

Performance Comparison of a Locally Formulated Demulsifier and a Conventional Demulsifier in Crude Oil Demulsification

Anthony Ogbagbe Chikwe, Christian Emelu Okalla and Andra Oluomachi Ihuoma

Department of Petroleum Engineering
Federal University of Technology Owerri
Imo State, Nigeria.

Abstract— Crude oil emulsion formation has been a challenging problem in the oil and gas industry. This is normally formed when water is present in crude oil during production and transportation of crude oil, thus, reducing the quality of the crude oil. This could cause problems to the processing facilities and as well increase the cost of operation as it needs to be treated. In this study, bottle test method was conducted using three conventional demulsifier; xylene, sulphuric acid and commercially available demulsifier (CAD), to compare its efficiency to a locally formulated demulsifier at various temperatures, concentrations and time. It was observed from the results that the commercially available demulsifier (CAD) produced a better result in separating a higher volume of water compared to the other demulsifiers used, as it was able to remove a volume of 3.1ml of water at 60oC and 0.4ml of demulsifier concentration. An economic analysis was conducted on the four demulsifiers using the production index, internal rate of return (IRR), payback period and net present value (NPV) as the economic parameters for this study. It was observed from the results gotten that the local demulsifier gave a higher value of NPV, IRR, and PI, indicating the possibility of reducing cost and making it the most lucrative choice.

Keywords— Emulsion; Demulsification; CAD; IRR; NPV; PI.

1. INTRODUCTION

Crude oil is a dark viscous liquid that originates from fossilized remains of plants and animals transformed over millions of years through geological processes. It comprises of resins, asphaltenes and naphthenic acid which acts as natural emulsifiers that enhance the stability of an emulsion. An emulsion is simply a system that consists of two phases namely; the dispersed phase (water) and continuous phase (oil). The presence of water in crude oil is formed when there is a presence of an emulsifier and a significant amount of energy or agitation to aid the mixing of the two immiscible fluids. Crude oil and water emulsions can occur at various stages during drilling, production, transportation and processing of crude oils and in many locations such as in hydrocarbon reservoirs, wellbores, surface facilities, transportation systems and refineries [1]. These immiscible fluids are readily emulsified by the simultaneous action of pressure and shear reduction at the wellhead, valves and chokes [2]. Although, emulsions cannot be easily broken due to the emulsion being stable caused by several factors. Some of the causes of the stability of the emulsion are agitation, the grain size, surfactant, effect of pH, the composition of brine, viscosity, and temperature [3]. Emulsion in the production field can be classified into three types, water in oil (W/O), oil in water (O/W), and complex emulsion (multiple/complex) [3]. Amongst all these types of emulsion, the water in oil emulsion is mostly encountered in the oil and gas industry. Although, Oil in water emulsion is very rare, deliberately produced to reduce the viscosity of highly viscous crude oil so that they can be transported easily through pipelines [4]. Transporting and manufacturing companies do not receive emulsions because it is highly capable of producing a stable composition, unless well treated, leading to many problems, especially in the process of refining [5]. For this reason, it is pertinent that the water present in crude oil be removed or separated from the crude oil. This can be achieved through a process known as demulsification. Demulsification can be defined as a process where an emulsion is broken down into its two components or phases. This can be done using chemical, electrical, mechanical or thermal method of demulsification [6]. Amongst all these methods, the chemical method of demulsification is mostly used due to its cost effectiveness and simplicity by the addition of chemicals. Demulsification can be done in various stages before the emulsion can be broken into its two phases [7]. This includes the stage of flocculation and coalescence. In the stage of flocculation, the water droplets begin to collide due to an increase in temperature. These collisions lead to the formation of aggregates. This does not fully break the emulsion as these water droplets could go back to its individual droplets [8]. The stage that succeeds flocculation after the formation of an aggregate is the stage of coalescence. Here, the aggregates formed from the former stage come together to form a larger droplet that settles at the bottom of the separating vessel. This then separates the emulsion into its different components (water and oil) [9].

Over the years, conventional demulsifier has been used to achieve this goal. But it has its own limitations, as it poses a threat to the environment and marine life when the water separated from the crude oil is disposed [10]. To this effect, locally formulated demulsifiers have come in very handy. This involves the synthesis of active ingredients from locally sourced raw materials [11]. With this connection, a local demulsifier was produced to evaluate the effect of concentration, temperature and speed on the demulsification of water in oil emulsion.

