Microbial recovery of oils from surface oil and gas production water by reducing surface and interfacial tensions at the petrochad (mangara) limited field in badila

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Abstract: Demulsifiers such as VX champion, BAD-106 and others injected into the Petrochad(Mangara) Limited field between 2014 and 2023 only recovered 43,501,365 barrels out of a forecast of 91,250,000 barrels, or 42.48%. The mean surface and interfacial tension related to this recovery is 56.42 and 59.8 mN/m respectively. The inadequacy of this recovery is linked to the ineffectiveness of demulsifiers in reducing the surface and interfacial tensions between the phases and releasing the oils sufficiently. The biosurfactants produced by isolates RPG14, RPG18 and RPG20 isolated and obtained by screening tests are very active in lowering surface (23.70, 0.5±, 22.45, 0.5± and 22.75, 0.5 mN/m) and interfacial (14.35, 0.5, 15.35, 0.5 and 15.45, 0.5 mN/m) tensions. This reduction in tensions made it possible to recover respectively 86518548.36 barrels or a percentage of 84.49% for the RPG14 isolate, 88126219.86 barrels or 86.06% for the RPG18 isolate and 87740542.5 barrels or 85.68% for the RPG20 isolate.

Keywords: surface tension-lowering-biosurfactants-recovery-oil-produced waterc

1. Introduction

Oil production on the Petrochad (Mangara) Limited field is the result of the flooding of water supported by pumps at the wellhead, so the rate of production has changed very quickly. This rate of production is responsible for the massive entrainment of oils in EPPGs (Carvalho et al. 2016). Crude oil (water-oil-gas) is processed at the Badila Central Processing Plant (CPU) by gravity separation devices, to separate the three components from each other. Measurements carried out regularly on these fields show an increase in surface tensions likely to lower the potential for oil recovery in Badila. These surface tensions retain the oils in the form of emulsions at various diameters, resulting in the retention by the EPPG of a considerable quantity of oil droplets (Sullivan Graham et al. 2017). The types of equipment used on many platforms such as those at Badila to recover oil in solution are units, skimmers, coalescers, hydrocyclones and filters. Chemicals are regularly added to the treatment stream to improve the efficiency of oil/water separation. PAHs, alkyl phenols and naphthenic acids of higher molecular weights and more toxicity are associated almost exclusively with oil droplets dispersed in petroleum production water (Christenson and Sims 2011). The efficiency of recovery of these toxic chemicals can be improved by removing droplets using high-speed centrifuges and membrane filters, which can remove particles from 0.01 to 2 µm (Rahmani 2019). However, droplets with diameters of less than 2 µm are still retained in EPPGs in the form of tiny oil/water emulsions (Dib, Laouer, and Driss 2022). At this level, the combination of mechanical and chemical treatment can improve the recovery of volatile compounds and the oil dispersed in the produced water (Ziani 2016), but it is ineffective in removing the dissolved organic compounds, ions and metals (Neff and ly., 2012). However, even with the most advanced separation equipment, oil/water separation is not 100% effective (Bourdet 2023), EPPG will still undergo some form of specific treatment to improve recovery before being discarded. One of the suspected very effective techniques is the addition of biosurfactants to the production line to reduce surface and interfacial tensions. This type of physico-biological combination seems to be effective for the complete elimination of dispersed fats and oils retained in EPPGs under high surface tensions. Our method consists of isolating mesophilic bacteria from oil and gas production water from the various oil fields of the Doba basin, likely to produce biosurfactants capable of drastically reducing the surface tension between the phases after addition to the treatment chain in Badila.

Materials and methods

1. Location of the study site

The Petrochad (Mangara) Limited field is composed of two sites (Mangara and Badila). These two fields are in the Doba basin south of the capital N'Djamena. This field was discovered in 1978 by the American company CONOCO and put into operation in 2013 by the company Griffiths International Energy (GIE). The Badila field is mainly located in the department of Nya Pendé. It is located between 08° 20' 25.25" north latitude and 16° 19' 40.32" east longitude, in southwestern Chad. In other words, it is about 430 km southwest of N'Djamena, and 60 km from the city of Moundou, the economic capital of Chad. This field is in the province of Logone Oriental, capital Doba, bordering the CAR and the Republic of Cameroon. The map below shows the location of the Badila Field where all the oil processing and shipping facilities of the Mangara project are located at the Petrochad site.

