OPTIMIZATION OF PARAMETERS FOR THE REDUCTION AND RECOVERY OF HEAVY FUEL OIL WASTE: THE CASE OF JIRAMA ANALAMANGA, MADAGASCAR

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ABSTRACT

Heavy fuel oil is the main fuel providing the energy needed to operate the Jirama thermal power plants. It is a toxic substance that is difficult to manage and store because of its viscosity, ease of explosion and corrosiveness. Jirama uses metal drums to store the fuel oil waste generated daily at these power plants, which creates a congestion problem at the power plant and an additional budgetary burden for the company.

The aim of this research work is to find a suitable solution to reduce the volume of waste fuel oil generated by the power plant and an appropriate technology to treat and recover this waste fuel oil for various purposes. The result of the research has shown that, firstly, two treatment and recovery technologies are possible: centrifugation and dry distillation, but the latter is the most appropriate; secondly, lateritic soil is the appropriate material, capable of reducing the volume of waste fuel oil by using it as a support during the dry distillation process; thirdly, the method of storage in metal drums practised by Jirama is no longer necessary, given the ideal granulometry of the lateritic soil. This granulometry plays an important role in reducing the volume of waste fuel oil generated by the plant and eliminating the method of storage in barrels. Two ranges of granulometry are the most interesting: range 1 (upper 0.400 mm, lower 0.800 mm) for reduction and range 2 (lower 0.400 mm) for the elimination of storage in metal drums.

After dry distillation tests using range 1 as a carrier, two (2) types of oil close to heavy fuel oils were obtained: No. 6 fuel oil and intermediate fuel oil. Thus, for every 200 ml of heavy fuel oil waste treated, 37.8% are crude oils that can be reused in the power plant. Other research work is in progress, such as the biological recycling of the lateritic soil, which is red in color and has become blackish after dry distillation.

Keyword: *Heavy fuel oil waste, recovery, dry distillation, lateritic soil optimization.*

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1. INTRODUCTION

JIRAMA is the major supplier of electrical energy in Madagascar. The electrical energy supplied is produced by hydroelectric or thermal power stations that run largely on heavy fuel oil. These heavy fuel oils generate waste consisting of liquid (waste water) and viscous discharges that are polluting and harmful to the environment. Its discharge into the natural environment can damage the quality of natural resources if action is not taken in time.

JIRAMA has opted for two (2) interim solutions to dispose of these wastes: storage in tanks in metal drums and/or collection by take-back companies. The first solution is not appropriate for this type of product because it creates problems of space or space management, while the second option, the collection of this waste depends on its need and is random.

A research work entitled "Treatment of waste fuel oil: the case of the JIRAMA thermal power plant" was carried out previously (RANDIMBISON.N. L, 2018) with a view to finding a technology for reducing, treating or even recovering waste fuel oil. This research work simply made it possible to use: "lateritic soil", a material that is capable not only of reducing the volume of heavy fuel oil waste but also of replacing the role of metal tanks for its storage. This lateritic soil therefore plays two (2) important roles: the reduction of the daily volume of waste generated by the thermal power plant and the reduction of the budget allocated to the purchase of metal tanks, which is a permanent burden for JIRAMA.

In addition, centrifugation was the technology deemed appropriate to separate the viscous components from the heavy fuel oil. Three main parameters were studied for the various centrifugation tests: the temperature set at 30°C, the speed (6300 to 6750 rpm) and the centrifugation time (45 to 50 minutes).

The present research work is therefore a logical continuation of the research work carried out previously (RANDIMBISON.N. L, 2018) and which was based on the three (3) principles of waste management: "reduce, reuse and recycle". In order to reduce the volume of fuel oil waste generated daily by JIRAMA's thermal power plants, we have applied the result obtained previously by using lateritic soil, which is the material deemed suitable to solve the problem (reduction of waste volume, reduction of the budget allocated to the purchase of metal drums) at JIRAMA. To reuse this fuel oil waste, our approach is to recover it by applying dry distillation technology instead of centrifugation. This technology has the advantage of facilitating the separation at high temperature of the different components of the heavy fuel oil waste while avoiding its explosion (around 70°C) thanks to the use of "lateritic soil" considered as a support. After distillation, the support (lateritic soil) initially red in color is polluted and becomes blackish. It can be recycled biologically using one of the following bacteria: Pseudomonas, Acinetobacter, Flavobacterium, Bacillus, Arthrobacter or Achromobacter to restore its initial (red) color while avoiding pollution of the natural environment.

The main aim of this research work is therefore to find a sustainable and reliable solution to optimize the various parameters for the reduction, treatment and recovery of JIRAMA's heavy fuel oil waste. It is within this framework that the idea for this research was born: "Optimization of the parameters for the reduction, treatment and recovery of heavy fuel oil waste: the case of the JIRAMA Analamanga company". Several questions arise, among others:

Apart from the composition of the lateritic soil (36% clay, 27% silt and 37% sand) (RANDIMBISON.N.L, 2018), is it possible to determine the appropriate granulometry of the lateritic soil for the storage of heavy fuel oil waste?

What volume of heavy fuel oil waste can be reduced by using lateritic soil with appropriate grain size?

The 30°C temperature of the centrifuge technology does not allow a clear differentiation of the components of the waste heavy fuel oil from the dry distillation technology. What are the different components of waste heating oil and what are the appropriate temperatures (first jet, last jet) for their respective separation?

Is the choice of dry distillation technology economical for the recovery of waste heavy fuel oil?

This research work attempts to shed light on these questions posed through this document.