2. MATERIAL AND METHOD

2.1 Material

The materials used for this study are alum, castor oil, locally sourced liquid soap, camphor, sodium chloride, potassium chloride, SLS, distilled water, xylene, sulphuric acid, and commercially available demulsifier (CAD).

2.2 Method

Preparation of Local Demulsifier

30ml of castor oil was measured with a measuring cylinder and poured into a beaker. The beaker was placed on the hotplate stirrer to stir it at 2rpm for 2mins. Afterwards, 12g of camphor was added to the oil and was stirred for 3mins. 5g of alum was added and stirred for 5mins before 50ml of the local liquid soap was added to the entire mixture and stirred for additional 5mins at 5rpm and at 100°C. Table 1 gives a tabular representation of the steps together with the functions of each of the materials.

Table 1 : Materials utilized for the Preparation of the local Demulsifier

S/N	Materials	function	Quantity
1	Castor oil	Lipophilic Agent	30ml
2	Camphor	Solvent for Lipophilic Agent	12g
3	Alum	To facilitate settling of sediments	5g
4	Locally Sourced Liquid Soap	It Serves as a Binder for Hydrophilic and Lipophilic End.	50ml

Preparation of Brine Solution

300ml of water was measured and poured into a beaker. This was placed on the hotplate and stirrer then 7.5g (2.5g /100ml of water) of sodium chloride was added to the mixture and stirred for 1 min at a speed of 5rpm. 1.5g (0.5g /100ml of water) of potassium chloride was added to the mixture and stirred. 3g (1g /100ml of water) of SLS was also added to the entire mixture and it was stirred for 5 min to ensure that they are well mixed at 5 rpm at 25°C. Table 2 represents the tabular representation of all the materials used and its quantity.

Table 2: Materials utilized for the preparation of brine solution

S/N	Material/Apparatus	Quantity
1	Sodium chloride (Nacl)	7.5g (2.5g/100ml of water)
2	Potassium chloride (Kcl)	1.5g (0.5g /100ml of water)
3	SLS	3g (1g /100ml of water)
4	water	300ml

Preparation of Crude Oil Emulsion

200ml of crude oil was measured and transferred into a beaker. Then 300ml of the brine solution was then added to the crude oil and the entire mixture was placed on a hotplate stirrer where it was set to stir the mixture at 10rpm for 15mins at 25°C. After thorough mixing, the mixture was placed in a separating funnel where it was allowed to settle for 48 hours under room temperature and the volume of free water gotten was measured and recorded. The volume of entrapped water in the crude oil was measured by subtracting the volume of free water from the original volume of water.

Table 3: Materials utilized for the Preparation of Emulsion

S/N	Materials	Quantity
1	Crude Oil Sample	200ml
2	Brine solution	300ml



Fig. 1. The emulsion prepared

Physiochemical Properties of the Crude Oil

The Specific Gravity, API Gravity, Viscosity, density and temperature tests were conducted on the crude oil. The density test was conducted using the density bottle and the viscosity test was done using the Ostwald viscometer. The following formulas were used to calculate the density, API, specific gravity and viscosity:

$$Density_{oil} = \frac{Weight_{oil+bottle} - Weight_{bottle}}{Volume_{oil}} \quad (1)$$

$$Specific\ Gravity_{oil} = \frac{Density_{oil}}{Density_{water}} \quad (2)$$

$$API^{\circ}@Temperature = \frac{141.5}{Specific\ Gravity} - 131.5 \quad (3)$$

$$\mu_{absolute} = \mu_{kinematic} * T_{avg} \quad (4)$$

Demulsification

The demulsification process was done using the bottle test method. Here, the 50ml of emulsion to be broken is poured into the 4 centrifuge test tubes where varying concentration of the four demulsifiers will be added to assess the performance of the demulsifier at various temperatures and time. The four demulsifiers that was used for this experiment consist of three conventional demulsifiers; xylene, sulphuric acid and commercially available demulsifier (CAD), and one local demulsifier. The proposed time interval, concentration and temperature to be used for this experiment can be shown in table 4.

Table 4: Proposed time, Concentration and Temperature

S/N	Concentration	Temperature	Time
1	0.2ml	30°C	5min
2	0.4ml	60°C	10min
3	0.6ml	90°C	15min

3. RESULTS AND DISCUSSION

3.1 Physiochemical Evaluation

Table 5 shows the results gotten from the experiments conducted to know the physiochemical properties of the crude oil and emulsion.

