Utilizing of Nanometal Oxides for Treatment of Refinery Product Water: A Review

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Abstract: The complicated effluent stream known as refinery wastewater is produced by the refining of petroleum and contains a range of pollutants. This complex composition contains oil, organic molecules and heavy metals, where poses significant obstacles to conventional treatment procedures including biological processes, filtration and sedimentation. Therefore, modern and effective solutions are being provided by the methods of advanced treatment such as the application of Nano-oxides, advanced oxidation processes (AOPs), and membrane filtration. Synthetic nanoparticles known as Nano-oxides, which include nickel oxide, magnesium oxide, copper oxide, and zinc oxide, hold promising ability to treating of wastewater which generated from operations of refining. One of the studies synthesized and incorporated Nano-oxides into refinery wastewater (RPW) to improve the turbidity of water, electrical conductivity, and pH. Manganese oxide nanoparticles were particularly useful in reducing turbidity because they have special chemical properties. In general, Nano-oxides show ability on improving the refinery wastewater treatment efficiency, legal compliance in the petroleum refining sector, and supporting environmental sustainability.

Keywords: Nano-oxide, Oxidation processes (AOPs), Refinery product water (RPW), Membrane filtration, Biological treatment.

1. Introduction

Refinery wastewater (RPW) is one of the various processes by-products that take place in petroleum refineries [1]. This wastewater stream poses particular issuers in terms of practical mitigation techniques and environmental impact because its diverse composition, which includes many pollutants. It build environmentally compatible solutions and technologically advanced that adhere to industry best practices and standards of environmental [2]. Refineries that process crude oil into marketable products are necessary to the economy of global energy. The vast amounts of wastewater generated by complex refining operations are referred to as refinery wastewater (RPW) [3]. This wastewater stream is the end product of many of refining processes, including cooling, desalting, and many of chemical reactions [4]. The wastewater pollutants are miscellaneous, encompassing several pollutants categories that deserve careful study, among them the following:

1. Oil and Grease:

Refining wastewater contains natural hydrocarbons, including greases and oils from the process of refining. These hydrophobic substances have the ability to harm the ecosystem as well as adversely affect quality of water [5].

2. Suspended Solids:

The suspended solids presence causes more challenge of the RPW treatment. Therefore, these materials which may include corrosion products, catalyst particles, and other particulates must effectively remove by using advanced separation techniques [6].

3. Heavy Metals:

Heavy metals such as lead, cadmium, and chromium find their way into refinery wastewater as a result of refining processes. There can be negative environmental impacts for these metals which are often extracted from catalysts and additives used in the refining process if not handled properly [7].

4. Dissolved Organic Matter (DOM):

Hydrocarbons degrade during refining processes, dissolving organic matter into the wastewater generated by refining. This complex mixture of chemical components makes conventional treatment technologies extremely challenging to implement, necessitating a unique strategy to achieve complete removal [8].

The untreated RPW wastewater flow into receiving water bodies is one of the greatest environmental concerns. The pollutants from these waters have the ability to contaminate water and soil, which disrupts ecosystems of aquatic and endangers health of human throughout the food chain [9]. Stringent regulatory frameworks are set standards for the treatment and disposal of RPW wastewater in order to mitigate these potential environmental concerns [10].

The issues of treatment which imposed by refined product wastewater (RPW) requires the advanced treatment solutions. The high water quality requirements which imposed by regulators may not be met by technologies of conventional treatment, despite their possible effectiveness [11]. Practitioners and researchers are investigating novel and sustainable treatment options in order to ensure resource recovery from RPW and environmental compliance [12].

Despite the advancements in the RPW, the comprehensive treatment techniques development and the synergistic interactions knowledge between different pollutants remain neglected researches priorities treatment techniques. Therefore, the aim of this research is to fill this gap by checking the effectiveness of advanced treatment technologies, and a focus on the using of nano-oxides to treat different pollutants found in RPW.

Treated wastewater (TWW) is a complex and multi-species stream filled with numerous pollutants, where considered a by-product of petroleum refining. It is necessary to understand the composition of TWW, its environmental implications, and the regulatory framework that guides its management in order to develop practical and long-term solutions. The subsequent sections of this study discuss the challenges of treating treated wastewater and verification the using nano-oxides possibility as a useful treatment method for several pollutants present. The aim of this research is to regulatory compliance, improve environmental sustainability, and the body of knowledge related to TWW treatment.

2. Treatment Challenges in Refinery Product Water (RPW):

Treatment of pollutants present in refinery wastewater presents a number of challenges because they are considered complex pollutants. Large quantities of several pollutants, including oils, greases, dissolved organic compounds, heavy metals, and suspended particles are commonly finding in refinery wastewater [13]. Physical, biological, and chemical treatments are among the traditional methods used to completely remove these pollutants [14].

One of the major obstacles of refinery wastewater treatment is emulsified oils and greases presence, which can be difficult to separate using conventional methods [15].

