# INNOVATIVE WAYS THAT CRUDE OIL TECHNOLOGY HAS BEEN KEEPING UP WITH GROWING DEMAND FOR CLEANER ENERGY

**The chemical processes of crude oil refining and biofuel synthesis have been the subject of extensive scientific research for decades. Economic growth and rising energy demand signal greater fuel consumption. As a result, the growing demand drives innovation in all sectors of energy. Crude oil refining and biofuel synthesis require more efficient chemical processes to limit environmental impact as well as match economic demand. An essential aspect of all fuel refinement and synthesis techniques is the catalytic conversion of chemical reactions. The majority of optimization potential lies here: choosing the right catalyst can reduce costs, improve process sustainability, and increase overall efficiency. These are some of the problems recent discoveries have aimed to solve. Recent discoveries show promise of a reduction in the environmental impact of crude oil processing through a novel nano catalyst, free of precious metals, while reducing coking and catalyst fragmentation. Additionally, a new Fe-promoted molybdenum carbides and nitrides catalyst outperforms traditional commercial catalysts in synthesizing cleaner fuel. We have also improved catalyst efficiency through a mixture derived from a growing air injection technique that minimizes undesired characteristics while increasing concentrations of aliphatic compounds. In Hydrocracking, a common catalyst technique in fuel refinement, efficiency was improved through an EDTA template-assisted $SiO_2$-$Al_2O_3$/NiMo catalyst. Innovation does not stop here; discoveries like this pave the way for further advances as novel strategies continue to emerge. This paper aims to review multiple novel innovations in crude oil refinement and biofuel synthesis techniques and their potential impacts.**

### Introduction

The world oil consumption rate is predicted to surpass 103.9 million barrels per day by 2025, driven by the ongoing industrialization process, population growth, and development of transportation networks [1]. Despite the surge in the development of renewable energy sources, petroleum oil continues to be a major player in the energy sector. Oil refineries that utilize petroleum oil face a dual challenge of ensuring maximum output while ensuring environmental sustainability. This has led to the development of catalytic innovation, which is the heart of oil refinery efficiency. The catalyst used has a major bearing on the efficiency of the oil refinery process, environmental sustainability, and economic viability of fuel production. In the face of increasing oil refinery challenges, catalyst innovation has become one of the most significant innovations in oil refinery development. This paper seeks to explore catalyst innovations in Air Injection, Hydrocracking, Heteroatom removal, and biomass upgrade.

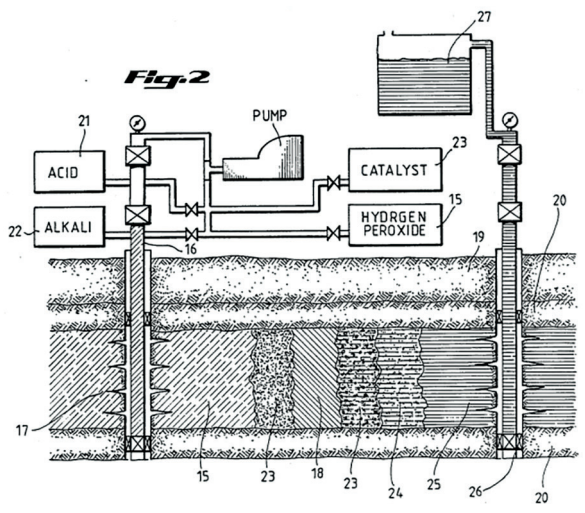


*Figure 1: A figure from US Patent 4,867,238, dated 1989, which shows the process of using hydrogen peroxide to recover viscous oil from geological reservoirs [2].*

### Hydrogen Peroxide Air Injection in Fuel Catalyst

Air Injection is a promising Enhanced Oil Recovery (EOR) technique that involves injecting air into large oil reservoirs to reduce oil viscosity and initiate oxidation reactions to process the crude oil [3]. Applications and studies using Air Injection show significant improvements in crude oil processing when compared to the process without it. Despite its promise, the complete adoption is limited by the cost of the gas supply [4]. However, recent work by O. Nouari et al. [5] has offered a potential solution. Theoretically, Hydrogen peroxide, like generic water-based steam injection, produces an acceptable, high-quality steam with desirable steam concentrations of 25-30%. Its application dates to 1989, when a proposed application was patented, as seen in Figure 1, where the decomposition of hydrogen peroxide releases heat to drive the reaction while producing non-toxic byproducts, water, and oxygen. The produced oxygen is not only an environmentally sustainable byproduct but also an additional heat source, reacting with existing hydrocarbons to release more heat [5]. The added heat reduces production costs, improving economic efficiency. Nouari aimed to investigate whether hydrogen peroxide is a viable source for Air Injection. This was done through a relatively accurate second-order model designed to simulate the optimal conditions for hydrogen peroxide Air Injection. The simulated model yielded results of 96.32% liquid oil, 3.018% residue, and 0.662% gas products under optimal conditions. The optimal conditions, determined by the simulation model, were 14.78% wt.% hydrogen peroxide, air injection for 21 minutes, and heating the crude oil at 354.05 °C for 40 min [5]. These results are corroborated by an experimental setup for the oxidative cracking of Algerian crude oil, which yielded a similar 96.07% liquid oil. The percentage of residue and gas products was not provided.

