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RESEARCH

Utilizing Jatropha Oil as a Gap Filler for Energy Balance in Sudan's Reconstruction: Case Study of Fula North East Heavy Crude Oil

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ABSTRACT

PURPOSE: The purpose of this paper is to demonstrate how jatropha oil can be used to reduce the viscosity of Sudanese heavy crude oil with the intention of increasing the throughput and fill a gap following the depletion of conventional oil fields in Sudan.

DESIGN: The paper is both research and a case study that examines the impact of jatropha oil on the viscosity of heavy crude oil. The case study shows how the viscosity of Fula North East (FNE) heavy crude oil can be reduced by using jatropha oil as a diluent.

RESEARCH LIMITATIONS: Being lab-based, research is limited by controlled conditions that may not reflect real-world complexities, scalability challenges, and constrained sample sizes or timeframes. Results may lack generalisability and require field validation. Instrument precision and model assumptions can further affect accuracy and applicability.

FINDINGS: As far as viscosity reduction for FNE Heavy Crude oil is concerned, the performance of jatropha oil proved to be the best among all solvents, including hydrocarbon solvents.

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ORIGINALITY: This is an original paper based on lab-based doctoral research of novel experiments, unique methodologies and new findings under controlled conditions. It introduces innovative approaches that provide first-time insights into specific scientific questions. Such work contributes significantly to advancing knowledge, even if conducted on a small scale.

IMPLICATIONS: Jatropha oil can provide a global solution for flow assurance problems concerning crudes that are similar in properties of FNE Heavy Crude Oil and can be utilised as an effective solvent for viscosity reduction purpose.

KEYWORDS: *Jatropha Oil; Biofuel; Energy Security; Sudan Reconstruction; Produced Water; Carbon Sink; Renewable Energy; Post-war Recovery.*

PURPOSE

With rising global energy demand, heavy crude oil's high viscosity poses a flow assurance challenge. This project aims to replace chemical additives with jatropha oil, an effective biofuel, to reduce viscosity and improve extraction and transport. Utilising produced water from Sudanese oil fields for jatropha cultivation supports this goal. Cold pressing is a recognised method for extracting jatropha oil, a proven biodiesel source (Ruatpuia *et al.*, 2024).

A wide range of bio-fuels, including biodiesel, can be obtained by pyrolysis of suitable biomass; extracting jatropha oil by cold pressing technology is a well-recognised process (Kiran *et al.*, 2014).

This study explores the potential of using jatropha oil as an alternative biofuel to support Sudan's energy needs during post-war reconstruction. The aim is to utilise produced water from oil fields to cultivate jatropha, bridging the energy gap while contributing to environmental sustainability and carbon dioxide reduction. With ample produced water, jatropha cultivation can yield surplus biodiesel, usable in standard engines. After oil field depletion, facilities could shift to biofuel production, an innovative environmental model. This study proposes jatropha oil as a sustainable energy solution for Sudan's post-war recovery, leveraging produced water to close the energy gap and cut CO_2 emissions.

Fula North East (FNE) Field holds 311.1 MMSTB (million stock tank barrels) of oil, with a 36.65% recovery factor, yielding an estimated 113.39 MMSTB. At a current output of 7,500 barrels of oil per day (BOPD), the field's lifespan is about 42 years. Addressing throughput constraints could boost production, accelerating revenue generation, vital for Sudan's post-war economic recovery and a much-needed fund for a nation emerging from a destructive war status.

DESIGN/METHODOLOGY/APPROACH

The research adopts an applied scientific approach, combining literature review, field data, and experimental insights from prior doctoral work. It evaluates the feasibility of jatropha plantations using produced water, assesses oil yield potential and analyses integration into existing energy infrastructure.

Description of Methodology

This study evaluates five diluents, three hydrocarbons (light crude, naphtha, kerosene) and two non-hydrocarbons (ethanol and jatropha oil) for reducing heavy crude oil viscosity. Literature suggests that up to 20% diluent by volume is needed to meet transport standards.

Experiments were conducted to assess solvent performance, with concentrations ranging from 0% (blank) to 30% in 5% intervals. Viscosity measurements were taken at temperatures between 65˚C and 20˚C for each concentration.