2. METHODOLOGIES

2.1. Study area: the company Jiro sy Rano Malagasy (JIRAMA) Analamanga

2.1.1. General information on JIRAMA

The company JIro sy Rano MAlagasy under the abbreviation JIRAMA created on October 17, 1975 is the result of the merger of the company Malagasy Water and Electricity (SMEE) and the company of Madagascar Energy (SEM), it is a company Anonyme (S.A) under common law whose capital is held entirely by the Malagasy State.

Its main activities are the production, transport and distribution of electrical energy as well as the production, treatment and distribution of drinking water.

With nearly 340,000 subscribers in 114 localities for electricity and nearly 110,000 subscribers in 65 centers for water, JIRAMA has recourse to two (2) types of energy production, including:

- The hydroelectric power plant which uses a large reservoir to create an artificial waterfall whose flow is controlled to produce electricity. The energy of the water in the artificial waterfall is used to turn a turbine, which in turn turns the alternator, which generates electrical energy. Sometimes the plant is not directly located at the dam site, so the water is transported to the plant via a headrace. After passing through the turbine, the water is returned to the river via a return channel.

- Thermal power plants are powered by fossil fuels and are more expensive to operate than hydroelectric plants. At present, JIRAMA uses the diesel-powered type of thermal power plant, which does not have a turbine. The fuel used is either diesel oil or heavy fuel oil. Mechanical energy is created by the diesel engine, which directly drives the alternator, which generates electrical energy.

Since 2017 the heavy fuel oil requirements for its generators is 161,543 m3 which generates a large quantity of waste fuel oil to be recovered.

2.1.2 Sybion Power's Mandroseza Thermal Power Plant

SYMBION POWER has been working closely with JIRAMA for some time. It manages the production of electricity for the city of Antananarivo through the Mandroseza thermal power station used by JIRAMA. SYMBION POWER is an independent American producer with active power plants in Africa. Across the African continent, it owns and operates power supply infrastructure that provides electricity to some of the most underserved regions in the world. SYMBION also carries out engineering, procurement and construction (EPC) work in the electricity supply sector and has worked on large-scale generation, transmission and distribution projects in the Middle East, Africa and Asia. Figures 3 and 4 show the study area for the Mandroseza Thermal Power Plant.

Figure 1: Site of the Symbion Power thermal power plant via Google Maps

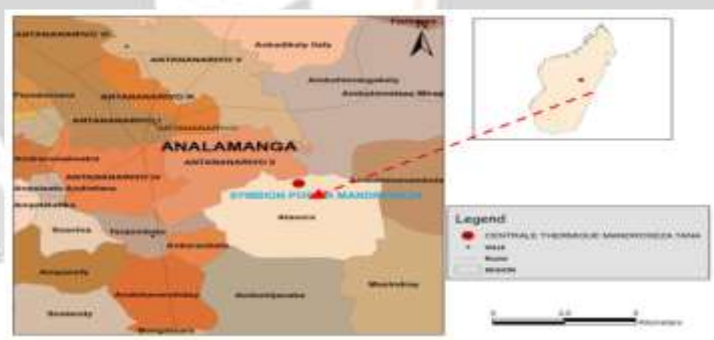

Figure 2: Location of the Symbion Power Mandroseza Thermal Power Plant

The solution to load shedding came from the United States. An American company called Symbion Power will invest in the construction of seven (7) power plants in Madagascar. They will operate with low-cost and renewable energy, and will produce one hundred eighty (180) megawatts in total. The future facilities will be built in Mahajanga, Sainte-Marie, Tsimiroro, Nosy-Be, Antsiranana and Toamasina. Depending on their size, the construction period is between one (1) and three (3) years.

2.2. General information on fluid and viscous waste (waste water, heavy fuel oil) from jirama thermal power stations

Heavy fuel oil is the energy source currently used by JIRAMA to operate its thermal power plants. These energy sources generate fuel oil waste, which consists mainly of a fluid part (oily water) and a viscous part (sediment).

The water that circulates in a closed circuit is essential for the operation of the power plant. However, the plant must be supplied with make-up water on a regular basis to compensate for evaporation and steam leaks and for periodic boiler blowdown and flushing operations. Whether fluid or viscous waste, it is highly toxic to the environment and requires careful management.

2.3. Heavy fuel oil waste potential of the Jirama Analamanga thermal power station

In 2017, JIRAMA has a waste oil stock of 149,286 liters, which is summarized in Table 1 (Jirama, 2017).

Table 1: JIRAMA's waste oil potential for 2017

Year	Centre	Unit	Final stock (End of December 2017)
2017	DERI	L	0
2017	Antsiranana	L	18 000
2017	Mahajanga	L	19 916
2017	Toamasina	L	94 500
2017	Toliara	L	16 870
TOTAL	-	L	149 286

This table and the resulting curve summaries the waste fuel oils stored at the JIRAMA stations in these locations.

Figure 3: JIRAMA's final stock curve for waste heating oil for the year 2017

2.4. Experimental work

Before starting the experimental work, we would like to remind you in this section that this research work is a logical continuation of the work carried out previously (RANDIMBISON N.L, 2018) on the theme: "Treatment of fuel oil waste from thermal power stations: the case of the JIRAMA company". The result of the above-mentioned research work has highlighted several important points, among others:

- The sieved lateritic soil (laterite) of respective contents: 36% clay, 27% silt and 37% sand is the adequate solution to replace the role of the metallic tank for the storage and the reduction of the volume of the heavy fuel oil waste generated daily;
- Three (3) main parameters were studied for the different centrifugation tests: the temperature set at 30°C, the speed (6300 to 6750 rpm) and the centrifugation time (45 to 50 minutes).
- Centrifugation at a temperature of 30°C made it possible to detect five (5) different phases, including a fluid phase: water polluted with oil and four (4) phases of different viscosity levels.