The simulated model accuracy was characterized by the R-squared value, which indicates how well the independent variable explains the variation of the dependent variable. The R-squared value was computed by comparing simulated values with experimental values. The values range from 0 to 1, with 1 representing a perfect model of the dependent variable [6]. The r-squared values shown in Figure 2 indicate that the models are not perfect but do a good job of predicting the true values. These high percentages of produced liquid oil indicate a promising future for Hydrogen peroxide air injection in oxidative cracking processing [5]. However, the advantages offered by hydrogen

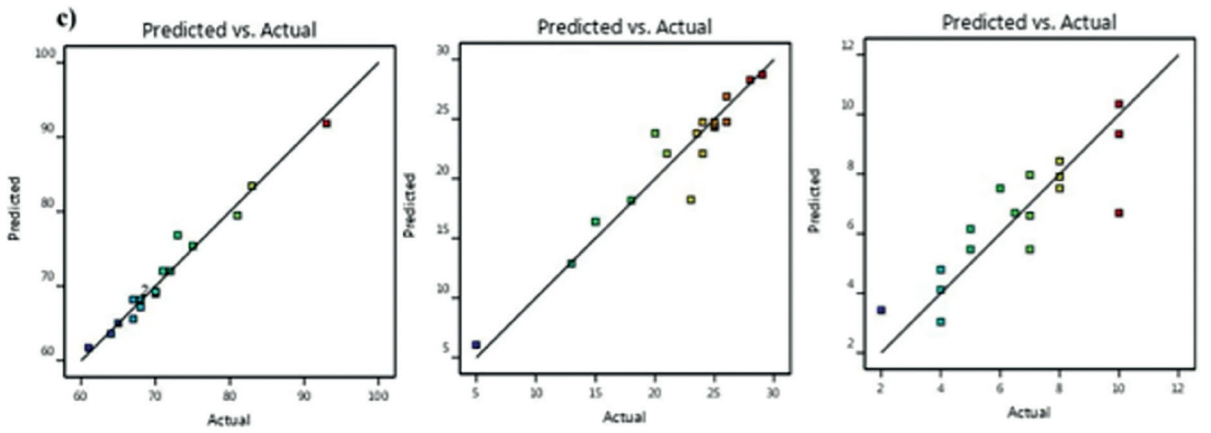


*Figure 2: The predicted values are plotted against the actual values. The r-squared values $R^2$= 0.9727 for liquid oil, $R^2$= 0.9176 for residue, and $R^2$= 0.7399 for gas phases [4].*

peroxide might be outweighed by its costs. Water, the more prevalent option in air injection, closely matches yield, at 91% at optimal conditions. Water offers its advantages in abundance and lower vaporization energy costs. Hydrogen peroxide's viability falters at large scales due to its inconveniences; instead of a direct replacement, the supplementation of hydrogen peroxide provides a potential solution to make air injections more viable.

**Improving Hydrocracking**

Hydrocracking is the combination of the two processes involving the "cracking" or breaking heavy hydrocarbons into higher value lighter hydrocarbons (hydrocarbons with fewer carbons) and the addition of hydrogen to saturate aromatics (double bonds) [7]. Hydrocracking is a catalytic process essential for crude oil refinement. Improvements are made continually to keep up with growing energy demands. Recently, discoveries by Z. Fanani et al. [7] aim to improve the yields of bio-aviation fuel and bio-gasoline from crude palm oil. This was done through studying $SiO_2$-$Al_2O_3$ and NiMo catalysts. More specifically, this process, supported by EDTA, was studied under different aluminum (Al) mass compositions in $SiO_2$-$Al_2O_3$. In this process, NiMo acts as the active metal, while the Silica and Aluminum catalyst ($SiO_2$-$Al_2O_3$) serves as a mesoporous support that aids NiMo by providing various benefits. The EDTA is present to improve the physicochemical properties of NiMo and $SiO_2$-$Al_2O_3$ [8].