The laboratory experiment involves diluting crude oil with various solvents (naphtha, kerosene, light crude oil, ethanol, and jatropha oil) to measure the viscosity using a Brookfield RV-DV1 viscometer. The goal is to investigate the impact of different diluents on crude oil viscosity, with tests conducted at various concentrations and temperatures.

Preparation of Samples

A total of 5 litres of pure liquids (crude oil, naphtha, bioethanol, jatropha) were collected for the experiments. Dynamic viscosities of all samples at 50°C were measured and registered.

Apparatus

Viscosity measurements were performed using the latest version of a Brookfield digital viscometer at a renowned laboratory (Central Petroleum Laboratories).

Procedure:

Experiment procedure for viscosity measurement was as follows:

1. An homogenised sample of heavy crude oil was prepared by thoroughly stirring.
2. The viscosity of the pure heavy crude oil sample was measured using the viscometer (measurements were repeated until three successive values coincided), at a shear rate of $5S^{-1}$.
3. The viscosity for pure heavy crude oil was measured, starting at 20°C all the way to 65°C: this is the blank viscosity temperature profile.
4. The first solvent was blended thoroughly with the heavy crude oil in a ratio of 5% solvent and 95% heavy crude oil by volume. The measurement was carried out as per Step 3 above.

5. The blending and viscosity measurements (from 20℃ to 65℃) were carried out for blending ratios of 10%, 15%, 20% ,25% and 30% solvent by volume.
6. The measurement results of the viscosity profile were recorded for each blending ratio in tabulated form.
7. Steps 4, 5 and 6 above were repeated for all solvents.
8. All laboratory results for viscosity profiles for all experiments were tabulated for further analyses, evaluation and discussions.

Data Analysis

Laboratory results data were analysed by application of the analysis of variance (ANOVA) technique ($p \leq 0.05$).

Findings

Jatropha oil has strong potential as a supplementary energy source, particularly in arid regions where it can be grown using produced water, minimising freshwater use. The study shows that jatropha biodiesel can be blended with conventional fuels, offering a significant reduction in Sudan's reliance on fossil fuel imports.

First Hand Laboratory Results

The viscosity profile was tabulated for the blank specimen, Fula North East Heavy Crude Oil; the results are tabulated in Table 1. The temperature ranges from 20℃ to 65℃, the viscosity is measured in cp at shear rate of $5S^{-1}$:

Table 1: International Organisation Funded Gum Arabic Sector in the Area

Temp. (℃)	*Viscosity (in cp)*
20	4,093.26
25	3,360.63
30	2,759.08
35	1,760.97
40	1,189.70
45	799.83
50	584.75
55	433.52
60	332.70
65	272.21

Source: Author's own data

The research crude Fula North East Heavy Crude Oil (FNE HCO) was tested for viscosity; Figure 1 shows the viscosity profile for the blank:

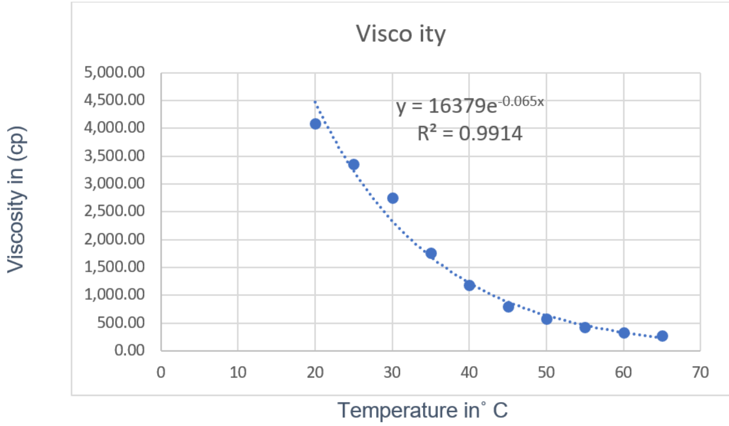

Figure 1: Viscosity Profile for Fula North East Heavy Crude Oil
Source: Author's own data

The performance of jatropha oil as a solvent for FNE Heavy crude oil is illustrated in Table 2 where the viscosity is measured in cp at shear rate of $5S^{-1}$.

