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THE QUALITY OF CRUDE OIL FROM THE MUANDA FIELD AND ITS CONSEQUENCES ON THE INSTALLATIONS

Jean Ondontshia Nkoyi [1]*
Benjamin Safari Kachunga [1]
Joel Kabesa Kilungu [1]
Jerry Ponge Otshudi [2]
Dominique Wetshondo Osomba [3]

[1] University of Kinshasa, Faculty of Oil, Gas and Renewable Energy, Department of Exploration and Production Engineering, Democratic Republic of Congo
[2] Analysis - Quality Engineer at Hydrac, Democratic Republic of Congo
[3] University of Kinshasa, Faculty of Science, Department of Geosciences, Democratic Republic of Congo
* e-mail: jean.ondontshia@unikin.ac.cd

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ABSTRACT

The study on the quality of the crude oil of the Muanda field and its consequences on the installations, was carried out within the framework of our scientific research of study of Advanced Diploma (DEA). The objective of this study was to determine upstream the physical properties and composition of the Muanda field crude oil, in order to determine the conditions of asphaltene deposits in the tubing and other installations. To achieve this, the samples collected in the field were analysed in our laboratories and at the PVT Laboratory of Sonangol in Luanda to constitute the results of this manuscript.

The results of these analyses show that the crude oil of the Muanda field is a Medium Crude Oil (29.7°API) on the API density scale with the hypothesis of two sources: one of Light Oil, the other of Medium Oil). These two sources of crude oil, induce the establishment of two oils of different viscosities and pour points of which one more viscous (Mu 23) and the other less viscous (Mu 16 and Mu 2) having the average pour point at 15° C (60°F).

The Standing correlation gave acceptable results and close to those of the Electromagnetic Viscometer (EMV).

The chemical composition showed that the crude oil is composed of 18.63% of gas and 81.37 % of Paraffins and Asphaltenes, and that this oil is of low sulfur content type (Low Sulfur Content (LSC) <0.6% weight). A solid sample collected from the oil field was characterized through melting, further heating and solidification point (28 ^{o}C).

Keywords: quality, characterization, crude oil, Muanda field

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1. INTRODUCTION

Crude oil is a complex mixture of several chemical compounds of various origins [1, 2]. These compounds, define the quality and physical, hydrodynamic and commercial properties of the Crude Oi, and even foresee the behaviour of it during its exploitation.

According to [3,4,5], API Gravity (engineeringtoolbox.com), and other researchers, crude oil is classified in four orders of density in API degree. These are:

1. Light oil whose density varies between 45 - 30 °API,
2. Medium oil whose density varies between 30 - 20 °API,
3. Heavy oil with density between 20-10° API,
4. Extra heavy oil whose density varies between 10 - 0° API.

The limit between light and medium oil is 31.1°API according to Corporate Finance Institute (https://corporatefinanceinstitute.com/resources/economics/crude-oil-overview/). On the other hand, any oil whose density is less than 10°API is considered as Bitumen or Extra Heavy Oil [6]. This type of oil cannot be exploited by ordinary techniques but has some special methods for its exploitation: hydraulic fracturing or by in situ combustion if the deposit is very deep or by open pit mining (quarry) for the case of sub-surface deposit (located at low depth).

To this end, the quality of the crude oil influences in turn the performance of the exploitation system. This is especially true since light oil will be extracted easily with low cost, while heavy or medium oil will impose a high operating cost with a low yield.

2. PROBLEMS

Located in the western part of the DRC, in the Moanda Territory near the SOCIR refinery complex, the Muanda Field has been producing oil since 1987 in the onshore part as illustrated in figure 1.

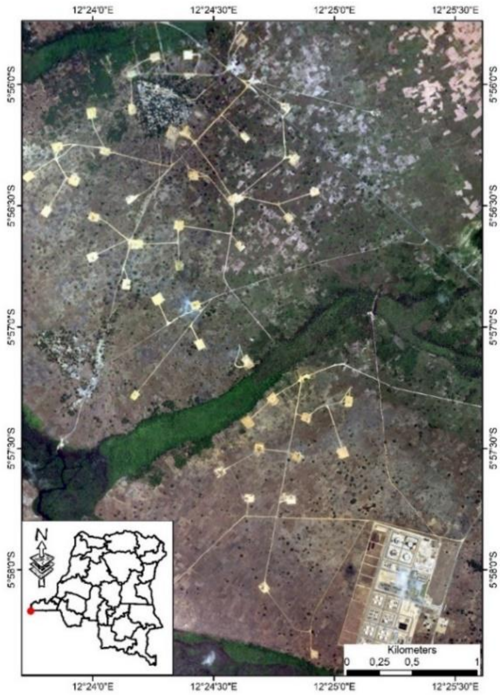

***Figure 1**. Location of the Muanda field in the DRC.*

The quality of the oil exploited and the behavior of the geological reservoir in this field have imposed on the operating company a certain methodology to extract the crude oil found in its deposit: activation of all the wells by progressive cavity pumping (PCP) and rod pumping (SRP) with water injection in some wells. Despite this, some problems remain and hinder the operational profitability of the wells. We can see the coagulation of crude oil in the wells and in the transfer lines, as shown in figure 2.

