to handle the variety of feedstocks and fulfill fuel quality requirements as well as environmental limits. Therefore, it is crucial to have a clear understanding of the connection between crude oil characteristics and refining process utilization for both current refinery optimization and directing future technology development (Decote et al., 2022).

3.3 Comparative Analysis of Refining Processes.

Separation, conversion and upgradation of crude oils in the Petroleum Refinery The refining of petroleum is basically a matter of separation-into fractions. Although the fundamentals of single section refineries are strong, their performance, flexibility, and environmental impact are highly feeder stock quality dependent and vary with operating conditions and refining objectives. In this chapter, the comparison between the primary refining processes is presented with their advantages, disadvantages and developmental trends. Atmospheric and vacuum distillation processes are the basic separation procedures in every refinery, and as such form a preliminary upper level of further process stages. These units are a reliable and power-conservative way of dividing the crude oil into boiling- range fractions, but they do not change the molecular structure with the result that heavy fractions cannot be upgraded. In consideration of reduced supplies of light crude oils, distillation has been no longer adequate for satisfying the demand for product, making conversion processes an indispensable part. Thermal conversion processes, as visbreaking and delayed coking, are commonly employed for heavy fractions upgrading. Visbreaking is mainly a process for viscosity reduction, with only minimal amounts of lighter products and thus it is used as one of moderate upgrading methods. In contrast, delayed coking is capable of producing a more complete conversion of heavy portions to lighter components with byproduct coke. Despite the fact that coking enhances overall conversion, it leads to high energetic demand, solid waste production and environmental issues in terms of coke handling process (Robinson, 2006).

Catalytic cracking technologies, such as the fluid catalytic cracking (FCC), are one of the pillars supporting today’s refineries for its capability to convert vacuum gas oils into high-octane gasoline and valuable olefins. It has better selectivity and product quality than thermal cracking but it is more susceptible to feedstock impurities such as sulfur, metal and nitrogen. With the processing of heavier feedstocks, it becomes more and more important to improve

FCC behaviors via innovative catalyst formulations as well as pre-treatments techniques. Hydrocracking is characterized by high conversion of the feed and flexibility in products, yielding clean fuels with low levels of sulfur and aromatic content. Hydrocracking, on the other hand, occurs in a hydrogen-rich atmosphere and also can effect both cracking and hydrotreatment. This renders hydrocracking particularly suitable for heavy and sour stock processing as well as to the requirements of strict fuel quality specifications. However, hydrocracking is capital intensive and burdened with a high hydrogen demand that may make it uneconomical in case of hydrogen constrained refineries. In all refinery configurations, hydrotreating operations act as an important ancillary step to removing sulfur, nitrogen and metals (among other impurities) from intermediate and end products. Hydrotreating does not provide high gains in product yield, but is necessary for environmental reasons and to avoid deactivation of the downstream catalysts. The increasing need for untra low-sulfur fuels has resulted in higher severity and hydrogen consumption in hydrotreating units, adding to the importance of managing hydrogen costs. On comparison, no refining process can be said to be universal best for all times. On the contrary, contemporary refineries apply complex schemes in order to integrate processing steps, optimize the conversion efficiency, ensure that products meet stringent specifications and standards as well as environmental constraints and maximize profitability. The choice and optimization of refinery processes increasingly represent wider industry trends such as processing more heavy crudes, cleaner emission standards and the drive to cleaner fuels, along with petrochemicals integration (Suyunova & Shadiyeva, 2023).

Table 2: Summarizes a Comparative Analysis of Major Petroleum Refining Processes, Highlighting Their Feedstock Requirements, Advantages, Limitations, and Environmental Implications.

Refining Process	**Primary Function**	**Typical Feedstock**	**Main Products**	**Key Advantages**	**Main Limitations**	**Environmental Considerations**
Atmospheric dan Vacuum Distillation	Physical separation of crude oil into fractions	Whole crude oil	LPG, naphtha, kerosene, gas oil, residue	Simple, reliable, low chemical consumption	No quality upgrading of heavy fractions	Energy-intensive; indirect CO_2 emissions
Visbreaking	Mild thermal cracking to reduce residue viscosity	Vacuum residue	Fuel oil, small amounts of distillates	Low capital cost; improves residue handling	Limited conversion; modest product upgrading	High energy demand; limited emission reduction
Delayed Coking	Deep thermal conversion of heavy residues	Vacuum residue, heavy crude	Naphtha, gas oil, petroleum coke	High conversion of heavy feedstocks	Coke production; solid waste handling	High CO_2 emissions; coke-related environmental issues
Fluid Catalytic Cracking (FCC)	Catalytic conversion of gas oils to lighter products	Vacuum gas oil	Gasoline, LPG, light olefins	High gasoline yield; good flexibility	Catalyst sensitivity to metals and sulfur	Catalyst regeneration emissions
Hydrocracking	Catalytic cracking in hydrogen atmosphere	Gas oil, heavy distillates	Diesel, jet fuel, naphtha	High-quality clean fuels; flexible product slate	High capital and hydrogen consumption	CO_2 emissions from hydrogen production
Hydrotreating	Removal of sulfur, nitrogen, and metals	Naphtha, distillates, residues	Low-sulfur fuels	Essential for environmental compliance	Does not increase yield; high H_2 demand	Reduced SOx emissions; increased energy use
Catalytic Reforming	Upgrading naphtha to high-octane products	Naphtha	Reformate, hydrogen, aromatics	Produces high-octane gasoline and hydrogen	Feedstock quality sensitive	Aromatics-related environmental concerns

3.4 Cleaner Fuels and Environmental Regulations.

The worldwide refining business has seen more than significant change brought about by growing environmental legislation and human societal desire for cleaner fuels. In particular, regulations limiting sulfur levels in gasoline and diesel fuel imposed limits on aromatics as well as particulate matter and greenhouse gas such that the rules have fundamentally changed refinery process technologies with more emphasis on upgrading and treating capabilities. A key regulatory driver has been the gradual lowering of sulfur in transportation fuels. As a result, specifications for ultra-low sulfur diesel (ULSD) and low-sulfur gasoline have led to the commercialization of deep hydrotreating and hydrodesulfurization units. Although these tools reduce SO_2 emissions and provide better air quality, they lead to H_2 consumption, energy expenditure and higher operation costs; new considerations which require advanced solutions in refinery optimization. Regulations to mitigate sulphur, as well as quality and combustion efficiency objectives have led to the reformulation of gasoline and diesel products. The aromatic and sulfur content reduction, together with the enhancement of cetane and octane numbers have led to benefiting from advanced catalytic reforming/isomerization/ blending technologies. These factors lead to improved fuel performance and reduced noxious exhaust, especially in urban areas. Environmental issues are not limited to fuel quality but also cover refinery-wide carbon dioxide and other emissions. Refineries are power-intensive plants and their role as major contributors to the world's GHG footprint has been becoming more of a concern. Accordingly, energy saving alternatives, heat recovery and process optimization have become integral to refinery design and operation in the modern world. This cleaner fuels technology is therefore very closely related to sustainability overall, and not just to individual unit initiatives. But the switch to cleaner fuels has changed refining forever, refocusing priorities away from volume maximization and towards quality, environmental considerations and energy efficiency. This shift has put increasing emphasis on the importance of holistic processing strategies combining both product specification compliance, regulatory consideration and environmental performance (Al-Enazi et al., 2021).

3.5 Integration of Refining with Petrochemicals

In the last few years, linking of petroleum refining with petrochemicals manufacturing has become a highly integrated approach to increase both refinery profitability and flexibility. Refinery configurations were originally designed for fuel production, but with varying market demand and the tightening environmental regulations as well as the increasing requirements for petrochemicals have forced a structural change that involves refinery-petrochemical integration. Combined or integrated refinery–petrochemical complexes, which have the capability of converting directly various refinery intermediates into valuable chemicals including olefins and aromatics. Procedures like fluid catalytic cracking, catalytic reforming, and steam cracking may be fine-tuned in order to increase petrochemical production and preserve fuel quality. This combination results in higher carbon efficiency through decreased intermediates handling and minimized heat losses. Comparatively a refinery integrated with petrochemical units is more robust to market stresses. The demand for fuels may vary somewhat with electrification and efficiency enhancements, but the demand for petrochemicals—plastics, synthetic fibres and specialty chemicals—is especially increasing. This allows integrated complexes the flexibility to shift product slates based on market conditions. Nevertheless, refinery–petrochemical integration is not without technical and operational problems. These factors include higher process complexity, more stringent feedstock specifications and the requirement for advanced catalysts and separation technologies. However, efficient implementation of such an energy and cost-efficient process requires a well-designed process unit operation (or reactor), a reliable control framework, and tactical planning to meet the fuel-chemical production trade-off (Alabdullah et al., 2020).

3.6 Role of Hydrogen and Carbon Capture, Utilization, and Storage (CCUS) in Modern Refineries.

Hydrogen is an important component of the modern oil refining practice, especially in hydrotreating and hydrocracking technologies for clean fuel production. Hydrogen demand in the refineries is increasing significantly, due to environmental regulations being more stringent and crude oil feedstock becoming heavier and dirtier. Therefore, efficient hydrogen control has developed into a key component of refining operation and viability. Conventional production of hydrogen includes: steam methane reforming (SMR) and catalytic reforming off-gas recycle. Although these procedures are well-established, they have large carbon dioxide emissions. In response, refineries are considered to be increasingly looking at low carbon hydrogen routes, including blue hydrogen in combination with CCUS and, on a longer-term timeframe, green hydrogen derived from renewables. Carbon capture and storage technologies present themselves as a potential proposition to reduce refinery related GHG emissions. CCSU can be used for large emitters in refineries like hydrogen plant and furnaces. The captured CO_2 can be used for enhanced oil recovery or stored in geological formations, thus lowering the net carbon footprint of refineries. The coupling of hydrogen supply/management and carbon management/CCUS is an important strategic direction in which petroleum refining can adjust to global decarbonization ambitions. However, there are serious technical challenges in terms of cost, infrastructure, and scalability. Long-term research and policy support is therefore needed for the expansion of such technologies in the refining industry (Fratalocchi & Rossini, 2026).

