

**PERFORMANCE AND IMPACT OF POLYMER NANOCOMPOSITES ON  
ENHANCED OIL RECOVERY**

**SOWUNMI, AKINLEYE OLAMILEKAN**

**(05CF02623)**

**AUGUST, 2021**

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**A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES IN  
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UNIVERSITY, OTA.**

**AUGUST, 2021**

## ACCEPTANCE

This is to attest that this thesis is accepted in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy (Ph.D) in Chemical Engineering in the Department of Chemical Engineering, College of Engineering, Covenant University, Ota.

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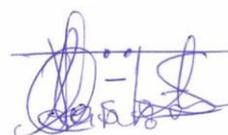
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## DECLARATION

I, **SOWUNMI, AKINLEYE OLAMILEKAN (05CF02623)** declare that this research was carried out by me under the supervision of Prof. Vincent E. Efevbokhan of the Department of Chemical Engineering and Prof. Oyinkepreye D. Orodu of the Department of Petroleum Engineering, College of Engineering, Covenant University, Ota. I attest that the thesis has not been presented either wholly or partially for the award of any degree elsewhere. All sources of data and scholarly information used in this thesis are duly acknowledged.

**SOWUNMI, AKINLEYE OLAMILEKAN**



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## CERTIFICATION

We certify that this thesis titled “**Performance and Impact of Polymer Nanocomposites on Enhanced Oil Recovery**” is an original research work carried out by **SOWUNMI, AKINLEYE OLAMILEKAN (05CF02623)** in the Department of Chemical Engineering, College of Engineering, Covenant University, Ota, Ogun State, Nigeria, under the supervision of Prof. Vincent E. Efeovbokhan and Prof. Oyinkepreye D. Orodu. We have examined and found the work acceptable as part of the requirements for the award of Doctor of Philosophy (Ph.D) degree in Chemical Engineering.

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## **DEDICATION**

To God Almighty who makes all things beautiful in his time, who crowns effort with success and gives strength in our time of weakness. I am thankful to God for giving me the fortitude to go through the rigor of actualizing this thesis.

This thesis is dedicated to my parents: Mr. and Mrs. Sowunmi for their prayers and support, and for giving me the best education that they can afford, which has helped me thus far. May God continually bless them and grant them long life and good health to enjoy the fruit of their labour.

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## LIST OF ABBREVIATIONS

AFM	Atomic Force Microscopy
AOS	Alpha-Olefin Sulfonate
AP	Alkaline Polymer
API	American Petroleum Institute
APTES	Aminopropyltriethoxy Silane
ASP	Alkaline-Surfactant-Polymer
ASTM	American Society for Testing and Materials
ATR	Attenuated Total Reflectance
BPD	Barrels Per Day
CDG	Nano-sized Colloidal Dispersion Gels
CNT	Carbon Nanotubes
CVC	Chemical Vapour Condensation
CVD	Chemical Vapour Deposition
DCMS	Dichloro dimethyl Silane
DLS	Dynamic Light Scattering
DNA	Deoxyribonucleic Acid
DPR	Department of Petroleum Resources
DTA	Differential Thermal Analysis
EOR	Enhanced Oil Recovery
EUR	Estimated Ultimate Recovery
FCM	First Contact Miscible
FTIR	Fourier Transform Infrared Spectroscopy
GA	Gum Arabic
GC-MS	Gas Chromatography - Mass Spectrometry
GDP	Gross Domestic Product
GG	Guar Gum
GPTMS	Glycidyloxypropyltrimethoxy Silane
HFU	Hydraulic Flow Unit
HLP	Hydrophobic and Lipophilic Polysilicon
HLPN	Hydrophobic Lipophilic Polysilicon Nanoparticles
HPAM	Hydrolyzed Poly Acrylamide
HPLC	High-Pressure Liquid Chromatography

