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« Production of heavy fuel oil 180 from Tsimiroro heavy oil and Jatropha oil »

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Abstract

In the global economic context created by the war in Ukraine, the cost of fossil fuels, the main source of energy, is a serious problem. The heavy oil from Tsimiroro, in the Morondava sedimentary basin, exploited by Société Madagascar Oil, could be used as a fuel for power generation. The problem with this heavy oil is that it is difficult to use because of its viscosity and high density. Mixed with diesel, it has been possible to produce HFO 380 and heavy fuel oil 700. In view of the skyrocketing price per barrel, the use of *Jatropha curcas* vegetable oil instead of diesel is being considered to improve the properties of this unconventional oil, since, according to previous research, its properties are similar to those of diesel, except for density and viscosity, according to previous research. At the end of this work, the parameters analyzed for the blends studied with 15%, 20%, 30% and 40% by volume of Jatropha oil, respectively, all conformed to the specifications for heavy fuel oil 180 authorized in Madagascar by a ministerial decree in agreement with the Office Malgache des Hydrocarbures (OMH). In fact with a Jatropha content of 30%, the kinematic viscosity of the heavy oil at 50°C of 890 cSt becomes 121.7 cSt, its density at 15°C of 0.976 becomes 0.965 and its flash point of 93°C becomes 82°C. Studies on the use of this innovative, more environmentally friendly solution could be envisaged with the national water and electricity company JIRAMA.

Keywords

Dilution, Heavy fuel oil 180, Gasoil, Tsimiroro heavy oil, *Jatropha curcas*, blend

1. Introduction

In the global context, fossil fuels are still the main energy source used, even if the greenhouse gas emissions they generate are recognized as being directly linked to the problem of global warming and climate change. The dominant needs are for electricity and fuels. In the face of global population growth, supply seems to be struggling to keep pace with demand. Following the sharp rise in the price of a barrel of oil since the war in Ukraine, it is important to better develop the use of unconventional heavy oils as alternative energies. Indeed, Madagascar's Tsimiroro region has a potential unconventional heavy oil deposit estimated at up to 1.7 billion barrels, of which 1.1 billion are potentially exploitable [1]. On the other hand, *Jatropha curcas* occurs naturally almost everywhere in the country. This plant has attracted the interest of researchers because it is a non-edible oil, does not create a conflict between food and fuel, and can be used to produce biodiesel with the same or better performance when tested in diesel engines [2] [3].

The heavy oil is located in the Tsimiroro Block 3104, a large oilfield in the onshore Morondava Basin on Madagascar's West coast, straddling the Melaky and Menabe regions, at latitude 20° 17' 05 ''South, longitude 44° 19' 03 ''East. Tsimiroro is 300km from Tananarive and 70km from the Bemolanga deposit. The oil is found at depths of between 40 and 300m, and is currently extracted by steam injection [1]. Tsimiroro heavy oil is one of the highly viscous, high-density unconventional petroleum products, requiring fluidization before it can be used properly. It is of exceptionally high quality, with a low sulfur content of just 0.3% and a very low ash content [4]. [5]. [6] [7].

To overcome these problems of viscosity and high density, Madagascar Oil has blended this heavy oil with another petroleum products, notably diesel at 10% and 15%, thus generating 2 new, less expensive heavy petroleum products: HFO 380 and heavy fuel oil 700, but which do not meet the specifications of the 180 cSt heavy fuel oil authorized since 2015 in Madagascar. They have already been tested with conclusive results at the HOLCIM cement plant in 2015 [8] and at JIRAMA, the national water and electricity distribution company, in 2016, in partnership with the producer Madagascar Oil [9]. Recently, in 2022, after a production stoppage due to saturation of the company's storage systems, a resumption of heavy oil production was formalized with food and textile operators in the Vakinankaratra Region [10].

The aim of this work is to use *Jatropha curcas* oil, a renewable and biodegradable product, to improve the fluidity of Tsimiroro heavy oil, based on the specifications of heavy fuel oil 180 [11] authorized by an interministerial decree agreed with the Office Malgache des Hydrocarbures (OMH) since 2015 in Madagascar (*cf.* Table 1)

Jatropha curcas oil is a renewable, biodegradable product with a very low sulphur content of around 0.13%, compared with diesel oil, which can contain up to 2.5% [12]. Could *Jatropha curcas* oil, a renewable and biodegradable product, contribute to improving the viscous properties of Tsimiroro heavy oil, while meeting the specifications of heavy fuel oil 180 authorized for use in Madagascar? Studies were carried out on 4 formulations with respective volume percentages of 15%, 20%, 30% and 40% Jatropha oil blended with heavy oil.