Also suspended sediments can reduce treatment efficiency and cause contamination of its equipment [16]. In addition, the heavy metals presence poses environmental risks which require specific treatment methods application to eliminate them [17].

The heterogeneous nature of the pollutants presents in refinery wastewater (RPW) requires using a multimodal strategy for treatment. Where by used advanced technologies such as electrocoagulation, membrane filtration, and advanced oxidation processes (AOPs), the particular challenges posed by RPW successfully addressed [18]. And by using membrane technologies including reverse osmosis and ultrafiltration the organics and suspended solids can be efficiently removed [19].

In addition, technologies of advanced oxidation such as ozone and hydrogen peroxide help improve the overall efficacy of RPW treatment and degrade organic contaminants [20]. Electrocoagulation is considered another promising method for RPW treatment, which uses electric current to destabilize and agglomerate impurities [21].

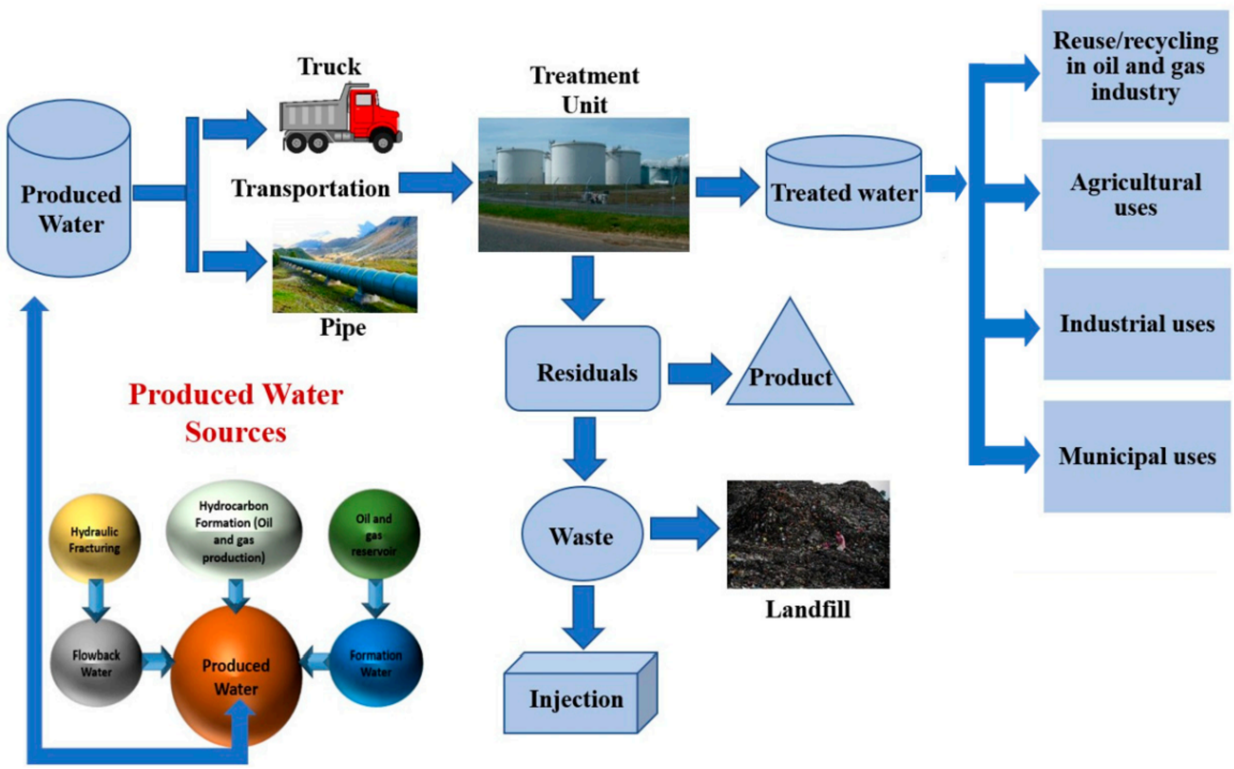

Figure 1. Typical produced water management strategies.[22]

3. Conventional Treatment Methods for Refinery Product Water (RPW)

Effective treatment of refinery wastewater is severely hampered by its complex nature, which is characterized by high concentrations of many contaminants. Although traditional approaches offer a foundation for care, their numerous drawbacks frequently need the use of cutting-edge technologies. In this context, we examine three widely used conventional treatment approaches, emphasizing their shortcomings in the management of RPW:

1. Sedimentation:

Sedimentation relies on gravity to separate suspended solids from water. However, its effectiveness in RPW treatment is hampered by the presence of colloidal and finely dispersed particles (less than 1 μm) [23]. These tiny particles remain suspended due to Brownian motion, hindering their settling and leading to inadequate removal of suspended solids. Additionally, the complex composition of RPW, often containing emulsified oil droplets and other stabilized particles, further reduces the efficiency of sedimentation [24].

