

RESEARCH PAPER

## Potential Applications of Aluminum Oxide Nanoparticles in the Oil and Gas Industry

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### ABSTRACT

In the oil and gas industry, different kinds of nanoparticles have been studied and reported to enhance various oil and gas operations. In this review, however, the focus is on identifying different applications of aluminum oxide (Al<sub>2</sub>O<sub>3</sub>) nanoparticles in the petroleum industry because of its various potentials. Al<sub>2</sub>O<sub>3</sub> nanoparticle has been reported to be a good enhanced oil recovery agent that can alter rock wettability, reduce oil viscosity and reduce interfacial tension between oil and water.

Al<sub>2</sub>O<sub>3</sub> nanoparticle militates against kaolinite mobilization during hydrocarbon production, improves rheological properties in drilling fluids, improves the quality of cementation during well installations, and improves engine performance and thermal efficiency in brakes. Al<sub>2</sub>O<sub>3</sub> nanoparticle has the capacity to inhibit the growth of microbes. It is also a catalyst in crude oil refining, eliminates asphaltene from crude oil and is used to detect water oil interface. In diesel, Al<sub>2</sub>O<sub>3</sub> nanoparticle reduces emissions and enhances fuel consumption.

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### 1. INTRODUCTION

There are many applications for nanoparticles (NPs). It cuts across many fields of study including medicine, agriculture, material science, pharmacy, optics, environmental science, ceramic, construction, automotive and the energy industries. There are numerous kinds of NPs with specific characteristics that can be harnessed to solve problems. There are indications that several challenges in the oil and gas industry can be addressed by using the potentials inherent in

different kinds of NPs. Aluminum oxide (Al<sub>2</sub>O<sub>3</sub>) nanoparticle (NP) has been of interest in several disciplines because of its many unique properties. Hence, the aim of this review is to identify the potential applications of Al<sub>2</sub>O<sub>3</sub> NPs in the particular field of oil and gas industry. The areas where Al<sub>2</sub>O<sub>3</sub> NPs can play significant roles in meeting the growing challenges of petroleum exploration and production are outlined. Applying the innovative properties of Al<sub>2</sub>O<sub>3</sub> NPs can foster breakthrough in research especially in the petroleum sector, thus moving the industry forward.

On a worldwide scale, about 45 million tons

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of  $\text{Al}_2\text{O}_3$  is produced industrially [1] with different grades of the powder having different crystalline structures which have been discussed in literature [2]. Various methods of alumina (another name for  $\text{Al}_2\text{O}_3$ ) extraction have been reviewed and several processes of  $\text{Al}_2\text{O}_3$  NPs production which include arc plasma, hydrothermal, sol-gel and precipitation have been also discussed in detail. In addition, its functionalities with different functional groups have been analyzed [3]. It is reported that  $\text{Al}_2\text{O}_3$  NPs account for about 20% of all nano-materials produced in 2012 [4].

### 1.1. Characteristics of $\text{Al}_2\text{O}_3$ nanoparticle (NP)

$\text{Al}_2\text{O}_3$  NP has unique characteristics that render it useful in various industries. It has different crystallographic (such as the alpha and gamma) forms, high thermal conductivity of approximately 25W/Km and low thermal expansion coefficient of  $7.4 \times 10^{-6}\text{K}^{-1}$ . It has high melting point of about 2045°C, high surface area, surface energies and chemical reactivity.  $\text{Al}_2\text{O}_3$  NPs have hydrophilic surfaces; it is chemically inert, non-toxic, hard and tough. It has been widely used in high performance materials as fillers to increase toughness, ductility scratch resistance and also as an absorbent material for thermocouples. It has good chemical synthesis, low dielectric constant of 10 and high electrical conductivity that is greater than  $10^{14}$  ohm cm [5, 6].

$\text{Al}_2\text{O}_3$  NPs have exceptional physico-chemical and structural features such as resistance to wear chemicals and mechanical stresses. They also have optical properties, low-cost preparation and easy handling.  $\text{Al}_2\text{O}_3$  NP is thermally stable, ductile, hard, and is not flammable. It constitutes a good abrasive, adsorbent, low friction, composite and blasting material. It is a high- temperature component for heat resistance, a desiccant for drying gases, and is used as an electrical insulator, a catalyst carrier and adsorbent in the petroleum and chemical industries.  $\text{Al}_2\text{O}_3$  NPs can be mixed with other materials and used in the ceramic, construction and glass industry; it is also biocompatible. These properties make it invaluable for diverse medical applications.  $\text{Al}_2\text{O}_3$  NPs are used in medicine, pharmacy, cosmetics, dentistry, furnace lining and for machining tools [7]. Modified  $\text{Al}_2\text{O}_3$  NPs have been reported to effectively eliminate industrially-generated organic dye from water [8]. Moreover, synthesized  $\text{Al}_2\text{O}_3$  NPs have been used for arsenic removal

from water [9] and gamma  $\text{Al}_2\text{O}_3$  NP can eliminate arsenic from contaminated ground water [10].