In Table 1, the sixrows represent different aluminum masses and their effect on the conversion rate, with and without NiMo loaded. The effect of both the mesoporous catalyst and the addition of a higher mass of Al. Higher Al masses have a significant impact on the conversion percent. Al at 25 grams greatly increases total acidity and acid site density of the catalyst, ultimately improving the hydrocracking performance of the catalyst. There was little to no effect when NiMo was involved as well. This behavior aligns with further catalyst characterization done by the researchers. Less Al results in large NiMo crystallines which lead to poor NiMo dispersion. This further supports the significance of Al's role in $SiO_2$-$Al_2O_3$ and NiMo catalysts. Looking at the conversion rates for bio-gasoline, bio-aviation fuel, and biodiesel, it can be observed that the increase in Al and the addition of NiMo had their own effects on the yield. For one, the higher Al mass increased the yields of bio-gasoline and bio-aviation fuel. The addition of NiMo was reported to yield even higher bio-aviation fuel yields. This was attributed to NiMo-loaded catalysts being more effective at cracking carbon chains, suppressing long chains like biodiesel, and favoring shorter chains like bio-aviation fuel. The culmination of this study was that under higher Al masses, the catalytic reaction showed significant efficiency improvements when compared to their parent catalysts that have low aluminum content [8]. This development provides a precedent for more effective catalysts and possible targeted selectivity for the conversion of crude oils.

*Table 1: Conversion Percentages of Bio-diesel, Bio-gasoline, and Bio-aviation fuels for different Aluminum masses[8].*

| Catalysts | Conversion (%) | Bio-gasoline (C5–C9) (%) | Bio-aviation (C10–C14) (%) | Biodiesel (C15–C22) (%) |
|---|---|---|---|---|
| $SiO_2$-$Al_2O_3$–5 | 75.78 | 2.28 | 34.26 | 17.22 |
| $SiO_2$-$Al_2O_3$–10 | 84.47 | 2.85 | 44.55 | 8.58 |
| $SiO_2$-$Al_2O_3$–25 | 91.2 | 11.15 | 46.31 | 11.76 |
| $SiO_2$-$Al_2O_3$–5/NiMo | 92.99 | 18.13 | 62.92 | 1.7 |
| $SiO_2$-$Al_2O_3$–10/NiMo | 91.34 | 13.26 | 61.31 | 2.34 |
| $SiO_2$-$Al_2O_3$–25/NiMo | 91.73 | 18.47 | 58 | 2 |

**New Iron molybdenum carbides and nitrides catalyst**

Crude oil processing, without question, produces pollutants. Common pollutants include sulfur and nitrogen oxides, which are heavily regulated by the government, limiting their presence to 15 ppm or lower [9]. Typically, these hydrotreatments, like hydrodesulfurization (HDS), are done to reduce emissions, catalyzed by molybdenum disulfide. Heteroatoms, organic compounds that contain sulfur and nitrogen, contaminate the final crude oil, causing corrosion in refining equipment, environmental issues, and reducing fuel stability [10]. Therefore, (HDS) and hydrodenitrogenation (HDN) are essential parts of crude oil refining because they remove these critical contaminants. Y. Villasana et al. [9] aimed to study an up-and-coming catalyst and compare it with the common, commercially used Cobalt Molybdenum (CoMo), which is already used to address the issue of heteroatoms. To accomplish this, they characterized the asphaltenes after HDS to assess the catalyst's effectiveness. Asphaltenes are large, complex organic compounds that contain significant amounts of sulfur and must be removed [11].

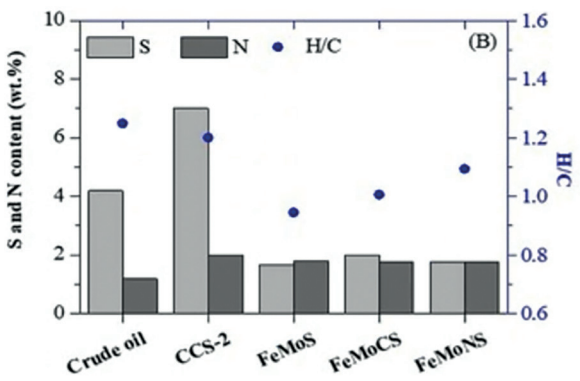


*Figure 3: The Sulfur and Nitrogen Content in wt% after HDS in asphaltenes in crude oil, cobalt molybdenum, FeMoS, FeMoCS, and FeMoNS [9].*

Figure 3 shows the S and N content in asphaltenes after HDS. It is very clear that the new FeMo catalysts greatly outperformed conventional CoMo catalysts in sulfur removal. Additionally, aromaticity increases in reactions catalyzed by FeMoNs. Researchers justified this with NMR characterization, which showed a slight increase in aromatic carbon content. However, it is difficult to attribute any significance to this discovery, as conventional catalysts such as CoMo or CCS-2's ability to change aromatization is not available. Possible future experimentation to compare these catalysts in this aspect could develop FeMoNs as a stronger, more specialized catalyst. Aromatic conversion, even at such a minor amount, in the case of about 5%, could provide valuable improvements to the catalyst's efficiency. Changing a less stable saturated naphthene ring into a stable, planar aromatic ring structure through dehydrogenation at this step could reduce the resources required to produce a high-quality product. This theoretical catalyst is a promising alternative to conventional cobalt-molybdenum catalysts [9].