Figure 2. *Illustration of the sampling process in some wells of the Muanda field as of March 18, 2022*.

The coagulation of crude oil is today at the base of low production of most wells in these fields. To understand the real causes of these coagulation, it is necessary to make a thorough qualitative analysis of the samples of this crude oil in order to opt for good practices that can limit them. It is in this context that this study was conducted to know the composition and physical properties of this oil in order to better adapt the operating equipment in another ongoing research project.

The objective of this scientific paper is to determine the composition and physical properties (density, viscosity, pour point) of the Muanda field crude oil.

3. METHOD & MATERIALS

For this study, we carried out a field trip as part of our scientific research for the dissertation of the Diploma of Advanced Study (DEA) in March 2022 as shown in Figure 2 above. During this run, we collected three crude oil samples from the Muanda 2, Muanda 16, Muanda 23 wellhead and one solid oil sample (Figure 2).

These samples were brought to our laboratory at the University of Kinshasa to determine some physical properties (density, viscosity, pour point). A part of these same liquid samples was brought to Luanda to the PVT Laboratory of SONANGOL to make the compositional analysis of the crude oil of the Muanda 2 well sample.

As for the sample of solid oil, we carried out an experiment (in our GeReMiPe laboratory) of its dilution by the hexane molecule and its conditions of fusion and solidification thanks to the Fe-CuNi Thermocouple, in order to understand under which conditions this crude oil solidifies in the wells of the Muanda field and in the installations of transport and storage.

The equipment used to determine the physical properties in the laboratory of the Faculty of Science in the Department of Physics are the portable balance OHAUS CS2000 and the glass measuring cylinder, the viscosimeter with ball drop coupled to a thermostat for the temperature variation.

As for the composition of the oil, the Liquid Phase Chromatograph and Gas of the PVT laboratory of Sonangol were used for this analysis.

4. RESULTS AND DISCUSSION

4.1. Density of the Muanda field crude oil samples

The parameters of the laboratory measurements to determine the densities of our samples are presented in Table 1 below. We had three samples of crude oil (abbreviated as Mu 2; Mu 23, Mu 16). We worked with oil at 27°C to avoid congelation at 15.56 ºC (the standard temperature for density measurements), and to simulate the storage conditions of this crude oil when it crosses in the reservoir from the bottom (where it is at 55°C) to the surface at 27°C. The three crude oil samples were named Mu 2; Mu 23; Mu 16 to represent the Muanda 2; Muanda 23; Muanda 16 wells respectively. The measurement temperature was 27°C (80.6°F).

Table 1. *Parameters measured and calculated at the Physics Laboratory B17 of the Faculty of Science of the University of Kinshasa.*

Sample No.	T,°C	Weight (g)	V (ml)	Density at 27°C, g/ml	Correction coefficient c, g/mL*	Density at 15.56°C, g/mL	Specific density $d_{15.56}^{15.56}$	°API
Mu 2	27	33	38	0.8684	0.000655	0.8691	0.8700	30.0
Mu 23	27	34	38	0.8947	0.000640	0.8954	0.8963	26.4
Mu 16	27	32.7	38	0.8605	0.000655	0.8612	0.8621	32.6

*according to standard SR EN ISO 3675/2003

A volume of 38 milliliter (ml) of each of these samples was measured in the graduated cylinder and weighed on the balance after taring the masses corresponding to the third column of the Table 1, and calculating density at 27 ºC with formula 1:

$$\rho_{27\,C} = \frac{m}{V} \tag{Eq.1}$$

The density is corrected at 15.56 ºC with the following formula:

$$\rho_{15.56\,C} = \rho_t + c\,(t - t_0) = \rho_{27} + c\,(27 - 15.56) \tag{Eq.2}$$

where the correction coefficient *c* is tabulated in SR EN ISO 3675/2003, in function of density interval (0.86-0.87; 0.89-0.90, respectively)

Then, the specific density (relative to water at 15.56 ºC) is calculated with formula:

$$d_{15.56}^{15.56} = \frac{\rho_{oil,15.56\,C}}{\rho_{water,15.56\,C}} \tag{Eq.3}$$

For the calculation of density in °API, the following formula is applied [8,11]:

$$°API = \frac{141.5}{d_{15.56}^{15.56}} - 131.5 \quad \text{(Eq.4)}$$

Our results show that Mu 2 is, according to all classifications, a light oil (32.6 °API), Mu 16 is a medium oil at the limit with light oil (30 °API) and the Mu 23 sample is a medium oil (26.4 °API). The average density of samples is 29.7 °API, so definitely a medium oil.