Table 2: Fula North East HCO Viscosity Profile at different blend ratios with Jatropha

Temp. (°C)	Viscosity at Blank (in cp)	Viscosity at 5% Blend (in cp)	Viscosity at 10% Blend (in cp)	Viscosity at 15% Blend (in cp)	Viscosity at 20% Blend (in cp)	Viscosity at 25% Blend (in cp)
20	4,093.26	3,595.78	3,612.67	2,228.10	1,680.31	205.00
25	3,360.63	3,048.09	2,244.90	1,394.66	1,092.20	144.51
30	2,759.08	1,982.77	1,465.23	934.25	746.06	114.26
35	1,760.97	1,290.48	984.66	651.96	514.18	87.38
40	1,189.70	887.21	688.93	457.05	379.75	67.21
45	799.83	621.72	480.57	329.34	278.93	53.77
50	584.75	460.41	356.23	248.69	211.72	43.69
55	433.52	342.78	268.85	194.92	164.67	40.33
60	332.70	268.85	211.72	168.03	137.79	36.97
65	272.21	231.88	174.75	154.59	127.70	23.52

Source: Compiled by the author

The summary shown in Table 3 shows the competitive rank of jatropha oil among the solvents; it is second in rank in terms of volumetric percentage and optimum temperature.

Table 3: Ranking of Jatropha Oil as a Solvent among other Solvents

Solvent	*Blending Percentage (%)*	*Temperature ˚C*
Ethanol	20	47
Naphtha	5	46
Kerosene	5	48
Light Crude Oil	15	48
Jatropha Oil	10	47

Source: Compiled by the author

As it can be seen from Table 3, the performance of jatropha oil is ranked right next to the light expensive hydrocarbon solvents and performs better than light crude oil and ethanol.

At a fixed landing temperature of 40°C and a target viscosity of 1000cp (design requirement for Khartoum refinery), 20% below the baseline at 50-56°C without blending, jatropha oil ranks just below costly light hydrocarbon solvents and outperforms light crude oil in reducing viscosity.

It is evident that diluting heavy crude at 40°C is more cost-effective than heating it to 50°C to meet viscosity requirements for safe pipeline operation under maximum allowable operating pressure (MAOP) constraints.

At 15% blending and 40°C, jatropha oil reduces heavy crude viscosity by 61.58%, outperforming light crude and ethanol, and ranking just below naphtha and kerosene. The resulting viscosity (457.05cp) is well below the pipeline's minimum flow threshold (500cp), proving jatropha's strong efficiency as a diluent.

Figure 2 shows the viscosity profiles of the five solvents blended with Fula North Heavy Crude at 20% ratio and a shear rate of $5S^{-1}$. Jatropha oil outperforms ethanol, which ranks lowest, and shows improved performance with higher blending. Light crude ranks just above ethanol.

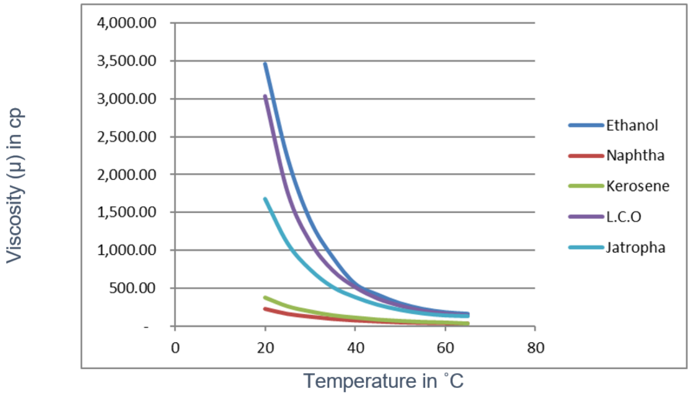

Figure 2: Viscosity Profile for Different Solvents @20% Blending Vs Temperature at Shear Rate of 5 S^{-1}

Source: Author's own data

Correlation of Parameters at Different Dilution Ratios

Correlation of volume versus fixed temperature – jatropha oil effect

Table 4 shows the correlation between viscosity and the volume percentage of jatropha oil blended with heavy crude oil at various temperatures from 20°C to 65°C. The strong logarithmic correlation (R^2 ranging from 0.994 to 0.8417) indicates that jatropha oil effectively reduces viscosity as its volume in the blend increases at a fixed temperature. The viscosity reduction decreases with higher jatropha oil volumes, with a consistent reduction starting at a 15% jatropha oil blend.