On the other hand, the present research work, still based on the three (3) waste management principles of "reduce, reuse, recycle", consists respectively of:

- First, determine the most efficient lateritic soil granulometry required to replace the role of the metal drum tank;
- Second, to evaluate the volume of heavy fuel oil waste reduced by the use of lateritic soil;
- Third, to identify the ideal temperature for separating the various components (viscous phase) of the heavy fuel oil waste by dry distillation technology?

Before starting the actual laboratory work, we will first expose the different materials we have used in order to carry out our work.

2.4.1 The lateritic soil

(a) Lateritic ground connection

For our research work, we took two (2) types of lateritic soil: lateritic soil 1 or laterite 1 and lateritic soil 2 or laterite 2 with their respective geographic coordinates summarized in the following table.

Table 2: Geographic coordinates of the laterite catch

Name of lateritic soil	South Latitude	East Longitude
Lateritic soil 1 (Laterite 1)	18°58’51.9’’S	47°24’43.6’’E
Lateritic soil 2 (Laterite 2)	18°58’15.3’’S	47°25’29.9’’E

The following satellite photograph shows the location of the collection areas:

Figure 4: Location of laterite collection areas (source: Google Earth February 2014)

b) Characteristics of laterite soils

Table 3 below shows the geotechnical characteristics of the two (2) lateritic soil types:

Physical and mechanical feature		Latérite 1	Latérite 2
Content in natural water W (%)		13,10	5,45
Specific weight s (t/m3)		3,02	2,78
Apparent density? d (t/m3)		1,78	1,45
Pilled density	relate (has (t/m3)	1,78	1,45
	dry (s (t/m3)	1,57	1,33
Limits of Atterberg	Limit of liquidity W_l (%)	62,10	35,95
	Limit of malleability W_p (%)	40,10	24,35
	The cup flow test I_p (%)	22,00	11,60
Test of Proctor compressibility	Optimal moisture content W_{opt} (%)	26,00	20,35
	Maximal dry volume weight $\gamma_{d\ opt}$ (t/m^3)	1,62	1,75
Test of lift or Test C.B.R.	Sinking 2,5mm (%)	30,30	-
	Sinking 5mm (%)	31,00	-

And the following Table 4 shows the respective chemical compositions of the two (2) lateritic soils 1 and 2:

Table 4: Chemical compositions of the two (2) lateritic soils

Elements	**Latérite 1**	**Latérite 2**
SiO_2 (%)	31,54	13,80
Al_2O_3 (%)	25,94	45,70
CaO (%)	Trace	Trace
MgO (%)	Trace	Trace
Fe_2O_3 (%)	26,01	15,70
TiO_2 (%)	4,40	2,20
SO_3 (%)	Trace	Trace
K_2O (%)	Trace	Trace
Cr_2O_3 (%)	Trace	Trace
MnO (%)	0,21	Trace
Na_2O (%)	0,09	Trace
P_2O_5 (%)	0,51	Trace
Ignition loss (%)	11,29	19,00

2.4.2. The sieve size test

The sieve size test is a test that resides on the study of the dimensions and different sizes of a soil grain sample. It allows to obtain the percentage distribution of solid grains according to their dimensions.

- Purpose of the test: to obtain three (3) samples with different grain sizes.
- Materials used: two (2) sieves of respective sizes: 0.800 [mm], 0.400 [mm].

- **-Description of the trial:**

First, we took the two (2) types of lateritic soil to dry them, then we started sieving with the two (2) types of sieves. We thus obtained three (3) different samples with their respective dimensions,

- For laterite 1 :

Lat1 REFUSAL 1: this is the first rejection after manual sieving where the grain size is greater than 0,800 [mm].

Lat1 REFUSAL 2: this is the second sample from the second sieving, with a grain size of between 0,400 and 0,800 [mm].

Lat1 Sieve 1: this is the third sample from the third sieving, the size of the grains is less than 0,400 [mm].

- For laterite 2:

Lat2 REFUSAL 1: this is the first refusal following the first sieving, the size of the grains being greater than 0,800 [mm].

Lat2 REFUSAL 2: this is the second sample from the second sieving, with a grain size between 0,400 and 0,800 [mm].

Lat2 Sieve 2: this is the third sample from the third sieving; the size of the grains shall be less than 0,400 [mm].

2.4.3. Determination of fuel oil infiltration rate in laterite samples

Following the sieve size test, we were able to obtain three (3) laterite soil samples: laterite 1 and three (3) other laterite 2 soil samples. They were then placed in cylinders with a diameter of 9 [cm] and a height of 11 [cm].

We thus have six (6) samples which are distributed according to the size of their respective grains:

- For laterite 1: Lat1 REFUSE 1, Lat1 REFUSE 2 and Lat1 sieve 1
- For laterite 2: Lat2 REFUSE 1, Lat 2 REFUSE 2 and Lat2 sieve 2

Then we poured 200 ml of waste heavy fuel oil into each sample.

The following tables show the respective infiltration rates of the 200 ml of waste fuel oil into laterites 1 and 2:

This curve shows that since 11/02/19, until 25/02/19 when the evolution of the infiltration was followed, it was possible to observe that

-for laterite 1 Refusal 1; the infiltration increased from 3 cm from the start at 8.30 am and stopped this evolution at 10.45 am at 9.85 cm of infiltration.