### 1.2. Stability of $\text{Al}_2\text{O}_3$ nanoparticles

Nanoparticles are particles in the range of 1-100nm. As particle sizes decrease in the nano sizes, the material properties change with higher energies compared to the bulk materials. These changes in material properties affect the stability of the material which in the context of NPs describes the preservation of nano structure properties as a function of composition, shape, size, aggregation and surface chemistry [11]. NPs solubility in fluids is highly dependent on the properties of the solvent [12]. However, NPs do not really dissolve in water but can be dispersed in it and persist as particles in aqueous systems. Poor stability due to particles interactions, and particles and liquid interactions which have been discussed in literature is one of the challenges facing the commercialization of nanofluids [13]. In terms of nanofluid stability, zeta potential has been used to describe different levels of stability as given in Table 1 [14, 15].

Table 1. Zeta potential Values for Stability [14, 15]

Zeta Potential Values	Stability Description
$> \pm 60$ mV	Excellent stability
$\pm 40 - 60$ mV	Very good stability
$\pm 30 - 40$ mV	Stability
$< 30$ mV	Highly agglomeration

Various factors affect the stability of nanofluids and a major one is pH value. Some laboratory results of the effect of pH on the zeta potential of some nanofluids and on the zeta potential of  $\text{Al}_2\text{O}_3$  nanofluids at different concentrations are presented in Figures 1(a) and (b) respectively [14, 16]. It has been shown that commercial  $\text{Al}_2\text{O}_3$  NPs of 15-50nm particle size have a high dispersion rate at a pH of 8 [17], and controlling the pH of water-based nanofluid improves the stability of  $\text{Al}_2\text{O}_3$  Nps in water [18].

Studying the stability of  $\text{Al}_2\text{O}_3$  NPs in different fluids, it was observed that the zeta potential of the nanofluids is higher in the acidic region than the basic region [19] and that gamma  $\text{Al}_2\text{O}_3$  NPs maintain better stability than alpha  $\text{Al}_2\text{O}_3$  NPs [20] while  $\text{Al}_2\text{O}_3$  NPs maintain better stability in the presence of surfactants [21]. It is also reported that  $\text{Al}_2\text{O}_3$  nanofluid of pH 7.8 is highly unstable compared to the same sample at 6.3 pH value [22].

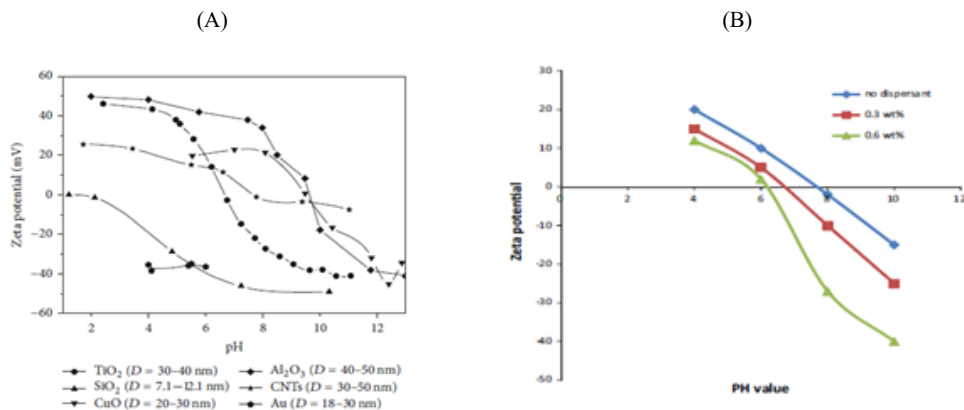


Figure 1. Zeta potential values as a function of pH for (a) different NPs in water [14] and (b) alumina nanofluid at different concentrations [16].

The investigation of the stability of gamma Al<sub>2</sub>O<sub>3</sub> NPs as a function of pH ionic strength, humic acid and clay minerals concentration has shown that high ionic strength, the presence of Montmorillonite and pH of the dispersants fluids all affect the stability of the NPs [23]. A study of different concentrations of Al<sub>2</sub>O<sub>3</sub> NPs in water in the presence of sodium dodecylbenzene-sulfonate also showed that the nanofluids with high mass fraction of Al<sub>2</sub>O<sub>3</sub> NPs were more unstable than the nanofluids with lower mass fractions which implies that the concentration of Al<sub>2</sub>O<sub>3</sub> NPs also affect stability. It was also pointed out that higher pH values created strong surface charges on the NPs which prevented agglomeration [16].

Stability of NPs in dispersion media is important to prevent the unwanted NPs concentration, agglomeration and deposition along pore spaces in porous media or in other process. Methods of stabilizing nanofluids include the use of surfactants, surface modification techniques, pH control and ultrasonic agitation. The agglomeration of Al<sub>2</sub>O<sub>3</sub> NPs has been reported to be reduced for about 5 hours by using ultrasonic vibration [24, 25]. Challenges facing the petroleum industry are numerous; it ranges from oil and gas exploration to drilling, production, crude oil refining, natural gas processing and environmental challenges. These problems can be solved or adequately managed using the right kind of technology and materials. The problems that the application of Al<sub>2</sub>O<sub>3</sub> NP can most likely address in the petroleum industry are thus reviewed.

## 2. Enhanced oil recovery (EOR)

Enhanced oil recovery is the injection of substances other than natural gas and water into petroleum reservoirs to improve oil recovery efficiency after primary and secondary oil recovery stages. The most commonly injected substances are alkaline, surfactants and polymers. They modify either the rock or fluid properties on the interaction, which leads to releasing trapped hydrocarbons. Some mechanisms through which this occurs include the reduction of interfacial tension between oil and water, the reduction of oil viscosity, viscosity increase of displacing fluids and wettability alterations.