3.7 Challenges and Gaps in Petroleum Refinery for Future Work.

Petroleum refining still has a number of technical, environmental and economic challenges that need further research and development even with the major technological progress achieved. One of the most significant issues is that there is an ever increasing percentage of heavier, more complex, more contaminated crude oil being processed. These feed stocks are a source of major operating challenges, including high energy requirements, catalyst rapid deactivation, corrosion and waste production. Therefore, further investigations should focus on developing stronger catalysts and more effective pretreatment processes as well as flexible process integration that could accommodate varying feedstock quality.

Fuel quality needs as opposed to environmental and sustainability goals also present a significant challenge. This direction has also caused more hydrogen demand and higher carbon intensity in refining pathways when producing ultra low sulfur and cleaner fuels. The existence of such a paradox underscores the urgent need for new research to clarify and optimize hydrogen use with low net greenhouse gas emissions. Novel hydrogen management schemes, low carbon hydrogen feedstock integration and higher energy efficiency among refinery units are the areas of future research.

The co-production of refining with petrochemical (RVSP) has also opportunities as well as mysteries. When designing an integrated combustion strategy, higher level of separation capabilities, precisely controlled process and in-depth knowledge of reaction pathways would be needed to enhance economy resilience and carbon efficient. Research issues exist regarding catalyst selectivity, process intensification and co-optimisation of fuel and petrochemical product slates.

From a decarbonization perspective, the wide application of carbon capture, utilization and storage technology into refineries is still at its dawn. Technical issues concerning capture efficiency, cost reduction and integration with infrastructure, as well as safety of long-term storage are current barriers to large-scale implementation. Additional studies are therefore required to optimize CCUS options for refineries and assess their techno-economic and environmental effectiveness when applied in an operating context.

Digitalization, advanced process monitoring are finally the other research directions, which are emerging but not widely explored in petroleum refining. The use of data analytics, machine learning and digital twins can drive improvements in process optimization, predictive maintenance and emissions reduction. Yet, integration and application of those digital tools in the traditional refinery processes are still low reflecting a gap between technological potential and industrial practice.

These challenges will not be met in isolation, rather through a multidisciplinary approach combining catalysis, process engineering, materials science, energy systems and environmental analysis. Through these research gaps and future directions, academic research and industrial innovation can help lead to more efficient, flexible, and environmentally sustainable petroleum refining systems.

3.8 Petrochemical Products.

Petroleum products include refinery gas, ethane, LPG, naphtha, gasoline, aviation, marine, kerosene, diesel, distillate, residual, and gas fuels, as well as lubricants, white oil, grease, wax, asphalt, and coke. Any products derived from petroleum that can be refined are considered petroleum products. Some important petroleum products are described in the paragraphs that follow (Hsu & Robinson, 2019b; R. F. Hussain et al., 2023).

3.8.1 Kerosene

Kerosene and paraffin are highly flammable, colourless or yellowish, but bluish when burned, oily liquids with a characteristic smell, petroleum mixtures similar to this (or refined through distillation) such as jet fuel are commonly used as fuels. It distills between 125°C (257°F) to 260 °C (500°F). Kerosene, a refined petroleum distillate having a flash point of approximately 25 °C (77 °F) when burned in a large lamp may be used as an illuminant. Any liquid fuel, regardless of which petroleum product created it, that becomes a power source when burned in an engine or is employed as a heat source within certified equipment is called "fuel oil." The term 'kerosene' itself is overly and inappropriately applied to different fuel oils far too often. It was the most important product of the oil industry of that time, and it enabled several refineries to upgrade crude petroleum using a broad boiling cut (up to 300 degrees Celsius), which could be processed using existing technology, around heavier oils. This gave an undesirably high boiling fraction and dangerous low flash point. As burning oils are being produced today from selected crudes, or by special refining techniques in order to produce the desired volatility and excellent burning qualities. Kerosene is a frequent jet fuel for aircraft and some rocket engines. It is also heavily utilized as light and cooking fuel. In some parts of Asia, kerosene is sometimes used by farmers as fuel for their tractors and other farm machinery. Kerosene is used everywhere in the world for many things. Daily worldwide kerosene consumption amounts to around 1.2 million barrels per day (50 million US gallons; 42 million imperial gallons; 190 million liters) of all types (Bedda, 2023, 2024; Doranehgard et al., 2021; R. F. Hussain et al., 2023).

3.8.2 Petrol (Gasoline)

The most common types of fuel for an internal combustion engine (such as spark-ignition or diesel engines) are a colorless, flammable liquid derived from petroleum; they are often paired and referred to with the word "fuel" in American English, but the English has old roots and can mean any type of energy source. It is employed, also, as a solvent of fats and oils. It consists of all sorts of organic chemicals and is mostly formed from hexane, heptane, and octane found in hydrocarbon mixes. B. ADDITIVES: Corrosion inhibitors and antiknock compounds are often added to gasoline. Motor gasoline boils between -1°C (30°F) and 215°C (420°F), and may contain hundreds of hydrocarbon isomers (Busca, 2021). This boiling range has three principal types of hydrocarbon components C4 to C12: (1) Paraffins (comprising branching material and cyclo-paraffins); (2) Aromatics; (3) Olefins.

Gasoline lies between naphtha (a precursor to gasoline) and kerosene, but boils lower than both. Gasoline was initially derived from distillation only of the most volatile, and thus more valuable, parts of crude petroleum) leaving the heavier fractions behind. Cracking is the process in which heavier fractions with high molecular weights are converted into lighter products with lower molecular weight by certain methods to increase gasoline production from crude oil. Thermal cracking, utilizing high pressures and heat, was first used in 1913. Catalytic cracking, however, with its catalyzing agents that speed up a chemical reaction and produce more gasoline, replaced it in 1937. Other methods of improving gasoline quality and supply include polymerization, turning gaseous olefins like propylene and butylene into larger molecules in the gasoline range; alkylation, where an olefin and a paraffin like isobutane are combined; isomerization, converting straight-chain hydrocarbons to branched-chain ones; and reforming, rearranging molecular structure through heat or a catalyst. The susceptibility of gasoline to premature detonation upon combustion with air in the cylinder of an internal-combustion engine is expressed by its octane number, also called antiknock rating. It gauges the fuel’s antiknock characteristics — its resistance to knocking, a condition in which the fuel vapor in the cylinder burns too quickly for optimal performance. The octane number is determined by measuring the knock strength when a given fuel is used according to reference conditions, and comparing that value with mixes of two reference fuels--one having good detonation resistance (iso-octane) and the other having poor detonation resistance (heptane) (Doranehgard et al., 2021). "In a standard test engine, the octane rating is the percentage of (v/v) iso-octane in an iso-octane–heptane mixture that would have the same anti-knocking capacity as the product under consideration". Additives such as detergents reduce buildup of deposits in the carburetor and on the intake valves, counteracting oxidation inhibitors which inhibit gummy deposits (Hawthorne & Miller, 2019).

3.8.3 Diesel

The middle distillates are a category of petroleum products that includes jet fuel, kerosene and diesel. These are so called because of their boiling point, which is between that of gasoline and gas oil. The middle distillates boil in the range 175° to 375°C (350° to 700°F) and have a carbon number from approximately C_8 to C_{24}. These products were similar in characteristics, though their specifications varied according to there intended applications. Diesel fuels were originally straight-run products obtained from the distillation of crude oil. Diesel-quality fuel may now also include different amounts of some shallow distillation products to increase volume. Whereas with petrol engines the spark ignites fuel, diesel engines ignite fuel using the heat generated by compressed air from within the engine in a cylinder. The fuel is then injected into the heated compressed air. As diesel fuel contains more energy per liter than an equivalent volume of gasoline, combustion in the diesel engine is much more efficient. Also, diesel fuel is cheaper to produce because it doesn't take as much refining for the oil during production (provided they aren't high taxes and regulations in place that artificially deflate or inflate prices). Diesel fuel, by contrast at least as generally manufactured, generates larger amounts of certain types of air pollution, like sulfur and solid carbon particles. Added refining processes and emissions-controlling efforts to reduce such pollution may make the economic case of diesel versus gasoline less compelling in terms of prices. In addition, some of the fuel efficiency advantages of diesel fuel was negated by its higher amount of CO_2 emitted per unit as compared to gasoline .There are various grades of diesel fuel, including marine oils for low- and medium-speed engines (such as those used on trains, ships and stationary engines) with the same speed and load at all times; light-middle distillates for high-speed engines (like those in trucks or cars) experiencing frequent or heavy load changes and variations in speed. The performance standards are three in number: cetane number (a measure of ignitability), sulfur content, and rate of volatilization. The lowest grades are the least volatile, leave a high carbon residue, and contain high levels of sulfur for low-speed engines. For cars and trucks, the highest grades are most volatile. Diesel contains sulfur, which is a major source of pollution under heavy legal restrictions. Conventional diesel fuel standard grades may contain sulfur at up to about 5000 parts per million (ppm) by weight. In 1990s, low sulfur grades with a maximum of 500 parts per million became initially available and then the sulfur levels were decreased further over time. Sulfur: heavy duty vehicles - highway Highway vehicles should use ultra-low sulfur (ULSD) grades of fuel, which have no more than 15 ppm sulfur. Under E.U. regulations, only so-called zero-sulfur or sulfur-free diesels, with 10 parts per million as the maximum permissible level, can be sold for use in motor vehicles as of 2009. A lower sulfur content also reduces the level of sulfur compounds emitted when diesel fuel is burned which are responsible for acid rain and enables so called 'wet' catalysts to be used in cars which would otherwise suffer degradation due to higher levels of sulfur. Heavier fuel grades, which are used with off-road vehicles, ships and boats or stationary engines as diesel fuel for which sulfur content is allowed to higher value while trending in reducing standard also (Busca, 2021; Hancsók et al., 2020; Jennerwein et al., 2017).