-for laterite 1 Refusal 2: the infiltration started at 0.5 cm at 8 h 30 and reached 2.55 cm on 25/02/19.

-for laterite 1 Sieve 1: infiltration started at 0.05 cm at 8.30 am on 11/02/19 and reached 0.3 cm on 25/0219

The following curve proves it.

Figure5: Progress curve of the infiltration of waste oil into laterite 1

The curve in figure 6 shows the evolution of the infiltration of two hundred (200) milliliters of waste fuel oil in the three (3) samples of laterite 1, it can be seen that after the spillage of the waste fuel oil, the latter infiltrates quite rapidly into the first sample which is composed of large grains with dimensions greater than 0.800mm. The speed of infiltration of the fuel oil is due to the fact that the coarse grains are spaced apart and that the waste fuel oil finds its way into the sample. After only 2 h 35 min from the start of the experiment, the waste fuel oil is completely infiltrated.

For the case of sample 2, the grain size is between 0.400mm and 0.800mm, i.e. of average size, it is noted that the waste fuel oil infiltrates but slowly, after thirteen (13) days of monitoring, its infiltration does not exceed three (3) centimeters.

For the third sample, whose grain size is less than 0.400mm, it is noted that the infiltration speed is very slow, after thirteen (13) days of monitoring, the infiltration of the fuel oil does not exceed 0.3 cm, and after this value, the fuel oil does not infiltrate any more. After two (2) days from the beginning of the experiment, it is noticed that only the water composing the waste fuel oil infiltrates into the lateritic soil and that its infiltration does not exceed 3 cm.

Essentially, the larger the grain sizes of the lateritic soil, the faster the waste fuel oil infiltrates into the soil. The smaller the grain size, the more difficult it is for the fuel oil to infiltrate, i.e. the infiltration is very slow and at a value of 0.3 cm, it no longer infiltrates but only water infiltrates into the laterite not exceeding the height of 3 cm.

The following curve shows the evolution of the infiltration of waste fuel oil into laterite 2. The experiment started on 11/0219 and ended on 25/0219. The evolution of the infiltration rate is as follows

- For laterite 2 Refusal 1: the infiltration started from 2.85 cm and did not evolve any more until the end of the experiment;
- For laterite 2 Refusal 2: the infiltration started at 0.45 cm on 11/02/19 and reached 2.85 cm on 25/02/19;
- For laterite 2 Sieve 2: infiltration started at 0.2 cm on 11/02/19 and reached 0.7 cm at the end of the experiment.

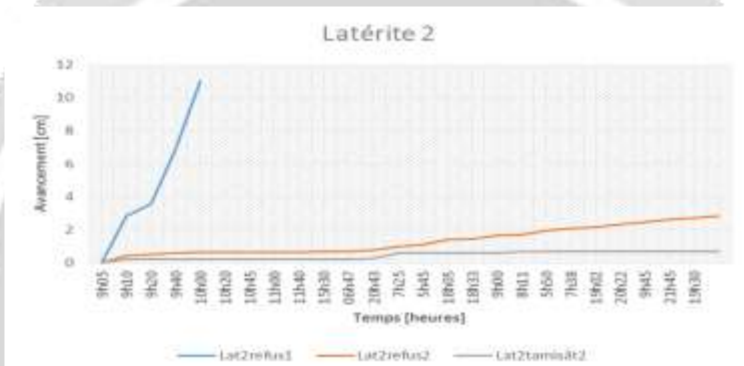

Figure6: Progress curve of the infiltration of waste heavy fuel oil into laterite 2

Figure 6 shows the evolution of the infiltration of two hundred (200) milliliters of waste fuel oil into laterite 2. In the case of the first sample, it can be seen that after only 1 hour, the entire waste fuel oil is infiltrated due to the fact that the grain size (greater than 0.800mm.) are spaced apart leaving the waste fuel oil free to infiltrate.

In the case of sample 2 with a grain size between 0,400 and 0,800 mm, it is noted that the waste fuel oil infiltrates slowly and that its infiltration does not exceed 3 cm.

For the third sample, it is noted that the waste fuel oil infiltrates very slowly and that after thirteen (13) days its infiltration does not exceed 0.7 cm, which is not much, but compared with that of laterite 1 (not exceeding 0.3 cm), there is a difference. We can also notice that from the third day, water infiltrates into the laterite soil but does not exceed 3cm.

The conclusions are the same as before: the larger the grain size, the faster the waste fuel oil infiltrates the laterite (for laterite 2, the grains are even more widely spaced than for laterite 1). The smaller the grain size, the slower the oil seeps into the laterite, but at a value of 0.7 cm it no longer seeps into the laterite, but only water seeps into the laterite, but no more than 3 cm.

2.4.3. Dry distillation tests of heavy fuel oil waste

Five (5) dry-process distillation tests were carried out during the laboratory work carried out at the laboratory of the Energy Department of CNRIT. The course of the experiments is presented as follows:

a) <u>Test:</u> 1st test

Date of completion: 28/02/19

In this first trial we used 1004 g of a mixture of 200 ml of waste fuel oil spilled into laterite which only acts as a carrier for dry distillation.

We used 1500g of coal for the distillation furnace.

When the distillation furnace cooled down, we collected 798g of undissolved black compound in the vessel, and 130g of coal ash.