The ability of Al<sub>2</sub>O<sub>3</sub> Nps to modify certain rock properties like wettability and fluid properties like the reduction of interfacial tension in order to enhance oil recovery following laboratory work have been reported [26 - 30]. Al<sub>2</sub>O<sub>3</sub> NPs can reduce the interfacial tension between oil and water, thus enhancing the oil recovery [31, 32]. The effect of Al<sub>2</sub>O<sub>3</sub> NPs and other types of NPs on the stability of CO<sub>2</sub> for EOR has been studied with concentrations of 0.1, 0.3, 0.5 and 1% wt. Results show that the foam stability of CO<sub>2</sub> using Al<sub>2</sub>O<sub>3</sub> NPs is better than the performance of silica, copper oxide and titanium dioxide NPs [33]. A comparative study on three types of NP (Al<sub>2</sub>O<sub>3</sub>, SiO and MgO) in a water flooding experiments has shown that Al<sub>2</sub>O<sub>3</sub> NPs improve oil recovery better than SiO and MgO. One set of the experimental results is presented in Figure 2 [34].

Wettability is an important rock property that affects oil recovery efficiency. Therefore, substances that can favorably alter the wettability of a rock is desired.

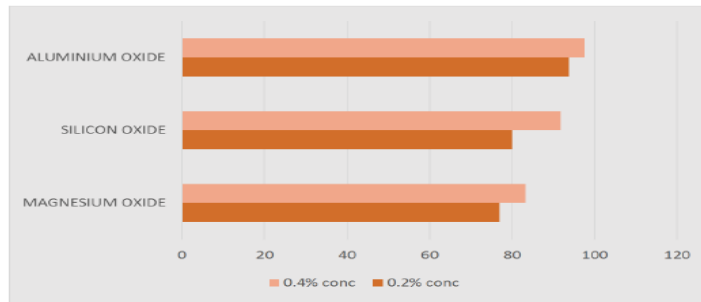


Figure 2. Percentage oil recovery in nanoparticle assisted EOR [34]

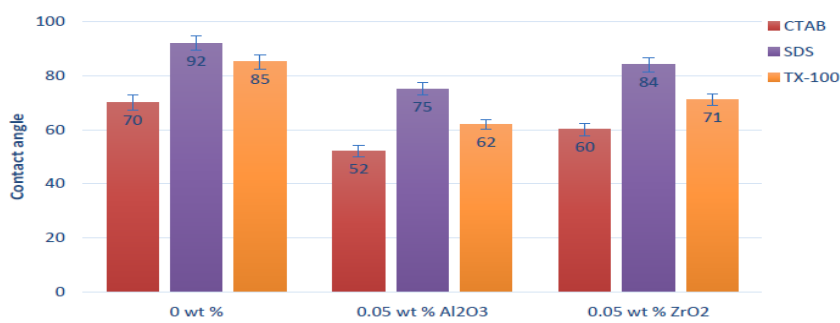


Figure 3. Wettability measurements using contact angle [43]

The effect of NPs on wettability alterations has been noted [35]. It has been proved that injecting alumina nanofluid into sandstone formations can alter wettability to water wet by enhancing the performance of surfactants [36]. A study has been carried out on the change of rock wettability to improve oil recovery using aluminum oxide, copper oxide and silica NPs dispersed in different fluids. Results showed that Al<sub>2</sub>O<sub>3</sub> NPs can alter the wettability of reservoir rocks [37]. The capacity of

Al<sub>2</sub>O<sub>3</sub> NPs to alter the wettability of carbonate cores has also been investigated and reported [38]. Al<sub>2</sub>O<sub>3</sub> NPs of 50nm and 100nm have been used for EOR experiments to study their effects on wettability alteration and oil recovery factor, and the results showed that oil recovery factor increased as the NP concentration increased [39].

Both ZrO and Al<sub>2</sub>O<sub>3</sub> Nps have been reported to change oil wet and naturally wet dolomite rocks to water wet rocks [40 - 42].

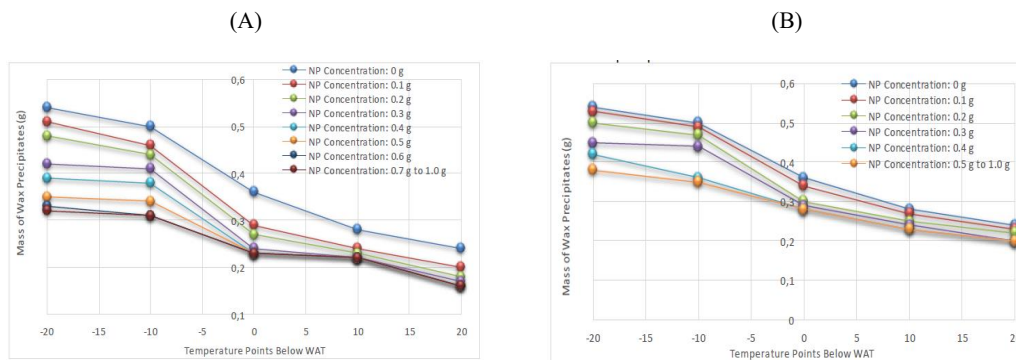


Figure 4. Wax precipitation from crude oil below the wax appearance temperature using NP of (A) Al<sub>2</sub>O<sub>3</sub> and (B) CuO [44]

However, another work compared the performance of ZrO and Al<sub>2</sub>O<sub>3</sub> NPs in changing the rock wettability. The wettability values were measured using contact angle and the interfacial tension between oil and the nanofluids were determined. The experimental results revealed that Al<sub>2</sub>O<sub>3</sub> NPs rendered the dolomite rocks more water wet than ZrO NPs for the different NP dispersing fluids used. The contact angle experimental results are presented in Figure 3, [43]. It can be seen that the contact angles of the dolomite rock surfaces rendered more water wet with Al<sub>2</sub>O<sub>3</sub> NPs than with ZrO NPs.