2. Materials and methods

2.1 Materials

2.1.1 Unconventional heavy oil from Tsimiroro, Madagascar

This is the main raw material used in this study, in an attempt to produce a heavy oil derivative in line with heavy fuel oil 180, the specifications of which are authorized in Madagascar by an interministerial decree agreed with the OMH. The oil is found at depths of between 40 and 300m, and is currently extracted using a steam injection system [1]. According to the literature and the results of previous research work found, the characteristics of Tsimiroro heavy oil samples are of better quality (*cf.* Table 2). Sources [4] [5]. Tsimiroro heavy oil is a very heavy, viscous, high-density, highly viscous unconventional oil from the local deposit at Tsimiroro Madagascar [4], [5], [6]. Tsimiroro heavy oil has a density of 14° to 16°API, and its physico-chemical properties are judged to be of excellent quality, since the sulfur content is only 0.3% [1], [4], [6], [7]. It is therefore less polluting than the diesel oil generally used as fuel for diesel engines, and the ash content is also very low [8], so the smoke produced by its combustion would be negligible. It is composed respectively of asphaltenes from precipitation with n-heptane or n-pentane, saturates from a first elution with normal heptane by column chromatography, aromatics from the second elution with methyl ethyl ketone, resin from the third elution with tetrahydrofuran. [4].

2.1.2 Jatropha curcas vegetable oil

Jatropha curcas is a perennial energy plant capable of producing oil-rich, inedible seeds. It belongs to the *Euphorbiaceae* family. Like all vegetable oils, Jatropha oil contains 95% triglycerides, small quantities of mono- and di-glycerides, 1 to 5% free fatty acids and sometimes phospholipids, phosphatides, carotenes, tocopherols and certain compounds such as sulfur at low levels [13].

The Jatropha oil used to try and improve the fluidity of the heavy oil was obtained by cold pressing the well-dried and sorted oil seeds. Extraction was carried out at the Centre National de Recherches Industrielle et Technologique (CNRIT), using a locally-designed manual Bielenberg press. This oil is used in this research work without any additives. It is a biodegradable product of renewable origin, with characteristics similar to those of fossil diesel.

After pressing, the crude oil was decanted and filtered, then mixed with the heavy oil instead of diesel, in an attempt to improve the fluidity of the latter. The vegetable oil used underwent no chemical modification.

Jatropha oil is very viscous compared with diesel. Its viscosity is around 10 times higher than that of petroleum diesel, yet it has a very low sulfur content of around 0.13%, compared with 2.5% for diesel. What sets this oil apart, however, is its cetane number, which is almost identical to that of diesel oil [12].

2.2 Methodology

2.2.1 Mixture proportions

2.2.1.1 First wave of dilution trials with 30% and 40% Jatropha oil by volume

To start with, double the 15% rate, i.e. 30% Jatropha oil, was chosen as the minimum volume used.

This choice was justified by the very high viscosity of Jatropha oil, around 10 times higher than that of the diesel used by Madagascar Oil. Once both products had been measured using graduated test tubes, they were poured into a beaker and stirred at a slow, steady speed by magnetic agitation, without heating.

The first 2 formulations E30 and E40 were prepared. Respectively :

- ✓ Or E30, the sample with 30% Jatropha oil and 70% heavy oil.
- ✓ And E40 the sample with 40% Jatropha oil and 60% heavy oil.

Heavy oil and Jatropha vegetable oil are perfectly miscible in any proportion. The mixtures are stable without any additional additives. This first step is vital if we are to pursue this methodology in the development of a heavy fuel oil 180 from these blends.

2.2.1.2 Second wave of dilution trials with 15% and 20% Jatropha oil

In order to refine the results obtained with 30% and 40% Jatropha, 2 other blends were prepared by halving the volume percentages of Jatropha oil. The volume percentages used with the heavy oil were 15% and 20%.

The other 2 formulations, E15 and E20, therefore contain 15% and 20% Jatropha vegetable oil respectively.

- ✓ Or E15 the sample with 15% Jatropha oil and 85% heavy oil.
- ✓ And E20 the sample with 20% Jatropha oil and 80% heavy oil.

The mixtures prepared are always homogeneous; the 2 oils remain fully miscible even in these new proportions.

2.2.2 Determining characteristics that can influence fuel combustion

Samples E15, E20, E30 and E40 with 15%, 20%, 30% and 40% Jatropha oil respectively were then analyzed. For this purpose, density, viscosity and flash point were measured, some of the parameters that can influence the combustion of the fuel used in a diesel engine.