IFT	Interfacial Tension
IOR	Improved Oil Recovery
KOH	Potassium Hydroxide
LPG	Liquefied Petroleum Gas
MCM	Multiple Contact Miscible
MWNT	Multiwalled Carbon Nanotubes
MS	Mass Spectroscopy
NMR	Nuclear Magnetic Resonance
NP	Nanoparticle
NVP	N-Vinylpyrrolidone
NWP	Neutrally Wet Polysilicon Nanoparticles
OFITE	OFI Testing Equipment
OGJ	Oil Gas Journal
OOIP	Original Oil in Place
OPEC	Organization of Petroleum Exporting Countries
PAM	Polyacrylamide
PCS	Photon-Correlation Spectroscopy
PDI	Polydispersity Index
PDMS	Polydimethylsiloxane
PEG	Polyethene Glycol
PNC	Polymer Nanoparticle Composite
PNP	Polymer Coated Nanoparticle
PSNP	Polysilicon Nanoparticle
PV	Pore Volumes
PVP	Polyvinylpyrrolidone
QD	Quantum Dots
RPM	Revolutions Per Minute
RPT	Reservoir Permeability Tester
SAC	Steam-Alternating-CO <sub>2</sub>
SAGD	Steam-Assisted Gravity Drainage
SDS	Sodium Dodecyl Sulphate
SEM	Scanning Electron Microscope
SFC	Supercritical Fluid Chromatography
SP	Surfactant Polymer

SPS	School of Post Graduate Studies
SSC	Simultaneous Steam-CO <sub>2</sub>
TAN	Total Acid Number
TCF	Trillion Cubic Feet
TEM	Transmission Electron Microscope
TGA	Thermo-gravimetric Analyzer
TMPM	Trimethoxysilylpropyl Methacrylate
USBM	United States Bureau of Mines Wettability Test
WAG	Water Alternating Gas
WOR	Water to Oil Ratio
WTI	West Texas Intermediate
XG	Xanthan Gum
XRD	X-Ray Diffraction

## ABSTRACT

The increasing human population has given rise to greater energy demand which continues to place a burden on energy production worldwide. This has intensified the need for innovation, both in the petroleum industry and renewable energy sector. The petroleum industry has in recent years experienced the gradual disappearance of “easy oil.” In addition to this, only about 30% of the original oil in place (OOIP) can be extracted using conventional techniques, leaving about 70% of crude oil in the reservoir after primary and secondary oil recoveries have been exhausted. For this reason, new approaches to oil recovery called enhanced oil recovery (EOR) have been developed to recover more oil from existing reservoirs. One of the most common methods is chemical EOR, which involves the injection of chemicals into the reservoir to increase the overall efficiency of the process. In this work, innovative mixtures of polymer nanocomposites (PNC) were explored for viscosity and core flooding experiments as a route for chemical EOR. Three polymers: xanthan gum, guar gum and gum arabic; and two nanoparticles: alumina and silica, were mixed in different proportions and used for core flooding experiments with a reservoir permeability tester (RPT). Cupric nanoparticle was used in addition to the two other nanoparticles and three polymers for viscosity tests using a viscometer. The effects of temperature, salinity, shear rate, polymer concentration and nanocomposites on viscosity were investigated. Spectral analysis of the polymers was done using Fourier-Transform Infrared (FTIR); thermal stability of the polymers was tested using thermogravimetric analyzer (TGA). Scanning Electron Microscope (SEM) was used to obtain micrographs of the nanoparticles and study the morphology of core plugs used in the flooding process. The results showed that the viscosity of the polymers increased with polymer concentration, with xanthan gum having the highest viscosity among the three polymers (1645 cP at 1.0% w/w) and gum arabic having the lowest viscosity (180 cP at 1.0% w/w). For all the nanocomposite combinations considered, the addition of the nanoparticles caused their viscosities to increase. The cupric oxide nanoparticles produced the highest effect on the viscosities of the polymer nanocomposites. As the temperature increased from 30 to 90°C, the viscosities of the polymers were observed to reduce; the polymer viscosities also reduced with salinity. In the core flooding experiments, xanthan gum, guar gum and gum arabic achieved total oil recoveries of 62.8, 54.2 and 52.5%, respectively: Eclipse software provided validation for the observed trend. Across the six PNC used for core flooding, alumina had a greater impact on oil recovery than silica. Also, xanthan gum-alumina PNC recorded the highest recovery of 72.8%. The TGA results showed that gum arabic had the greatest stability above 70°C, while xanthan gum had the lowest. It was deduced from the SEM images that each nanocomposite impaired the permeability of the core plugs to some extent. The results obtained in this work make a strong case for the adoption of polymer nanocomposites for EOR, especially for nanocomposites containing gum arabic, which is locally produced and available in large quantities.

**Keywords:** Enhanced oil recovery, nanocomposite, nanoparticles, polymers, viscosity