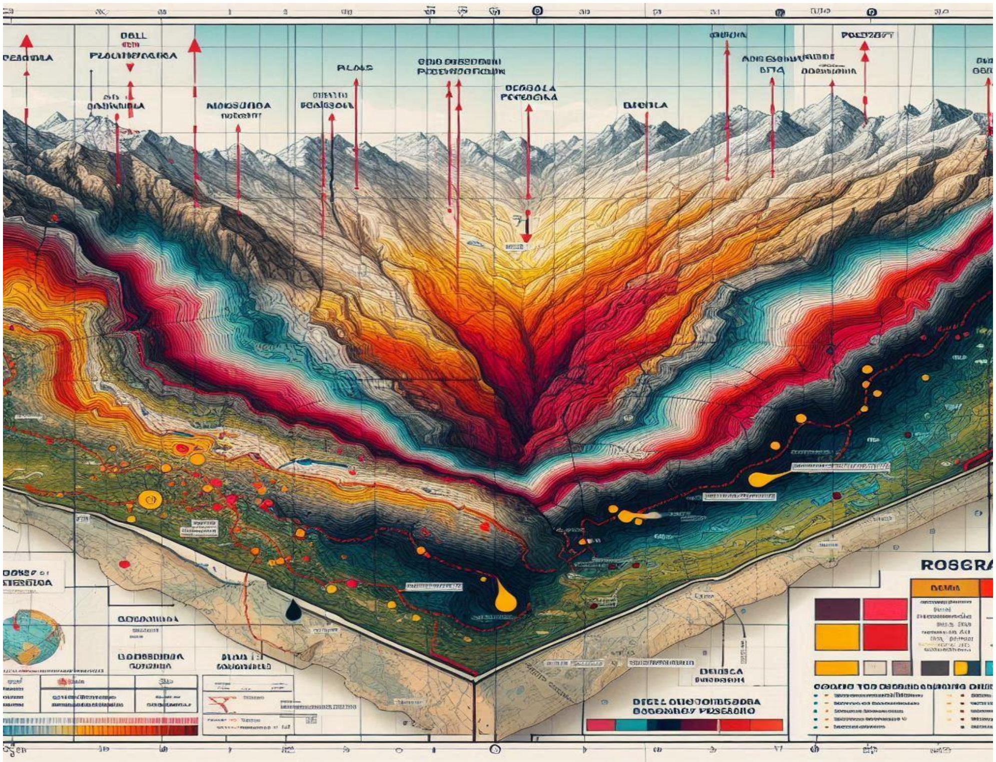

Figure 1 Study site map

2. Data collection and collection

Data collection: we recorded the quantities of oils and water produced according to the surface and interfacial tension after injection of several demulsifiers between 2014 and 2023 at the exit of the central treatment plant.

Collection: Thirty-seven (37) samples of EPPG and sloughs were collected in May and June 2022. However, samples are taken by special syringes at the exit of the factory and by plastic cups in the retention sub-basins. This is done by taking the usual precautions for disinfecting tools (flaming with 90° ethyl alcohol) to avoid any risk of contamination of the samples that have been collected in the sterile plastic bottles.

3. Sampling and physicochemical analyses

The samples taken were first subjected to a physicochemical analysis, so the pH and electrical conductivity were measured by the multi-parameter type HANNA, the sodium, potassium, magnesium, sulphate, chloride, ammonium ions were analyzed by flame spectrometer and the DR 2400 spectrophotometer.

Principle: The DR 2400 is an easy-to-use, comfortable power meter. Its spectral range is between 400 and 880 nm with a operating temperature range of 0 to 40°C. When a beam of monochromatic light with wavelength λ of intensity Io, passes through a solution to be analyzed, it undergoes absorption and exits with a weakened intensity I. This decrease in intensity is due to the absorption of one or more frequencies by the medium through which it passes. From the proportion of light intensity absorbed by the solution, the concentration C (mg/l) of the absorbing substance can be deduced by the Beer-Lamber relationship according to the expression: D = log = alc Where a is the molar absorption coefficient; it depends on the nature of the absorbing substance, on the wavelength. L is the optical path of the radiation through the solution. C: is the concentration of the solution. The inorganic components of the water sample are placed in the presence of special reagents. The intensity of the color produced is measured. This is a measure of the concentration of inorganic ions to be analyzed. For each test, a blank analysis is carried out with distilled water and the reagents.

Flame spectrophotometer: Potassium and sodium ions were analyzed by this device.

Principle: This method uses the property that neutral atoms must absorb a quantum of energy at a certain wavelength. The "BWB-XP" flame photometer is an instrument for the simultaneous determination of 5 elements: Na, K, Ca, Li and Ba in clear waters. The "BWB-XP" photometer uses the flame at low temperature using a mixture of air and fuel (propane or butane)

Culturing and isolation: The analyzed samples are then cultured. The approach followed for the isolation of Haloanaerobium is that of Ozcan et al., (2006), which consists of pre-enriching the samples, where 10 ml of the oil produced water is introduced into 90 ml of liquid Sehgal-Gibbons (SG) medium, contained in a 250 ml Erlenmeyer flask. The mixture is then shaken for 40 minutes to obtain a good homogenization of the particles and then incubated at 37°C for 20 days. Then, a series of dilutions is carried out, in which 100 µl of the 10-1 up to 10-3, are surface seeded on the GF solid culture medium (Ozcan et al., 2006). The Petri dishes are incubated at 37°C for 20 to 25 days in plastic bags, to avoid rapid drying of the culture medium and crystallization of its salts.

Purification of isolates: All isolates are first purified by successive transplanting of well-separated and visibly distinct colonies on the SG solid culture medium. Once purified, each isolate was assigned a code number, which consists of three letters RPG, followed by a serial number.

Preservation of isolates: The conservation of isolates so designated is carried out by several methods in accordance with the objectives assigned. In general, two conservation techniques are used. The first aims to preserve the isolates for a short period, it most often consists of transplanting on agar slopes with storage at 4°C, and the culture will be transplanted every 03 to 06 months. Whereas the second preservation technique aims to preserve for a long period, where the purified isolates are transferred into sterile 1.5 ml Eppendorf microtubes, containing 20% glycerol and therefore the preservation is done at -10°C.