Table 5: Physiochemical Properties of the Crude Oil and emulsion

S/N	Properties	Values
1	Crude oil Emulsion API	33.23
2	Crude oil Emulsion Viscosity	2.732
3	Pure Crude Oil API	33.99
4	Pure Crude Oil Viscosity	4.421
5	Specific gravity / density of crude oil	0.855
6	Specific gravity / density of emulsion	0.859
7	Temperature	32°C

From the above results, it can be seen that the API gravity of the crude oil was 33.99 meaning the crude oil is a light crude. The drop in API gravity from 33.99 to 33.23, when water was present shows us the effect of oil present and how it can reduce the quality of the crude oil, and of course, the price as well. From the viscosity of the crude oil and emulsion, it dropped from 4.421 to 2.732. The drop in the viscosity also shows the presence of water molecules in the crude oil. There was also a drop in the density showing that the presence of water has made the crude oil less dense than usual.

3.2 Demulsification performance

Table 6 to table 9 shows the demulsification performance of 0.2ml and 0.4ml of xylene (XY), local demulsifier (DEF), commercially available demulsifier (CAD) and sulphuric acid (SO₄) at 1000rpm-30°C and 1000rpm-60°C. The table also shows the quantity of water separated (ml) after 5mins, 10mins and 15mins of observation time.

From the plots and the tables below, it was observed that at 1000RPM, 30°C, and at 0.2ml, the quantity of water separated from the emulsion increased as the time interval increased. This is in line with the study of ^[4]. A further increase in temperature and concentration had a higher water efficiency. This observation is in line with the theories governing the demulsification as an increase in concentration and temperature will lead to an increase to the volume of water removed. This is in line with the study of ^[3].

Table 6: Volume of water separated at 30°C at 0.2ml

1000RPM 30°C 0.2ML				
Time	XY	DEF	CAD	SO-4
5	0.25ml	0.7ml	2ml	2ml
10	0.5ml	1.2ml	2.4ml	2.6ml
15	1.0ml	1.7ml	2.8ml	2.6ml

Table 7: volume of water separated at 60°C at 0.2ml

1000RPM 60°C 0.2ML				
Time	XY	DEF	CAD	SO-4
5	1ml	2ml	2.8ml	2.8ml
10	1ml	2.1ml	3ml	2.8ml
15	1.2ml	2.4ml	3ML	2.8ml

Table 8: volume of water separated at 30°C at 0.4ml

1000RPM 30°C 0.4ML				
Time	XY	DEF	CAD	SO-4
5	1.5ml	2ml	3ml	2.8ml
10	1.7ml	2ml	3ml	2.8ml
15	1.75ml	2ml	3ml	3ml

Table 9: volume of water separated at 60°C at 0.4ml

1000RPM 60°C 0.4ML				
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Time	XY	DEF	CAD	SO-4
5	1.4ml	2.2ml	3ml	2.8ml
10	1.4ml	2.3ml	3.1ml	2.85ml
15	1.4ml	2.4ml	3.1ml	3ml

The following plots shows the diagrammatical representation of the water removal efficiency of the four demulsifiers used.