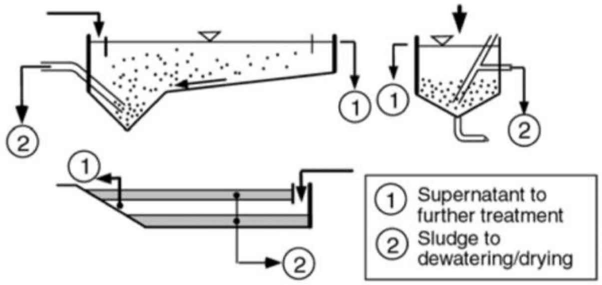

Figure 2. Schematic diagram of sedimentation treatment [25].

2. Filtration:

Filtration methods, such as sand filtration and microfiltration, are effective for removing larger particles exceeding 10 µm. However, they encounter limitations in capturing finer particulate matter and dissolved constituents prevalent in RPW [26]. The presence of colloidal particles with diameters ranging from 1-100 nm necessitates specialized filtration techniques beyond the scope of conventional methods. Additionally, dissolved organic matter (DOM), a significant contaminant in RPW, readily passes through conventional filters, requiring alternative approaches for its removal [27].

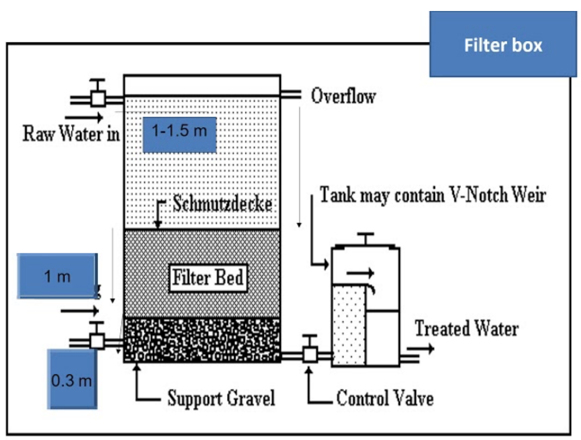

Figure 3. Water Purification by Slow Sand filtration

3. Biological Treatment:

Biological treatment processes, typically employing activated sludge systems, utilize microorganisms to degrade organic contaminants. While they effective for readily biodegradable organic matter, these systems struggle with the high load and recalcitrant nature of organic compounds present in RPW [28]. The intricate blend of hydrocarbons and additional organic pollutants may impede microorganisms' biological activity, hence impeding the overall efficacy of treatment. Furthermore, the efficacy of biological treatment may be further hampered by the negative impact that heavy metals and other hazardous compounds may have on microbial communities when present in RPW [29].

(a) (b) (c)

Figure 4. Biological Treatment (a) Membrane bioreactor, (b) Examples of media available for biological wastewater treatment, (c) Types of bacteria typically involved in biological wastewater treatment: (L-R) daphnia; stalked ciliates; filamentous; tardigrades [30].

4. Advanced Treatment Technologies for Refinery Product Water (RPW)

The complex composition of refinery wastewater (RPW) leads to disability of the traditional treatment techniques efficacy. These conventional procedures are often invalid to handle the large quantities and diverse of pollutants, such as oils, greases, persistent organic compounds, and heavy metals. So, research has focused on investigating solutions of advanced treatment with better environmental compliance and increased efficiency. This section discusses three techniques of potential advanced treatment for refinery wastewater treatment such as membrane filtration, advanced oxidation processes (AOPs), and Nano-oxides.

1. Advanced Oxidation Processes (AOPs):

Highly reactive species such as hydroxyl radicals ($OH^{\bullet}$) generated through the use of advanced oxidation processes (AOPs) can be using in order to effectively degraded of refinery wastewater (RPW) containing complex organic pollutants [31], and contaminants that are resistant to conventional chemical or biological treatment. Two advanced oxidation processes used in refinery wastewater treatment include: [32]

- **Ozonation:** Ozone (O_3) decomposes to form hydroxyl radicals or reacts directly with organic pollutants, which leads to oxidize and mineralize the pollutants [34]. This method works particularly well when analyzing refractory organic chemicals and aromatic hydrocarbons, which are frequently found in refinery wastewater (RPW) [35].

• **Photo catalysis:** Ultraviolet (UV) light in ion photocatalytic processes is used to excite semiconductor catalysts such as titanium dioxide (TiO_2). Through this activation, electron-hole pairs are produced which initiates a chain of events that ultimately leads to the production of hydroxyl radicals which leads to breaking organic pollutants present in refinery wastewater (RPW) [32]. Ion photocatalytic procedures may be able to address the challenges of conventional treatment techniques which arise from Heat-resistant organic compounds. Moreover, these activities help in mineralizing the pollutants, converting them into less toxic and simpler by-products such as carbon dioxide and water [36].