Table 4: Jatropha Oil Blend Viscosity Correlation at Different Temperatures

Temperature (˚C)	*Correlation Equation*	*R^2*
20	$\mu = -1678Ln(X) - 997.18$	0.8417
25	$\mu = -1471Ln(X) - 1299$	0.9891
30	$\mu = -933.5Ln(X) - 777.11$	0.99
35	$\mu = -591Ln(X) - 446.26$	0.9875
40	$\mu = -671Ln(X) - 688.9$	0.9535
45	$\mu = -258.5Ln(X) - 142.18$	0.9884
50	$\mu = -187.5Ln(X) - 94.235$	0.9897
55	$\mu = -134.5Ln(X) - 54.111$	0.9909
60	$\mu = -98.25Ln(X) - 20.927$	0.994
65	$\mu = -76.48Ln(X) +2.7894$	0.9911

Source: Compiled by the author

Correlation of fixed volume vs temperature – jatropha oil effect:

Table 5 demonstrates the correlation of volume versus temperature showing the viscosity profile for a kerosene blend of 5% to 25% with Fula North Heavy Oil for temperatures between 20˚C and 65˚C. The exponential correlation factor (R^2) indicates that the relationship is quite strong (R^2 ranges between 0.9879 and 0.9703).

This means that the trend of viscosity profile for jatropha oil blend with Fula North East Heavy Crude Oil shows a reduction of viscosity upon increase of temperature, while the pattern shows that the percentage in the viscosity reduction decreases with the increase of temperature. It is significantly noted that percentage of viscosity reduction is more at low temperatures (20˚C to 35˚C), indicating good performance of jatropha oil at low temperatures.

Table 5: Jatropha Oil Blend Viscosity Correlation at Different Volumetric Ratios

Volumetric Ratio (X %)	Correlation Equation	R^2
5	$\mu = 13303e^{-0.065T}$	0.9879
10	$\mu = 11465e^{-0.067T}$	0.9856
15	$\mu = 5908.4e^{-0.06T}$	0.9703
20	$\mu = 4411.9^{e-0.058T}$	0.976
25	$\mu = 2426.1e^{-0.052T}$	0.9772

Source: Compiled by the author

Modelling

Viscosity reduction is the driving element for this research and in order to compare the jatropha oil with other solvents the modelling was carried out bearing in mind the most appropriate correlation type. The modelling was carried out for all solvents using the SPSS computer program and the results were thoroughly evaluated. The research revealed that jatropha oil is the best performing solvent among all solvents, including naphtha.

The driving in SPSS

The driving interpretation element is ANOVA, a statistical test that was developed by Ronald Fisher in 1918 and has been in use ever since. ANOVA tells exactly if there are any statistical differences between the means of three or more independent groups (Cronk, 2018).

There was a choice to use either the Ln-Ln correlation or Ln-Linear correlation; the Ln-Linear correlation proved to be the appropriate one.

Log-Log model regression

This model was carried out for pure FNE Heavy Crude Oil data. The ANOVA test showed that the residual is 0.03 (highlighted in yellow).

Descriptive Statistics (Ran by author)

	Mean	Std. Deviation	N
hco_ln	6.9456	0.94557	50
temp_ln	3.6855	0.37349	50

Correlations

		hco_ln	temp_ln
Pearson Correlation	hco_ln	1.000	-0.983
	temp_ln	-0.983	1.000
Sig. (1-tailed)	hco_ln	.	0.000
	temp_ln	0.000	.

		hco_ln	temp_ln
N	hco_ln	50	50
	temp_ln	50	50

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	temp_lnb	.	Enter

a. Dependent Variable: hco_ln
b. All requested variables entered

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.983a	0.967	0.966	0.17410	0.899

a. Predictors: (Constant), temp_ln
b. Dependent Variable: hco_ln

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	42.356	1	42.356	1397.382	0.000[b]
	Residual	1.455	48	0.030		
	Total	43.811	49			

a. Dependent Variable: hco_ln
b. Predictors: (Constant), temp_ln

Coefficients[a]