Table 5: Weights of the components of dry-process distillation (1st trial)

Weight of the mixture	1004 g	Residuals :	798 g
Charcoal:	1500 g	Remaining coal:	130 g

Table 6: Summary table of 1st distillation

Time	Température [°C]	Rejection 1 [ml]	Rejection 2 [ml]	Observation
09h20	39	_	_	**Date of start Test: 28/02/19**
09h33	444	_	_	Appearance of the 1st drop of light color
09h53	720	28	_	Appearance of a new dark color phase
Date : 04/03/19				
07h52	_	49,5	19,5	Collection and measurement of the oils obtained

Figure 7: Curve of the evolution of discharges as a function of temperature and time (Test 1)

Figure 7 shows us the evolution of the distillate as a function of temperature and time, we notice that when the temperature reaches 444°C, there is the appearance of the 1st drops of light color and that at a temperature of 720°C, a 2nd darker color appears. During this test 49.5ml of light oil and 19.5ml of dark oil were collected.

b) <u>Test</u>: 2nd test
Date of completion: 04/03/19
During this second test we used 1022g of mixture including 200ml of waste fuel oil but also laterite which is only a support for dry distillation.
We used 1500g of coal.
After cooling the dry distillation furnace, we collected 770g of undissolved solid compound in the receptacle and 130g of coal ash.

Table 7: Weights of the components of the dry distillation process (2nd trial)

Weight :	1022 g	Residuals :	770 g
Charcoal:	1500 g	Remaining coal:	130 g

Durant l'expérimentation, on a pu constater que:

- 09 h32 : début de l'expérimentation ;
- 09 h 45 : apparition de petite fumée ;
- 09 h 46 : apparition de 1ère phase de couleur claire ;
- 09 h 54 : apparition de seconde phase de couleur sombre

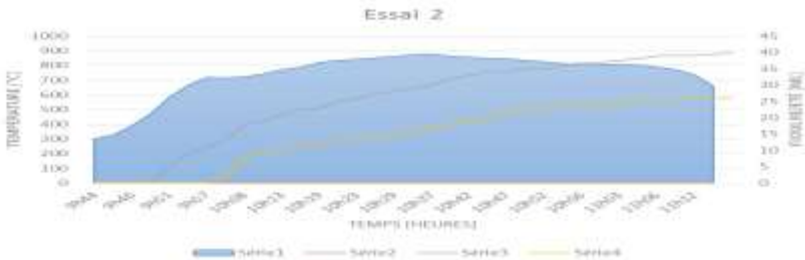

Figure 8: Curve of the evolution of emissions as a function of temperature and time (Test 2)

During this test, it was noted that at 326°C smoke appears at the outlet of the steam conductor and at 390°C the first drops of the light-colored oil appear and at 666°C the first drops of the second dark-colored oil already appear. On collection, 40ml of the light oil and 27.5ml of the dark oil were recovered. We noticed leaks in the distillation oven, steam was escaping.

c) <u>Trial</u>: 3rd trial
Date of completion: 05/03/19
In this third trial we used 1054g of a mixture of 200ml of waste fuel oil spilled into laterite, which is only used as a carrier for dry distillation.
We used 1500g of coal for the distillation furnace.
The next day after the distillation furnace had cooled down, we collected 768g of undissolved black compound in the receptacle, and 131g of coal ash.

Table 8: Weights of the components of the dry distillation process (3rd trial)

weight:	1054 g	Residuals:	768 g
Charcoal:	1500 g	Remaining coal:	131 g

During the experimentation, it was found that:
- 09:29 a.m: Beginning of the experiment;
- 9:34 a.m.: Appearance of small smoke;
- 9:37 a.m.: Appearance of first light-colored smoke:
- 9:40 a.m.: Appearance of noise;
- 09:47: appearance of second dark phase

Figure 9: Curve of the evolution of emissions as a function of temperature and time (Test 3)

For this test, the smoke was seen at 358°C and the first drops of clear oil were seen at 464°C. But this time the dark oil appeared at 643°C. After collection the next day, 63ml of clear oil and 27.5ml of dark oil were collected.

d) <u>Trial</u>: 4th trial
Date of completion: 06/03/19
In this fourth trial we used 1010g of a mixture of 200ml of waste fuel oil spilled into laterite which is only used as a carrier for dry distillation.
We used 1500g of coal for the distillation furnace.

The next day after the distillation furnace cooled down, we collected 742g of undissolved black compound in the receptacle, and 96g of coal ash.

Table 9: The weights of the components of the dry distillation process (4th trial)

Weight:	1010 g	Residuals:	742 g
Charcoal:	1500 g	Remaining coal:	96 g

The experiment started at 09:51 on 07/03/19 and ended at 11:16. During the experiment it was observed that:
- 10:06 a.m.: Appearance of small smoke;
- 10:10 a.m.: Appearance of 1st clear phase;
- 10:22 a.m.: appearance of second dark phase;
- 10:26 a.m.: White smoke appeared;
- 10:54 a.m.: change of color of the smoke to yellow.

Figure 10: Curve of the evolution of discharges as a function of temperature and time (Test 3)

For this test, small fumes were observed at 309°C, followed by the first drops of clear oil at 416°C. The temperature progresses exponentially, at 635°C, we observe the appearance of the second oil. We did not notice too many leaks during this test, at 665°C, the smoke at the exit of the steam conductor became white and at 892°C it changes this time to yellow. During the collection, we were able to obtain 47ml of clear oil and 39ml of dark oil.

e) <u>Test</u>: 5th test
Date of completion: 07/03/19
During this last test we used 1049g of mixture composed of 200ml of waste fuel oil spilled into laterite which is only used as a carrier for dry distillation.
We used 1500g of coal for the distillation furnace.
The next day after the distillation furnace had cooled down, we collected 784g of undissolved black compound in the receptacle, and 92g of coal ash.