The difference of 6.2°API between the Muanda 23 and Muanda 2 well samples of the same field is quite high, leading us to believe that the oil produced in this field (reservoir) would have two different origins (two different source rocks), because oil of the same origin and exploited in the same reservoir, could not have such a large difference in their densities.

4.2. Viscosity of Muanda field crude oil

Viscosity is an important parameter that characterizes not only the frictional forces of a fluid during flow, but also the quality of the oil. It is a parameter dependent on temperature and pressure in the case that concerns liquids like oil.

4.2.1. Determination of viscosity by Standing correlation

Standing's correlation of 1981 and the PVT results from Sonangol's laboratory were used determine viscosity and to compare the results.

Standing's (1981) correlation for calculating the viscosity of crude oil is used together with the following set of equations from the books [7,9] and the website [10]:

$$\mu_{0d} = \left(0{,}32 + \frac{1{,}8\times10^7}{API^{4{,}53}}\right)\left(\frac{360}{t+200}\right)^A \quad \text{(Eq.5)}$$

$$A = 10^{\left(0{,}43+\frac{8{,}33}{API}\right)} \quad \text{(Eq.6)}$$

$$\mu_{ob} = 10^a \mu_{0d}^b \quad \text{(Eq.7)}$$

where μ_{ob} is the viscosity of saturated crude in cP

$$a = R_S(2{,}2\times10^{-7}R_s - 7{,}4\times10^{-4})$$

$$b = \frac{0{,}68}{10^C} + \frac{0{,}25}{10^d} + \frac{0{,}062}{10^e}$$

$$c = 8{,}62\times10^{-5}R_s$$

$$d = 1{,}10\times10^{-3}R_s$$

$$e = 3{,}74\times10^{-3}R_s$$

where R_s is the solution gas-liquid ratio.

Standing's (1981) correlation for unsaturated crude oil is expressed as follows:

$$\mu_0 = \mu_{0b} + 0{,}001(P - Pb)\left(0{,}024\mu_{0b}^{1{,}6} + 0{,}38\mu_{0b}^{0{,}56}\right) \quad \text{(Eq.8)}$$

In Table 2 are shown the results of the viscosities (centipoise) of the Muanda field crude oil samples from Standing correlations. The variation of the viscosity with temperature is represented in Cartesian graphs as follows (Figure 3). The four curves show the evolution of viscosities of the crude oil samples according to the temperature variation from the bottom to the surface. As can be clearly seen, the sample from the Mu 23 well had a higher viscosity than the other two. Its viscosity ranges from 7.48 to 24.8 cP for temperature ranging from 131 °F to 59 °F. This value of viscosity is justified by the fact that the crude oil of this well is medium crude oil according to the value of its density found in this work which is 26.4° API, since the light oil has a viscosity between 2.97 to 8 cP, in the same range of temperatures.

***Table 2**. Viscosity results from Standing correlation*

T °F	Pressure Psia	Pb (Psia)	Rs (Sfc/Stb)	Visco Mu2 (cP)	Visco Mu23 (cP)	Visco Mu16 (cP)	Average Visco
131	1530	1530	275	3.82	7.48	2.97	4.76
122	1530	1530	275	4.30	8.56	3.32	5.39
113	1530	1530	275	4.85	9.84	3.72	6.13
104	1530	1530	275	5.49	11.34	4.19	7.00
95	1530	1530	275	6.23	13.14	4.73	8.03
86	1530	1530	275	7.11	15.29	5.36	9.25
77	1530	1530	275	8.14	17.87	6.10	11.04
68	1530	1530	275	9.36	21.00	6.97	12.44
59	1530	1530	275	10.82	24.82	8.00	14.55