**Sustainable Nano-catalysts**

As the human population grows, human activity increases. That means greater consumption of disposable products, such as plastics, tires, and old clothes. Municipal waste has grown ever faster since the 1950s, introducing more and non-decomposable petroleum-based plastics into our environment. Plastic waste makes up 10% of global trash by weight, and this percentage will continue to grow as it outlasts other types of municipal waste [12]. Researchers W. Nabgan et al. [12] proposed a solution as well as a framework for a circular plastic economy. Their method uses a highly effective nano catalyst that contains no precious metals. The formulation 3Ti3Cu offers nearly complete conversion (97.90% at 800 °C) of phenol to hydrogen fuels. Phenol is a foundational monomer for polycarbonates and epoxy resins. This research study offers itself as a foundational reference for plastic recycling to build upon. Taking a closer look at the results, the researchers mainly compared three catalysts in their experimental design. Ti, 4Ti3Cu, and 3Ti3Cu, with 3Ti3Cu showing the best characteristics. The main advantage of 3Ti3Cu is its superior basicity and the highest catalytic activity, as seen in Figure 4 [12].

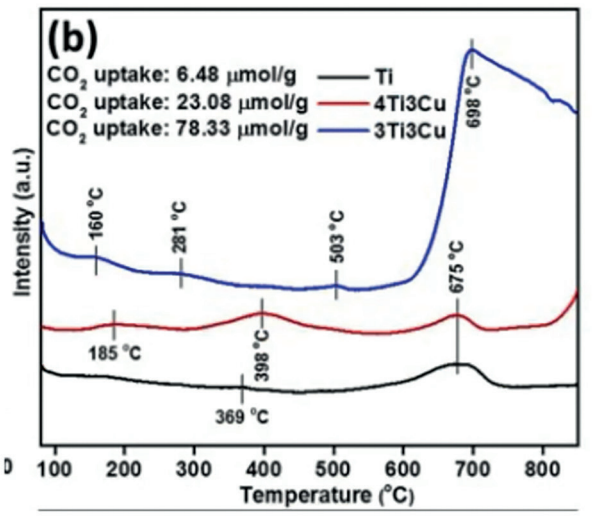


*Figure 4: The curves show the surface-adsorbed CO2 as an indication of the catalyst's basicity [12].*

Basic sites are considered activation sites for phenol conversion reactions. 3Ti3Cu demonstrates the highest basicity intensity, at 78.33 µmol/g. This indication of 3Ti3Cu as the most optimal catalyst is further corroborated by the percent yield of hydrogen fuel at 500 °C and 800 °C. 3Ti3Cu showed a 67.8% and 97.90% yield at those respective temperatures [12]. In addition, the increased number of activation sites on 3Ti3Cu, as well as the particular silt-shaped pores on the catalyst, directly reduces the formation of coke on the catalyst. When coke does form, carbon is primarily carbon nanofibers that do not inhibit reactions. The catalyst's spherical thermostable structure, as well as the strong Cu-Ti make this catalyst extremely stable. The strength of the Cu-Ti bond prevents fragmentation from the formation of carbon nanofibers. The concept of a non-precious metal nano-catalyst in phenol conversion aligns with recent research by A. K. Manal et al that has shown that plastic waste could be converted into liquid phenol [13]. Many of the steps are in place, with the solutions offered economically viable, and the necessary infrastructure could be developed; these processes could be implemented in the coming years.

**Conclusion**

The advancements discussed in this paper all share a common link in that they demonstrate how the design of a catalyst can impact improvements in process efficiency, environmental impact, and real-world economic constraints. While these advances individually show improvements in well-established processes, taken as a whole, these advances show a refining and biofuel production process in which catalyst design plays a key role in process improvements rather than process conditions. As refining capacity continues to grow and environmental regulations tighten, such improvements in processes via catalyst design will likely become more important [14].

The biggest hurdle that remains in these advances is the industrial application of laboratory innovations. While challenges such as scalability and capital costs still need to be overcome in these processes, the combination of nano-catalyst design, biomass upgrading, and well-established hydro processes creates a viable and increasingly practical solution for an energy future that can meet growing energy demands without compromising environmental concerns.

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