Model	Unstandardised Coefficients		Standardised Coefficients	t	Sig.	95.0% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
1 (Constant)	16.120	0.247		65.354	0.000	15.624	16.616
temp_ln	-2.489	0.067	-0.983	-37.382	0.000	-2.623	-2.355

a. Dependent Variable: hco_ln

Log-Linear Model Regression

This model was carried out for pure FNE Heavy Crude Oil data. The ANOVA Test showed that the residual is 0.008 (highlighted in yellow). No doubt the log -linear model is more accurate compared with the log -log model.

	Mean	Std. Deviation	N
hco_ln	6.9456	0.94557	50
temp	42.5000	14.50721	50

Correlations

		hco_ln	Temp.
Pearson Correlation	hco_ln	1.000	-0.996
	temp	-0.996	1.000
Sig. (1-tailed)	hco_ln	.	0.000
	temp	0.000	.
N	hco_ln	50	50
	Temp.	50	50

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Temp[b]	.	Enter

a. Dependent Variable: hco_ln

b. All requested variables entered

Model Summary (Compiled by the author)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.996a	0.991	0.991	0.08858	1.496

a. Predictors: (Constant), temp.

b. Dependent Variable: hco_ln

Coefficients*

Model	Unstandardised Coefficients		Standardised Coefficients	t	Sig.	95.0% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
1 (Constant)	9.704	0.039		247.979	0.000	9.625	9.782
Temp.	-0.065	0.001	-0.996	-74.400	0.000	-0.067	-0.063

a. Dependent Variable: hco_ln

Based on the ANOVA analysis, the log linear regression model for the viscosity reduction was carried out for all solvents and the results were tabulated using SPSS software.

Model Correlations for Viscosity Reduction

Ethanol models for viscosity reduction (at different blend concentrations – Table 6)

Linear model formula as: $\mathrm{Ln}(\mu) = \alpha + \beta T_i$

Where: μ is the viscosity of the mixture, T is the temperature

Table 6: Log-Linear Correlation Model for Ethanol Viscosity Reduction

Blend %	R^2	Residuals Mean Square	F	Prediction Equation	Standardised Beta	Optimum Temp. (C°)	Viscosity Reduction (%)
5	0.987	0.017	594.087	$Ln(\mu) = 9.547-0.070T_i$	-0.993	**55**	**37.98**
10	0.978	0.031	361.466	$Ln(\mu) = 9.604-0.073T_i$	-0.989	50	52.87
15	0.984	0.023	502.191	$Ln(\mu) = 9.425-0.075T_i$	-0.992	55	57.37
20	0.976	0.031	323.405	$Ln(\mu) = 9.348-0.070T_i$	-0.988	40	53.11
25	0.985	0.024	515.793	$Ln(\mu) = 9.330-0.078T_i$	-0.992	60	67.68

Source: Compiled by the author

Naphtha models for viscosity reduction (at different blend concentrations – Table 7)

Linear model formula as: $Ln(\mu) = \alpha + \beta\ T_i$

Where: μ is the viscosity of the mixture, T is the temperature.

Table 7: Log-Linear Correlation Model for Naphtha Viscosity Reduction

Blend %	R^2	Residuals Mean Square	F	Prediction Equation	Standardised Beta	Optimum Temp. (C°)	Viscosity Reduction (%)
5	0.966	0.032	225.984	$Ln(\mu) = 8.842-0.060T_i$	-0.983	30	59.56
10	0.971	0.022	268.375	$Ln(\mu) = 7.789-0.054T_i$	-0.985	30	82.83
15	0.989	0.007	749.367	$Ln(\mu) = 7.298-0.052T_i$	-0.995	**30**	**89.16**
20	0.969	0.014	246.212	$Ln(\mu) = 6.095-0.041T_i$	-0.984	30	95.37
25	0.967	0.014	235.222	$Ln(\mu) = 5.619-0.040T_i$	-0.983	30	97.08

Source: Compiled by the author

Light crude oil models for viscosity reduction (at different blend concentrations – Table 8)

Linear model formula as: $Ln(\mu)= \alpha + \beta\ T_i$

Where: μ is the viscosity of the mixture, T is the temperature.