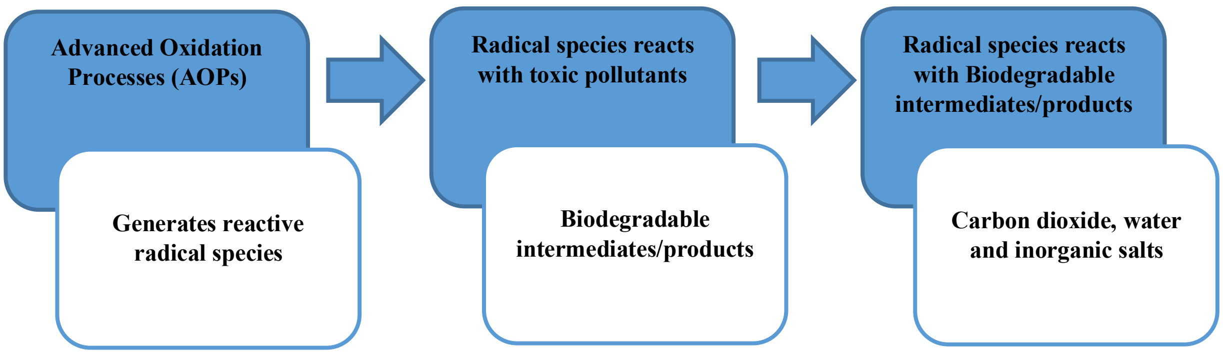

Figure 5. Schematic diagram explaining the processes involved in AOPs.[33]

2. Membrane Filtration:

Techniques of Membrane filtration technologies such as Nano filtration and ultrafiltration (UF) by increasing the efficiency of particle removal and separation (NF) provide practical treatment for refinery wastewater (RPW) [37]. Where pressure-operated semi-permeable membranes are used that selectively allow water molecules to pass through trapping larger contaminants. By this method, the difficulties caused by the presence of emulsified oil droplets particles, colloidal, and other suspended solids in RPW are successfully handled [38].

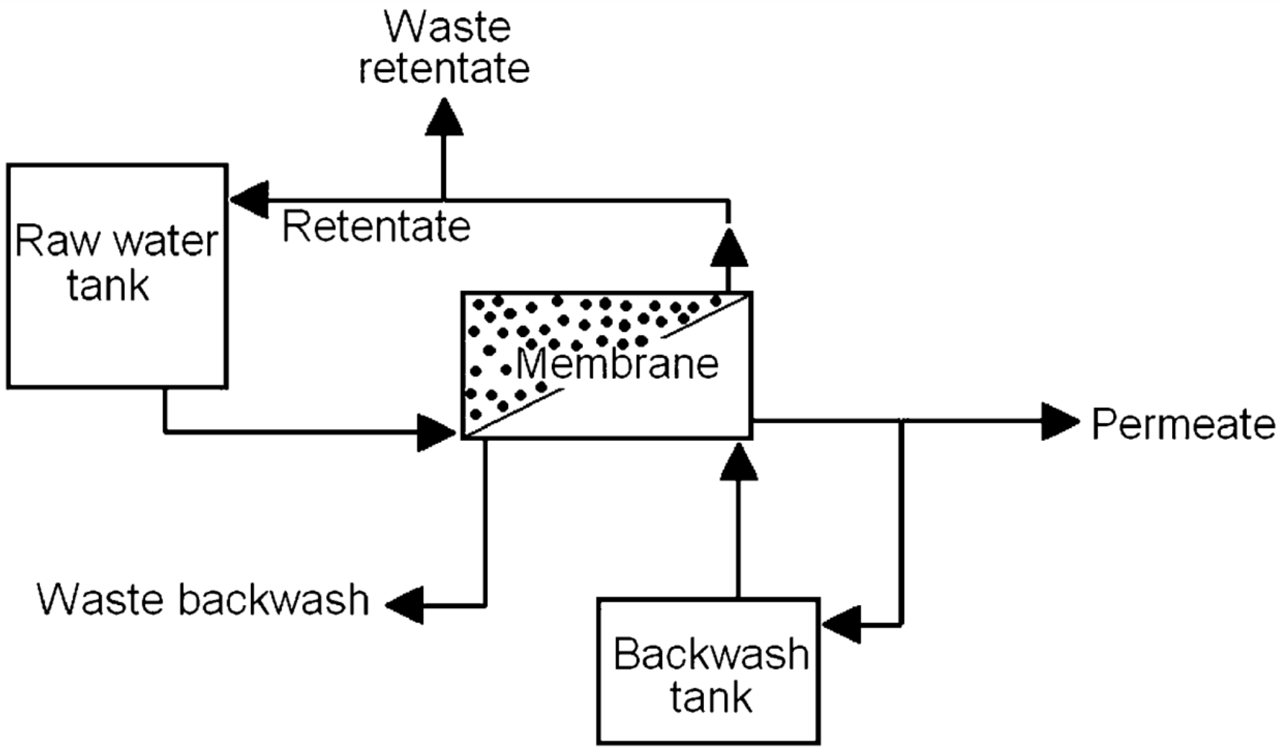

Figure 6. Schematic of the separation process during membrane filtration using a semi-permeable membrane [39].

