# PERFORMANCE AND IMPACT OF POLYMER NANOCOMPOSITES ON ENHANCED OIL RECOVERY

**SOWUNMI, AKINLEYE OLAMILEKAN**

**(05CF02623)**

**AUGUST, 2021**

# PERFORMANCE AND IMPACT OF POLYMER NANOCOMPOSITES ON ENHANCED OIL RECOVERY

**BY**

**SOWUNMI, AKINLEYE OLAMILEKAN**

**(05CF02623)**

B.Eng (Hons) Chemical Engineering, Covenant University, Ota;

M.Sc Chemical Engineering, Masdar Institute of Science and Technology (Now Khalifa University of Science and Technology), Abu Dhabi, UAE

**A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (Ph.D) IN THE DEPARTMENT OF CHEMICAL ENGINEERING, COLLEGE OF ENGINEERING, COVENANT 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.

**Mr. John A. Philip** ……………………………………

(Secretary, School of Postgraduate Studies) Signature and Date

**Prof. Akan B. Williams** ………………………………………

(Dean, School of Postgraduate Studies) Signature and Date

# DECLARATION

I, **SOWUNMI, AKINLEYE OLAMILEKAN (05CF02623)** declare that this research was carried out by me under the supervision of Prof. Vincent E. Efeovbokhan 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** ……………………………………

Signature and Date

# 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.

**Prof. Vincent E. Efeovbokhan** ……………………………..
Supervisor Signature and Date

**Prof. Oyinkepreye D. Orodu** ……………………………..
Co-Supervisor Signature and Date

**Prof. Vincent E. Efeovbokhan** ……………………………..
HOD, Chemical Engineering Signature and Date

**Prof. Sunday S. Ikiensikimama** ……………………………..
External Examiner Signature and Date

**Prof. Akan B. Williams** ……………………………..
Dean, School of Postgraduate Studies Signature and Date

# 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.

## ACKNOWLEDGEMENTS

I give thanks to God Almighty who gives strength and grace through every kind of challenge. My gratitude to the Chancellor of Covenant University, Dr. David O. Oyedepo, who established the platform on which the research was conducted. I am thankful to the Vice Chancellor, Prof. Abiodun H. Adebayo; the Registrar, Dr. Oluwasegun P. Omidiora; the Dean of the School of Post-Graduate Studies (SPS), Prof. Akan B. Williams; the Sub-Dean SPS, Dr. Emmanuel O. Amoo; and the Dean of the College of Engineering, Prof. David O. Omole.

In going through the different stages of this work, there were inputs from different people and I would like to acknowledge their contribution to the completion of this degree. I am grateful to my supervisors: Prof. Vincent E. Efeovbokhan and Prof. Oyinkepreye D. Orodu, who were kind to me and assisted me in every way possible during this research work. I want to thank them for their patience and the constant guidance towards the completion of the work.

I am thankful to the faculty and staff members of the Chemical and Petroleum Engineering Departments at Covenant University; their insights and ideas made the work robust. Hence I say thank you to Prof. James Omoleye, Dr. Augustine Ayeni, Dr. Oluranti Agboola, Dr. Ayodeji Ayoola, Dr. Sanmi Olabode, Mr. Tomiwa Oguntade, Mr. Temiloluwa Ojo, Dr. Francis Elehinafe, Dr. Angela Mamudu, Mrs. Damilola Abraham, Dr. Emmanuel Okoro, Mr. Oluwatosin Adegbite, Mr. Babalola Oni and Mrs. Bosede Adeniji. I also say a big thank you to Mr. Olakunle Daramola and Mr. Felix Iyala for their assistance in the laboratory.

I am thankful to Samuel Sofela at New York University, Abu Dhabi and Adetunji Alabi at Khalifa University of Science and Technology, Abu Dhabi for connection to some of the equipment I used.

Lastly, I want to express my deepest gratitude to my parents, Mr. and Mrs. Sowunmi who have supported me financially and emotionally throughout the entire thesis work. I would also like to acknowledge the support of my siblings and other family members who encouraged me to keep pushing until the thesis was done.

May God bless you all.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF PLATES

# 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-$CO_2$ |
| 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-CO2 |
| 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℃, 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℃, 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