Wax precipitation is another challenge during the oil production that has plagued the petroleum industry. However, there are reports that some NPs can be used to tackle this problem. In fact, a study has shown that Al<sub>2</sub>O<sub>3</sub> NP is more effective than copper oxide NP in reducing wax precipitation and deposition in crude [44]. Some results of the experimental work are shown in Figure 4 [44].

**3. Control of migrating clayey fines in reservoirs**

Several laboratory investigations using sand packs to determine the best performing Nps that can trap migrating clayey fines in sand amongst nine selected NPs were conducted by Ogolo and others [45 - 47]. The best performing and recommended NP for trapping fines in sand was Al<sub>2</sub>O<sub>3</sub> NP. Table 2 [45] and Figure 5 [46] display results obtained from experimental work indicate that Al<sub>2</sub>O<sub>3</sub> NP is good for preventing kaolinite particles from the mobilization in hydrocarbon sands. In order to identify the best performing nanoparticle, further work was conducted using Al<sub>2</sub>O<sub>3</sub> NPs. The aim was to evaluate its performance at varying flow rates and water salinity values using light and medium crude oil samples [48, 49]. Results showed that Al<sub>2</sub>O<sub>3</sub> NPs can prevent the migration of clayey fines even in the presence of trigger factors. Thus, Al<sub>2</sub>O<sub>3</sub> NP was recommended to be used for the control of fine particles migration in hydrocarbon sands.

Table 2. Rate experimental results in the presence of crude oil [45]

S/No.	Type of Nanoparticles	Rate at which fine particles were mobilized (ml/min.)		
		Distilled water	Brine	Ethanol
1.	Reference Experiment	0.2	0.5	0.8
2.	Aluminium Oxide	9.1	8.2	0.7
3.	Magnesium Oxide	1.7	1.4	1.8
4.	Iron Oxide	0.2	1.2	1.8
5.	Nickel Oxide	0.2	8.5	8.0
6.	Tin Oxide	0.2	1.4	1.7
7.	Zinc Oxide	0.2	0.7	1.2
8.	Zirconium Oxide	0.2	8.1	1.5
9.	Silane Treated Silicon Oxide	0.2	8.0	1.9
10.	Hydrophobic Silicon Oxide	X	X	0.9

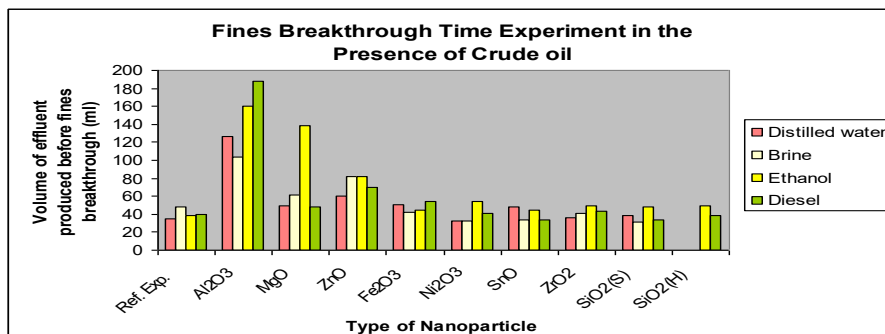


Figure 5. Volume of clean effluent produced before breakthrough of particles [46].

#### 4. Drilling operations

There is a need to find alternatives to oil-based muds used in advanced drilling especially in deep waters and in very harsh environments of high temperatures and pressures. The high cost of drilling and environmental concerns associated with drilling especially with oil-based mud have further prompted the need for alternatives. A study was conducted with  $Al_2O_3$  and silica NPs in water-based mud. The results showed that  $Al_2O_3$  NPs can enhance the properties of water-based drilling fluids such as thermal stability at high temperatures and with low environmental impact better. In comparison with nano silica, the

performance of  $Al_2O_3$  NP is better as presented in Figure 6 [50].  $Al_2O_3$  NP has the potential to improve the physiochemical properties of drilling fluids. The presence of NPs in water-based drilling fluids has been reported to reduce fluid loss while the filtration volume is dependent on the distribution of particles in the fluid [51]. It has also been found that under high temperatures, the presence of  $Al_2O_3$  NPs in drilling fluids maintain the shear stress of the fluid as presented in Figure 7 [52]. In fact, the thermal stability of water-based drilling fluid increased as the fraction of  $Al_2O_3$  NPs increased [52].