• **Ultrafiltration (UF):** The emulsified oil droplets, bacteria, and larger particles found in refinery wastewater (RPW) can be removed using ultrafiltration (UF) membranes, which typically have pores ranging in size from 1 to 10 nm [37]. This procedure helps improve overall water quality and reduces stress in later stages of treatment.

• **Nano filtration (NF):** Nano filtration (NF) membranes have smaller and tighter pore diameters (0.1–1 nm) compared to UF membranes, which enabling them to remove dissolved salts and dissolved organic matter (DOM) as well as other inorganic compounds, a common contaminant in refinery wastewater (RPW) [40]. Nano filtration technique is the effective technique in producing wastewater of high enough quality to be used in applications of reuse.

Membrane filtration techniques are useful for treating residual petroleum waste (RPW) due to their ease of use and high separation efficiency, they may also be tailored to meet individual treatment needs by choosing the pore sizes and right membrane types, also these techniques produce less secondary waste than traditional techniques [41].

3. Nano-oxides:

The use of Nano-oxides is an effective technique for treating refinery product waste water (RPW), it is a type of manufactured nanoparticles with special features [42].

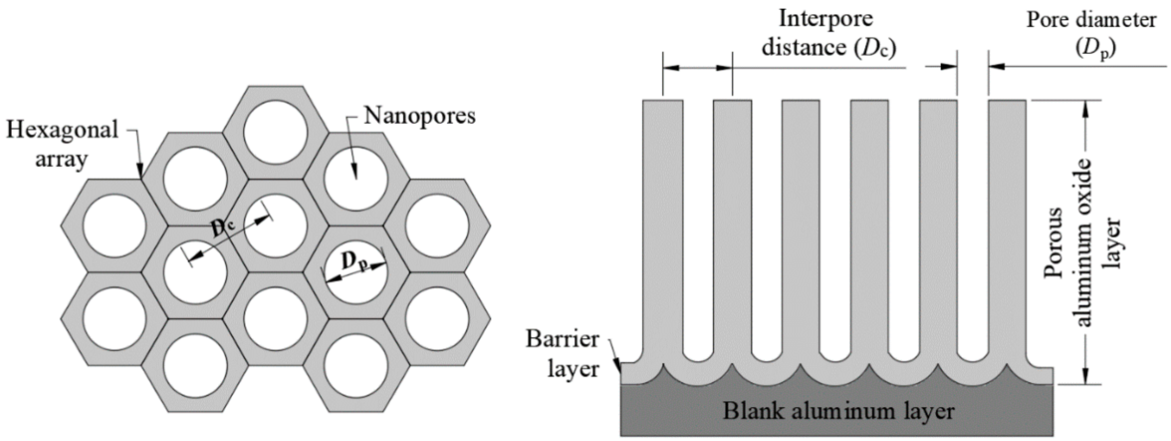

Figure 7. A schematic view of a typical hexagonally arranged nano porous anodic aluminum oxide , which can be used as a fibro-active nano filter [43].

These nanomaterials possess a greater capacity for adsorption and interaction with contaminants given that a high surface area due to their extremely small size. In addition, certain Nano-oxides show photocatalytic activity, which enhances their potential for degradation pollutants. The most commonly explored Nano-oxides for RPW treatment include:

Titanium dioxide (TiO_2): This photocatalytic Nano-oxide leading to the formation of hydroxyl radicals which generates electron-hole pairs when activated by UV light that initiate a series of reactions. These radicals then degrade organic pollutants present in RPW [32].

- **Iron oxide (Fe_2O_3):** Iron oxide nanoparticles show strong adsorption ability for several contaminants, including phosphate ions and heavy metals commonly found in RPW [44]. This feature allows for the effective removal of these pollutants from the wastewater stream.
- **Nickel oxide (NiO):** Nickel oxide nanoparticles have demonstrated prominent effectiveness of the removal of heavy metals from refinery wastewater (RPW), including cadmium and lead, through complexation and adsorption processes [45].
- **Copper Oxide (CuO):** Copper oxide nanoparticles have the large surface area and active sites which lead to a strong adsorption

capacity for many organic pollutants present in refinery wastewater (RPW) such as benzene and phenol [46].

- **Magnesium Oxide (MgO):** MgO nanoparticles can efficiently remove oil and grease from refinery wastewater by adsorption and filtration, MgO nanoparticles are effective in capturing and separating oil droplets due to their hydrophilic properties and large surface area [47].
- **Zinc Oxide (ZnO):** Zinc oxide (ZnO) nanoparticles have shown strong efficacy in removing phosphate ions from refinery wastewater (RPW) through adsorption and precipitation processes. By the large surface area of ZnO nanoparticles and hydroxyl groups, the binding of phosphate ions is effectively facilitated [44].

The use of Nano-oxides has many benefits, their large surface area helps in effective adsorption of pollutants such as residual petroleum waste (RPW) treatment, and their photo activity accelerates the degradation of organic pollutants. It is necessary to consider the potential risks to the human health and environment that may arise from the use of nanomaterials, and to develop appropriate measures to mitigate these risks.