3.8.4 Jet Fuel

Examples of aviation fuels include various grades of jet fuel, avgas (aviation gasoline), and avtur (aviation turbine fuel). Hydrocarbon- and sulfur/oxygen-containing impurities are present in aviation fuels, but they are rigorously regulated. Aviation gasoline shall consist purely of hydrocarbons except for such trace compounds as may be found necessary by approved additives, per composition demands. The Naphtha And Kerosene Type Jet Fuels The two fundamental types and the most frequently used of jet fuels are gasoline (naphtha) and kerosene (kerosene type jet fuel). The kerosene-type jet fuel is a relatively low-cost (compared to other fuels),contemporary adaptation of the type of oil that used to be widely used in gas turbine engines. This gasoline type jet fuel includes some gasoline fractions and has a wider boiling range. In addition, there are various specialty fuel grades sold for use in military high-performance aircraft. The medium distillate for use in turbine power units is a kerosene type jet fuel and generally possesses a flash point and distillation characteristics similar to those of (130°-300°1-) also has the same boundaries as does kerosene on the low side, not normally above 250°C. In addition, there are specific requirements set by the International Air Transport Association (IATA) for this fuel, among which is the freezing point of that fuel . The properties required for aviation gasoline are different from those for aircraft gas turbine engines, however. The most important difference is that with aircraft turbine engines, fuel from the upper heat value and favourable combustion properties are required. But the fuel standards are now more arbitrary and narrower as the design of engines and fuel systems have become more sophisticated (G. Liu et al., 2013).

3.8.5 Liquefied Petroleum Gas (LPG)

These are the liquid volatile hydrocarbons, as liquids they can be referred to as LPG (liquefied petroleum gases), such as propene, propane, butene and butane. These are flammable mixtures of hydrocarbon gases that we use for fuel in our cars, kitchen stoves and heaters. It became a popular commercial energy source in 1860 and was consequently produced and used for industrial and residential applications. A typical commercial blend may also contain ethane, ethylene and a volatile odorant, such as mercaptan, added for safety. Types of LPG: Purchased and Sold LPG mixture composition there are mixtures that are largely propane (C_3H_8), mostly butane (C_4H_{10}) and most commonly, a combination of the two, usually well dissolved. Propane can be produced as a by-product during natural gas processing and petroleum refining and refined from other petroleum products. In other words, it is made entirely from fossil fuels. It now accounts for about 3 percent of total energy use and burns clean, emitting no soot and comparatively little sulfur. It can pollute the air because it is a gas, but it does not harm the land or water. LPG typically has a calorific value of 46.1MJ/kg, which is greater than that of premium grade gasoline (43.5 MJ/kg) and fuel oil (42.5 MJ/kg) [9]. LPG has lower boiling point and can vaporize at normal temperature (at low pressure) which is why it's kept in pressurized steel bottles. They do not generally fill the former more than 80–85% of its capacity, so that the liquid can expand thermally within the vessel. Average vaporized to liquid gas ratio is approximately 250:1 although it changes with temperature, pressure and composition. Vapor pressure, the pressure under which LPG can convert into liquid, also covers temperature and composition. As an example, at 20 °C (68 °F), pure butane has a vapor pressure of approximately 220 kilopascals (32 psi). where pure propane at 55°C (131°F) has a vapor pressure of about 2200 kPa (320 psi). Unlike natural gas, which will naturally sink lower in places like basements, LPG is heavier than air and will spread across floors. On this account, LPG presents two main dangers: the first due to a possible explosion in presence of an altire near the mix of LPG with air. Second is asphyxiation due to the displacement of air by LPG reducing the percentage oxygen (Alfarraj et al., 2022; Zhang et al., 2020) (Alfarraj et al., 2022; Zhang et al., 2020).

3.8.6 Lubricating Oils

The physical form of lubricating oils, which are significant petroleum derivatives, ranges from light, liquid oils to heavy, high-viscosity oils and greases. They differ from other crude oil fractions primarily due to their high viscosity and high boiling point, which usually surpasses 400 °C (750 °F). While heavy petroleum residues may contain relatively larger molecules with 50–80 carbon atoms, hydrocarbons with 25–35 carbon atoms per molecule make up the majority of the basic materials used in the production of lubricating oils (P. Liu et al., 2015; Zhou et al., 2024)

3.8.7 Wax made with petroleum

Petroleum wax comes in two basic forms: paraffin wax, which is found in petroleum distillates, and microcrystalline wax, which is found in crude oil residues. Waxes' melting and boiling points are unrelated because the hydrocarbons that make them up have different chemical structures. Typically, waxes are categorized according to their melting point and oil content. Straight-chain (regular) hydrocarbons with molecular weights between C_2^1 and C_3^1 and higher make up the majority of paraffin wax, a solid crystalline mixture. While petrolatum contains both liquid and solid components, the wax components stay solid at room temperature (25 °C, 77 °F) (Ibrahim et al., 2021).

3.8.8 Asphalt

Bitumen, another name for road asphalt, is used in conjunction with different grades of asphalt for roofing and waterproofing, all of which are made from the non-volatile residue of crude oil. It is made using meticulously regulated vacuum distillation procedures to meet particular requirements for plasticity or hardness. Even at the highest vacuum levels, asphalt cannot be distilled because the temperatures needed to volatilize the residue cause coke to form. The properties of asphalt vary based on the petroleum source from which it was extracted, and it has a complex chemical and physical composition (Jiang et al., 2014; Najjar & Heidari, 2018).

3.8.9 Coke

Petroleum coke is a derivative of the liquid and is produced through a process known as destructive distillation. In catalytic cracking reaction systems the catalyst is typically burned as the reactants are somewhat given credit for that part of the coke product so that only unrecoverable coupling areas deposited off of the catalyst surface will contribute to results. Coke is heterogeneous and depends on the source of its crude oil, however it consists of a variety of hydrocarbons with high molecular weights and is rich in carbon but contains little hydrogen. Coke is a type of solid hard-to-process carbonized material with honeycomb structure produced by thermal treatment, thus it is not correct to state that coking yields 50-80% solubilisation in carbon disulfide.Although it finds many applications, petroleum coke is primarily used in the manufacture of carbon electrodes for aluminum smelting processes where clean sulfur-free low-ash carbon is necessary. It is also used as precursor for other forms of structural carbon (such as tubes and Rashig rings), carbon brushes, and silicon carbide, which is commonly used as an abrasive. It is also employed in the manufacture of calcium carbide and hence acetylene (Murthy et al., 2014).

3.9 The Drawbacks of Petroleum

Despite the fact that petroleum is widely used in contemporary life, both its extraction and use are detrimental to the environment. Underwater drilling results in leaks, fracking lowers the water table, and oil sands extraction uses valuable water or depletes the ground. Petroleum transportation via pipelines can damage the local ecosystem in addition to consuming energy and creating a leak risk (Y. Q. Chen & Yan, 2023).

3.10 The Process of Crude Oil Fractionation

Even though petroleum, or crude oil is not really used as such. It is composed of thousands of chemical substances, from methane (CH_4; molecular weight 16) to species with molecular weights greater than 2,000. Because they display such a wide range of molecular weights, boiling points vary from –160 °C (–288 °F) to 1,100 °C (2,000 °F) .Fractional distillation, or sometimes called fractionation or refining, is the main technique for separating a hydrocarbon mixture into its components. Thus, any oil refinery is a set of complex combinations as well as integrated processes and operating units in order to obtain various products (see Table 2). Refinery process stages The refinery is divided into the three major operations as follows (Jones, 2014) (Fig 1):

Separation: C rude oil is separated into its fractions at atmospheric pressure or low vacuums according to the types of crude feed and unit design using several processes such as fractionation, distillation or within specific limits fractional distillation. Conversion: Process of transforming molecules present in the crude into salable products, like cracking (breaking down molecules) or isomerization or hydroprocessing and so on. Finish: This includes refining the streams of product in a variety of ways to eliminate contaminants and impurities. Catalytic molecular rearrangement processes (reforming, etc.) are included in the aforesaid procedures for practical purposes as well (Atta et al., 2024; Fan et al., 2020).