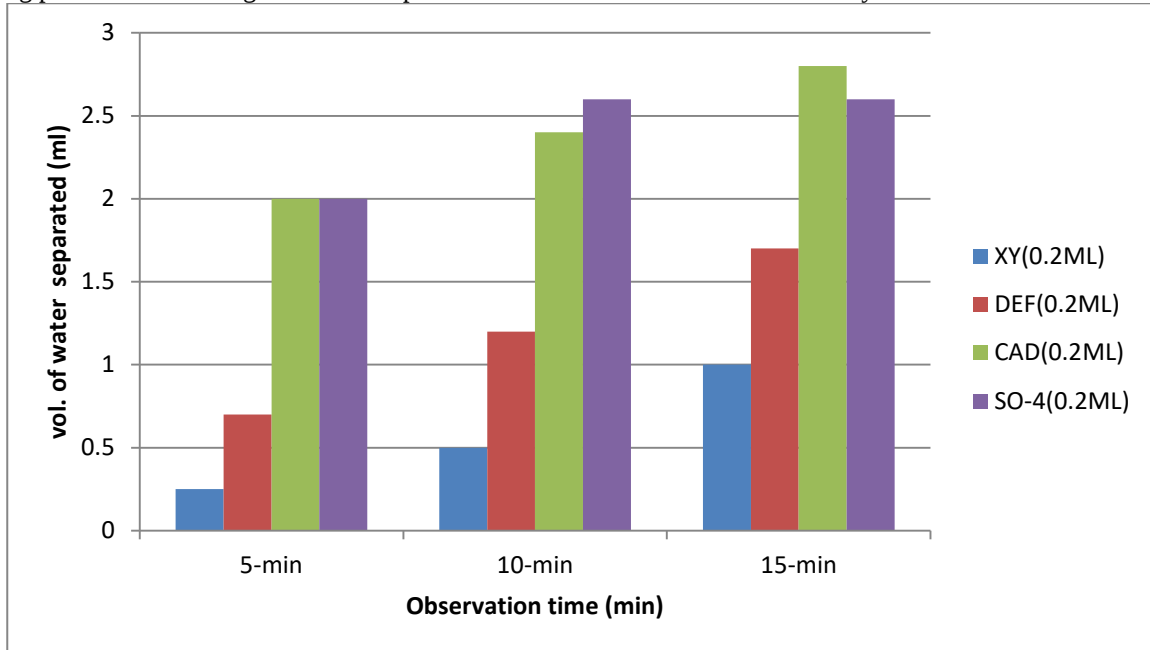


Fig. 2. Demulsification Performance of Selected Demulsifier at 1000RPM, 30°C and 0.2ml concentration

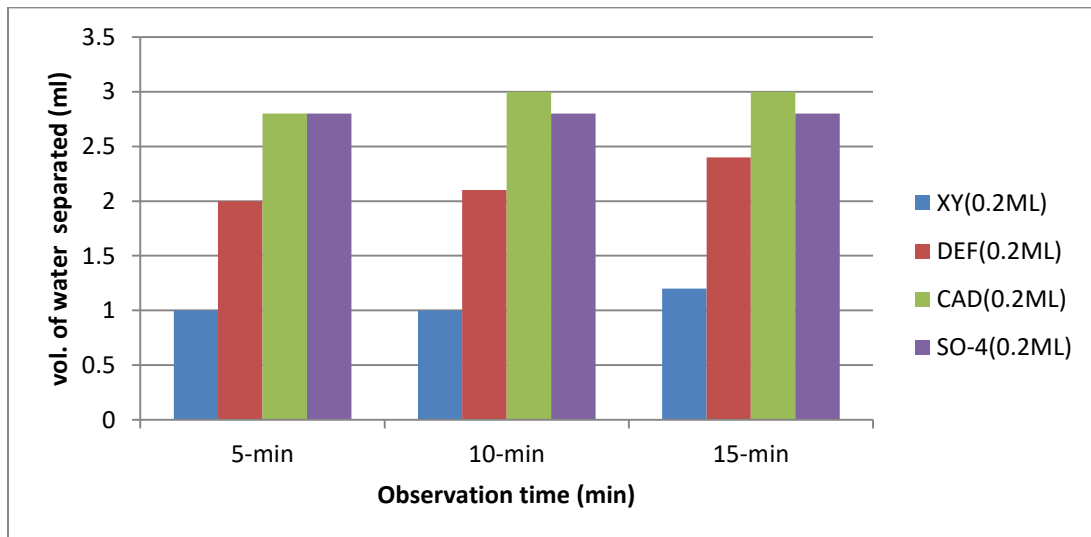


Fig. 3. Demulsification Performance of Selected Demulsifier at 1000RPM, 60°C and 0.2ml concentration