4. Screening of biosurfactant-producing isolates

To do the screening, ten isolates (RPG11, RPG12, RPG13, RPG14, RPG15, RPG16, RPG17, RPG18, RPG19, RPG20) were chosen from each of the collection sites. Biosurfactant-producing isolates were selected using the following four methods: drop collapse test, oil dispersion test, emulsion stability test (ES%), surface and interfacial tension measurement. The experiments were carried out in three repetitions.

5. Gout Collapse Test

This test is based on the destabilization of a droplet of the oil by surfactants. It consists of using a 96-well microplate, each containing 100µl of an oil phase. However, the oils that have been tested are sunflower oil, olive oil, mineral oil, car oil and diesel oil. These oils were balanced for one hour at room temperature. 10µL of the culture of each isolate to be tested is added to the wells, the observation is made after 1 min using a binocular magnifying glass. If the liquid does not contain surfactants (biosurfactants), the polar water molecules grow back from the hydrophobic surface and the drop remains stable. If the liquid contains the surfactants, the gout spreads because the interfacial force or tension between the aqueous phase and the oil phase is reduced. The results were interpreted as follows: from "+" to "++++" corresponding to partial or total diffusion on the oil surface. Drops that resulted in a rounded shape were marked as "-" indicating the absence of biosurfactant production (Déziel 1996; Perron 2021; Loganathan et al. 2010).

6. Oil Dispersion Test

In the oil dispersion test, 50 ml of synthetic seawater was added to the surface of a glass petri dish of (90 × 15 mm) dimension, more than a volume of 20µl of crude oil or mineral oil, making a thin layer on the surface of the water. 10µl of the culture was added to the surface of the oil (Fontanay, Mougenot, and Duval 2015), the tests were performed due to three replicates for each sample (Vidal et al. 2018).

7. Emulsification test

This test consists of mixing 2 ml of the culture with 2 ml of diesel oil in a test tube (15×125 mm). The mixture was stirred for 4 minutes and left to rest. Emulsion volume (EV%) and emulsion stability (ES%) were measured as follows:

EV% = (emulsion height (mm) × surface (mm2)) / (Total liquid Volume (mm3)) × 100
ES% = (Emulsion Volume % at 24h)/ (Emulsion volume % at 0h) × 100
Emulsions formed by bacterial cultures were compared to those formed by a 1% solution of a synthetic surfactant (SDS) as a positive control and by the sterile culture medium as a negative control (Kebbouche-Gana et al., 2009). A criterion cited to confirm the production of biosurfactants is the ability to maintain at least 50% of the initial volume of the emulsion after 24 hours of its formation (Nasr et al., 2009).

8. Surface and interfacial tension measurement:

Surface tension measurements of bacterial cell-free supernatants were determined using a blood pressure monitor (TD1C LAUDA). The reported values are the average of three measurements. 50 ml samples were collected at 24-hour time intervals and centrifuged at (10,000 ×g for 25 min) at room temperature. The criterion used for the selection of biosurfactant-producing isolates is the reduction of the surface tension of the medium over time below 40 mN.m-1 (Grousson, 2021).

Results and discussions.

Performance of demulsifiers injected into the treatment line for the recovery of oils in EPPGs

3-1. The quantities of demulsifiers injected into the different platforms

Table 1 presents the results of the volume of products injected at the outlet of the free water separator to reduce surface and interfacial tension to improve effluent separation. The full volume of demulsifiers injected into the various platforms for the treatment of produced water is measured in liters. Table 1 also gives the results of the quantities of demulsifiers injected from 2014 to 2023 according to the quantity of oils recovered. On this count, we note between 2014 and 2023 for the BAD 106 product, a total quantity of 239,807 liters was injected at the first platform. While at the second platform (EPF), a total of 319,375 liters of VX CHAMPION was injected between 2014 and 2023. At the CPF, the RBW-264X with a volume of 716,130 liters was also injected. The magnitude of this quantity of demulsifiers during this period is related to the number of plants responsible for separating the emulsions and the excessive rise in surface tensions, making recovery very difficult. But in the SPT, the same demulsifiers were injected at a height of 248,930 liters during the same period. The drop in quantity is also linked to the fall in oil production. It should also be noted that the quantity of demulsifiers depends on the quantity of the volume of fluid produced in the two fields. The last column indicates the total amount of oils in bbl recovered over each year. According to the work of Mailhe and ly., 2012, a demulsifier is injected, capable of generating an inverted emulsion just before the inversion, the emulsion is destroyed, and the phases can separate. But the resistance of surface tensions linked to the decrease in temperature can make demulsifiers ineffective (Flesinski 2011). From 2014 to 2023, all these demulsifiers injected into the production line could only generate 46,841,041 barrels, far from the forecasts of about 70,000,000 barrels (Mailhé et al. 2008).

Table 1: Results of the volume of chemicals injected at the outlet of the free water separator.