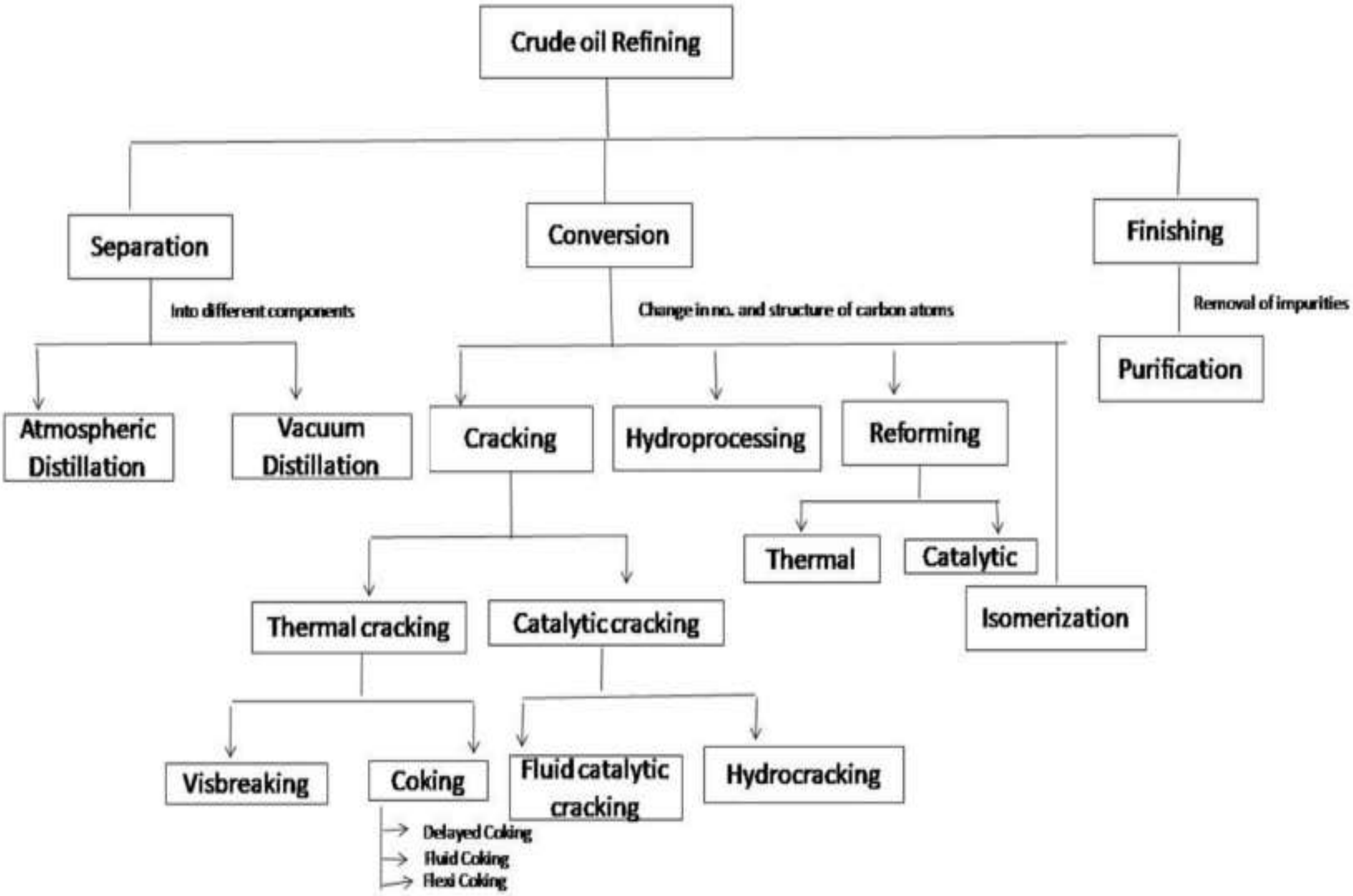

Figure 1: Important Processes in Crude Oil Refining

3.12.1 Methods of Separation—Fractional Distillation

As previously stated, crude oil refining is the process of converting crude oil into finished petroleum products (that the market requires), with fractional distillation being an essential first step. The fractional distillation process is based on the notion that different substances boil at different temperatures. For example, valuable fractions of crude oil include kerosene and naphtha, which is used to make gasoline for cars and jet fuel is created from kerosene(Al-Muntaser et al., 2021). When a mixture of kerosene and naphtha is evaporated and subsequently cooled down, the former condenses at higher temp, than the latter. Kerosene first, followed by naphtha are condensed as the blend cools. That is, fractional distillation works like that. A fractionator (or fractional distillation column, see Fig.2) is the main item of equipment, in this case a high column. Inside this column there are a number of trays or horizontal plates at different levels. And when each rotor cools down to its own it boils and condenses a unique fraction. At 350°C, most of the crude oil evaporates and from this point on the liquid is fed into the column. As the vapor rise through the fractionator, each of these fractions cools and condense at a unique temperature. The liquid is collected in the trays as it condenses out fraction after fraction. Substances with higher boiling points condense on the trays near to the base of the column. Trays above the top allow substances with lower boiling points to condense (Evans et al., 2020). The vapor is able to bubble through the liquid in that trays below because of the valves. So as a consequence, the vapor cools and condenses more quickly. Subsequently, the liquid of each tray is fed out of column (P. Liu et al., 2015). These are the major discrepancies between the top and bottom products from distillation column, as listed in Table 3. Descriptions of crude oil fractions and their properties are presented in Table 4.

Table 3: Separation processes and conversion processes

Products	Feedstock(s)	Purpose	Method	Action	Process
Gas, naphtha, gas oil, residua	Desalted crude oil	Separate feedstock	Thermal	Separation	Atmospheric distillation
Gas oil, lube stock, residua	Atmospheric residua	Separate without cracking	Thermal	Separation	Vacuum distillation
Conversion Processes					
Products	**Feedstock(s)**	**Purpose**	**Method**	**Action**	**Process**
Naphtha, petrochemical feedstock	Gas oil	Upgrading	Catalytic	Alteration	Catalytic cracking
Naphtha, petrochemical feedstock	Gas oil, coke distillate	Convert residua	Thermal	Polymerization	Coking
Lower-boiling products	Gas oil, residua	Convert to lower boiling products	Catalytic	Hydrogenation	Hydrocracking
Distillate, fuel oil	Atmospheric residua	Reduce viscosity	Thermal	Decomposition	Vis-breaking

Table 4: Comparison of Various Products

At the Top of the Distillation Column	At the Bottom of the Distillation Column
Short carbon chains	Long carbon chains
Light molecules	Heavy molecules
Low boiling points	High boiling points
Gases and very runny liquids	Thick, viscous liquids
Very volatile	Low volatility
Light color	Dark color
Highly flammable	Not very flammable

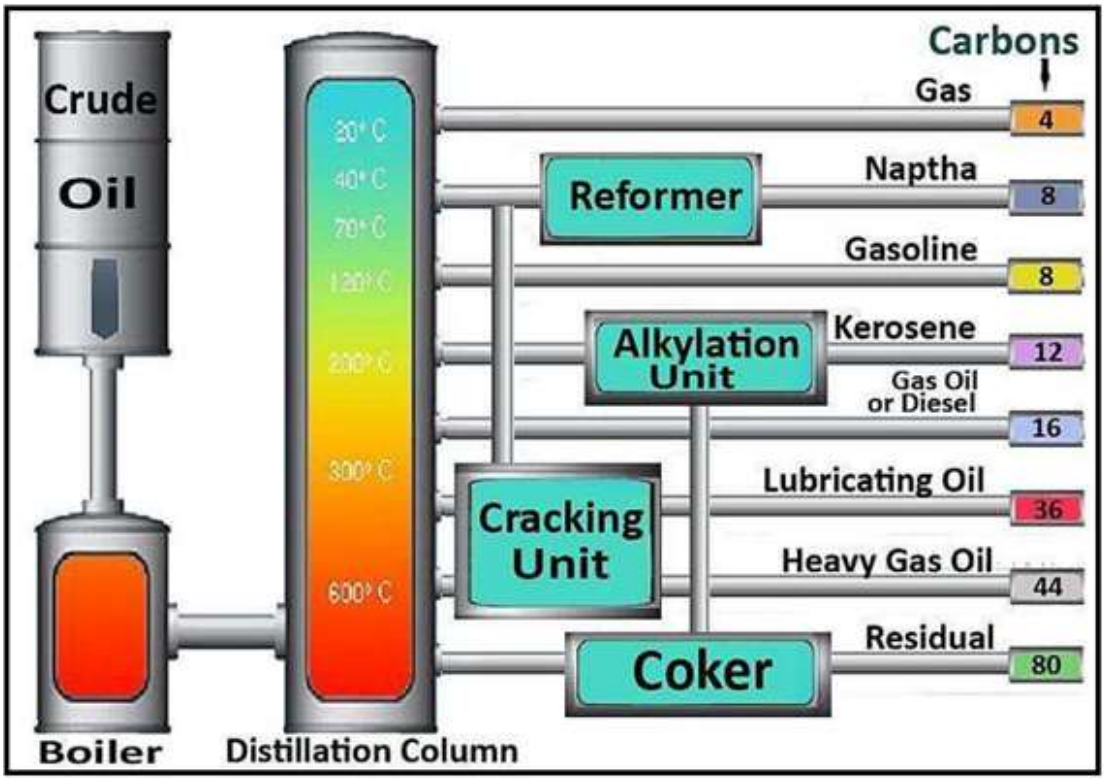

Figure 2: Crude Oil Refining (Hsu & Robinson, 2019a)

3.12.2 Conversion and Final Process

In the finishing process, various product streams are purified using a variety of techniques that essentially remove impurities from the finished product; in the conversion process, petroleum constituents are usually changed skeletally or even chemically to produce salable materials. Distillation or even treatment with a wash solution to remove impurities or, in the case of distillation, to produce a substance that boils over a smaller range are examples of the simple chemistry of the separation and finishing processes. Conversion processes are those that alter the molecular hydrogen-to-carbon ratio, alter the number of carbon atoms in each molecule, or alter the molecular structure of the material without altering the number of carbon atoms in each molecule. These subsequent processes, known as isomerization, are used to improve the product's quality and essentially change the molecules' structure (Tan et al., 2022).

Table 5: Fractions of Crude Oil and Their (Fanchi & Christiansen, 2016)

Uses	Boiling point (°C)	Number of carbon atoms	Name
Bottled gas (propane or butane)	below 30	3 or 4	Refinery gas
Fuel for car engines	100–150	7–9	Gasoline
Solvents and used in gasoline	70–200	6–11	Naphtha
Fuel for aircraft and stoves	200–300	11–18	Kerosene (paraffin)
Fuel for road vehicles and trains	200–300	11–18	Diesel oil
Lubricant for engines and machines	300–400	18–25	Lubricating oil
Fuel for ships and heating	350–450	20–27	Fuel oil
Lubricants and candles	400–500	25–30	Greases and wax
Road surface and roofing	above 500	above 35	Bitumen

3.12.3 Cracking

An essential procedure in oil refineries is cracking. In complex organic compounds, particularly long-chain hydrocarbons, it breaks carbon-carbon (C-C) bonds to transform them into simpler molecules like lighter hydrocarbons (like gasoline and diesel). Temperature and the presence of catalysts are two important factors that affect the rate of cracking and the nature of the final products. For cracking to be effective, high temperatures and pressure are usually needed.Cracking processes are divided into two main types:

1. Thermal cracking:

Thermal cracking is a method that uses heat to break down, reorganize, or join hydrocarbon molecules without the use of catalysts. Vis-breaking and coking are two examples of thermal cracking techniques that are now in use. Thermal cracking is typically utilized to convert petroleum residue into distillable liquid products. In order to break down lengthy hydrocarbon chains, high heat and pressure must be applied. It is among the earliest techniques for cracking. Despite being straightforward, it has lower gasoline yields than catalytic cracking and can produce large amounts of coke and unwanted products.(Voge & Good, 1949)

2. Catalytic cracking:

In contrast to thermal cracking, this catalytic cracks relies on the use of solid catalysts to speed up the breaking of carbon bonds at comparatively lower temperatures and pressures. This process uses high pressure and hydrogen to produce high-quality products like clean diesel and jet fuel while lowering the sulfur content. A fine powder catalyst is transported by a stream of steam or gas in the Fluid Catalytic Cracking (FCC) process. It is one of the most popular methods for making diesel and high-octane gasoline (Doranehgard et al., 2021; Hawthorne & Miller, 2019).