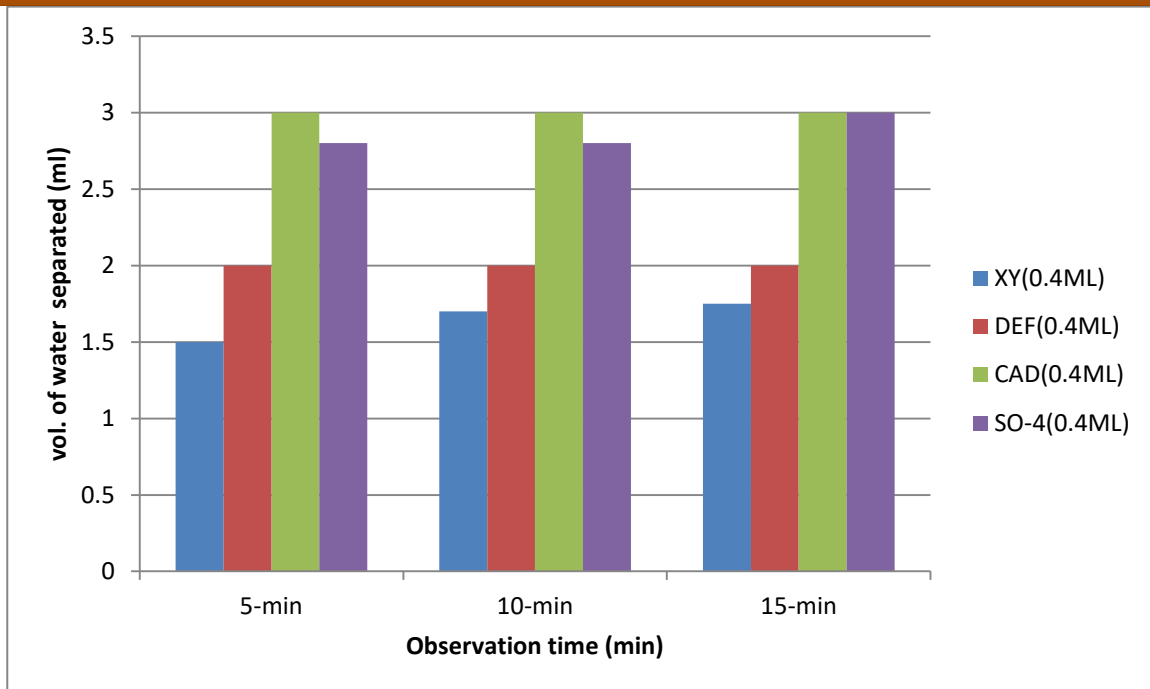


Fig. 4. Demulsification Performance of Selected Demulsifier at 1000RPM, 30°C and 0.4ml concentration

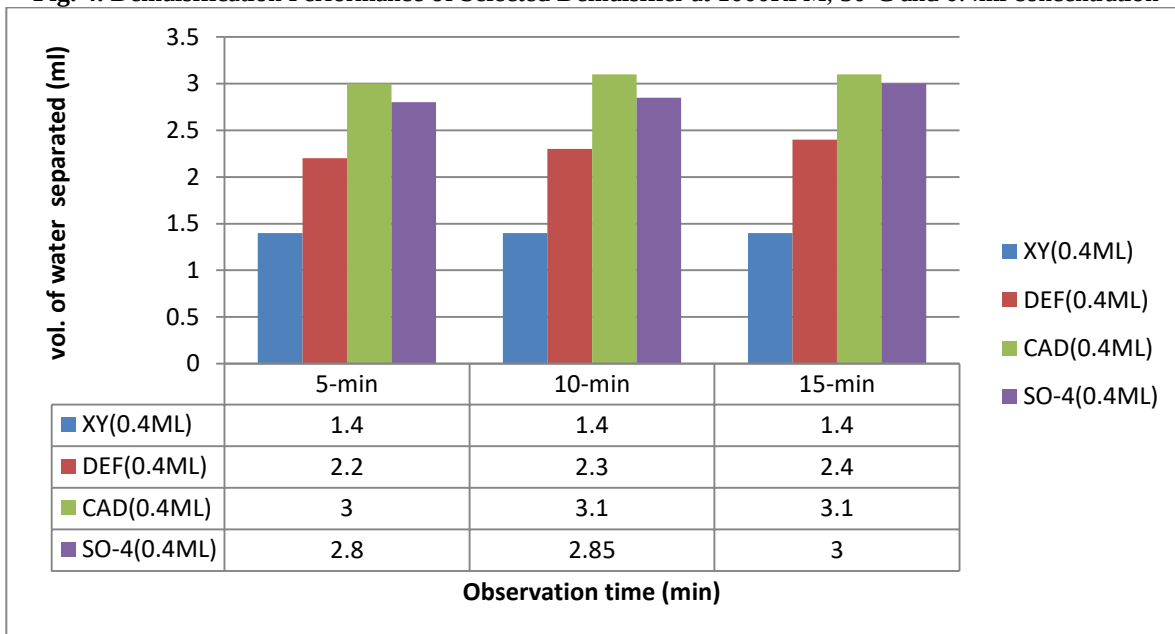


Fig. 5. Demulsification Performance of Selected Demulsifier at 1000RPM, 60°C and 0.4ml concentration