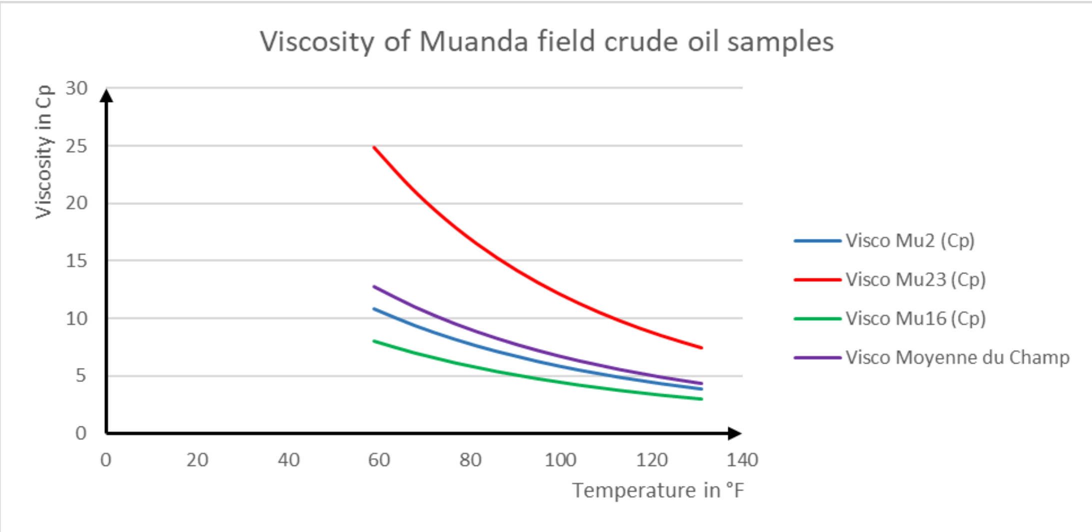

***Figure 3**. Viscosity vs. temperature of Muanda field crude oil samples and the average sample*

Based on these viscosity values, the average viscosity of the Muanda field crude oil in purple in figure 3 can be found. It varies between 4.76 and 14.55 cP as the temperature changes from 131°F to 59°F. The change in temperature conditions between the bottom and the surface has a direct impact on the physical properties of the crude (e.g. viscosity), and an indirect impact on the quality of the crude. This effect is noticeable in the viscosity variation of the crude oil samples studied above. The values of viscosities found by the application of Standing's correlation will be compared to the values of viscosity from the PVT studies of a sample analysed in Luanda.

4.2.2. PVT Viscosity Measurement

Fluid viscosity is measured at the desired pressure and temperature using a DBR modified Electromagnetic Viscometer (EMV). The fluid being tested is monophasically charged to the viscometer cell, which contains a piston. The piston is moved from end to end within the cell by imparting a force on the piston using the electromagnetic coils, which are located at each end of the sensor body. After traveling the length of the EMV test cell the piston is returned to the starting location by reversing the magnetic field of the electromagnet. The motion of the piston inside the vessel is impeded by viscous flow in the annulus between the piston and the wall of the measurement chamber. Viscosity is determined by measuring the piston transit time for a complete cycle of piston movement and comparing this to transit times obtained by using calibration standards.

Table 3: *The reservoir fluid viscosity at 57. 2°C (134. 96°F)*

Pressure (Psia)	Viscosity (cP)
5000	7.134
3000	5.882
2000	5.330
1000	4.824
750	4.698
500	4.578
435	4.550
325	4.891
225	5.111
150	5.753
100	6.501
14.5	7.733

The viscosity measurement results from the PVT laboratory show that the viscosity of the crude oil sample, varies with pressure (Figure 4).

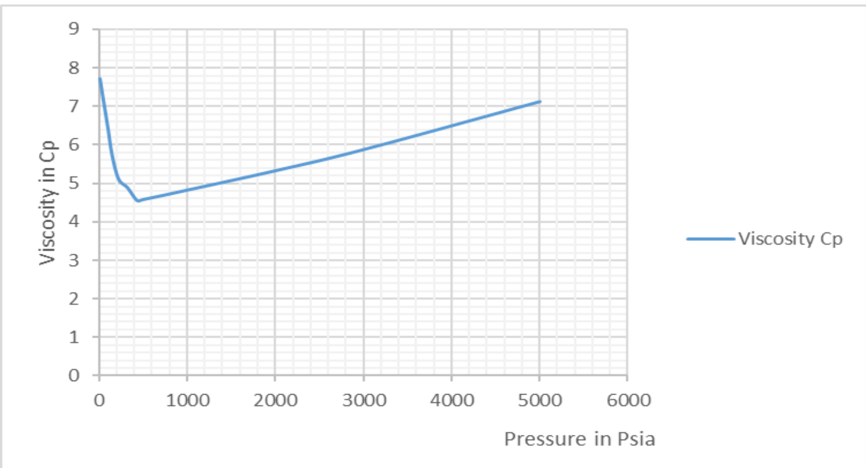

Figure 4. *Viscosity versus pressure curve*

The graph viscosity versus pressure curve (Figure 4) show the followings:

- As the pressure decreases, the viscosity also decreases.
- At a certain pressure (500 psia), the viscosity value does not decrease anymore. This is the saturation pressure of the fluid that has been reached.