3.12.4 Vis-breaking

Vis breaking is a simple "heat" process for heavy residues which does not results neither in more convenient Rheometer/Flow properties nor in suitable feed for advanced usages (ie:(further work-up, processing,...)); This operation features a gentle thermal cracking that partially decrease the viscocity without full determination into distillates. Thus, it is less energy intensive and less expensive than other cracking processes. This process depends on nothing more than a brief interval in the furnace tubes to prevent polymerisation reactions and coking, with rapid quenching of the hot products serving both to stop them and also avoid overconversion. Agents are also employed to lower coke formation on the walls of the furnace tube. The vis-breaking unit comprises usually three sections:

1. Reaction furnace: where heavy feed and most reactions go through it.
2. Recycled oil quenching-system: They stop thermal reactions instantly.

3. Fractionation section: Separates the product stream into multiple streams according to physical characteristics (Sung et al., 1945; Yan et al., 2019).

3.12.5 Coking

In petroleum refining, coking is a crucial thermal process that produces low-boiling products and petroleum coke from heavy, non-distillable petroleum fractions. Coking is frequently employed as a substitute for catalytic cracking because metals and nitrogen compounds poison catalysts. The three primary coking techniques are flexi-coking, fluid coking, and delayed coking (K. Chen et al., 2012).

1. Delayed Coking:

This is the earliest and still most practical method, and its configuration has not changed substantially in the half-century it has been in use commercially at refineries. The petroleum slurry or another denser feed is heated to temperature for cracking / coking (> 350 °C, > 660 °F), usually about 480 °C (895 °F). The hot liquid is then sent to a coke drum, where the cracking occurs. The coke is accumulated in the drum as soon as liquid and gaseous products are removed and forwarded to a fractionation unit. In order to keep the system running, each of these drums is usually presented in pairs (where one is on and the other off) and the pair cycled periodically back and forth. The duration of each cycle is usually 24-48 hours. The primary products of this process are propane-propylene, butane-butane, naphtha, light gas oil, heavy gas oil and fuel gas comprising ethane and low-molecular-weight gases. The products differ widely in yield and quality depending on the type of feed. Coke is crushed with hydraulic breakers.

2. Fluid Coking:

Such coking is performed in a continuous process vessel with fluidized coke particles and transported in the liquid state. The feed is thermally cracked above the heated coke particles to form gas, liquid and coke by breaking of thermal bonds within the feed. The coke is partly burnt to supply heat for the process and, as by-product, the other part of the coke is withdrawn. A thin layer of new formed coke covers the particles. These fluidize particles travel from chamber to chamber to serve as a heat transfer vehicle, thus avoiding a high-temperature preheating oven. It is carried out at temperatures above 485 °C (900 °F) and pressures near atmospheric pressure with a residence time of 1–30 seconds. The process results in higher yields of liquid products as compared to delayed coking, but the coke is typically richer in olefins and may be less suited for processing into value-added fractions (Sawarkar et al., 2007).

3. Flexi-coking:

An enhanced form of fluid coking is called flexi-coking. In order to transform extra coke into a clean fuel gas with a calorific value of about 90 Btu/ft^3, it includes a gasifier close to the coke burner/regenerator. The coke gasification process can be run at a lower level to produce both gas and coke, or it can be adjusted to burn about 95% of the coke to produce gas. In order to meet the demands of the coke market, this flexibility enables adaptation to changing feed quality requirements (Kapustin & Glagoleva, 2016).

3.12.6 Cracking by Catalysis

Heavy oil passes through metal chambers at high temperatures and pressures with a catalyst, such as silicon oxide-aluminum oxide zeolite, which cleaves the long carbon chains and changes them into lighter molecules like gasoline. Catalytic cracking is more versatile than thermal cracking and its reaction conditions are milder and easier to regulate.Catalytic cracking also allows the use of lower-quality, less expensive crudes as source materials. On account of its capability to make greater amounts of high octane gasoline, catalytic cracking is almost a perfect replacement for thermal cracking. It generates side product gases rich of carbon-carbon double bonds (olefins), enhancing its economical potential (Y.-M. Chen, 2006). For catalytic cracking, carbonium ion theory is used to describe how long hydrocarbons are cracked into shorter ones. In consequence, the catalyst catalyzes the addition of a positive proton (H^+) to an olefinic, or the removal of a negative hydride ion from a paraffinic. This creates an intermediate carbonium ion which carries the positive charge along the hydrocarbon. This process proceeds at the catalytic active sites, resulting in breaking carbon bonds and formation of lighter molecules (Speight, 2011).

The two primary forms of catalytic cracking are hydrocracking and fluid catalytic cracking (FCC). Fluid catalytic cracking operates with a continuous feed flow in a fluidized catalyst bed. This was firstly described in 1942. Synthetic zeolite or alumina is generally employed as catalyst, and various feeds used are direct gas oil, vacuum gas oil, atmospheric residue, asphalt-free oil and vacuum residue. The usual operating temperature is between 900 and 1020 °F (480 to 550 °C) and the pressure is the range of 1–2 atm. The catalyst was originally natural silica-alumina clay, but zeolitic and molecular sieve catalysts have been most popular since the mid-1970s as they produce higher yield selectivity with decreased gas and coke production (O'Connor, 2001).

Contemporary fluid catalyst cracking devices are predominantly addressed according to the process of using a finely divided solid catalyst with a gas or oil vapor make it to look like liquid and perform as such. The regenerator and reactor are positioned adjacent each other. At the oil feed point, catalyst is heated for vaporizing the oil material and catalytic vapor generated is introduced into a high-speed reactor to perform only catalytic reactions. The catalyst is separated from the products in a cyclone vessel after reaction. The catalyst is reblended into the regenerator with a high temperature air stream (675–785 °C or 1250–1450 °F), with some fresh catalyst added to preserve activity.

The mixture coming from the reactor is separated with a distillation column. Conversion levels are generally determined by the production of light products that boil at temperatures less than or equal to 220 °C (430 °F). Conversion within Europe and Asia general averages are 60–70%, with some US refineries exceeding 80%. Fuel gas and gaseous hydrocarbons make up approximately one-third of the product, while propylene and butylene, both valuable feedstocks for polymerization and alkylation, comprise about half. Cracked naphtha, the principal product in the 90–94 octane gasoline range is major product as regard to volume. By contrast, European and Asian conversion units which are converted to a lesser extent yield more distillate oils and less naphtha and light hydrocarbons (Yen, 2014).

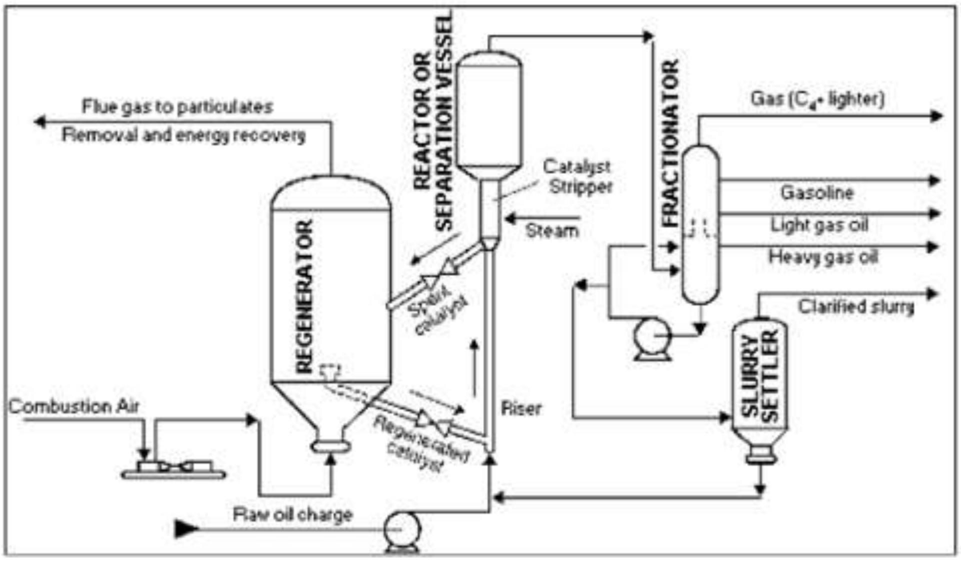

Figure 3: Schematic Diagram of Fluid Catalytic Cracking

3.12.7 Hydrocracking

Hydrocracking closely resembles catalytic cracking in that both processes include a hydrogenation step accompanying or following the cracking. Hydrocracking (which also utilizes hydrogen produced as a byproduct of catalytic reforming) was one of the most important refining breakthroughs of the 20th century, with commercial production beginning in the 1950's. In recent decades, hydrogen production units have also gained attention in refinery operations due to their significance in this context. While the feedstocks in hydrocracking units generally closely resemble those of catalytic cracking units, hydrocracking technologies provide better flexibility regarding yields. It can generate high-grade lubricating stocks, transform heavy residues to lighter oils or produce gasolines and jet fuels from feedstocks of heavy gas oils. The resultant distillate oil and jet fuel products are of high quality and very low in sulphur, enabling them to be mixed with other re fined product blends without further treatment. Nevertheless, the octane number of HC naptha is low and thus they need further reforming step in a catalyst to produce high quality gasoline (Yu et al., 2025).