3.3 Economic analysis

Based on the performance of the four demulsifiers, an economic analysis was conducted to show the economic viability of each demulsifiers to see which would yield more profit with time. The economic parameters considered for this analysis are:

1. **Net Present Value (NPV):** NPV measures the net monetary value that is generated by an investment after accounting for the time value of money. It is calculated by summing the discounted cash flows over the project's life span and subtracting the capital expenditure (CAPEX). The present value of the projected cash flows is discounted at a 10% rate. The formula for this can be written as:

$$NPV = \sum \frac{cashflow}{(1+i)^t} - initial\ investment \quad (5)$$

Where: i is discount rate

t is number of years

initial investment = CAPEX when t=0

2. **Internal Rate of Return (IRR):** IRR represents the discount rate at which the Net Present Value becomes zero. A higher IRR reflects a more desirable investment, as it indicates greater profitability relative to the capital invested. This can be written mathematically as:

$$NPV=0 \quad (6)$$

OR

$$\sum \frac{cashflow}{(1+i)^t} - initial\ investment = 0$$

3. **Payback Period:** This refers to the number of years required to recover the initial cost of investment from cumulative cash flows. A shorter payback period is generally preferred, as it reduces investment risk.
4. **Profitability Index (PI):** PI measures the relative value generated per dollar invested. The project is considered profitable when the P.I value is greater than one, break even when the value of P.I equals 1, and non-profitable when its less than 1^[12]. That is a higher PI indicates a more efficient investment. This can be written mathematically as:

$$P.I = \frac{NPV}{initial\ investment} \quad (7)$$

Assumptions:

The assumptions made to aid the calculations of this analysis will be summarized in the table10 below:

Table 10: various assumptions made

Initial volume of oil	10,000bbl
OPEX	Cost of demulsifiers
Production duration	15 years
CAPEX	\$30,000,000
Price of oil	\$60/bbl
Discount rate	10%

The respective cost of the local and conventional demulsifiers will be summarized in table 11 and table 12.

Table 11: Cost of the Conventional Demulsifiers

S/N	Material	Quantity	Cost	Scaled cost (0.1ml)	Dollar equivalent (\$)
1	Commercially Available Demulsifier (CAD)	2500ml	6,125	0.245	0.00015312
2	Sulphuric acid	2500ml	21,500	0.86	0.0005375
3	Xylene	2500ml	14,000	0.56	0.00035

Table 12: cost of formulating the local demulsifier

S/N	Material	Quantity	Cost (Naira)	Scaled cost (Naira)	Form. Conc.	Final cost (Naira)
1	Alum	20g	300	15	5g	75
2	Camphor	30g	400	13.333	12g	159.996
3	Liquid soap	1000ml	1500	1.5	50ml	75
4	Castor oil	1000ml	5000	5	30ml	150
Total cost= 459.996 or \$0.2874						

By simulating the crude oil production process and associated cash flows, the study provides a quantitative framework for identifying the most cost-effective demulsifier. Additionally, this study considers essential factors such as concentration, material costs, and market-driven parameters like oil price and discount rate. The economic performance of each demulsifier is summarized in the following bar charts:

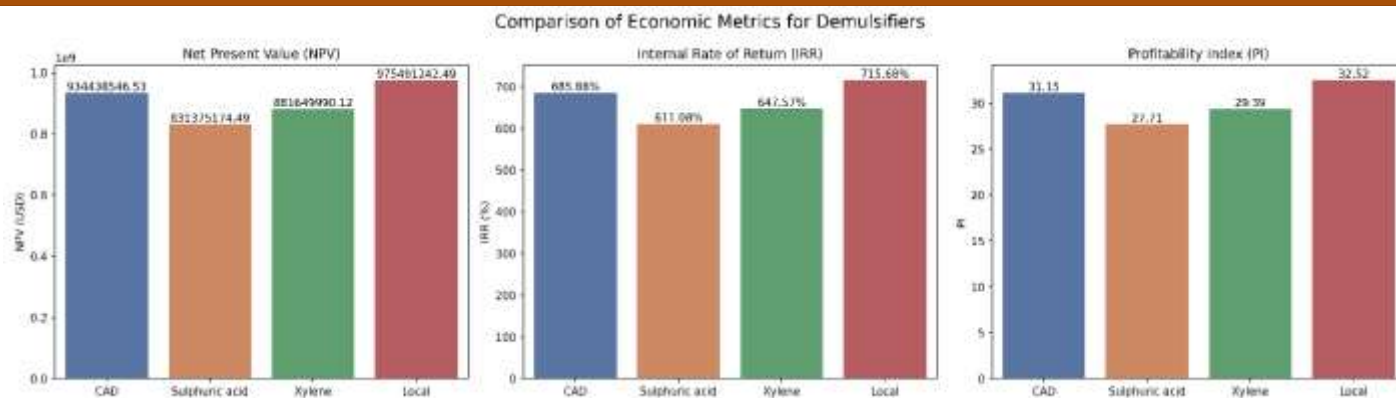


Fig. 6. Plot of the Economic Metrics for the Demulsifiers

From the visual analysis, the local demulsifier outperforms the three conventional options in most economic metrics, indicating its potential to generate greater profitability over the project's lifespan. From the NPV plot, the Local Demulsifier Achieves the highest NPV of \$975,491,242.49, signifying a substantial long-term benefit and its ability to generate greater cumulative cash flow. The Commercially Available Demulsifier (CAD) Secures the second-highest NPV of \$934,438,546.53, also reflecting strong economic feasibility. From the IRR plots, the Local Demulsifier Exhibits the highest IRR at 715.68%, highlighting its remarkable ability to deliver returns and implies that the local demulsifier stands out as the most profitable option. Commercially Available Demulsifier (CAD) Shows an IRR of 685.88%, also reflecting a highly attractive investment. All four demulsifiers achieves a payback period of 1 year, reflecting the strong cash flows generated in the initial stages of the project. From the production index plot, the Local Demulsifier Achieves the highest PI of 32.52, indicating the most value per dollar invested. This implies that the local demulsifier excels in generating the highest relative value, affirming its cost-effectiveness. The Commercially Available Demulsifier (CAD) recorded a PI of 31.15 positions it as the second-best option. All these can be summarized in table 13:

Table 13: Summary of Economic Parameters

Summary of economic parameters				
Demulsifier	NPV (USD)	IRR (%)	Payback Period (Years)	Profitability Index (PI)
CAD	\$934,438,546.53	685.88	1	31.15
Sulphuric Acid	\$831,375,174.49	611.08	1	27.71
Xylene	\$881,649,990.12	647.57	1	29.39
Local Demulsifier	\$975,491,242.49	715.68	1	32.52

4. Conclusion

From the experimental study, the following conclusion can be drawn:

- (1) From the API gravity of the crude, the crude oil is a light crude
- (2) From the API gravity of the emulsion, the presence of water reduces the API gravity of the oil, thus reducing its quality
- (3) From the demulsification experiment, at varying temperature, an increase in temperature leads to an increase of the volume of water separated.
- (4) Amongst all the demulsifiers, CAD recorded the best results of yielding high volume of water compared to others.
- (5) From the demulsification experiment, at varying concentration, an increase in concentration yields to an increase of the volume of water separated.

- (6) At 1000RPM, 60^oC and 0.4ml concentration, Commercially Available Demulsifier (CAD) recorded the highest result of separating 3.1ml of water
- (7) The local demulsifier is the most economically viable option, with the highest NPV, IRR, and PI. While all demulsifiers are profitable, the local demulsifier outperforms its conventional counterparts, providing the greatest economic advantage over the project's lifespan.

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Authors



Anthony Ogbagbe Chikwe, is a senior lecturer in the department of Petroleum Engineering, Federal University of Technology, Owerri. He holds both BSc. and MSc. degree in Petrochemical Engineering from the University of Oil and Gas Moscow. He also holds Post graduate certificate in advance studies in academic practice from Newcastle University upon Tyne, UK and Ph.D degree in Petroleum Engineering from the Federal University of Technology, Owerri. His research interests are in Production, Reservoir, Natural Gas and Drilling Engineering. He is also a fellow of the Higher Education Academy, UK.



Christian Emelu Okalla, is a Technologist and Researcher at the Department of Petroleum Engineering, Federal University of Technology Owerri, Nigeria. He holds both B.Eng and M.Eng in Petroleum Engineering from the Federal University of Technology Owerri. His research interests are in drilling engineering, production engineering, natural gas engineering, reservoir engineering, and reservoir simulation.



Ihuoma Andra Oluomachi, is a graduate from the department of petroleum engineering, Federal University of Technology Owerri. Her research interest is in drilling, production and reservoir engineering.