These characteristics were also determined beforehand for the Tsimiroro heavy oil sample in its pure state.

2.2.2.1 Determination of density at 15°C using the ASTM D 1298 method.

The density of a liquid body is the ratio between its density and the density of a reference body, which is water. The term API gravity or API density is an approach to the specific weight of crude oil according to the classification of the American Petroleum Institute. The lower the API gravity, the heavier the crude oil.

Equipment used: pycnometer and precision balance

Principle:

The pycnometer method involves performing 3 respective weighings, knowing the mass of one volume of sample and the mass of the same volume of water.

The density is obtained by the formula :

$$Density = \frac{P3 - P1}{P2 - P1}$$

with P1 = mass of empty pycnometer

P2 = mass of pycnometer filled with distilled water
P3 = mass of pycnometer filled with sample

As this is a petroleum product, the API gravity is calculated by the formula:

$$\text{API} = \frac{141.5}{\text{Specific gravity at } 15°C} - 131{,}5$$

2.2.2.2 Determination of viscosity at 50°C using the ASTD 445 method

Kinematic viscosity is the internal resistance to fluid flow caused by molecules rubbing against each other.

- ✓ It is the most important property of a lubricant, determining its application.
- ✓ The viscosity of a body decreases with increasing temperature.

Equipment: Canon Fenske double-calibration capillary viscometer and thermostatic bath.
A thermostatic bath is required for viscosity measurement, to maintain temperature.
Principle:
Viscosity is determined using a viscometer, a container with a standardized orifice at the bottom. The speed at which the fluid flows through this orifice is used to determine the viscosity of the fluid. This involves measuring the time taken for the sample to travel through the upper and lower bulbs.

2.2.2.3 Determination of flash point by ASTMD 3278 method

This is the minimum temperature at which the vapors released by the product explode when a flame is applied. The flash point indicates the temperature to which a product can be safely heated. A drop in flash point compared to new oil could increase the risk of fire.
Equipment: Pensky Martens apparatus, and thermometer
Principle:
A test sample is poured into the measuring vessel and gently heated at a uniform rate until vaporization begins, indicated by a small explosion caused by the presence of a flame. A thermometer immersed in the product indicates the flash point temperature.

3. Results

3.1 Results obtained from blending Jatropha oil with heavy oil

With all the proportions used, the two oils are perfectly miscible with each other. The blends obtained are homogeneous with 15%, 20%, 30% and 40% Jatropha oil respectively.

3.2 Tsimiroro heavy oil analysis results:

The heavy oil sample used in this study was previously analyzed and the results found are respectively:

- 0.976 for density measurement at 15°C,
- 890cSt for kinematic viscosity at 50°C,
- 93°C for flash point measurement.

3.3 Results obtained with the formulations studied with 15%, 20%, 30% and 40% vegetable oil

In Table 3 are presented the results of the measured densities, viscosities and flash points of the HFO T, HFO 180 and each studied formulations (E15, E20, E30, E40). All the obtained values complied with the specifications for heavy fuel oil 180 authorized in Madagascar: densities are all below 0.991, viscosities below 180cSt and flash points above 60°C.

4. Discussions

At the end of this work, the effects of blending Jatropha vegetable oil with local non-conventional heavy oil in order to improve its characteristics to meet the specifications of heavy fuel oil 180 authorized in Madagascar were effectively verified. In fact, all the parameters measured on the 4 blending samples prepared gave values in line with Heavy Fuel Oil 180, as follows: maximum density equal to 0.991; maximum viscosity 180cSt and flash point above 60°C.

In addition, the various proportions of 15%, 20%, 30% and 40% by volume of Jatropha vegetable oil used in blends with this local heavy oil have enabled us to verify that in all cases, the blends are homogeneous; the two oils are perfectly miscible with each other. Based on these results, the samples studied can be considered as heavy fuel oil suitable for use in industrial boilers at thermal power plants producing electricity, and for industrial diesel engines.

It would therefore be possible to use *Jatropha curcas* vegetable oil instead of petroleum diesel for the pre-treatment of heavy oil to improve its properties as a fuel. This is an innovative result, based on a scientific approach, which deserves to be pursued in depth, given that Jatropha oil is from a renewable and biodegradable source, unlike petroleum diesel. Its use in place of diesel could be beneficial in reducing greenhouse gas emissions caused mainly by products of fossil origin. Compared with previous results obtained by Madagascar Oil by blending this Tsimiroro heavy oil with petroleum diesel, these results are original in that the replacement product here is from a renewable source [7]. In fact, with 10% and 15% diesel oil, this method produced two cheaper products, HFO 380 and heavy fuel oil 700, with viscosities of 380cSt and 700cst respectively, which do not meet the specifications authorized in Madagascar. Industrial trials of these products have nevertheless produced conclusive results, according to JIRAMA and Madagascar Oil.