3.12.8 Reforming

By using reforming techniques, the natural chemical structures of the hydrocarbons present in crude oil distillation fractions can be transformed into new compounds. For example, this process can be used to turn a barrel of crude oil into more gasoline or petrol. Despite having about the same number of carbon atoms as gasoline, the hydrocarbons in the naphtha stream have a somewhat complicated structure. During reforming, naphtha hydrocarbons are rearranged into gasoline molecules. Thermal and catalytic reforming are the two types (Aznárez et al., 2024).

3.12.9 Catalytic reforming

Catalytic reforming: One of the key refinery processes today. It changes straight-run or catalytically cracked fractions into new compounds by superheating and pressurizing them in the presence of a catalyst. Hydrogen gas is a very important product generated in this process and dehydrogenation is one of the most significant reactions. Recycling of hydrogen to catalytic reactor is keeping reaction atmosphere and preventing carbon deposition at the catalysts surface, allowing for prolonged operational life. It should also be noted that the catalytic reforming operation generates hydrogen gas in excess of that which is actually utilized, rendering it the only refinery process that generates hydrogen as a primary by-product (Hu et al., 2021).

A typical catalytic reforming unit comprises three series-connected catalytic reactors that are each operated at controlled conditions of pressure and temperature. Naptha is added along with hydrogen and fed through the reactors one at a time. In the formation of these light gases, the most significant product is called reformate, which is a blending component for higher-octane gasoline. It is very significant that catalytic reforming can directly change the octane number of commercial gasoline for sale. The higher temperature or lower feed rate at which the reformate can be produced with the desired octane rating results in a decrease in product yield to achieve increased octane. On the other hand, if high-octane gasoline is not in demand, the operating conditions can be influenced to produce a higher yield of reformate with lower octane number.

In marked contrast, thermal reforming is typically conducted in the absence of a catalyst. It is practically the same as in thermal cracking, except that feedstock temperatures are between 510 and 595°C (950 to 1100°F) and still higher pressures from about 400 to almost 1000 psi (27 to up to about 68 atm) are used. After leaving the oven, the heated naphtha is first quenched with cold naphtha and then subjected to fractional distillation for separation of heavy constituents. The lighter ones are separated in the form of a gas-gasoline mixture (reformate). The high octane number of the gasoline product is primarily due to the cracking of long chain paraffins into higher octane olefins.

The thermal reforming products are gases, gasoline, and sludge or tar up to 1% oils. The amount and the quality of gasoline thus obtained largely depend on the temperature. Reformate has a lower quantum yield than the higher temperature range, although octane number of each reformate is higher. Although of historic significance, thermal reforming has largely been discontinued in favor of catalytic processes because they are more efficient and economic (Rodríguez & Ancheyta, 2011).

3.12.10 Hydro-processing

The hydro processing is the basis processes of contemporary oil refineries. It is based on the simultaneous action of temperature, residence time and hydrogen pressure for treating feedstock to generate new product with enhanced performance requirements. This can be broken down into two primary types: hydrocracking and hydrotreating. Although hydrotreatment is intended to treat feedstocks or products by adding hydrogen to remove impurities heteroatomic species like SO2, NOx and O2 at moderate temperatures, hydrocracking refers to a thermal decomposition reaction with the aid of hydrogen, breaking carbon-carbon (C–C) bounds and turning non-carbon impurities into their isotopes: (1) Sulfur → Hydrogen Sulfide (H_2S); (2) Nitrogen → Ammonia (NH_3); (3) Oxygen → Water (H_2O). In reality hydrocracking and hydrotreatment can be carried out concurrently in the same unit, depending on the kind of feedstock based on operating conditions [3]. Hydrotreating is more significant in generating various high-quality liquid fuels; low-sulfur diesel, jet oils and petrochemical feedstocks. This is in contrast to the Vis-breaking process, whose primary function lies under such applications as improving qualities of heavy fuel oil and not making light fuel which is economically beneficial (Song & Ma, 2004).

3.12.11 Isomerization

Isomerization is an important process in petroleum refineries, used to reform or recombine light distillates to produce new products. This process involves converting straight-chain hydrocarbons into branched hydrocarbons. The primary goal of isomerization currently is to obtain high-octane fractions used in gasoline blending or as additional feedstocks for alkylation units. This is effected by means of catalysts based on aluminum chloride or noble metals where straight chain paraffins, such as n-butane, n-pentane and n-hexane are changed into their branched iso hydrocarbons. Hydrogen gas is also added to the reaction in order to diminish undesired side reactions, but it is not consumed or actually generated. Process monitoring is commonly conducted by means of molecular sieve/extractive distillation.

$$\underset{n\text{-heptane}}{CH_3{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_3} \longrightarrow \underset{\text{iso-heptane}}{CH_3{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH{-}(CH_3){-}CH_3}$$

This process is quite satisfactory in removing low octane compounds from the gasoline blend per se, but since the resultant product does not have a sufficient octane value to have any real effect on unleaded gas manufacturing it has never been proposed as being useful for that purpose. Nevertheless, it still is a significant starting point since the initial feedstock can be sourced from fractionation of natural gasoline or straight-run light gasoline. The isomerization has excellent volumetric yield (>95%) and 40–60% conversion per run. This is carried out using aluminum chloride supported on alumina with hydrogen chloride gas as a catalyst. Commercial techniques have also been found for branching isomerizing low octane pentane and normal hexane to higher octane branch isomers. In some instances, platinum is included to improve the efficiency of the catalyst. It is similar to catalytic reforming because hydrogen can control the reactions but is not consumed or produced in the process (Chekantsev et al., 2014).

3.11 Environmental Impacts of Petroleum

3.11.1 Emissions

From the combustion of petroleum fuels, a number of air pollutants are emitted including sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs) and particulate matter. The emissions are responsible for smog, respiratory illnesses, and acid rain in many urban and industrial locations. In addition, burning oil refining products also produces greenhouse gases like carbon dioxide (CO_2) and methane (CH_4), contributing to global warming (Mastropasqua et al., 2024).

3.11.2 Oil Spills

Spills also are among the most serious environmental concerns of petroleum production and transportation. This can result from offshore drilling, leaky pipelines or accidents involving tankers. They do long-term ecological harm by polluting in marine ecosystems, killing fish and seabirds and ruining coastal habitats like mangroves and coral reefs. The cost to clean up these spills is huge and the environment of the affected area, in some cases, will not be repaired for generations.

3.11.3 Water Contamination

Wastewater produced during the extraction and refining of petroleum contains hazardous substances such as benzene, toluene, heavy metals, pyrene, and polycyclic aromatic hydrocarbons (PAHs). These materials have the potential to contaminate groundwater or surface water and threaten human health and wildlife. Further, poor handling of drilling muds and produced waters can erode soil and impact crop productivity.

3.11.4 Climate Impact

90 % of the worldwide industrial CO_2 emissions from human activities derived from three main sources – coal, natural gas and oil. The burning of gasoline, the product derived from petroleum that's used to power most cars and trucks, contributes a significant share of the greenhouse gases that trap heat in the atmosphere. Moreover, the energy intensive extraction processes from unconvetional sources such as oil sands leads to increased emissions which futher adds to carbon footprint of petroleum (Adebiyi, 2022).

3.11.5 Challenges of Extraction and Transportation

Petroleum exploration at that depth necessitates advanced technologies, which may alter the land surface and habitat distribution and intensify the geological hazards of e.g. land subsidence. Hydraulic fracturing (fracking) is associated with induced seismic reactions, and the use of water in fracking has been excessive. The risk of leaks, breaks or spills increases when crude oil is transported through pipeline or by tanker. The scenes underscore the importance of greater safety measures and oversight.

3.12 Modern Trends in Refining

3.12.1 Integration with Petrochemical Units

In order to be more efficient and profitable, The refineries of the present times get integrated further into petrochemical plants. Such integration enables crude-oil conversion not only to fuels but also to high-value petrochemicals, such as ethylene, propylene and aromatics. Hybrid complexes of this type minimize waste, conserve energy and contribute to overall process flexibility (Thanh et al., 2012).

3.12.2 Cleaner Fuels

Increasing worldwide request for cleaner, low sulfur fuels to help meet air pollution standards and environmental regulations. More sophisticated hydroprocessing facilities are now common for desulfurization, nitrogen removal and aromatics reduction of fuel streams. Refineries also use catalytic reforming and isomerization to make low-emission gasoline blends with high-octane rating.

3.12.3 Hydrogen Economy

Refining Hydrogen is critical in the refining process, we're talking hydrocracking and hydrotreating. With the world increasingly focused on low carbon energy, it is hoped many refineries will look at producing green hydrogen from renewable-powered electrolysis. The move from Fossil based hydrogen (Grey Hydrogen) to green hydrogen reduces the net carbon foot print of refining (Speight, 2016).

3.12.4 Carbon Capture in Refineries

CCUS technologies are becoming increasingly established as a viable option to cut refinery CO_2 emissions. These systems extract CO_2 from flue gases before they are released into the atmosphere and either store it underground or use it in industrial processes. With CCUS, refineries can reach the world's climate goals and move to a more sustainable operation (Dalei & Joshi, 2022).

4. CONCLUSION

In summary, two paragraphs have given a broad and critical overview of petroleum refining technologies and products in the context of interdependent linkages between crude oil properties, refinery process choice, product yield pattern, and environmental performance. Leveraging findings from an extensive body of peer-reviewed research, the review illustrates how emerging feedstock quality and standards requirements continue to drive contemporary refinery deployments.

Furthermore, based on a comparative study of the major refining operations, it is clear that no individual technology is suffice to respond to both the increasing complexity of crude oil stocks and market requirements. Rather, fully-integrated refinery systems comprised of separation, conversion and upgrading units (backed up by advanced catalysts and hydrogen management) are required for achieving the economic feasibility along with environmental sustainability. The focus on clean-fuel production has also added to the demand for efficient hydrotreating, energy savings and process integration.