Table 8: Log-Linear Correlation Model for Light Crude Oil Viscosity Reduction

Blend %	R^2	Residuals Mean Square	F	Prediction Equation	Standardised Beta	Optimum Temp. (C°)	Viscosity Reduction (%)
5	0.977	0.024	334.090	$Ln(\mu) = 9.453-0.62T_i$	-0.988	30	23.75
10	0.989	0.012	721.892	$Ln(\mu) = 9.555-0.066T_i$	-0.995	**30**	**25.21**
15	0.979	0.026	365.596	$Ln(\mu) = 9.309-0.068T_i$	-0.989	30	44.57
20	0.976	0.029	329.623	$Ln(\mu) = 9.110-0.068T_i$	-0.988	30	59.68
25	0.958	0.047	184.620	$Ln(\mu) = 8.935-0.065T_i$	-0.979	30	62.97

Source: Compiled by the author

Kerosene models for viscosity reduction (at different blend concentrations – Table 9)

Linear model formula as: $Ln(\mu) = \alpha + \beta\ T_i$

Where: μ is the viscosity of the mixture, T is the temperature.

Table 9: Log-Linear Correlation Model for Kerosene Viscosity Reduction

Blend %	*R^2*	*Residuals Mean Square*	*F*	*Prediction Equation*	*Standardised Beta*	*Optimum Temp. (C°)*	*Viscosity Reduction (%)*
5	0.972	0.030	277.525	$Ln(\mu) = 9.66\text{-}0.64T_i$	-0.986	30	54.93
10	0.975	0.021	311.442	$Ln(\mu) = 8.232\text{-}0.057T_i$	-0.987	30	75.76
15	0.973	0.019	291.714	$Ln(\mu) = 7.489\text{-}0.051T_i$	-0.987	30	86.36
20	0.991	0.006	910.117	$Ln(\mu) = 6.825\text{-}0.051T_i$	-0.996	**30**	**93.06**
25	0.978	0.011	361.969	$Ln(\mu) = 6.065\text{-}0.044T_i$	-0.989	30	95.86

Source: Compiled by the author

Jatropha oil models for viscosity reduction (at different blend concentrations – Table 10)

Linear model formula as: $Ln(\mu)= \alpha + \beta\ T_i$

Where: μ is the viscosity of the mixture, T is the temperature.

Table 10: Log-Linear Correlation Model for Jatropha Oil Viscosity Reduction

Blend %	*R^2*	*Residuals Mean Square*	*F*	*Prediction Equation*	*Standardised Beta*	*Optimum Temp. (C°)*	*Viscosity Reduction (%)*
5	0.988	0.013	652.803	$Ln(\mu) = 9.496\text{-}0.065T_i$	-0.994	30	28.14
10	0.986	0.017	547.055	$Ln(\mu) = 9.347\text{-}0.067T_i$	-0.993	30	46.98
15	0.970	0.029	261.490	$Ln(\mu) = 8.684\text{-}0.060T_i$	-0.985	30	66.14
20	0.976	0.022	324.983	$Ln(\mu) = 8.392\text{-}0.058T_i$	-0.988	30	72.96
25	0.979	0.011	366.136	$Ln(\mu) = 6.076\text{-}0.044T_i$	-0.989	30	95.86

Source: Compiled by the author

As clearly seen from the above presented tabulation of viscosity reduction models for solvents, the performance of jatropha oil proved to be the best among all, including naphtha and kerosene.

The evaluation of performance depends on the minimum residual mean square value; this is 0.017 for ethanol, 0.007 for naphtha, 0.012 for light crude oil, 0.006 for kerosene and 0.011 for jatropha oil. At its minimum residual mean square value (0.011), the jatropha oil resulted in the maximum viscosity reduction of 95.86%, followed by kerosene (93.06%), naphtha (89.16%), ethanol (37.98%), and the least performer is light crude oil with viscosity reduction of 25.21%.

