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Current-Potential Characteristics of Electrolysis Cell Used for Crude Oil Refining: Design Consideration

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Abstract

In this work, the current-potential characteristics of the electrolysis cell and their effects on the refining level of crude oil were presented and discussed. At low voltages, very little refining occurs. As the potential increases, refining activity ramps up significantly in the active region. Beyond a certain point (around 3 V), the curve levels off, indicating limited gains in refining due to side reactions or inefficiencies. Low current (0–2 A): Minimal refining occurs; insufficient ion/electron flow. Threshold region (2–5 A): Refining starts becoming noticeable. Active region (5–8 A): Significant refining takes place. Plateau (>8 A): Efficiency gains level off; excess current may cause unwanted side effects like heating or secondary reactions.

Keywords: Electrolysis cell; Crude oil refining; Current-potential characteristics; Refining level

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1. Introduction

Crude oil refining is a critical process in the petroleum industry, transforming raw crude oil into valuable products such as gasoline, diesel, jet fuel, and petrochemical feedstocks [1]. Traditional refining methods, such as fractional distillation, hydroprocessing, and catalytic cracking, have been widely used for decades [2,3]. However, emerging technologies like electrolysis-based refining are gaining attention due to their potential for improved efficiency, reduced environmental impact, and enhanced product quality [4].

Electrolysis is an electrochemical process that uses direct electric current (DC) to drive non-spontaneous chemical reactions [5]. In crude oil refining, electrolysis can be employed to break down complex hydrocarbons, remove impurities, and even produce hydrogen for further refining processes [6].

As basic principles of electrolysis, the electrolyte selection is the first. A suitable electrolyte (often an ionic liquid or molten salt) is chosen to facilitate the movement of ions between electrodes [7]. An anode (positive electrode) and cathode (negative electrode) are immersed in the electrolyte. The crude oil or its fractions are introduced into the cell [8]. At the anode, oxidation occurs, breaking down heavy hydrocarbons into lighter fractions. At the cathode, reduction reactions help in desulfurization and de-nitrogenation [9]. Water or hydrocarbons can be electrolyzed to produce hydrogen, which is useful in hydroprocessing [10].

This paper explores the fundamentals of chemical refining using electrolysis cells, its advantages over conventional methods, and its potential applications in the petroleum industry. Heavy hydrocarbon chains are broken into lighter, more valuable fractions [11]

$C_{20}H_{42} \rightarrow C_{10}H_{22} + C_{10}H_{20}$

Throughout desulfurization, the sulfur-containing compounds are converted into hydrogen sulfide, which can be removed, according to the following reaction

$R{-}SH + 2H^+ + 2e^- \rightarrow RH + H_2S$

In de-nitrogenation process, nitrogen compounds are converted into ammonia, which can be separated, as

$R{-}NH_2 + 2H^+ + 2e^- \rightarrow RH + NH_3$

The types of electrolysis cells used in refining include proton exchange membrane (PEM) electrolysis cells. They are efficient for hydrogen production and light hydrocarbon processing [12]. In molten salt electrolysis, effective breakdown of heavy crude fractions can be achieved. The alkaline electrolysis cells are used for sulfur and nitrogen removal.

Electrolytic refining offers several benefits compared to traditional thermal and catalytic processes. Electrolysis can be powered by renewable electricity (solar, wind), reducing reliance on fossil

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fuels. Lower operating temperatures compared to thermal cracking (which requires 450–750°C). Lower CO_2 emissions since no combustion is involved [13]. Efficient removal of sulfur and nitrogen compounds, reducing SO_x and NO_x emissions. Minimal waste generation compared to chemical solvent-based refining. Selective cracking of hydrocarbons leads to higher yields of valuable light fractions. Better control over reaction conditions improves product consistency [14,15]. Electrolysis produces hydrogen in situ, which can be used for hydrotreating and hydrocracking without external hydrogen supply. Electrolysis cells can be deployed in small, modular units, making them suitable for remote or offshore refining [16].