The review highlights the growing relevance of refinery–petrochemical integration as a strategic option to adapt to more volatile fuel demand and higher petrochemical supply. Concurrently, hydrogen utilization and carbon capture, utilization transport and storage are recognised as key enablers to decarbonize the petroleum refining industry with the global road map toward low-carbon extraction from fossil fuel feedstock or zero emissions facilities even though there are technical and economic challenges.

Finally, this review highlights research gaps and future challenges on processing heavy feedstock, hydrogen efficiency, catalyst durability; digitalisation and CCUS integration. These challenges can be met through integrated development of process engineering, catalysis, materials science, and systems optimization. The overall objective of the knowledge provided in this review is to serve academia and industry communities for the advancement of more sustainable, flexible and efficient petroleum refineries.

5. REFERENCE

Adebiyi, F. M. (2022). Air quality and management in petroleum refining industry: A review. *Environmental Chemistry and Ecotoxicology*, *4*, 89–96. https://doi.org/10.1016/J.ENCECO.2022.02.001

Akhtar, M. S., Ali, S., & Zaman, W. (2024). Recent Advancements in Catalysts for Petroleum Refining. *Catalysts*, *14*. https://doi.org/10.3390/CATAL14120841

Al-Enazi, A., Okonkwo, E. C., Bicer, Y., & Al-Ansari, T. (2021). A review of cleaner alternative fuels for maritime transportation. *Energy Reports*, *7*, 1962–1985. https://doi.org/10.1016/J.EGYR.2021.03.036

Al-Muntaser, A. A., Varfolomeev, M. A., Suwaid, M. A., Feoktistov, D. A., Yuan, C., Klimovitskii, A. E., Gareev, B. I., Djimasbe, R., Nurgaliev, D. K., E, S. I. K., Egorova, E. V., Fomkin, A. V., Petrashov, O. V., Afanasiev, I. S., & Fedorchenko, G. D. (2021). Hydrogen donating capacity of water in catalytic and non-catalytic aquathermolysis of extra-heavy oil: Deuterium tracing study. *Fuel*, *283*. https://doi.org/10.1016/J.FUEL.2020.118957

Alabdullah, M. A., Gomez, A. R., Vittenet, J., Bendjeriou-Sedjerari, A., Xu, W., Abba, I. A., & Gascon, J. (2020). A Viewpoint on the Refinery of the Future: Catalyst and Process Challenges. *ACS Catalysis*, *10*(15), 8131–8140. https://doi.org/10.1021/ACSCATAL.0C02209

Alfarraj, B., Alharbi, A., Binjuwair, S. A., & Alkhedhair, A. M. (2022). The Characterization of Liquefied Petroleum Gas (LPG) Using a Modified Bunsen Burner. *Journal of Combustion*, *2022*(1). https://doi.org/10.1155/2022/6977930

Alhassan, A. M., Yusuf, B. O., Hussain, I., Tanimu, A., Alhooshani, K. R., Ali, B. El, & Ganiyu, S. A. (2025). Crude-to-Chemical Revolution: Integrating Technologies, Economic Feasibility, and Policy Frameworks for Sustainable Light Olefin Production. *The Chemical Record*, *25*(8:e202500011). https://doi.org/10.1002/TCR.202500011

Arezki, R., Jakab, Z., Laxton, D., Matsumoto, A., Nurbekyan, A., Wang, H., & Yao, J. (2017). Oil Prices and the Global Economy. *IMF Working Papers*, *17*(15). https://doi.org/10.5089/9781475572360.001

Atta, M. S., Khan, H., Ali, M., Tariq, R., Yasir, A. U., Iqbal, M. M., Din, S. U., & Krzywanski, J. (2024). Simulation of Vacuum Distillation Unit in Oil Refinery: Operational Strategies for Optimal Yield Efficiency. *Energies*, *17*(15). https://doi.org/10.3390/EN17153806

Aznárez, A., Korili, S. A., & Gil, A. (2024). Progress and recent novelties in naphtha reforming catalysts. *Journal of Environmental Chemical Engineering*, *12*(3). https://doi.org/10.1016/J.JECE.2024.113066

Bedda, K. (2023). Prediction of Smoke Points of Kerosene Distillates Using Simple Laboratory Tests: Artificial Neural Network versus Conventional Correlations. *Theoretical Foundations of Chemical Engineering*, *57*(5), 908–916. https://doi.org/10.1134/S0040579523050366

Bedda, K. (2024). Prediction of Flash Points of Petroleum Middle Distillates Using an Artificial Neural Network Model. *Petroleum Chemistry 2024 64:6*, *64*(6), 648–656. https://doi.org/10.1134/S0965544124040066

Busca, G. (2021). Production of Gasolines and Monocyclic Aromatic Hydrocarbons: From Fossil Raw Materials to Green Processes. *Energies*, *14*(13), 4061. https://doi.org/10.3390/EN14134061

Chekantsev, N. V., Gyngazova, M. S., & Ivanchina, E. D. (2014). Mathematical modeling of light naphtha (C5, C6) isomerization process. *Chemical Engineering Journal*, *238*, 120–128. https://doi.org/10.1016/J.CEJ.2013.08.088

Chen, K., Liu, H., Guo, A., Ge, D., & Wang, Z. (2012). Study of the thermal performance and interaction of petroleum residue fractions during the coking process. *ACS Publications*, *26*(10), 6343–6351. https://doi.org/10.1021/EF301378G

Chen, Y.-M. (2006). Recent advances in FCC technology. *Powder Technology*, *163*(1–2), 2–8. https://doi.org/10.1016/J.POWTEC.2006.01.001

Chen, Y. Q., & Yan, B. H. (2023). The technology of shielding design for nuclear reactor: A review. *Progress in Nuclear Energy*, *16,104741*. https://doi.org/10.1016/J.PNUCENE.2023.104741

Coutinho, D. M., França, D., Vanini, G., Gomes, A. O., & Azevedo, D. A. (2022). Understanding the molecular composition of petroleum and its distillation cuts. *Fuel*, *311*, *12259*. https://doi.org/10.1016/J.FUEL.2021.122594

Dalei, N. N., & Joshi, J. (2022). Potential matching of carbon capture storage and utilization (CCSU) as enhanced oil recovery in perspective to Indian oil refineries. *Clean Technologies and Environmental Policy 2022 24:9*, *24*(9), 2701–2717. https://doi.org/10.1007/S10098-022-02359-1

Decote, P. A. P., Negris, L., Vidoto, A. P., Mendes, L. A. N., Flores, E. M. M., Vicente, M. A., & Santos, M. F. P. (2022). Determination of the total acid number of Brazilian crude oil samples: Theoretical and experimental evaluation of three standard methods. *Fuel*, *313*, *12264*. https://doi.org/10.1016/J.FUEL.2021.122642

Doranehgard, M. H., Tran, S., & Dehghanpour, H. (2021). Modeling of natural-gas diffusion in oil-saturated tight porous media. *Fuel*, *300*. https://doi.org/10.1016/J.FUEL.2021.120999

Evans, R. D., Wilson, S. K., Fisher, R., Ryan, N. M., Babcock, R., Blakeway, D., B, T. B., Dorji, P., Dufois, F., Fearns, P., Lowe, R. J., Stoddart, J., & Thomson, D. P. (2020). Early recovery dynamics of turbid coral reefs after recurring bleaching events. *Journal of Environmental Management*, *268*, *11066*. https://doi.org/10.1016/J.JENVMAN.2020.110666

Fan, C., Liu, F., Zhao, X., Ma, Y., Yang, F., Chang, Z., & Xiao, X. (2020). An alternative comprehensive index to quantify the interactive effect of temperature and relative humidity on hand, foot and mouth disease: A two-stage time series study including 143 cities in mainland China. *Science of The Total Environment*, *740*. https://doi.org/10.1016/J.SCITOTENV.2020.140106

Fanchi, J. R., & Christiansen, R. L. (2016). Introduction to petroleum engineering. In *Introduction to Petroleum Engineering, 1–335*. https://doi.org/10.1002/9781119193463

Feng, S., Cui, C., Li, K., Zhang, L., Shi, Q., Zhao, S., & Xu, C. (2019). Molecular composition modelling of petroleum fractions based on a hybrid structural unit and bond-electron matrix (SU-BEM) framework. *Chemical Engineering Science*, *201*, 145–156. https://doi.org/10.1016/J.CES.2019.01.050

Fratalocchi, L., & Rossini, S. (2026). A review on the role of carbon capture, utilization and storage (CCUS) in energy transition: An industrial perspective. *Applied Catalysis A: General*, *709*. https://doi.org/10.1016/J.APCATA.2025.120660

Hancsók, J., Kasza, T., & Visnye, O. (2020). Isomerization of n-C5/C6 Bioparaffins to Gasoline Components with High Octane Number. *Energies*, *13*. https://doi.org/10.3390/EN13071672

Hawthorne, S. B., & Miller, D. J. (2019). A comparison of crude oil hydrocarbon mobilization by vaporization gas drive into methane, ethane, and carbon dioxide at 15.6 MPa and 42 °C. *Fuel*, *249*, 392–399. https://doi.org/10.1016/J.FUEL.2019.03.118

Hsu, C. S., & Robinson, P. R. (2019a). *Chemical Composition BT - Petroleum Science and Technology* (C. S. Hsu & P. R. Robinson (eds.); pp. 39–56). Springer International Publishing. https://doi.org/10.1007/978-3-030-16275-7_3

Hsu, C. S., & Robinson, P. R. (2019b). *Natural Gas and Petroleum Products BT - Petroleum Science and Technology* (C. S. Hsu & P. R. Robinson (eds.); pp. 301–342). Springer International Publishing. https://doi.org/10.1007/978-3-030-16275-7_15

Hu, D., Zeng, X., Wang, F., Adamu, M. H., & Xu, G. (2021). Comparison of tar thermal cracking and catalytic reforming by char in a micro fluidized bed reaction analyzer. *Fuel*, *290*. https://doi.org/10.1016/J.FUEL.2020.120038

Hussain, A., Ghaffar, I., Sattar, S., Muneeb, M., Hasan, A., & Deepanraj, B. (2024). Eco-friendly Catalysts