Therefore, it can be said that the variation of this viscosity as a function of pressure is in the range of 4.5 to 7 cP. The value of the pressure of 500 Psia can be considered as the optimal value of the pressure that the fluid will not be able to reach in the reservoir under penalty of causing an increase in the viscosity of the crude oil.

The viscosity of the sample analysed in EMV test are in the same order of magnitude with the values obtained by Standing's correlation (Table 2 and Table 3).

4.3. Flow points of the Muanda field crude

Based on our tests in the ball viscometer at different temperatures, and keeping the pressure constant (1.4 bar), the temperature at which the ball was no longer moving (crystallization temperature of the samples) was reached at: 14°C for Mu16, 15°C for Mu 2, 17°C for Mu 23. It should be said that our pour point was reached at the average temperature of 15.3°C or (60°F) for all our samples corresponding to the average viscosity varied between 4.3 to 12 cP. This point was considered as the temperature at which the ball in the viscometer could no longer move due to solidification or crystallization of the liquid oil samples.

4.4. Study on the solid oil sample (dead oil) collected from the Muanda 32 well

This study was done in order to understand the conditions that prevailed for this oil to become solid, thus hindering the effective exploitation of the wells. Thus, an experiment was conducted in the laboratory. This one consisted in heating 102.07g of sample of solid oil in the open air in order to measure the temperature of complete fusion of this one and to let it cool until becoming solid to finally determine the temperature of solidification in the open air. This experiment was done in order to compare its solidification temperature with the pour point temperature of the liquid samples in order to confirm if it was the liquid oil that was solidifying following the temperature drop between the reservoir and the wellhead. Figure 5, shows the heating process in the laboratory.

***Figure 5**. Heating process of the solid oil sample from the Muanda field.*

The heating results of this solid sample are shown in Figure 6. The figure on the left shows the temperature gradient of heating the sample for up to 800 seconds. The different colors on the right of the temperature gradient simply show the increase in temperature from cold (blue) to hot (red).

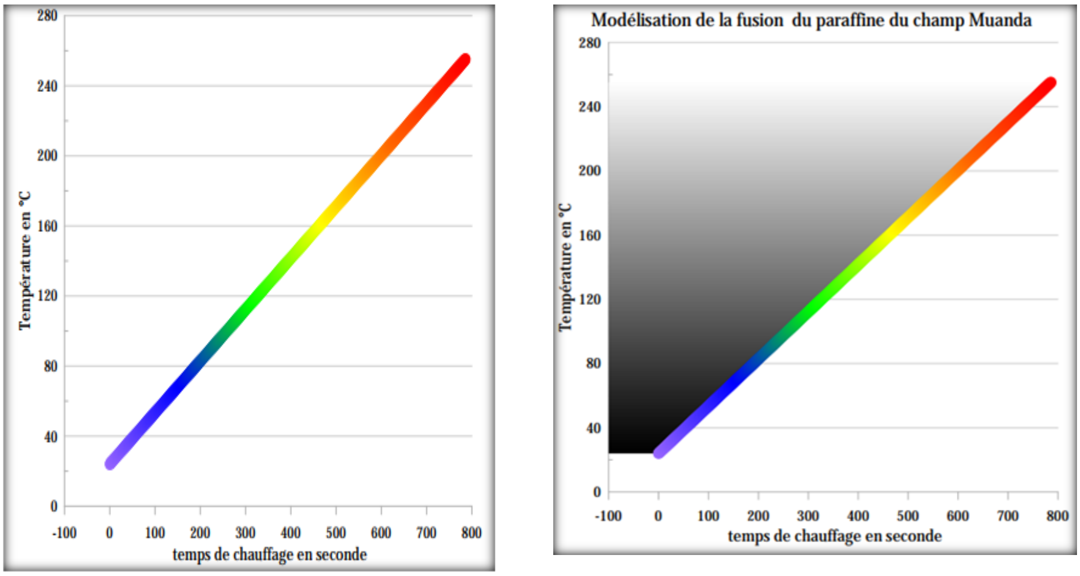

Figure 6. *Modeling of the melting process of the solid petroleum sample.*

As for the figure on the right, it illustrates the superposition of the heating gradient model and the evolution of the state of the sample under the effect of the temperature. It can be seen together in the figure on the right how the state of the sample is changing as the temperature increases. This means that each time a certain temperature is reached, the sample changes state as described below in the table 4.