The 4 formulations studied here are therefore by far the best in terms of meeting locally authorized specifications. This work has an innovative aspect which deserves to be studied in greater depth before proceeding with practical application tests on an industrial scale, as the densities of the E15 and E20 samples remain well below 0.991, in line with the range for heavy fuel oil 180, but slightly higher compared with the density of Tsimiroro heavy oil.

5. Conclusion

Tsimiroro heavy oil is an unconventional petroleum product with very high viscosity, while *Jatropha curcas* oil is both a renewable source and a biodegradable product, already recognized as an auxiliary biofuel for certain diesel engines that can significantly reduce the greenhouse gas emissions responsible for current climate disruption. The effects of blending this vegetable oil with Tsimiroro heavy oil on density, viscosity and flash point are remarkable. The characteristics of the E15, E20, E30 and E40 blends, with respectively 15%, 20%, 30% and 40% by volume effectively meet the specifications of Heavy Fuel Oil 180 authorized in Madagascar since 2015 according to an interministerial decree agreed with the OMH.

The viscosity values found ranged from 121.7cSt to 172.4cSt, all below 180cSt, which is the threshold viscosity value for heavy fuel oil 180, and at the same time well below the viscosity of Tsimiroro heavy oil, which is 890cSt. In conclusion, the properties of this vegetable oil could replace petroleum diesel in the protocol for using this unconventional heavy oil in the future. This process would be an innovative approach to reducing greenhouse gas emissions linked to climate change.

In-depth studies are recommended in the continuation of this work, to better define the ideal, cost-competitive proportion of the product derived from this Tsimiroro heavy oil to be adopted. Pilot-scale application trials with JIRAMA, the first potential local beneficiary, deserve to be undertaken in consultation with the partners directly involved. And finally, the goodwill of the State and the private sector is required to support and activate the professional cultivation of *Jatropha curcas* with multidisciplinary researchers. *Jatropha curcas* is a perennial energy plant that contributes to the reforestation of degraded soils, environmental protection and the production of biodegradable, non-edible energy oil. Its planting in Madagascar will not compete in space with food crops.

For future international dissemination of such a result, a comparison could be made between this process using crude *Jatropha curcas* oil and the process using chemically esterified Jatropha biodiesel, even if this is initially more expensive.

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Tables

Table 1: Specifications for Heavy Fuel Oil 180 (source: OMH)

Specifications	Values		Standard
	Min	Max	
Viscosity at 122°F (cSt)		180	ASTM D 445
Density at 15°C		0.991	ASTM D 1298
Flash point PMMC (°C)	60		ASTM D 93
Total sulfur % (m/m)		2.5	ASTM D 1552
Pour point (°C)		+30	ASTM D 97
Sediment % wt		0.1	ASTM D 473
Ash % (m/m)		0.1	ASTM D 482
Conradson on residue % (m/m)		1.5	ASTM D 189
Water % (V/V)		0.5	ASTM D 95

(Source : OMH Madagascar)

Table 2 : Physico-chemical characteristics of Tsimiroro heavy oil [4] [5].

Parameters	Value	Observations
Density at 15°C	0. 953- 0. 970	
API Density	14.346 – 17. 025	Between 10 and 22.3° API (heavy oïl)
Kinematic viscosity at 50°C	1012 - 1187cSt	
Flash point °C	88°C- 98°C	
Pour point °C	22 – 25°C	
Ash content % m/m	0.100 – 0. 215	
Water content % m/m	0.050 – 0.072	
Sediment content % m/m	0.766 -1. 666	
Conradson residue % m/m	8.498 – 10.025	Residual carbon content
Asphaltene content	8.632 - 13.584%	
Percentage of saturated hydrocarbons	26.828- 29.744 %	1st elution with normal heptane
Percent aromatic	28.690 – 30.804%	2 nd elution with methylethylketone
Percent resin	30.820 – 30. 898%	3rd elution with tetrahydrofuran

Table 3 : Characteristics of heavy oil samples E15, E20, E30 and E40

Parameters	Unit	HFO T	HFO 180	E15	E20	E30	E40
Flash point	**°C**	93	60 Min	81	81	81.5	82
Viscosity at 50°C	**CSt**	890	180 Max	0.990	0.982	0.975	0. 965
Density at 15°C		0.976	0.991Max	172.4	158.8	124.5	121.7