5. Nano-oxide Applications in Refinery Product Water (RPW) Treatment

Nano-oxides, a class of specially designed nanoparticles with distinctive properties, have emerged as a leading approach to improving the treatment effectiveness of refinery wastewater which poses serious challenges to conventional treatment techniques due to them complex composition. This section studies the several uses of Nano-oxides in the treatment of petroleum residual wastewater (RPW) and considers how they can be used for removal of contaminants and enhance effectiveness of treatment.

- **Oil and Grease Removal:**

Due to large surface area, strong affinity, and hydrophobic properties of Nano-oxides, they are a viable option for removing wastewater (PRW) hydrophobic pollutants due such as oil and grease by binding and adsorbing oil and grease molecules on their surfaces, nanoparticles can create clusters that make them easy to separate from the aqueous phase through the use of sedimentation, filtration, or other separation methods [48]. Aluminum oxide (Al_2O_3) and magnesium oxide (MgO) where stand out among the common Nano-oxides used for oil and grease removal in (PRW) [49].

- **Heavy Metal Remediation:**

Refined petroleum wastewater (PRW) often contains heavy metals which are extremely hazardous to the human health and environment such as lead, cadmium and chromium. Nano-oxides have a high saliency in treating the heavy metals, due to their strong affinity for metal ions. Due to the surface properties of Nano-oxides such as surface charge and the presence of functional groups, which enhance adsorption and complex formation with metal ions, the effective removal of metal ions from the water stream is made possible [42]. Where iron oxide (Fe_3O_4) nanoparticles have been shown to be effectively remove lead and chromium from PRW by the adsorption processes [50].

- **Organic Compound Degradation:**

POPs are a class of persistent organic pollutants which hard-to-degrade. Frequently, treatment wastewater (RPW) contains them. On the other hand, some nanoparticles, including titanium dioxide (TiO2), have the ability to break down these organic contaminants due to their photo activity. UV light exposure causes TiO_2 nanoparticles to release extremely reactive species such hydroxyl radicals ($OH^{\cdot}$). Strong oxidizers, these radicals break down complex organic compounds into smaller, less toxic byproducts like water and carbon dioxide [51].

- **Enhanced Filtration:**

Membrane filtration is a widely employed technology for RPW treatment. However, limitations exist in capturing smaller particles and colloidal matter that can pass through the membrane pores. Nano-oxides can be incorporated into filtration membranes to address this challenge. These nanocomposite membranes function as adsorptive filters, enhancing the capture efficiency of fine particles and organic contaminants present in RPW [52]. The integration of Nano-oxides like ZrO_2 and Fe_2O_3 into filtration membranes has shown promising results in improving the removal of emulsified oil droplets and other micro pollutants from RPW [53].

6. Challenges and Considerations:

Despite the evident potential of Nano-oxides in RPW treatment, certain challenges and considerations require careful attention. These include:

- **Toxicity Concerns:** The potential human and environmental toxicity of certain nanomaterials necessitates thorough investigation to ensure safe implementation [54].
- **Nanomaterial Stability:** The stability of Nano-oxides in the complex RPW matrix needs to be evaluated to ensure their long-term effectiveness and prevent unintended release into the environment. [55]
- **Life Cycle Assessment:** A comprehensive life cycle assessment is crucial to understand the environmental impact of Nano-oxide synthesis, application, and disposal in RPW treatment processes. [56]

Future Directions:

Nanotechnology offers a transformative approach for tackling the intricate challenges associated with RPW treatment. Continued research and development efforts are focused on:

- **Optimizing Nano-oxide Synthesis:** Tailoring the synthesis methods of Nano-oxides to enhance their specific functionalities for targeted contaminant removal in RPW. [42]
- **Developing Nanocomposite Materials:** Exploring novel nanocomposite materials for filtration membranes to achieve superior separation efficiency and contaminant rejection. [57]
- **Environmental Impact Mitigation:** Developing strategies to mitigate the potential environmental risks associated with the use of nanomaterials in RPW treatment. [58]

The study synthesized nickel oxide, copper oxide, magnesium oxide, and zinc oxide using various methods and characterized them using X-ray diffraction (XRD) and scanning electron microscopy (SEM). These Nano-oxides were combined with product water from Samawah array production units at different ratios. The resulting mixture had a pH of approximately 7.7 and an electrical conductivity of 2450 micro Siemens/cm, increasing with dissolved salts concentration up to 1,347 mg/L. Turbidity initially increased after 1-2 hours due to oxide absorption, then decreased after 24 hours as oxide particles deposited suspended matter. The properties of manganese oxide nanoparticles unique chemical have been shown to be particularly beneficial in reducing turbidity by enhancing particle sedimentation. Nano-oxides have generally shown strong ability for uses in water filtration [59]. The production and use of Nano-oxides in water treatment have yielded satisfactory results in terms of pH, turbidity, and electrical conductivity. The manganese oxide nanoparticles have demonstrated remarkable effectiveness in treating water turbidity due to unique properties, indicating a promising future for the use of these particles in water purification procedures.