It appears that the melting started at 120°C and was completed at 170°C (temperature at which the sample became completely liquid), and this took 500 seconds. From 170°C to 252°C the sample was in the state of vaporisation and the cracking of longer molecules started (huge release of smoke with the smell of rubber) for 800 seconds: maximum time of the experiment.

To be sure how this sample of solid oil solidify in the well, we took the same sample in liquid state and in phase of sublimation (heated to 252°), we removed it from the fire and put its pan in a tub containing water at temperature of 18°C on the ground to cool it until it became solid. It solidified at 28°C during at least 1h32’07”. This made it possible to understand that the solidification of the liquid oil in the Muanda field well had as a primary cause, the drop in temperature along the tubing (between the reservoir and the wellhead).

Important Note from the Experiment:

As the heated solid sample reached maximum melting, less immersion in the pan, the superheated liquid became very adhesive to the metal with a deposition of a thin rubber layer. This observation also allowed us to understand that the liquid (the heated sample) contained a lot of resins and asphaltenes (heavy compounds in crude oil, containing the following elements C, H, N, S, O, and some metals), very black in color and which were deposited at the bottom of the pan during the evaporation phase of the sample. To confirm this, we applied the hexane molecule as a solvent and the hexane dissolved the thin rubber layer.

Table 4. *The different states of the solid oil sample as a function of heating.*

T,°C	Status of the sample
24	Solid
29.8	Solid
30	Pasty-solid
39.8	Pasty-solid
40	Liquid - pasteous - solid
99.8	Liquid - pasteous - solid
100	Liquid - pasteous
130.7	Liquid - pasteous
131	Liquid
170.7	Liquid
171	Boiling liquid
180	Boiling liquid
180	Evaporation +cracking
245	Evaporation+cracking
245	Evaporation+cracking
252	Evaporation+cracking

4.5. Chemical composition of the Muanda field crude based on compositional analysis

During our trip to Luanda in May 2022 to participate in the International Petroleum Conference (CAP VIII), we took a sample of crude oil to Sonangol's PVT laboratory in order to determine the chemical composition of the Muanda field crude oil and the production parameters. The results from this laboratory are presented in Table 5 below.

From this analysis, it follows that 34 elements were identified in the Muanda 2 well sample, ranging from those with one carbon atom (C1) to those with more than thirty carbon atoms (C30+). The absence of sulfur in this sample is remarkable by the concentration of hydrogen sulphide which is practically zero, which allows us to say that the crude oil of the Muanda field is not sulfurous. It should be noted that only one sample was analyzed (Mu 2).

From these results of compositional analysis, we can then group two types of hydrocarbons: the gas, that is to say the hydrocarbons whose numbers of carbon atoms vary from C1 to C4, and the others will be the liquids.

***Table 5**. Chemical composition of Muanda field crude oil*

Composition	MW	Flashed gases		Oil Flashes		Monophasic	
	g/mol	Wt %	Mole %	Wt %	Mole %	Wt %	Mole %
N2	28.01	0.39	0.48	0	0	0.01	0.08
CO2	44.01	1.06	0.73	0	0	0.03	0.14
H2S	34.08	0	0	0	0	0	0
C1	16.04	27.19	51.34	0	0	0.77	9.56
C2	30.07	15.16	15.27	0.03	0.21	0.45	3.02
C3	44.1	26.25	18.03	0.25	1.35	0.98	4.46
i-C4	58.12	7.19	3.75	0.19	0.78	0.39	1.33
n-C4	58.12	11.86	6.18	0.53	2.16	0.85	2.91
i-C5	72.15	3.64	1.53	0.45	1.5	0.54	1.5
n-C5	72.15	3.75	1.58	1.39	4.49	1.46	4.03
C6	84	1.75	0.64	0.73	2.06	0.76	1.8
C7	96	1.58	0.5	2.46	6.1	2.43	5.05
C8	107	0.16	0.05	3.35	7.46	3.26	6.8
C9	121	0.01	0	3.24	6.39	3.15	5.2
C10	134	0	0	3.28	5.84	3.19	4.75
C11	147	0	0	3.02	4.89	2.93	3.98
C12	161	0	0	2.94	4.35	2.85	3.54
C13	175	0	0	3.46	4.71	3.36	3.83
C14	190	0	0	3.18	3.99	3.09	3.25
C15	206	0	0	3.4	3.93	3.3	3.2
C16	222	0	0	2.93	3.15	2.85	2.56
C17	237	0	0	2.79	2.81	2.71	2.28
C18	251	0	0	3.28	3.07	3.14	2.5
C19	263	0	0	2.87	2.6	2.79	2.12
C20	275	0	0	2.61	2.26	2.54	1.84
C21	291	0	0	2.68	2.2	2.61	1.79
C22	300	0	0	2.56	2.03	2.48	1.65
C23	312	0	0	2.44	1.86	2.37	1.52
C24	324	0	0	2.36	1.74	2.3	1.41
C25	337	0	0	2.54	1.8	2.47	1.46
C26	349	0	0	2.23	1.52	2.16	1.24
C27	360	0	0	2.34	1.55	2.28	1.26
C28	372	0	0	2.38	1.53	2.32	1.24
C29	382	0	0	2.41	1.5	2.34	1.22
C30+	750	0	0	31.74	10.09	30.84	8.21
Mole %			18.63		81.37		