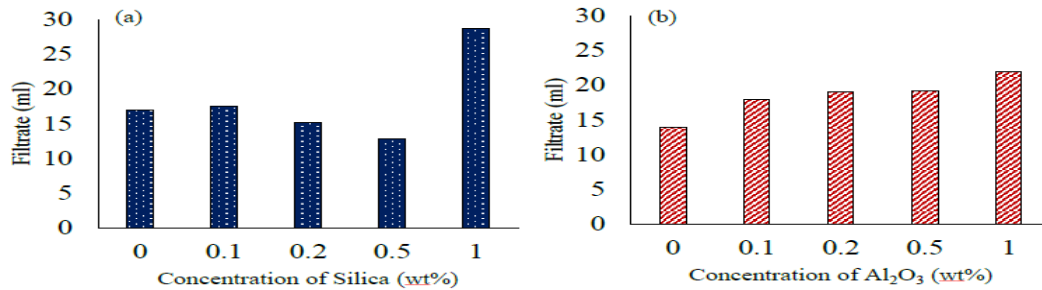


Figure 6. High pressure high temperature 30 minutes filtrate for different concentrations of nanoparticles of (a) Silica (b)  $Al_2O_3$  [50]

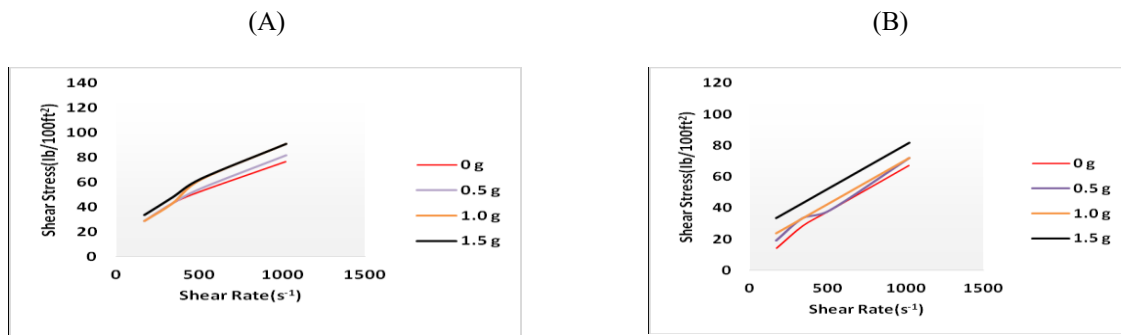


Figure 7. Rheogram showing the non-Newtonian behavior of  $Al_2O_3$  nanoparticles at different concentrations on water-based mud at (A) 40oC and (B) 90oC [52].

Improving the properties of water-based drilling fluid using different kinds of NPs have been also studied [53]. Laboratory results revealed that the yield point of plastic viscosity and gel strength of the drilling fluid improved as the multi wall carbon nanotube and  $Al_2O_3$  NPs concentrations increased. It was observed that increasing the concentration of  $Al_2O_3$  NPs improved the rheological properties of yield point which invariably reduced differential

pipe sticking tendency and reduced the velocity of cuttings settling. The study showed that the presence of  $Al_2O_3$  NPs in drilling mud dramatically reduced fluid loss, decreased formation damage, reduced mud filtrate volume and gave low permeable mud cake with reduced mud cake thickness which invariably reduced the pipe sticking [54]. Hence, the presence of  $Al_2O_3$  NPs in drilling fluids can enhance the drilling operations.

### 5. Asphaltene removal and reduction of crude oil viscosity

Through several investigations it has been found that  $\text{Al}_2\text{O}_3$  NP is a good agent that can eliminate asphaltene from crude oil through adsorption, making the remaining hydrocarbon fraction transportable. The effect of  $\text{Al}_2\text{O}_3$  NPs on the removal of asphaltene from an Iranian crude was studied. It was found that the asphaltene particles reacted with nano  $\text{Al}_2\text{O}_3$ , raising the average

molecular size of the asphaltene from 512.754 to 2949.557nm while the asphaltene separation increased from 60-85wt% to 90 – 97wt% [55]. The thermodynamics of asphaltene adsorption on the  $\text{Al}_2\text{O}_3$  NPs indicates that the adsorption was fast, spontaneous and exothermic in nature, and can be applied to asphaltene removal from heavy crude [56 - 58]. An experimental result of the asphaltene rejection using  $\text{Al}_2\text{O}_3$  NPs is presented in Figure 8 [59].

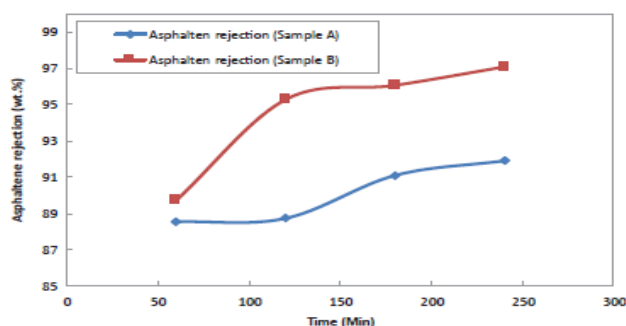


Figure 8. Asphaltene rejection with  $\text{Al}_2\text{O}_3$  NPs (Sample B) increased to about 97wt% as against 91wt% (Sample A) without  $\text{Al}_2\text{O}_3$  NPs [59]

In another study conducted on heavy crude oil derived from Gulf of Mexico, it was shown that  $\text{Al}_2\text{O}_3$  NPs supported on transition metals and on liquid transition metal catalysts have the capacity to decrease the oil viscosity. The API gravity increased from 12.5 to values between 21 – 26° API. The kinematic viscosity reduced, the asphaltene content was removed and the distillable oil fraction increased between 20 - 30 wt% [58]. The challenge lies with finding out if similar surface results can be obtained in-situ when  $\text{Al}_2\text{O}_3$  NPs and other metal catalysts dispersed in suitable fluids are introduced into the reservoir formations. If  $\text{Al}_2\text{O}_3$  NP can reduce the viscosity of heavy crudes in reservoirs to enhance the mobility and improve other oil characteristics, then the key to solve the problem of recovering oil from low API gravity hydrocarbons in reservoirs apart from the application of heat can be realized. The modification of NPs with unique catalytic properties that can effectively refine tar sands and convert heavy oil, bitumen and oil shale to profitable oil can be areas for further

research.