Volume of demulsifiers injected into the various platforms for the treatment of produced water (litre)					
Years	BAD-106 injected (PAD I, PAD Y, PAD Z)	VX CHAMPION injected into EPF	RBW-264X injected into CPF	Total RBW-264X injected into SPT	Total Amount of Recovered Oils (bbl)
2014	21.900	32.850	69.715	25.550	5.751.984
2015	22.630	33.580	70.445	27.375	7.703.931
2016	23.360	34.675	71.175	27.010	5 .264 .487
2017	24.090	34.675	71.905	28.835	3.471.570
2018	24.820	35.770	72.635	28.835	3.622.206
2019	24.820	36.135	73.000	29.200	3.305123
2020	25.550	36.500	73.000	29.200	5.356.990
2021	23.727	36.500	68.985	28.105	4.342.765
2022	23.725	36.135	72.270	27.375	4.897.550
2023	25.185	37.230	73.000	26.280	3.124.345
Total	239.807	354050	716.130	277.765	43.501.365

3-2- The distribution of the quantities of demulsifiers and other chemicals injected at the different treatment points

Chemicals can be added to the process stream to improve the efficiency of oil/gas/water separation. The combination of mechanical and chemical treatment is effective in removing volatile compounds and dispersed oil from the produced water, but it is ineffective in removing dissolved organic compounds, ions and metals and hydrocarbons (Lhuissier 2019). However, even with the most advanced separation equipment, oil/water separation is not 100% effective. Table 2 lists the different demulsifiers injected at the different treatment levels. In this Table 2, well grouping points, especially feeding stations, are mentioned as PADI, PADY and PADZ, which are preliminary treatment platforms. They are fed by types of demulsifiers so the products are BAD 106 brands which are injected from the manifolds at a rate varying from 60 to 70 L/D to treat about 35000 barrels of water per day (bwpd). At the level of the second EPF platform of the types of demulsifiers, the products are VX CHAMPION brands which are also injected from the manifolds at a rate of 100 L/D to treat about 34884 bbl of water per day (bwpd). But when the effluent arrives at the level of the CPF platform, types of demulsifiers (Water clarifier) so the products are of the RBW-264X brands which are also injected at the inlet of CPF at a rate of 200 L/D to treat about 34099 bbl of water per day (bwpd). At the same platform, a PERDEFOAM brand antifoamant was injected at the CPF inlet at a flow rate of 10 L/D.

Table 2: Results of the volume of chemicals injected into the three EPOG treatment units in Badila in 2023

Platforms	Type	Product	Injection point	Volume to be treated bbl/d	Injection flow rate (L/d)
SPT	Water clarifier	RBW-264X	T500 Input	36103	70
	Biocide	BAKER X CIDE	T500 Input	36103	0
	O2 Scavenger	BAKER- O2 Scav.	T500 Input	36103	0
	Corrosion	BAKER-Anticorrion	T500 Input	36103	100
	Demulsifier	VX CHAMPION	VZ-120	-	50
	Demulsifier	VX CHAMPION	VZ-130	-	50
	Demulsifier	VX CHAMPION	VZ-140	-	0
CPF	Water clarifier	RBW-264X	CPI Input	34099	200
	Anti-moss	PERDEFOAM	CPI Input		10
ETH	Demulsifier	VX CHAMPION	Manifold	34884	100

			prod		
PAD-I	Demulsifier	BAD- 106	Manifold prod	35000	60
PAD-Y	Demulsifier	BAD- 106	Manifold prod	35000	60
PAD-Z	Demulsifier	BAD- 106	Manifold prod		70

At the treatment center, several separation systems are operated to meet the needs of the technological process of treatment requiring the use of chemicals on the Badila oil platforms. These include:

The water clarifier: It is of the RBW-264X brand, regularly injected at the inlet of the T500 separator with a flow rate of 70 L/d, to treat a volume of water of 36103 bbl per day. This product is renowned for its treatment effectiveness and extended residence time (Boufir, 2022). However, the prolonged presence of this product in the oil or gas can adversely affect the viscoelastic properties of these effluents (Avendano 2012).

Biocides: BAKER X CIDE brand, designed to eliminate almost all microorganisms in oils. It has been designed to be injected at the inlet of the T500 separator, to treat an emulsion volume of 36103 bbl per day. Unfortunately, in its current state, this product has not been injected. The non-use of this product can give a possibility for the development of living beings in storage tanks, in retention basins and especially in the receiving water (Irid, 2023). Previous work has reported that the development of certain living things in receiving waters can be harmful to human and animal consumption (Cherrier et al., 2003).

The O2 Scavenger: this is a BAKER-O2 Scav brand oxygen absorber that is normally used to deplete the oxygen content. It is therefore injected at the inlet of the T500 separator for the daily treatment of 36103 bbl of water. Again, this product has never been injected, although it is included in the oil production water treatment program. This situation has caused an excessive presence of oxygen in Badila's EPPs, which can give rise to corrosion phenomena of various origins, to the degradation of the qualities of the oil and considerably increases the flammability trend (Biney et al., 2021). But if the O2 Scavenger had just been injected, the oxygen would be reduced and the integrity of all the facilities and the quality of the oil that had just been extracted would be preserved (Vauzour 2004). It will also reduce the risk of explosion and flames during the oil transport process (Miyake et al., 1999).