To conclude and summarise the comparison analysis in ranking the performance of solvents, jatropha oil is confirmed to be first among both hydrocarbon and non-hydrocarbon solvents. The following equations tell the correlation of viscosity reduction with regards to solvent volume versus temperature of the blend:

For Jatropha Oil: Ranked #1

$Ln(\mu) = 6.076 - .044T_i$ ---------------------- 1(from author's own data)

Where: μ is the viscosity of the blend, T is the temperature.

The optimum temperature is 30˚C and the viscosity reduction is 95.86 %

For Kerosene: Ranked #2

$Ln(\mu) = 6.825 - .051T_i$ ---------------------- 2 (from author's own data)

Where: μ is the viscosity of the blend, T is the temperature.

The optimum temperature is 30˚C and the viscosity reduction is 93.06 %

For Naphtha: Ranked #3

$Ln(\mu) = 7.298 - .052T_i$ ---------------------- 3 (from author's own data)

Where: μ is the viscosity of the mixture, T is the temperature.

The optimum temperature is 30˚C and the viscosity reduction is 89.16 %

For Ethanol: Ranked # 4

$Ln(\mu) = 9.547- .070T_i$---------------------- 4 (from author's own data)

Where: μ is the viscosity of the mixture, T is the temperature.

The optimum temperature is 55˚C and the viscosity reduction is 37.98 %

For Light Crude Oil: Ranked #5

$Ln(\mu) = 9.555- .066T_i$ --------------------- 5 (from author's own data)

Where: μ is the viscosity of the blend, T is the temperature.

Cost Benefit Analyses

Table 11 illustrates the appropriate volume of each solvent for different scenarios of Fula North East Heavy Crude Oil Production.

Table 11: Log-Linear Correlation Model for Jatropha Oil Viscosity Reduction

Volume of FNE HCO Blend (100%) (Barrels)	*Volume of Ethanol (5%) (Barrels)*	*Volume of Naphtha (15) (Barrels)*	*Volume of Kerosene (20) (Barrels)*	*Volume of Jatropha Oil (25) (Barrels)*
10,000	500	1500	2000	2500
20,000	1000	3000	4000	5000
30,000	1500	4500	6000	7500

Source: Compiled by the author

Table 12 illustrates briefly the cost of each solvent for different scenarios of Fula North East Heavy Crude Oil Production when the appropriate volume of solvent is used.

Table 12: Cost of each Solvent required for Different Scenarios of Fula North East Heavy Crude Oil Production

Volume of FNE HCO Blend (100%) (Barrels)	*Cost of Ethanol (5%) (US$)*	*Cost of Naphtha (15%) (US$)*	*Cost of Kerosene (20%) (US$)*	*Cost of Jatropha Oil (25%) (US$)*
10,000	114,840.00	196,020.00	344,520.00	42,075.00
20,000	229,680.00	392,040.00	689,040.00	84,150.00
30,000	344,520.00	588,060.00	1,033,560.00	126,225.00
Cost Rank				
(from cheapest to most expensive)	2	3	4	1

Source: Compiled by the author

From Table 12, it is clear that using jatropha oil as diluent for Fula North East Heavy Crude Oil is quite viable as far as the cost is concerned.

Originality/Value

This research presents a novel approach to energy diversification by converting oil field by-products into a renewable energy solution. It bridges energy, agriculture, and environmental management, offering a sustainable model for other post-conflict nations.

The research aims to fill a gap in the literature by researching dilution on Sudanese heavy crude oil for the first time. The introduction of jatropha oil as a solvent for heavy crude oil fills another gap, bearing in mind that jatropha oil has been well known in the literature for being a reliable source for biodiesel but has never been studied for being a viscosity reducer.

A third credibility of the research is the provision of a problem-solving technique for heavy crude oil across the world, e.g., extra heavy crude oil such as Venezuelan crude oil.

Research Limitations/Implications

The study faces limitations due to the absence of large-scale infrastructure for jatropha cultivation and biodiesel processing. To implement this project, further field trials and government policy support are necessary. Key challenges include the need for irrigation systems, technical expertise, and validation of oil yield and fuel blending potential, especially using produced water from oil fields.