### 6. Bacterial growth inhibition

The antibacterial effect of  $\text{Al}_2\text{O}_3$  NPs has been established [60].  $\text{Al}_2\text{O}_3$  NPs can destroy some bacteria in the environment just like silver NPs and this has raised some environmental concerns. The growth inhibition of microbes by  $\text{Al}_2\text{O}_3$  NPs has been reported [61 - 64]. In fact, experimental results have shown that  $\text{Al}_2\text{O}_3$  NPs inhibit the growth of microbes more than  $\text{Al}_2\text{O}_3$  powder as presented in Figure 9 [63]. However, this characteristic of  $\text{Al}_2\text{O}_3$  NPs can be applied in the oil and gas industry for the preparation of biocides used in the destruction of micro-organisms that cause problems during production such as Sulphur-reducing bacteria and other unwanted microbes. In addition, how  $\text{Al}_2\text{O}_3$  NPs can be used in preventing undesired bacterial growth during the petroleum production can be an area for further research. However, it should be noted that  $\text{Al}_2\text{O}_3$  NPs is one type of NPs that can inhibit both negative and positive bacteria as presented in Table 3 [65].

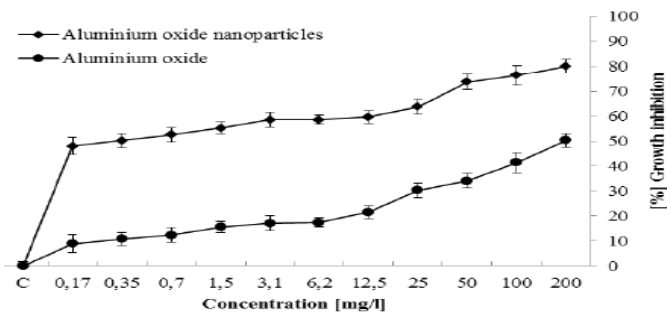


Figure 9. Comparison of growth inhibition of P. Putida using Al<sub>2</sub>O<sub>3</sub> NP and Al<sub>2</sub>O<sub>3</sub> powder [63]

Table 3: Minimum inhibitory concentration (MIC) values of metal Oxide NP [65]

Sample	gram negative bacteria		gram positive bacteria	
	MIC (mg/ml)		MIC (mg/ml)	
	<i>E.coli</i>	<i>P.vulgaris</i>	<i>S.aureus</i>	<i>S.mutans</i>
Al <sub>2</sub> O <sub>3</sub>	4	8	4	6
IO	2	2	4	8
CuO	6	4	4	4
ZnO	6	6	4	8

### 7. Petroleum refining

The products from crude oil refining include gasoline, kerosene, diesel, grease, lubricants, asphalt and bitumen. High-grade crude oil products are desired because they improve the performance and efficiency of engines. During crude oil refining, different kinds of catalysts are used at different stages and Al<sub>2</sub>O<sub>3</sub> NP has been used as a liquid fuel additive that improves the combustion and emission performance. Al<sub>2</sub>O<sub>3</sub> with nickel oxide NPs have been used to formulate a nano-catalyst for hydrocracking to enhance the thermal catalytic cracking of heavy crude during the refining process [66]. Different kinds of lubricants are used in almost every industry specially to grease the metallic parts of machines. Using Al<sub>2</sub>O<sub>3</sub> NPs as an additive in lubricants has been reported to increase the liquid viscosity, density and thermal conductivity as the mass fraction of the NP increases [67].

Al<sub>2</sub>O<sub>3</sub> NPs have been mixed in biodiesel at different concentrations. Considerable enhancement in brake thermal efficiency, specific fuel consumption and other benefits have been reported [68, 69]. A reduction in carbon monoxide emissions with an increasing concentration of Al<sub>2</sub>O<sub>3</sub> NPs which indicates better combustion and performance has been observed. Research has also shown that the

performance of Jatropha biodiesel with Al<sub>2</sub>O<sub>3</sub> NPs additive is better because it produces better combustion and emission characteristics than ordinary Jatropha biodiesel without Al<sub>2</sub>O<sub>3</sub> NP additive [70]. The flash point and calorific value of biodiesel increase with dosing levels of Al<sub>2</sub>O<sub>3</sub> NPs in blends and the rate of heat release reduces, leading to rapid combustion and reduced peak pressure. Improvement in brake thermal efficiency, reduced emission of nitrogen oxides and hydrocarbons, and reduced smoke opacity have all been observed with Al<sub>2</sub>O<sub>3</sub> NPs blends in biodiesel [71]. The improvement of Al<sub>2</sub>O<sub>3</sub> NPs on the brake specific fuel consumption and thermal efficiency of a diesel engine is presented in Figure 10 [72]. Reduced pollutant emissions with the use of Al<sub>2</sub>O<sub>3</sub> NPs on diesel engines are presented in Figures 11 and 12 [73, 74].