Anti-corrosion: They are from BAKER- Anticorrion, regularly injected at the inlet of the T500 separator with a flow rate of 100 L/d, to treat a volume of water of 36103 bbl per day. This product is renowned for its treatment effectiveness and extended residence time (Brahim, et al., 2024). Its presence in the emulsion preserves the installation and eliminates any greasy contamination on the walls of the pipe (Rabhi, Mamouni, and Promoter 2019). Demulsifiers: which are VX CHAMPION brands, regularly injected at the inlet of VZ120, VZ130, VZ140 separators with a flow rate of 50 L/d, to treat a volume of water of 36103 bbl per day. Only VZ140 is not injected until today. These demulsifiers do not resist temperature for long and are very quickly degraded, giving rise to an increase in surface tension in the effluents (Ollivon et al., 2005). These can cause the decline in surface oil recovery (Terescenco 2018)

Figure 1 illustrates the quantity of demulsifiers injected into the various platforms for the treatment of produced water (PFC) on the oil production field from 2014 to 2023. In this figure we can see a high injection of RBW-264X demulsifiers at the CPF which amounts to 73,000 liters in the years 2019, 2020 and 2023 with a total of 716,130 liters over the ten years. The high quantity of this demulsifier is mainly intended to deepen the treatment to lighten the treatment of this water intended for reinjection into the reservoir for pressure maintenance. The same RBW-264X was injected less at the processing terminal (SPT) by a total quantity of 277,765 liters over the ten years. This difference in the injection of this product is reflected in the importance of the quantity of water to be treated in the two units, but also in its lower cost. This product is suspected to be ineffective and has caused a lot of concern for the environment (Khodja 2008). Previous work has shown that these types of demulsifiers can persist in receiving waters and cause serious human health problems (Marie and Gallot 1976).

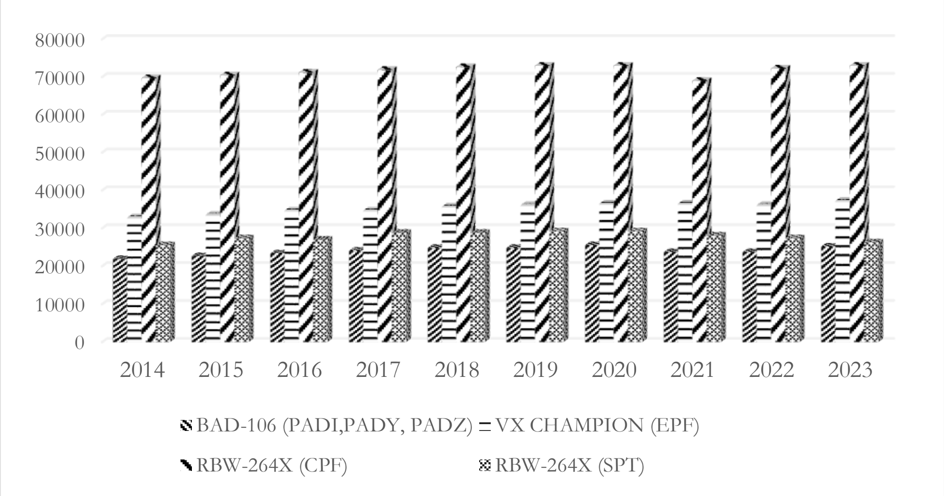

Figure 2: Quantity of demulsifiers injected into the different platforms for the treatment of produced water

1-3- Effectiveness of demulsifiers and other chemicals used for the treatment of EPPG

The table below details the degradation of chemicals during the recovery process. Several samples of demulsifiers, anti-corrosion and others are analyzed. They showed a degradation of physicochemical properties. This partly explains the poor effectiveness of the treatment. During these tests, there is the appearance of reverse emulsion with demulsifiers in high concentrations. None of the demulsifiers can reduce the water and sediment content in the oil below 1.2%. The degradation of these chemicals is related to their resistance to temperature and friction. During the test, the chemicals lost 30% of their viscosity and the dye of their color changed to another color as shown in Table 3.

Table 3: Results of the monitoring of the effectiveness of chemicals injected into the three EPPG treatment units in Badila in 2023

Number of Echoes	Type	Product	Physical appearance		Colours		Density at 15.6°C		Ph to 21°C		Viscosity (cp) to 15.6°C	
46 SPT			Before	After	Before	After	Av	Ap	Av	Ap	Av	Ap
	Water clarifier	RBW-264X	Liquid	Liquid	Rose	Yellow	0.937	0.6453	8.32	9.46	49	35
	Biocide	BAKER X CIDE	Liquid	Liquid	Rose	Yellow	0.9338	0.6453	8.32	9.65	52	32
	O2 Scavenger	BAKER-O2 Scav.	Liquid	Liquid	Rose	Yellow	0.9356	0.6453	8.32	10.44	44	37
	Corrosion	BAKER-Anticorrion	Liquid	liquid	Rose	Yellow	0.9385	0.6436	8.32	10.11	55	31
	Demulsifier	VX CHAMPION	Liquid	liquid	Rose	Yellow	0.9373	0.6427	8.47	9.76	49	32
	Demulsifier	VX CHAMPION	Liquid	liquid	Rose	Yellow	0.9368	0.6439	8.35	10.26	47	36
	Demulsifier	VX CHAMPIO	Liquid	liquid	Rose	Yellow	0.9324	0.6456	8.39	10.45	53	35