Revolutionizing Energy and Environmental Applications: An Overview. *Topics in Catalysis 2024 68:5*, *68*(5), 487–509. https://doi.org/10.1007/S11244-024-01976-Y

Hussain, R. F., Mokhtari, A., Ghalambor, A., & Salehi, M. A. (2023). Smart downstream sector of Odan G industry. In *IoT for Smart Operations in the Oil and Gas Industry, 105–131*. https://doi.org/10.1016/B978-0-32-391151-1.00013-7

Ibrahim, E. M. E., Sadik, W. A., Batouti, M. El, Nashed, A. W., Tarek, M. A., & Essam, E. R. (2021). Blending Petroleum Waxes with Suitable Polymeric Additives as a Simple and Promising Way to Improve the Quality of Petroleum Waxes for Numerous Industrial Applications. *Journal of Petroleum Science and Technology*, *11*(2), 30–42. https://doi.org/10.22078/JPST.2021.4394.1711

Jennerwein, M. K., Sutherland, A. C., Eschner, M., Gröger, T., Wilharm, T., & Zimmermann, R. (2017). Quantitative analysis of modern fuels derived from middle distillates – The impact of diverse compositions on standard methods evaluated by an offline hyphenation of HPLC-refractive index detection with GC×GC-TOFMS. *Fuel*, *187*, 16–25. https://doi.org/10.1016/J.FUEL.2016.09.033

Jiang, T., Zeng, F., Jia, X., & Gu, Y. (2014). A new solvent-based enhanced heavy oil recovery method: Cyclic production with continuous solvent injection. *Fuel*, *115*, 426–433. https://doi.org/10.1016/J.FUEL.2013.07.043

Jones, D. S. (2014). Atmospheric and Vacuum Crude Distillation Units in Petroleum Refineries. In *Handbook of Petroleum Processing, 1–61*. https://doi.org/10.1007/978-3-319-05545-9_25-1

Kapustin, V. M., & Glagoleva, V. F. (2016). Physicochemical aspects of petroleum coke formation. *Springer*, *56*(1), 1–9. https://doi.org/10.1134/S0965544116010035

Li, S., Wu, J., Wang, Y., Li, Y., Zhang, W., Zhang, Y., He, K., Cai, C., Bian, G., Wang, H., Ji, Y., & Shi, Q. (2023). Semi-quantitative analysis of molecular composition for petroleum fractions using electrospray ionization high-resolution mass spectrometry. *Fuel*, *335*. https://doi.org/10.1016/J.FUEL.2022.127049

Liu, G., Yan, B., & Chen, G. (2013). Technical review on jet fuel production. *Renewable and Sustainable Energy Reviews*, *25*, 59–70. https://doi.org/10.1016/J.RSER.2013.03.025

Liu, J., Wang, L., Chen, F., Hu, W., Dong, C., Wang, Y., & Han, Y. (2023). Molecular Characterization of Hydrocarbons in Petroleum by Ultrahigh-Resolution Mass Spectrometry. *Energies*, *16*. https://doi.org/10.3390/EN16114296

Liu, P., Yu, H., Ren, N., Lockwood, F. E., & Wang, Q. J. (2015). Pressure–Viscosity Coefficient of Hydrocarbon Base Oil through Molecular Dynamics Simulations. *Tribology Letters 2015 60:3*, *60*(3). https://doi.org/10.1007/S11249-015-0610-6

Mastropasqua, L., MacKinnon, M., Zhu, S., & Samuelsen, S. (2024). Reducing the air pollution impact of petroleum refineries by integrating high temperature electrochemical energy systems. *International Journal of Hydrogen Energy*, *110*, 880–897. https://doi.org/10.1016/J.IJHYDENE.2025.01.339

Murthy, B. N., Sawarkar, A. N., Deshmukh, N. A., Mathew, T., & Joshi, J. B. (2014). Petroleum coke gasification: A review. *Canadian Journal of Chemical Engineering*, *92*(3), 441–468. https://doi.org/10.1002/CJCE.21908

Najjar, R., & Heidari, S. (2018). Modified diesel prepared by stabilization of water as nanodroplets in diesel/colza oil blend: Study of phase behavior and affecting parameters. *Fuel*, *214*, 497–504. https://doi.org/10.1016/J.FUEL.2017.11.052

Nurlybayeva, A., Yermekova, A., Taubayeva, R., Sarova, N., Sapiyeva, A., Mateeva, S., Matniyazova, G., Bulekbayeva, K., Jetpisbayeva, G., & Tamabekova, M. (2025). Nurlybayeva, Aisha Yermekova, Ainura Taubayeva, Raushan Sarova, Nurbanu Sapiyeva, Ardak Mateeva, Sulushash Matniyazova, Gulsim Bulekbayeva, Kamila Jetpisbayeva, Gulim Tamabekova, Marzhan. *Polymers*, *17*. https://doi.org/10.3390/POLYM17060776

O'Connor, P. (2001). Kinetics and mechanisms of fluid catalytic cracking. *American Chemical Society, Division of Petroleum Chemistry, Preprints*, *46*(4), 318–321. https://doi.org/10.1007/978-0-387-25789-1_6

Robinson, P. R. (2006). *Petroleum Processing Overview BT - Practical Advances in Petroleum Processing* (C. S. Hsu & P. R. Robinson (eds.); pp. 1–78). New York: Springer New York. https://doi.org/10.1007/978-0-387-25789-1_1

Rodríguez, M. A., & Ancheyta, J. (2011). Detailed description of kinetic and reactor modeling for naphtha catalytic reforming. *Fuel*, *90*(12), 3492–3508. https://doi.org/10.1016/J.FUEL.2011.05.022

Sawarkar, A. N., Pandit, A. B., Samant, S. D., & Joshi, J. B. (2007). Petroleum residue upgrading via delayed coking: A review. *Wiley Online Library*, *85*(1), 1–24. https://doi.org/10.1002/CJCE.5450850101

Sengupta, D., Garnier, G., & Samudrala, S. P. (2025). Catalytic transformation of eucalyptus oil and its primary component, 1,8-cineole into value-added products: a state-of-the art review. *Green Chemistry Letters and Reviews, 18(1)*. https://doi.org/10.1080/17518253.2025.2582440

Song, C., & Ma, X. (2004). Ultra-deep Desulfurization of Liquid Hydrocarbon Fuels: Chemistry and Process. *International Journal of Green Energy*, *1*(2), 167–191. https://doi.org/10.1081/GE-120038751

Speight, J. G. (2011). Chapter 6 - Catalytic Cracking. In *B T - The Refinery of the Future* (pp. 181–208). Boston: William Andrew Publishing. https://doi.org/https://doi.org/10.1016/B978-0-8155-2041-2.10006-2

Speight, J. G. (2016). Hydrogen in Refineries. In *Hydrogen Science and Engineering: Materials, Processes, Systems* *and Technology* (Vol. 1, pp. 3–18). https://doi.org/10.1002/9783527674268.ch01

Sung, H. C., Brown, G. G., & White, R. R. (1945). Thermal cracking of petroleum. *Industrial & Engineering Chemistry*, *37*(12), 1153–1161. https://doi.org/10.1021/IE50432A010

Suyunova, F. S. qizi, & Shadiyeva, G. K. (2023). CRUDE OIL COMPONENTS AND ITS TREATMENT PROCESSES. *Journal of Humanities Dan Natural Sciences. 1, 1 (Jun. 2023), 184–187.*

Tan, H., Yan, W., Ren, Z., Wang, Q., & Mohamed, M. A. (2022). A robust dispatch model for integrated electricity and heat networks considering price-based integrated demand response. *Energy*, *239*. https://doi.org/10.1016/j.energy.2021.121875

Tanimu, A., Khan, A. A., Aitani, A. M., Aleisa, R. M., & Abdelaziz, O. Y. (2026). Perspectives on Crude Oil Conversion and Process Decarbonization. *Energy Dan Fuels*, *40*(5), 2289–2302. https://doi.org/10.1021/ACS.ENERGYFUELS.5C05027

Thanh, L. T., Okitsu, K., Boi, L. Van, & Maeda, Y. (2012). Catalytic Technologies for Biodiesel Fuel Production and Utilization of Glycerol: A Review. *Catalysts*, *2*(1), 191–222. https://doi.org/10.3390/CATAL2010191

Voge, H., & Good, G. M. (1949). Thermal cracking of higher paraffins. *Journal of the American Chemical Society*, *71*(2), 593–597. https://doi.org/10.1021/JA01170A059

Yan, C., Jiao, Y.-Y., & Zheng, H. (2019). A three-dimensional heat transfer and thermal cracking model considering the effect of cracks on heat transfer. *International Journal for Numerical and Analytical Methods in Geomechanics*, *43*(10), 1825–1853. https://doi.org/10.1002/NAG.2937

Yen, J. C. (2014). *Hydrocracking vs catalytic cracking*. FSC 432: Petroleum Refining Course Blog. https://fsc432.dutton.psu.edu/2014/07/06/hydrocracking-vs-catalytic-cracking/

Yu, L., Nie, H., Yang, P., Wang, L., Feng, S., Gao, H., & Wang, G. (2025). Recent advances in hydrotreating and hydrocracking catalysts for the preparation of light aromatics: Influencing factors, catalytic mechanisms and performance relationship descriptors. *Coordination Chemistry Reviews*, *529*. https://doi.org/10.1016/J.CCR.2025.216444

Zhang, X., Melchuna, A., Sa, J.-H., & Sum, A. K. (2020). Gas hydrates porosity and effective volume under multiphase flow conditions. *Journal of Natural Gas Science and Engineering*, *79*. https://doi.org/10.1016/J.JNGSE.2020.103340

Zhou, K., Che, X., Wei, C., Tang, Z., Yu, H., Wang, D., Wang, J., & Zhang, L. (2024). The Molecular Modeling, Simulation, and Design of Base Oils and Additives in Lubricating Oils: A Review. *Processes*, *12*(11). https://doi.org/10.3390/PR12112407