The use of electrolysis in crude oil refining is still in development, but several promising applications are emerging. Electrolysis can break down heavy hydrocarbons (e.g., bitumen from oil sands) into lighter, transportable oils. Reduces the need for energy-intensive coking or gasification. Electrolytic desulfurization can achieve near-zero sulfur levels in diesel and gasoline, meeting stringent environmental regulations [17]. Produces light olefins (ethylene, propylene) directly from crude oil fractions, bypassing steam cracking. Refineries can use excess renewable electricity (e.g., from wind or solar) to power electrolysis, making the process more sustainable. Compact electrolysis systems can be used on offshore platforms or in remote locations where traditional refining is impractical [18].

While electrolytic refining shows great promise, several challenges remain. Electrolysis cells require expensive materials (e.g., platinum, iridium catalysts). Electrodes degrade over time due to fouling and corrosion. Large-scale implementation needs further research. Future advancements in catalyst materials, membrane technology, and renewable energy integration could make electrolysis a mainstream refining technology [19,20].

This paper explores the fundamentals of chemical refining using electrolysis cells, its advantages over conventional methods, and its potential applications in the petroleum industry.

2. Experimental Work

The electrolysis system used for refining crude oil is an advanced electrochemical setup designed to break down hydrocarbons, remove impurities (such as sulfur and nitrogen), and produce hydrogen for further processing. Unlike conventional refining methods (like distillation or catalytic cracking), electrolysis operates at lower temperatures and can be powered by renewable electricity, making it a cleaner alternative. Figure (1) shows schematically the electrolysis system used for refining crude oil.

An electrolysis-based crude oil refining system consists of electrolysis cell (core unit), pre-treatment unit (for crude oil conditioning), power supply and control system, gas separation and purification unit, and product recovery section.

The heart of the system is the electrolysis cell, where electrochemical reactions take place. Different types of cells can be used such as proton exchange membrane (PEM) electrolysis cell. The design of this cell contains an anode coated with iridium oxide (IrO_2) or platinum (Pt) for oxidation reactions. It also contains a cathode made from platinum or nickel-based catalysts for reduction. It contains a membrane from Nafion® or similar PEM to allow proton (H^+) transport while blocking hydrocarbons.

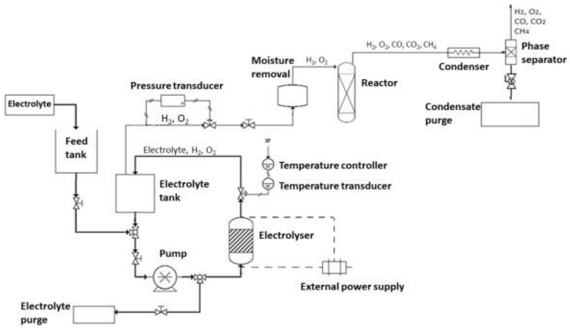

Fig. (1) The schematic diagram of the electrolysis system used for crude oil refining

In this cell, the crude oil fractions are fed near the anode. Heavy hydrocarbons are cracked into lighter fractions via oxidation. Sulfur/nitrogen compounds are converted into H_2S/NH_3. Hydrogen is produced at the cathode.

Another type of electrolysis cell is the molten salt electrolysis cell containing the electrolyte, which is typically molten alkali salts (e.g., NaCl-KCl at 500-800°C) and the electrodes made from graphite (anode) and steel/nickel (cathode). In this cell, high-temperature operation helps break heavy crude molecules. Effective for bitumen and residual oil upgrading.

Another type of the electrolysis cell is the alkaline electrolysis cell, in which, the electrolyte is KOH or NaOH solution, and the electrodes are nickel mesh with catalysts. This cell is used mainly for desulfurization and hydrogen production.