		N										
22 CPF	Water clarifier	RBW-264X	Liquid	liquid	Rose	Yellow	0.9372	0.6475	8.45	9.89	51	38
	Anti-moss	PERDEFOAM	Liquid	liquid	Rose	Yellow	0.9396	0.6422	8.65	9.55	54	29
10 ETH	Demulsifier	VX CHAMPION	Liquid	Liquid	Rose	Yellow	0.9389	0.6448	8.79	9.78	48	32
10 PAD -I	Demulsifier	BAD- 106	Liquid	Liquid	Rose	Yellow	0.9327	0.6437	8.32	10.46	49	30
10 PAD -Y	Demulsifier	BAD- 106	Liquid	Liquid	Rose	Yellow	0.9375	0.6465	8.24	10.16	52	35
10 PAD -Z	Demulsifier	BAD- 106	Liquid	Liquid	Rose	Yellow	0.9344	0.6475	8.56	10.67	53	36

The shear strength of effluents is mainly related to the inefficiency of the demulsifiers responsible for separating these fluids (AGIR 2014). This separation inefficiency leads to 0 poor recovery (Sayah and Nouaour 2017).

1-4- Quantity of total hydrocarbons recovered under the action of chemical demulsifiers at the Petrochad (Mangara) Limited site

Table 5 presents the results of the quantity of oil produced under the action of chemical demulsifiers from 2014 to 2023 at the Petrochad (Mangara) Limited site. The action of these demulsifiers freed the oils from the water. The demulsifiers are injected into the production line, so at the entrance to the plant, the surface and interfacial tensions are relatively low. This led to the recovery of the oils seen on the painting. The plant's network tranquilized the flow of the effluent causing the temperature and pressure to decline (Menet-Nedelec et al., 2018). The friction between the molecules under the effect of pressure and temperature profoundly affected the physical properties of the demulsifiers involved in the separation (Bélair 2012). This drop in pressure and temperature led to an increase in surface and interfacial tensions at the exit of the plant and caused insufficient recovery.

Table 5: Result of the quantity of oil produced under the action of chemical demulsifiers from 2014 to 2023 at the Petrochad (Mangara) Limited site.

Years	Surface tensions (mN/m)	Interfacial tensions (mN/m)	Total oil produced (bbl)	Amount of water produced (bbl)	% of water produced with oil	% oil in water
2014	52.15±	66	5.751.984	4.989.632	46.45	53.54
2015	64.22±	64	7.703.931	7.784.623	50.26	49.73
2016	55.71±	57	5.264.487	4.837.432	47.88	52.12
2017	55.72	45	3.471.570	6.302.435	64.48	35.52
2018	55.72	69	3.622.206	7.304.043	66.84	33.15
2019	52.28	52	3.305123	5.736.403	63.44	36.55
2020	64.22	47	3.925.576	5.654.876	64.41	40.97
2021	62.15	62	3.654.372	5.678.889	60.84	39.15
2022	53.6	70	3.677.681	5.655.832	60.59	39.40
2023	48.44	66	3.124.435	4.954.775	61.32	38.67
TOTAL	56.42	59.8	43.501.365	58.898.940	58.65	42.48

Overall, for the ten years of production shown in Figure 3, the volume of water is always higher than the quantity of oil produced, except for 2014 and 2016. This confirms the work of (Yang ming and ly. 2005, Bill Bailey et al., 2000) relayed by those of (Bouslihim and Torra 2020; Lahcen Nabzar 2011). The trend of the average over all years is 1.4 barrels of water for each barrel of oil, except for the year 2018 when the calculation specified the double volume of water over the volume of oil. The lowering of surface tension will reverse this trend. 2015 was a relatively good year. In all cases, success was only noted in 2014 and 2016. As a result, from 2017 to 2020, the volume of oil recovered is about the same, despite the fluctuation in the volume of water.

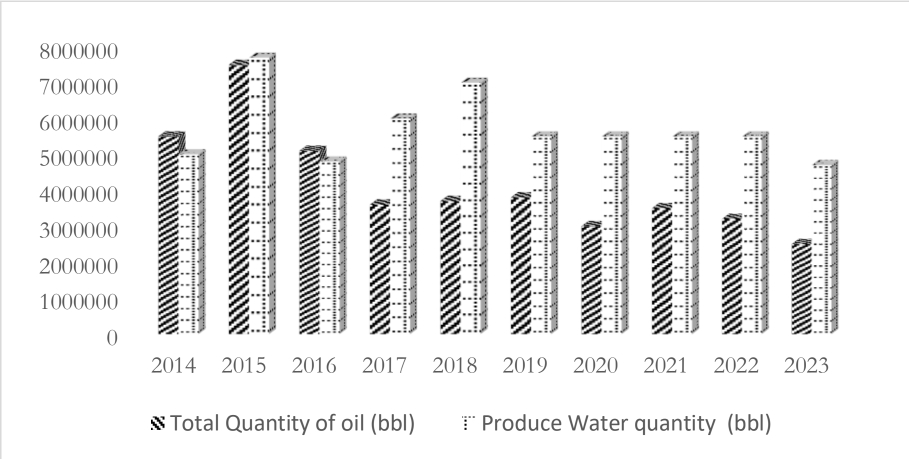

Figure 3: Oil-to-water recovery profile at the Petrochad (Mangara) Limited site.