### 8. Other potential applications

In the construction industry it has been reported that Al<sub>2</sub>O<sub>3</sub> NPs have the ability to improve the compressive strength in concrete and modify the negative effects of some additives [75]. In the oil and gas industry too, research has shown that the addition of Al<sub>2</sub>O<sub>3</sub> NPs in combination with other types of NPs can improve the properties of cements used in oil and gas well installations during the drilling.

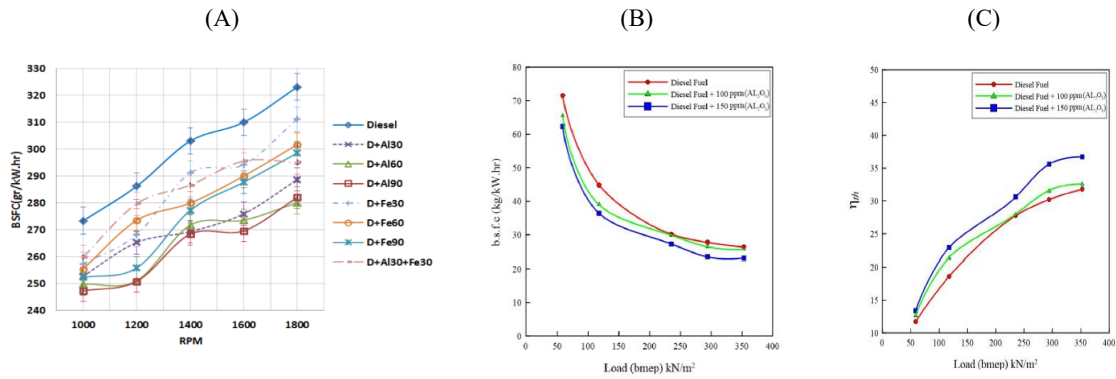


Figure 10. Effect of Al<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub> nanoparticles on (A and B) break specific fuel consumption, (C) break thermal efficiency of a diesel engine [72]

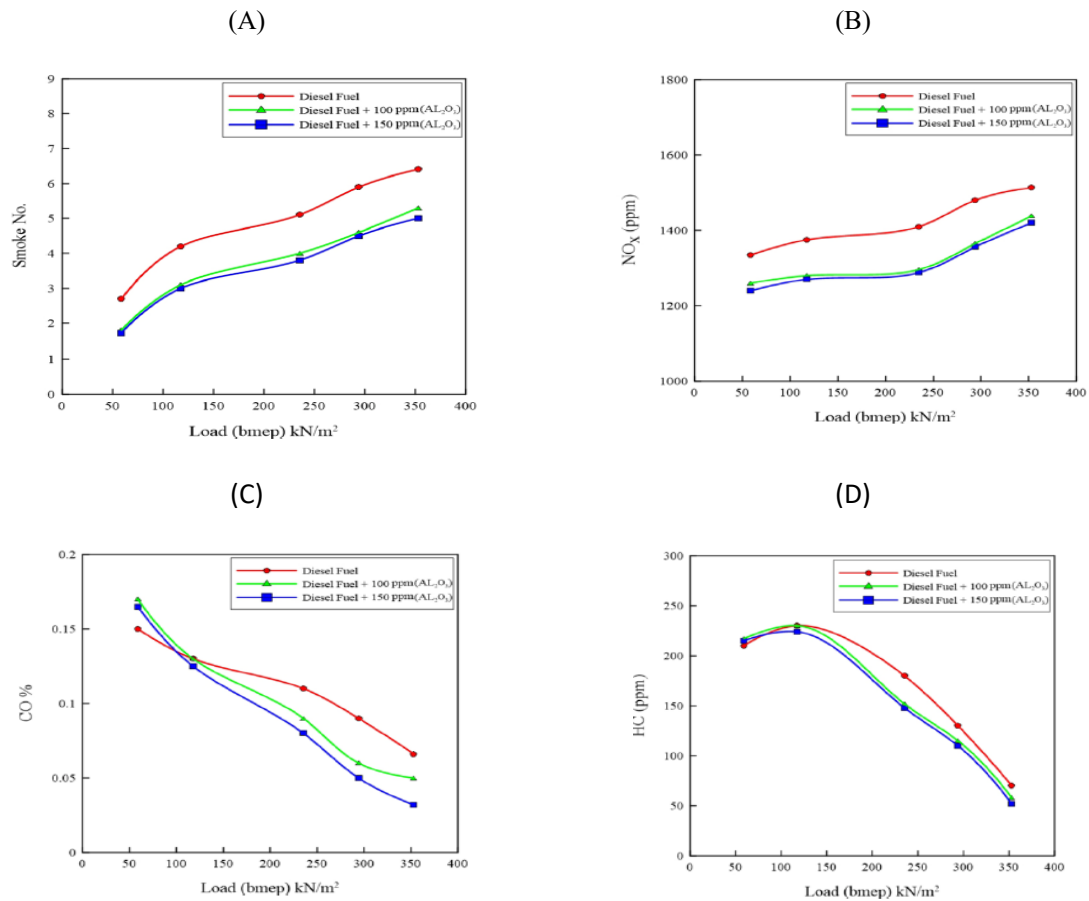


Figure 11. Effect of Al<sub>2</sub>O<sub>3</sub> NP on (A) smoke emission, (B) Nitrogen Oxide emission (C) CO emission and (D) Hydrocarbon emission for a diesel engine [73]