An initial investment of US$5 million will fund a pilot project covering land preparation, plantation set-up, small-scale biodiesel processing units, technical assessments, and capacity building. This project will serve as the foundation for a scalable national strategy, promoting rural development, carbon mitigation, energy diversification, and economic recovery. The value of this initiative far exceeds the required investment, aligning with national and global sustainability goals

Practical Implications

Implementing jatropha-based biofuel can revitalise rural economies, create jobs, and support national energy security. It also enhances carbon sink capacity, aligning with global climate goals and green recovery strategies.

Proposal for dilution plant (using jatropha oil as a solvent)

Figure 3 illustrates the proposal of the jatropha oil production process in relation to heavy crude oil viscosity reduction process.

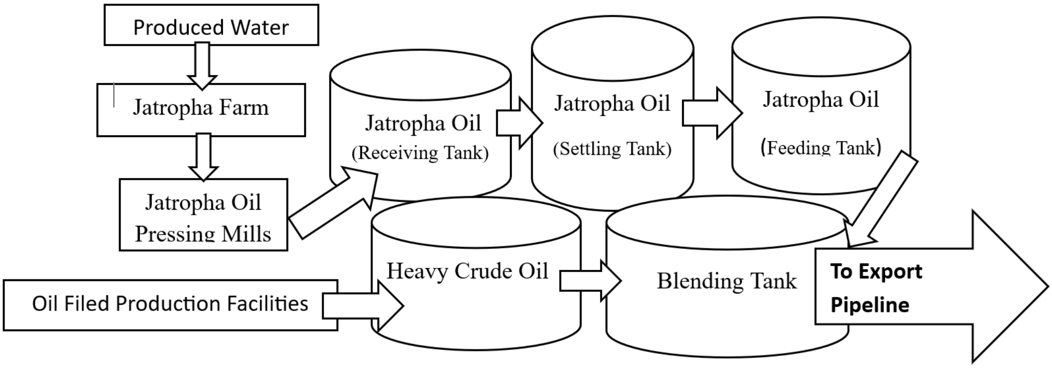

Figure 3: Schematic Diagram to show the main areas of Dilution Facilities
Source: Compiled by the author

CONCLUSIONS

Dilution is the most relevant technique for Sudanese heavy crude oil, and jatropha oil proved to be the most suitable viscosity reducer.

Jatropha oil has proven to be an effective diluent for Fula North Heavy Crude Oil, offering superior viscosity reduction compared to heating, particularly during shutdowns. Heating, while costly and time-consuming, does not enhance crude oil properties. While jatropha oil is widely known as a biodiesel source, this research is the first to explore its use as a solvent for heavy crude oil, successfully demonstrating its role in improving flow assurance.

Jatropha oil ranks highest among both hydrocarbon and non-hydrocarbon solvents, reducing viscosity by 95.86% at 25% volumetric percentage and 30˚C. It is also more cost-effective than other solvents. Jatropha oil offers a global solution for flow assurance in heavy crudes with similar properties to FNE Heavy Crude Oil, making it an effective solvent for viscosity reduction.

From an environmental perspective, cultivating jatropha enhances CO_2 absorption and supports Sudan's carbon credit preservation, while its use as a diluent for heavy crude, rather than as biodiesel, proves more effective for facilitating hydrocarbon transport to downstream facilities.

Jatropha oil outperforms other solvents by eliminating recycling needs, enhancing refinery yields when used as a diluent, and offering environmental and economic benefits through field-based cultivation using produced water.

Jatropha oil offers multiple advantages over naphtha, including use of seed cake for energy and fertiliser, CO_2 absorption, and job creation through plantation projects. A proposed blending plant would use produced water for jatropha irrigation, linking oil production with crude dilution. Cost analysis confirms jatropha as the most economical solvent for FNE heavy crude, far cheaper than ethanol, naphtha, or kerosene.

RECOMMENDATIONS

With abundant produced water, jatropha oil production is expected to surpass blending needs, reducing operational costs. The oil can be used in vehicles with minimal modifications. Upon field depletion, facilities can shift to biofuel production, pioneering a new environmental paradigm by transforming a fossil fuel field into a biofuel site.

This research uses mechanical pressing for oil extraction, but alternative techniques may yield different properties, warranting further study. Additionally, researching purification methods for jatropha oil and its economic feasibility is recommended to fully understand its co-benefits.

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