Figure 4 details the percentage of water produced with oil at the Petrochad Mangara site at the exit of the central processing plant. According to Cossé in 1998, this percentage tells us about the advanced instabilities of water production (water coning, tongue of water and digitation) and to anticipate the decision to recondition wells, intervention operations on producing wells, optimization and stimulation of the reservoir or well closure.

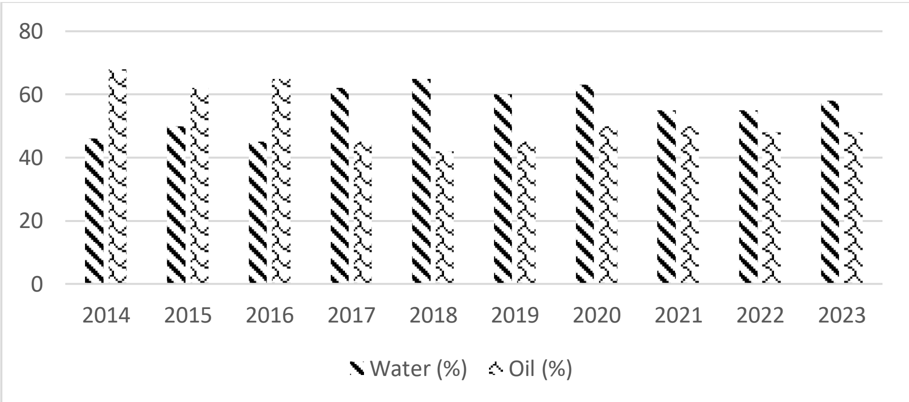

Figure 4: Percentage of oils to water produced at the Petrochad (Mangara) Limited site.

2- Microbial performance of enhanced surface oil recovery in EPPGs under the action of biodemulsifiers

2-1- Results of the direct measurement test of the surface and interfacial tension of the isolates

To understand the surface tension of the ten isolates (from RPG 11 to RPG 20), direct measurements were carried out in the laboratory just after the sample collection. Figure 6 shows the results of these measurements. The assessment was carried out in accordance with the method of Bodour and Maier (1998) which states that the surface tension is good for considering oil recovery when it is less than 40 mN/m. Based on this method, we can say that isolates RPG 14, RPG 18 and RPG 20 are those that can easily lend themselves to oil recovery since the surface tensions recorded were respectively 23.70 0.5 mN/m,± 22.45 0.5 mN/m± and 22.75 0.5 mN/m±. While for interfacial tension, these same isolates show 20.50 0.5 mN/m±, 21.35 0.5 mN/m± and 20.75 0.5 mN/m. These low surface tension values are in line with the collapse, dispersion and stability tests of the drop emulsion because when the emulsion is large, the surface tension is the lowest possible (Caiua et ±al., 2022). For the interfacial voltages of RPG11, RPG12, RPG13, RPG15, RPG16, RPG17 and RPG19, the values are relatively high as follows: 58.50 0.5 mN/m, 66.54 0.5 mN/m, 53.65 0.5 mN/m, 42.50 0.5 mN/m, 54.70 0.5 mN/m, 60.35 0.5 mN/m, 47.50 0.5 mN/m. Previous work has reported that the lower the surface tensions, the more easily the oils in solution are released (Homely et al., 2022).

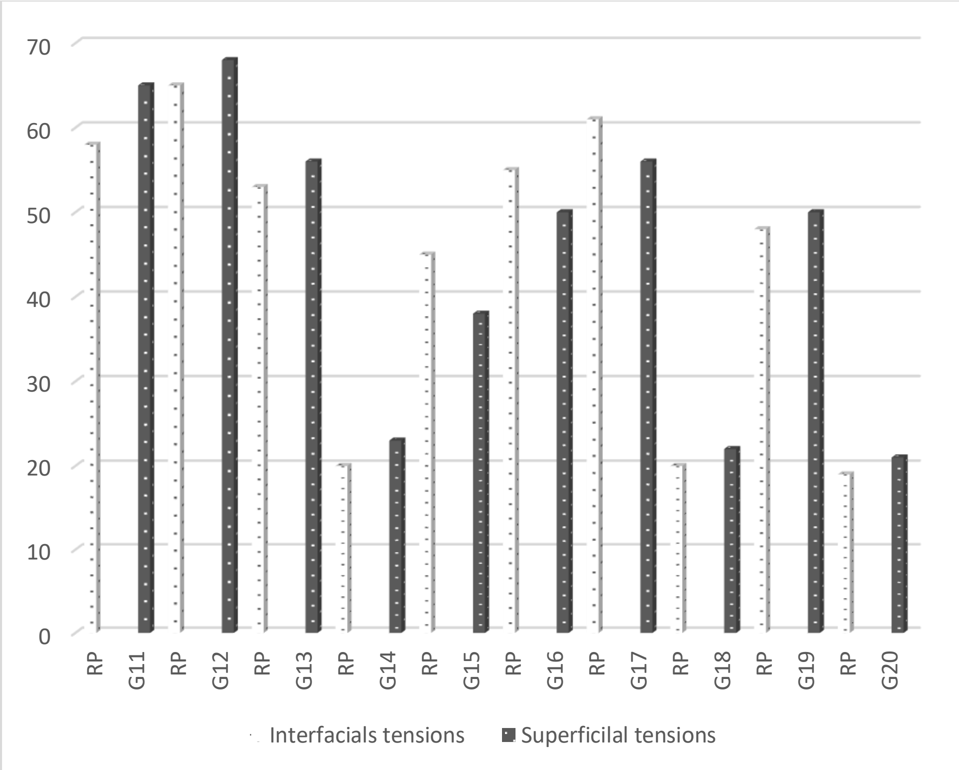

Figure 5: Illustration of the surface and interfacial tension test results

2-2- Recovery of dispersed oils by lowering interfacial tensions in surface oil and gas production water