Nano-oxides have tremendous potential to completely transform recycled wastewater treatment by treating a wide range of contaminants. The petroleum refining sector has a potential path forward in increasing treatment efficiency and improving environmental sustainability due to the special properties of these materials. Additional developments in nanotechnology research are probably to support the creation of effective and environmentally friendly nanomaterial-based RPW treatment options.

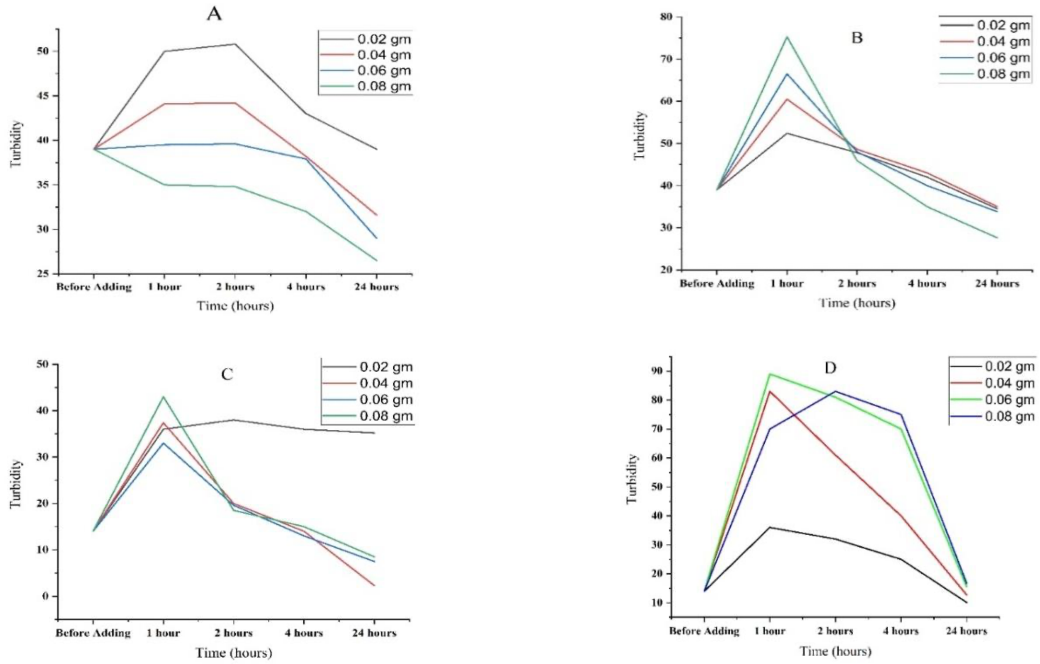

Figure 8. Turbidity as a function of reaction time at different concentrations of (A) (NiO) (B) (CuO) (C) (MgO) and (D) ZnO nanoparticles.

7. Challenges of Nano-oxides in Refinery Product Water (RPW) Treatment: Balancing Innovation with Environmental Responsibility

The uses of Nano-oxides have shown promising results in addressing the refined product water (RPW) complex problems. Their high capacity in eliminating pollutants stem from their outstanding chemical and physical properties, which include optical activity, high adsorption capacity, and large surface area. However, there are several related issues to the use of Nano-oxides in RPW treatment that need to be carefully studied in order to ensure the ethical and long-term use of this technique.

1. Potential for Environmental Release and Ecological Impact:

The potential for accidental discharge of nanoparticles for the treatment of refined product water (RPW) into the environment is one of the major related issues with the use of these particles. Nanoparticles may be unintentionally released at any point in their existence, from production and use to disposal, which raises important issues regarding the fate of nanoparticles and the long-term environmental impacts [60]. According to studies, some nanoparticles may be mobile in aquatic environments, which could lead to accidental exposure and bioaccumulation within aquatic animals disturbing ecosystems [61].

Mitigating Strategies:

• **Development of closed-loop systems:** Through implementing closed-loop systems to manufacture nano-oxides and use those oxides to treat refined product water (RPW), refineries can significantly reduce the risk of environmental release.

• **Engineering Nano-oxides for stability:** Through research activities directed at designing them for increased stability and controlled aggregation behavior, the tendency of nano-oxides to disperse into the environment can be reduced [62].

2. Optimizing Energy Consumption in Photocatalytic Processes:

A variety of Nano-oxides, most notably titanium dioxide (TiO_2), have useful photoactivity that can be used to disperse impurities in refinery product water (RPW) through producing photo reactive species. However, this process often requires a large amount of energy input, usually in the form of visible or ultraviolet light, in order to effectively activate photoreactions. The high energy requirements of these processes make it difficult to widely use nano-oxide photoreaction technologies in refineries due to issues related to overall sustainability and practicality [63].

Mitigating Strategies:

• **Exploring alternative light sources:** In order to activate photocatalysis, alternative light sources, such as visible light or solar radiation, are being sought. These sources can significantly reduce the energy required for these reactions.