4.5.1. Identification of gaseous hydrocarbons

The compositional results show that the crude oil sample from this field contains 18.63% mole of gas (methane, ethane and propane) which are visible in Figure 7.

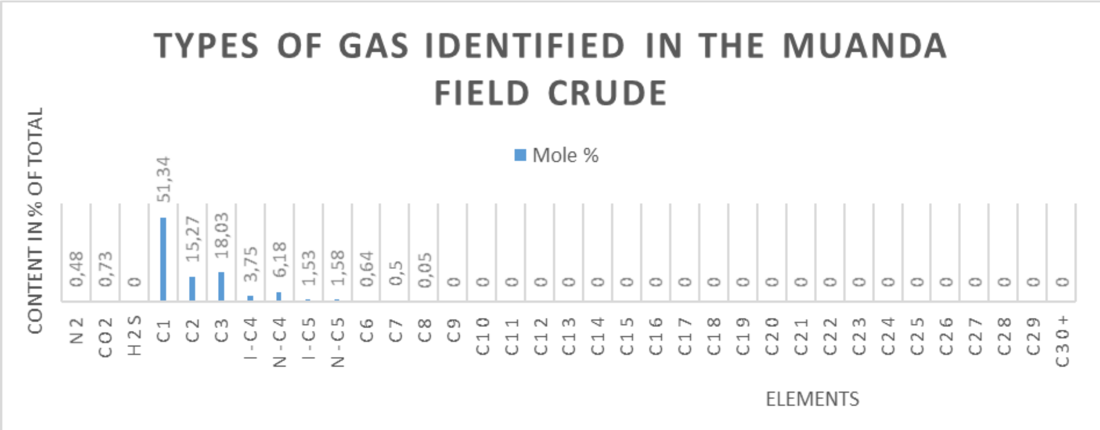

***Figure 7**. Types of gaseous hydrocarbons identified in the Muanda field crude.*

4.5.2 Liquid hydrocarbon identifications

The compositional results also shows that the crude oil sample from this field contains 81.37% mol of the liquid hydrocarbons that are visible in Figure 8.