Table10: The weights of the components of the dry distillation process (5th trial)

Weight:	1049 g	Residuals:	784 g
Charcoal:	1500 g	Remaining coal:	92 g

The experiment began at 8:57 a.m. on 10/03/19 and ended at 10:44 a.m. During the experiment, it was observed that:
- 9:18 a.m.: Appearance of small smoke;
-9:22 a.m.: Appearance of clear phase;
-9:24 a.m.: Appearance of noise;
-9:28 a.m.: Second dark phase appeared;
- 10:44 a.m.: 3 different phases appeared

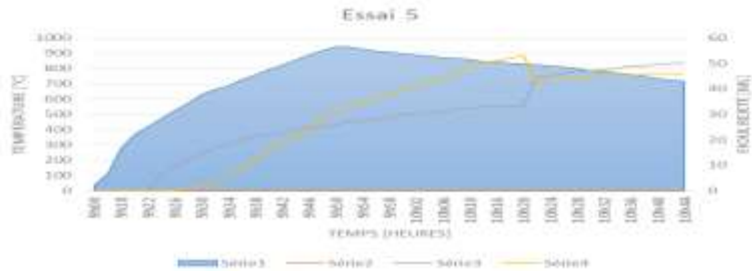

Figure 11: Curve of the evolution of emissions as a function of temperature and time (Test 5)

For test n°5, the appearance of small smokes is noted at 276°C and the first drops of light color at 414°C. The second dark-colored oil appeared only at 571°C. As before, the white smoke was observed from 856°C onwards. At 09:50 a.m. a black mass (like a third phase) was noticed but during collection it was found to be an impurity

3. RESULTS

This chapter tries to inform all the previous results relating to the treatment and recovery of waste heavy fuel oil from JIRAMA on the one hand and on the other hand all the results of this research work entitled: "Optimization of the parameters for the reduction, treatment and recovery of waste heavy fuel oil: the case of the JIRAMA Analamanga Company".

3.1. Previous results (RANDIMBISON. N.L, 2018)

a) Results of the analysis of the physic-chemical characteristics of JIRAMA's crude and waste heavy fuel oil

Table 11: Physical and Chemical Characteristics of Bunker C Fuel Oil and Waste Fuel Oil

N°	Samples	Densit y	Flash point (°C)	Moisture content (%)	Sediment content (%)	Viscosity
01	Fuel brut JIRAMA	0,9308	92	0,3	0,0594	231
02	Waste fuel oil JIRAMA	0,9796	99	12	0,0911	443
03	Fuel brut SYMBION	0,9518	93	0,45	0,0661	171
04	Waste fuel oil SYMBION	0,9939	96	14	0,0951	477
05	Waste fuel oil ENELEC	0,9632	103	2	0,0775	216

Table 11 shows that the physical and chemical characteristics of crude oil and waste oil differ greatly, particularly in terms of water content and viscosity. On the other hand, the difference is not significant in terms of density, flash point and sediment content.

b) Characteristics of lateritic soil

The chemical analysis of the lateritic soil sample studied in the laboratory allowed us to determine its following physical-chemical characteristics:

- Clay (%): 36
- Silt (%): 27
- Sand (%): 37

c) Centrifugation study parameters

Among the parameters studied, the following three (3) types of study parameters are the most important, including:

- Temperature: 30°C
- Centrifugation speed: oscillated around 6350 to 6750 revolutions/min.
- Centrifugation time: varied from: 45 minutes, 50 minutes to 85 minutes

3.2. Results of the appropriate grain size

After the various tests carried out in the laboratory to determine the appropriate granulometry to ensure the role of the metal drums used by JIRAMA to store heavy fuel oil waste from thermal power stations. Depending on the laboratory results, two grain size ranges are possible:

- Range N°1: Laterite grain size greater than 0.400 mm but less than 0.800 mm;
- Range N°2: Laterite grain size less than 0.400 mm;

3.3. Infiltration rate

Whatever the N°1 or N°2 range of granulometry used to store heavy fuel oil waste, its infiltration rate into the lateritic soil is not the same. The following table summarizes the infiltration speed of heavy fuel oil into the lateritic soil.

Table 12: Summary of seepage rates of heavy fuel oil (duration: 14 days)

Range	Appropriate grain size	Infiltration speed (cm) (For more than 14 days)
Range1	(Over 0.400 mm, under 0.800 mm)	3
Range 2	Inf 0.400 mm	0,3

Table 12 provides information on the infiltration rate of heavy fuel oils for an infiltration period of more than 14 days. If JIRAMA's preferred choice is to reduce the daily volume of waste oil, then range 1 is the most interesting. If, on the other hand, you want to replace the method of storage in metal drums with the use of lateritic soil, then range 2 is the best solution.

3.4. Heavy fuel oil waste reduction volume

To determine the volume of waste oil reduction using the lateritic soil of range 1, our approach consists respectively of:

- Taking into account the laboratory results, i.e.:
  - The rate of infiltration of waste fuel oil into the lateritic soil of range 1 is 3cm;
  - the maximum infiltration time of the waste fuel oil is: 14 days;
  - The size of the container used for the experiment is cylindrical in shape with: height = 11 cm, diameter = 9 cm, i.e. radius = 4.5 cm;
  - The container used for the experiment is of cylindrical shape with: height = 11 cm, diameter = 9 cm, i.e. radius = 4.5 cm.
- The volume of waste fuel oil that has infiltrated into the lateritic soil for 14 d is:
  - v= πr2h, where: r= 4.5 cm and h= 3 cm. Thus, v= 190.85 cm3;
- The total volume of fuel oil spilled into the lateritic soil is: 200 ml, or 200 cm3