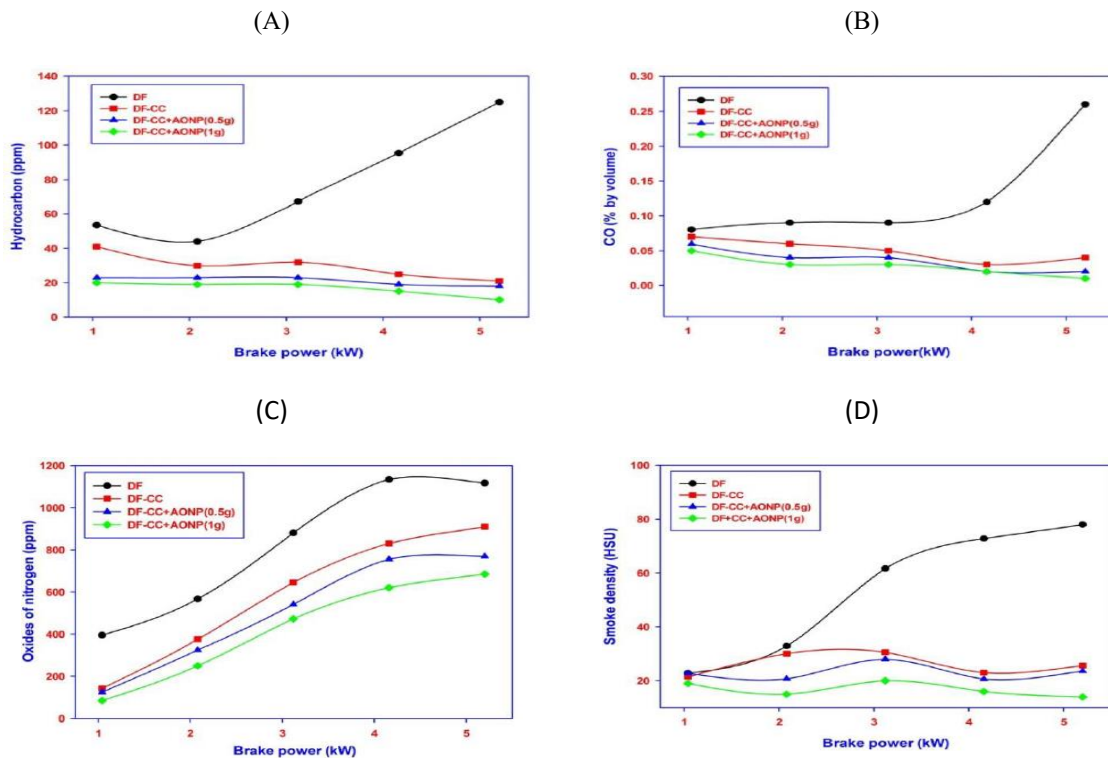


Figure 12. Effect of 1g and 0.5g Al<sub>2</sub>O<sub>3</sub> NP (AONP) on (A) Hydrocarbon Emission (B) CO Emission (C) NO<sub>x</sub> Emission and (D) Smoke Emission for Diesel Engines [74]

This NP strengthens and increases durability, improves resistance to water penetration, accelerates hydration reaction, improves impact and fracture toughness, enhances dry shrinkage and permeability resistance [76, 77].

There is a current line of research on using coated Al<sub>2</sub>O<sub>3</sub> NPs to detect the interface between crude oil and water [78]. An experiment has been conducted to show how Al<sub>2</sub>O<sub>3</sub> NPs and NiZnFeO NPs can be used to detect oil and water zones in sand packs. Both types of nano materials showed the same pattern of results [79]. This study can be tailored towards application in well logging to detect oil and water zones and shifts in water oil contacts as the production progresses over time. The study can also be deployed for sweep efficiency during EOR projects to determine suitable spots for infill drilling that will effectively drain oil from the brown fields.

## CONCLUSIONS

1. Al<sub>2</sub>O<sub>3</sub> NP has unique properties. Its application is vast but its stability is critical and is affected by several factors including pH.

2. Al<sub>2</sub>O<sub>3</sub> NPs can improve oil recovery efficiency through change of rock wettability, reduction of interfacial tension and decrease in oil viscosity.

3. Al<sub>2</sub>O<sub>3</sub> NP has been reported to be a good agent for the prevention of fine particles migration in reservoirs.

4. The presence of Al<sub>2</sub>O<sub>3</sub> NPs in biodiesel and fossil fuels can improve engine performance, reduce carbon monoxide and nitrogen oxide emissions, improve brake thermal efficiency and enhance fuel consumption as the concentration of the NPs increases in the blend.

5. Al<sub>2</sub>O<sub>3</sub> NPs can be used to detect oil and water zones and contacts in core plugs and it is suggested that the technique be tailored towards improving well log techniques. 6. Using Al<sub>2</sub>O<sub>3</sub> NPs as additives in water-based drilling fluids improves the rheological properties of the fluids and can be used to improve the quality of cementing during well installations after the drilling operations. 7. Al<sub>2</sub>O<sub>3</sub> NPs can be used to eliminate asphaltens from crude oil, reduce the viscosity of heavy crude and can serve as catalysts in oil refineries. 8. The anti-bacterial effect of Al<sub>2</sub>O<sub>3</sub> NPs can be deployed

in the preparation of biocides for the petroleum industry. However, this area requires more research.

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