• **Developing efficient catalyst designs:** Creating new catalyst designs, same those using composite materials, may increase the photocatalytic processes efficiency and reduce energy input [64].

3. Economic Considerations and Cost-Effectiveness:

The present high cost of nano-oxides in the treatment of refinery product water (RPW) is one major barrier to their widespread use due to necessity of using high-quality raw materials and exact control over reaction conditions for the complex processes involved in the fabrication of nanomaterials, which has a high production cost. These elements confirm how crucial importance analysis to the broad application of Nano-oxides, particularly for refineries looking for water treatment options that are cost-effective and ecologically friendly [65].

Mitigating Strategies:

• **Improving production methods:** By using alternative raw materials and improving manufacturing technology for producing Nano-oxides, can be reduced costs generally.

• **Reusing and regenerating Nano-oxides:** Study of the recycling or regenerating nano-oxides possibility after their use in purifying refined product water (RPW) may improve the financial sustainability of these techniques [66].

Research Needs in Nano-oxide Applications for Refinery Product Water Treatment: Bridging the Gap Between Promise and Practice

1. Optimizing Nano-Oxide-Based Treatment Processes:

Although preliminary studies suggest that nano-oxides may be useful in treating refined product water (RPW), further research is needed to improve their performance and tailor them to specific pollutant profiles. Important topics that need further research include:

• **Nano-oxide formulation and dosage:** The nano-oxide formulation and dosage must be optimized to achieve high pollutant removal efficacy. The study of different Nano-oxides, including titanium dioxide (TiO_2) and iron oxide (Fe_2O_3), in addition to their mixtures, should be the main aim of this research. The degradation and adsorption possibilities can be improved by investigating the effects of synergism between different nano-oxides [67].

• **Optimizing treatment conditions:** The design of efficient and flexible treatment systems for treating refined product water (RPW) becomes possible through understanding how treatment parameters such as pH, temperature, and reaction time affect how well nano-oxides work and processes of pollutant removal [68].

• **Integration with conventional methods:** There is much promise in hybrid treatment systems that combine filtration and adsorption together with the technique of nano-oxide. One of the aims of this research should be to find methods to integrate conventional techniques with nano-oxide in order to maximize the benefits of each. Investigation may include the synergistic effects of multiple treatment methods as well as optimization of operational parameters with the aim of enhancing the removal efficiency of a wide range of pollutants [69].

2. Long-Term Environmental and Health Impact Studies:

Nano-oxides in the treatment of refined product water are imperative that we fully understand their long-term effects on human health and the environment, given their increasing application. Important areas that still require research are:

• **Environmental fate and transport:** It is important to consider the persistence, movement, and nano-oxides as well as the residual degradation products after their release into the environment. Evaluation of their bioaccumulation possibility and environmental toxicity, along with possible impacts on aquatic ecosystems, should be one of this research main aims [70].

• **Human exposure and health risk assessment:** Evaluating quantities, potential exposure pathways, and health risks associated with human exposure to nano-oxides released during refinery product water (RPW) treatment processes is considered a very important evaluation. toxicological evaluations, exposure assessments, and epidemiological investigations can focus on potential health concerns associated with exposure to nano-oxides [71].

• **Risk mitigation strategies and regulatory frameworks:** The development of comprehensive regulatory frameworks and effective risk mitigation techniques is necessary to ensure the safety and responsible using of nano-oxides in refinery product water (RPW) treatment. Management standards, disposal strategies, and monitoring of the environment must be established to minimise the potential risks of the environment and human health associated with the use of nano-oxides [72].

Imperative to address the above-mentioned research needs in order to field of wastewater treatment using nano-oxides to grow and become sustainable. Scientists can pave the way for the creation of safe, efficient, and green wastewater treatment systems that address the increasing demands on the petroleum refining sector by improving the use of nano-oxides and conducting extensive and expanded studies to evaluate the environmental and human health impacts and bridging the gap between the potential of nanotechnology and the real-world uses of this technique.

8. Conclusion

Nano-oxides are interesting candidates for complicated refinery product water (RPW) treatment due to their special properties, particularly their large surface area and adsorption capability [59]. However, there are challenges in their usage. First, the manufacturing and disposal processes of Nano-oxides include the risks of environmental discharge that may endanger ecosystems. However, this risk can be reduced by implementing techniques such as closed-loop systems and stability engineering. Second, the high energy input requirements of photocatalytic nano-oxides, which limit their potential for widespread use, nevertheless, investigating different light sources and creating more efficient catalysts may help solve this issue. Finally, a major obstacle to the widespread applications of Nano-oxides is their high production costs, where improving production processes and considering reuse possibilities could help to solve this issue. In addition to examining the long-term effects of nano-oxides on human health and the environment, more research is needed to improve particle formulation, and modify manufacturing conditions and determine appropriate dosages. The safety of using of nano-oxide technologies depends on the establishment of regulatory frameworks and the development of risk mitigation techniques. By addressing these issues, refining wastewater (RPW) can be treated effectively and sustainably, helping the petroleum refining industry achieve a cleaner future.

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