Thus, the volume of waste fuel oil that has not infiltrated into the lateritic soil after 14 d is the difference between the total volume spilled and the volume that has infiltrated, i.e.:
200 cm3 - 190.85 cm3 = 9.15 cm3.
In short, the waste oil reduction volume every 14 d represents 95.43% of the total volume spilled into the lateritic soil and the waste oil that did not infiltrate represents 4.58% of the total volume of waste spilled.
By projecting these results in real size, i.e. if the total volume of fuel oil spilled in a storage facility of any cylindrical shape with radius R and height H is 1 m3 per day, the infiltration rate is 3 cm every 14 days, the volume of fuel oil that has infiltrated every 14 days is 95.43%, i.e. 0.95 m3.
In conclusion, to reduce the volume of fuel oil waste generated by the JIRAMA plant and stored in metal drums, the best solution is to opt for the use of range 1 lateritic soil. The volume of waste oil reduction every 14 days depends on the size of the storage tank. It is also possible to deduce the storage tank size from the planned waste volume to be reduced every 14 days.

3.5. Results of dry distillation tests

Five (5) distillation tests were carried out at the CNRIT laboratory to determine the most influential and promoting parameters. The following table summarizes the various parameters that were appropriate during this research work.

Table13: Summary of the various relevant parameters

Designation	Tests N°1	Tests N°2	Tests N°3	Tests s N°4	Tests N°5	Sum	Average	Percent(%)
Date of completion Test	28/02/2019	04/03/2019	05/03/2019	06/03/2019	07/03/2019			
Initial weight heavy fuel oil (g)	1004	1022	1054	1010	1049	5139	1027,8	100
Residual weight (g))	798	770	768	742	784	3862	772,4	75,15
Weight charcoal (g)	1500	1500	1500	1500	1500		1500	100
Unburnt weights(g)	130	130	131	96	92	579	115,8	7,72
Time of appearance of the 1st drop (mn)	13	14	8	19	25	79	15,8	
Color 1st drop	Claire	Claire	Claire	Claire	Claire			
Temperature 1st drop (°C)	444	390	464	416	414	2128	**425,6**	
Time of appearance of other phase (mn)	33	23	18	31	31	136	27,2	
Appearance temperature of other phase (°C)	720	666	643	635	671	3335	**667**	
Distillate volume (Reject 1) (ml)	49,5	40	63	47	51	250,5	50,1	
Distillate volume (Reject 2) (ml)	19,5	27,5	27,5	39	14	127,5	25,5	
Total distillation time	1 h 23	1 h 20	1 h 43	1 h 05	1 h 18		1 h 22	

Several points can be drawn from these five (5) tests of dry distillation of waste heavy fuel oil among others:

- Firstly, for an average of 1027.8 g of mixture (lateritic soil + 200 ml of heavy fuel oil), it was possible to obtain a distillation residue of 772.4 g, i.e. a yield of 75.15 %;
- Secondly, to distil the 1027.8 g of mixture (lateritic soil + 200 ml of heavy fuel oil), 1384.2 g of charcoal is needed for an average distillation time of 1 h 22 min;
- Thirdly, the first drop of light-colored distillate occurs after 15.8 minutes of the distillation process start time and this first drop only appears at an average temperature of around 425.6°C.
- Fourth, another distillate phase with a slightly darker color compared to the color of the first phase appears 27.2 minutes after the first drop appears;
- Quinto, with the 200 ml of heavy fuel oil waste, an average of 75.6 ml of distillate could be obtained from the five (5) dry distillation tests carried out, of which 50.1 ml of distillate (reject 1) and 25.5 ml of distillate (reject 2). In short, the 75.6 ml of distillate represents 37.8% of the 200 ml of waste fuel oil treated. The cost-effectiveness of this technology depends on the physical and chemical characteristics of these two (2) distillates which will be determined by the laboratory result.

3.6. Results of the analysis of the physic-chemical characteristics of the two distillates (reject 1 and reject 2) from dry distillation

The following table summarizes the result of the analysis of the physic-chemical characteristics of rejections 1 and 2.

Tabl14: Results of laboratory analysis for Rejection 1

Rejection 1			
Operations	Results	Usual value	Method
Density at 31°C	1003.65g/L	<880g/L	10mL
Relative density at 20°C	1.004		NF ISO 2790 660
Flash point	>100°C	55°C à 120°C	FD ISO/TR 11018

Table15: Results of laboratory analysis for release 2

Rejection 2			
Operations	Results	Usual value	Method
Density at 31°C	894.69g/L	<880g/L	Pycnometer 25mL
Relative density at 20°C	0.895		NF ISO 2790 660
Flash point	>100°C	55°C à 120°C	FD ISO/TR 11018

Taking into account the result of the distillate analysis (Discharge 1 and 2) and the properties of the main petroleum hydrocarbons (Fingas, 2013) summarized in the table below, it can be said that:

- Reject 1 with a density of 1.004, i.e. greater than 1, a flash point greater than 100°C has the property of No. 6 Heavy Fuel Oil;

- Reject 2 with a density of 0.895, a flash point above 100°C and a density of 894.69 g/l has the neighbouring property of intermediate fuel oil.