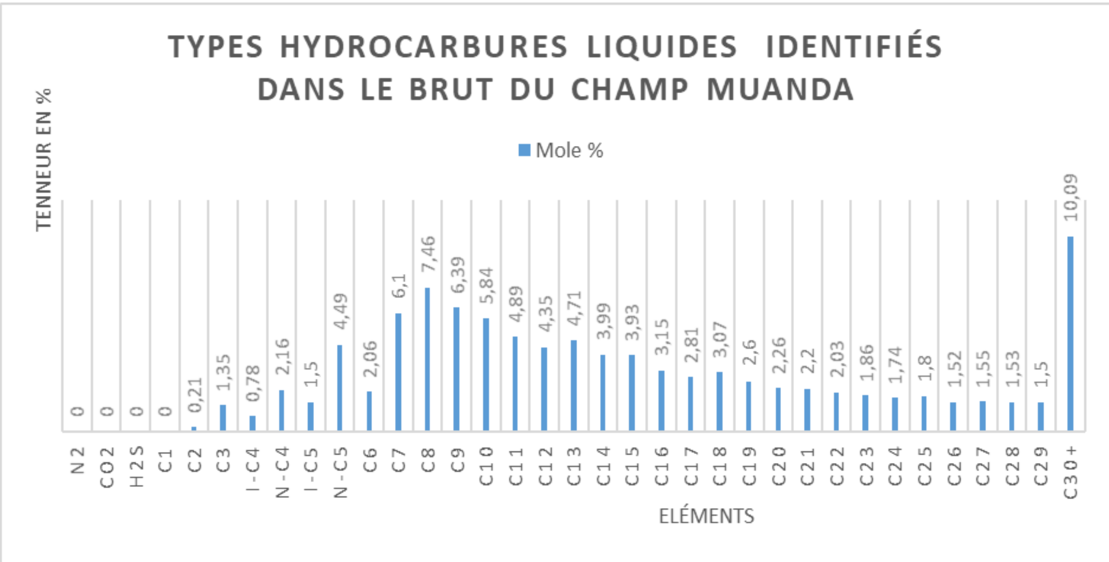

***Figure 8**. Types of liquid and solid hydrocarbons identified in the Muanda field crude.*

Of these liquid hydrocarbons, it can be seen that the concentration of hydrocarbons with more than thirty carbon atoms, C30+ (approx. 10% mol) is normal for a medium crude oil; the content in distillable hydrocarbon (up to C30) is high (approx. 90% mol), and the potential for "white products" (gasoline, kerosene and gas oil), distillable at atmospheric pressure, (up to C25) is exceptional (aprox.83% mol). Besides that, it is necessary to say that the sample is very rich in paraffins and that these hydrocarbons have such physical properties (e.g. high congelation point), and making the behavior of crude oil very complex due to changes in temperature and pressure.

5. CONCLUSION

The objective of this study was to determine the physical properties of the Muanda field crude oil in order to identify the major causes of its deposition in the wells. After field sampling and laboratory analysis, the following results were obtained:

- The oil of the Muanda field in the Democratic Republic of Congo is an oil classified in the API scale in the medium order. Its average density evaluated on the basis of three samples collected is 29.7°API. The remarkable difference of density values of each sample (between 32.6 and 26.4°API), allowed us to believe in the existence of oil types in its reservoir, one of which would be light and the other medium.
- The viscometric study identified two types of oil with the following remarks:
  - ✓ One very viscous (Mu 23) with values between 7.4 to 24.8 cP at the temperature of 131°F to 60°F.
  - ✓ And the other two less viscous (Mu 16 & Mu 2) with values between 2.97 to 10.83 cP at the same temperatures.
  - ✓ An average viscosity of all samples was deduced at 4.76 to 14.55 cP at the same temperatures with a pour point at the 15°C temperature.
- The Standings correlation gives acceptable results and of the same order of magnitude as those of the PVT laboratory.
- The chemical composition carried out on a single sample from the Muanda 2 well, attests that it is composed of a minority of gaseous hydrocarbons 18.63 % mol (methane, butane and propane) and a majority (81.37 % mol) of liquid hydrocarbons and solids (Parrafins and Asphaltenes) increasing its density and viscosity.
- The sulfur content is zero in our samples. In this case, it is a crude oil of Low Sulfur Content (BTS <0.6% weight).

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REFERENCES

[1] Tarek A., Meehan N. (2012) Advanced Reservoir management and engineering, Second edition, Gulf Professional Publishing, 705p.

[2] Okotie S., Ikporo B. (2019) Reservoir Engineering Fundamentals and Applications, Springer, 430p.

[3] Cannon S. (2018) Reservoir modelling: a practical guide, First edition, Wiley Blackwell, 329p.

[4] Tarek A. (2001) Reservoir engineering handbook, Second edition, Gulf Professional Publishing, Boston-London-Auckland-Johannesburg-Melbourne-New Delhi

[5] Dake L. (1978) Fundamentals of reservoir engineering, Elsevier, Amsterdam-London-New York-Tokyo

[6] Lyons C.W., Plisga G.J. (2005) Standard handbook of petroleum & natural gas engineering, Second edition, Gulf Professional Publishing, 1569p.

[7] Guo B., Lyons C.W., Ghalambor A. (2007) Petroleum production engineering a computer-assisted approach, Gulf Professional Publishing, Elsevier, Amsterdam, 309p.

[8] Alomair O., Jumaa M., Alkoriem A., Hamed M. (2015) Heavy oil viscosity and density prediction at normal and elevated temperatures, research paper, published in the journal J Petrol Explor Prod Technol (2016), 6:253–263, DOI 10.1007/s13202-015-0184-8, Springer.

[9] Pedersen K.S., Christensen P.L., Shaikh J.A. (2015) Phase Behavior of Petroleum Reservoir Fluids, Second edition, CRC Press, 463p.

[10] The Engineering ToolBox, (2023). *API Gravité*, https://www.engineeringtoolbox.com/api-gravity-d_1212.html [accessed on 03/01/2023].

[11] Hollebone B.P. (2015) The Oil Properties, *Handbook of Oil Spill Science and Technology*, First Edition. Edited by Merv Fingas. John Wiley & Sons Inc.

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