Before entering the electrolysis cell, crude oil undergoes filtration to remove solids, dehydration (water removal to avoid side reactions), and finally light fraction separation to prevent volatile losses.

A DC power source provides controlled voltage (1–5 V) and current. An automated control is employed to adjust voltage/current based on feedstock composition. Renewable integration can be powered by solar/wind energy for green refining.

After electrolysis, gases (H_2, H_2S, NH_3) are separated from liquid hydrocarbons as

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scrubbers: Remove H_2S and NH_3 using amine solutions, PSA (pressure swing adsorption) that purifies hydrogen for reuse in hydroprocessing, and finally condensers to recover light hydrocarbon fractions (C1–C5).

In the product recovery section, fractional distillation separates electrolyzed oil into gasoline, diesel, etc. The hydrotreater further purifies products using electrolytically produced H_2.

3. Results and Discussion

Figures (2) and (3) indicate the current-potential characteristics of the electrolysis system used for refining crude oil in terms of variation of refining level with both parameters (potential applied and current passing through the electrolysis system).

In Fig. (2), in the initial region (0–0.5 V), very low activity, almost no refining as the energy is not enough to drive electrochemical reactions. At threshold region (~0.5–1.5 V), the electrochemical activity starts and the refining level begins to increase slowly. The active region (~1.5–3.0 V) is an optimal range where significant separation and removal of impurities occur. The refining level increases steeply. Within the plateau/saturation Region (>3.0 V), the refining level plateaus as side reactions (e.g., water electrolysis, gas evolution, degradation of organics) may start dominating.

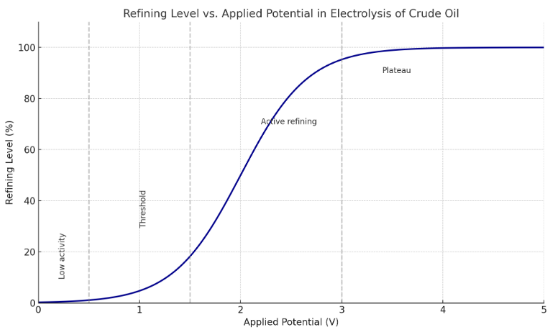

Fig. (2) Variation of refining level with the applied potential in electrolysis cell

Further increases in voltage don’t improve refining much and may decrease efficiency. Accordingly, at low voltages, very little refining occurs. As the potential increases, refining activity ramps up significantly in the active region. Beyond a certain point (around 3 V), the curve levels off, indicating limited gains in refining due to side reactions or inefficiencies.

In Fig. (3), in the low current region (0–2 A), minimal refining occurs due to insufficient ion/electron flow. In the threshold region (2–5 A), the refining starts becoming noticeable. In the active region (5–8 A), significant refining takes place. At plateau (>8 A), efficiency gains level off; excess current may cause unwanted side effects like heating or secondary reactions.

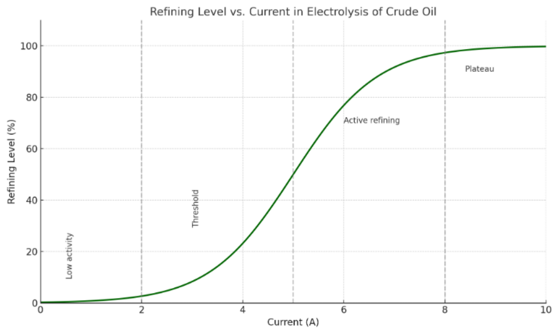

Fig. (3) Variation of refining level with the current passing through electrolysis cell

4. Conclusion

Chemical refining of crude oil using electrolysis cells represents a transformative approach to petroleum processing. By leveraging electrochemical reactions, this method offers significant advantages in energy efficiency, environmental sustainability, and product quality. While challenges remain, ongoing research and technological advancements could position electrolysis as a key player in the future of oil refining, particularly in applications involving heavy oil upgrading, ultra-clean fuels, and renewable energy integration.

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