Table16: Properties of major petroleum hydrocarbons (Fingas, 2013)

Propriété	Unité	Essence	Diesel	Pétrole brut		Mazout intermédiaire	Mazout lourd n°6
				Léger	Lourd		
Viscosité	mPa.s * (15 °C)	0,5	2,0	5 à 50	50 à 50 000	1 000 à 15 000	10 000 à 50 000
Point d'écoulement	°C	-	-35 à -10	-40 à 30	-40 à 30	-10 à 10	5 à 20
Densité	g/ml (15 °C)	0,72	0,84	0,78 à 0,88	0,88 à 1,00	0,94 à 0,99	0,96 à 1,04
Densité API	degré API	65	35	30 à 50	10 à 30	10 à 20	5 à 15
Solubilité dans l'eau	mg/l	200	40	10 à 50	5 à 30	10 à 30	1 à 5
Point d'éclair	°C	-35	45	-30 à 30	-30 à 60	80 à 100	> 100
Tension interfaciale	mN/m † (15 °C)	27	27	10 à 30	15 à 30	25 à 30	25 à 35

Source : Hydrocarbure.gouv.qc.ca/documents/études/GENV22-23.pdf

4. DISCUSSION

For Madagascar, the environment is an essential issue. Indeed, the island in the Indian Ocean where the biodiversity is remarkable and the pressures on natural environments are significant. The waste heavy fuel oil from JIRAMA's thermal power stations can have undesirable effects on the environment if it is poorly managed. It is in this context that this research work entitled: "Optimization of parameters for the reduction, treatment and recovery of heavy fuel oil waste: the case of JIRAMA" was born. Faced with numerous questions such as:

- Is it possible to determine the appropriate granulometry of the lateritic soil for the storage and reduction of heavy fuel oil waste?

- What are the different components of waste heating oil and what are the appropriate temperatures (first jet, last jet) for their respective separation?
- Is the choice of dry distillation technology cost-effective for the recovery of waste heavy fuel oil?

Apart from the composition of the lateritic soil (36% clay, 27% silt and 37% sand), this work was able to show that lateritic soil with an appropriate grain size can be used to store or reduce waste heating oil according to its needs. If JIRAMA's choice is the reduction of the daily volume of waste oil, range 1 (above 0.400 mm, below 0.800 mm) is the most interesting. If, on the other hand, one wants to replace the method of storage in metal drums by using lateritic soil, range 2 (below 0.400 mm) is the best solution.

Compared to the centrifugation method for heavy fuel oil waste, which presented difficulties in separating the different phases, the dry distillation method adopted in this work is better adapted because we have clearly distinguished between the two types of oil rejected (No. 6 heavy fuel oil for the 1st rejection and intermediate fuel oil for the 2nd rejection).

With the 200 ml of waste heavy fuel oil, an average of 75.6 ml of distillate was obtained from the five (5) dry distillation trials carried out, of which 50.1 ml was distillate (reject 1) and 25.5 ml distillate (reject 2).

In short, the 75.6 ml of distillate are reusable crude heavy fuel oils and represent 37.8% of the 200 ml of waste fuel oil treated. The fact that they are used for the operation of thermal power stations confirms our methodological approach based on the three waste management principles of "reduce, reuse, recycle" and where the other two principles of the "reuse and recycle" principle are proven here. Moreover, this reuse of raw fuel oils has several advantages for society among others:

- the reduction in the volume of crude oil imports impacting on the improvement of the country's economy through the reduction of currency leakage;
- the reduction of the volume of waste fuel oil stored at the thermal power plant, which subsequently allows the elimination of the budgetary charges allocated to the purchase of metal drums and, consequently, the improvement of the company's operating budget.

5. CONCLUSION

This research work has highlighted three main points: volume reduction, reuse and recycling of waste heavy fuel oil generated by JIRAMA's thermal power stations. The methodology adopted is both qualitative and quantitative. Its long-term realization requires a priori the passage through the chronological order of the different following activities:

- Collection of bibliographical and webographical data relating to the research work that will make it possible to define what heavy fuel oil is, to capitalize on the various studies or research on the subject and, finally, to make an inventory of the various technologies for the treatment and recovery of heavy fuel oil waste that have already been carried out;
- Descent in the study area allowing on the one hand to discuss with JIRAMA officials on the problems of the said company relating to heavy fuel oil waste and on the other hand to collect samples of these wastes for experimental work at the laboratory level;
- Carrying out the laboratory work with the samples collected on site using the appropriate technology for treating or recovering heavy fuel oil waste;
- Drafting of this memorandum

The results of this research work showed respectively that:

- Firstly, dry distillation technology is the appropriate technology for recovering heavy fuel oil waste for various purposes compared to centrifugation;
- Secondly, lateritic soil is the appropriate material used as a carrier material for dry distillation of waste heavy fuel oil. The required granulometry of lateritic soils that can reduce the daily volume of waste fuel oil generated by the thermal power plant is range 1 (upper 0.400 mm, lower 0.800 mm); however, to eliminate the method of storage in metal drums practised by JIRAMA, range 2 (lower 0.400) is the best solution;
- Thirdly, dry distillation was able to separate the solid components from the heavy fuel oil waste and generate two (2) crude oils: No. 6 heavy fuel oil and intermediate fuel oil which have the same physical and chemical characteristics as the crude oils;
- Fourthly, the appearance of the first drop of No. 6 heavy fuel oil is obtained at a temperature of 425.6°C after 15.8 minutes of the distillation process start-up time. On the other hand, intermediate fuel oil appears 27.2 minutes after the appearance of the first drop of No. 6 HFO at a temperature of around 667°C;
- Of the 200 ml of waste heavy fuel oil treated, 37.8% can still be reused as crude heavy fuel oil.

In short, the application of the results of this research work is very beneficial for the future of JIRAMA in several areas. There is still a lot to be done, including the clean-up of lateritic soils polluted by fuel oil waste after dry distillation using biological treatment.

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