At very low interfacial tension in EPPGs, there is a large number of small oil droplets dispersed (Lattes and Salager 2016). As the interfacial tension increases, the interface between the oil droplets and the water molecules expands and integrates more (Dalmazzone 2000) And with the increase in pressure, the droplets crash and only one phase appears. At this level, the recovery of oils by conventional techniques is poor (Vauzour 2004). The figure below illustrates the presence of oils dispersed in EPPGs under the action of interfacial tensions.

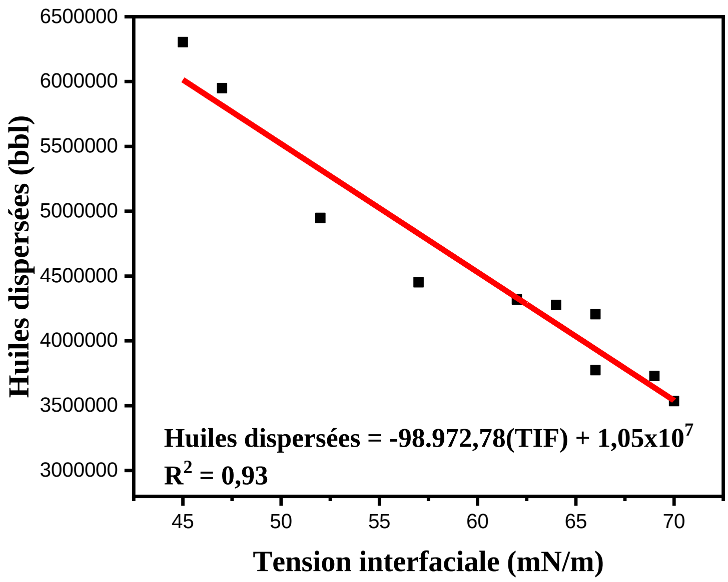

Figure 6: illustration of the recovery of oils dispersed in EPPGs under the effect of interfacial tensions

2-3- Influence of surface tensions on dissolved oils in oil and gas production water

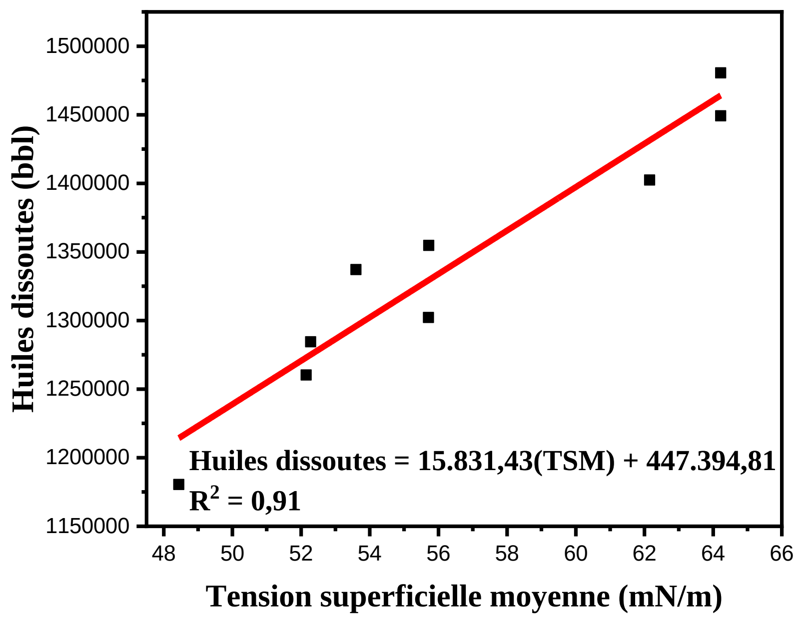

Figure 7: illustration of the presence of oils dissolved in EPPGs under the action of surface tensions

2-4- Recovery of dissolved oils by lowering the average surface tension in oil and gas produced water

The selected isolates produce biosurfactants and have better percentages of surface tension reduction. Figure 7 is the regression line that illustrates enhanced oil recovery under the effect of reducing the surface tensions of isolates. For average surface tension values obtained after action on microorganisms, the three isolates RPG14, RPG18 and RPG20 revealed a prediction in recovered oils of 8,745,742.85 bbl annually, higher than all the values obtained annually from 2014 to 2023 by injection of chemical demulsifiers. The 10-year forecast on the equation of the regression line, shows that it should have had a recovery of 87,457,428.5 bbl contrary to the value obtained by injection of chemical demulsifiers which was 46,841,041 bbl from 2014 to 2023. The surface tensions obtained by the isolates RPG14, RPG18 and RPG20 successively recover 8,651,854,836; 8.812.621,986; 8,774,037,87 bbl. Results for all isolates are reported in Table 7.

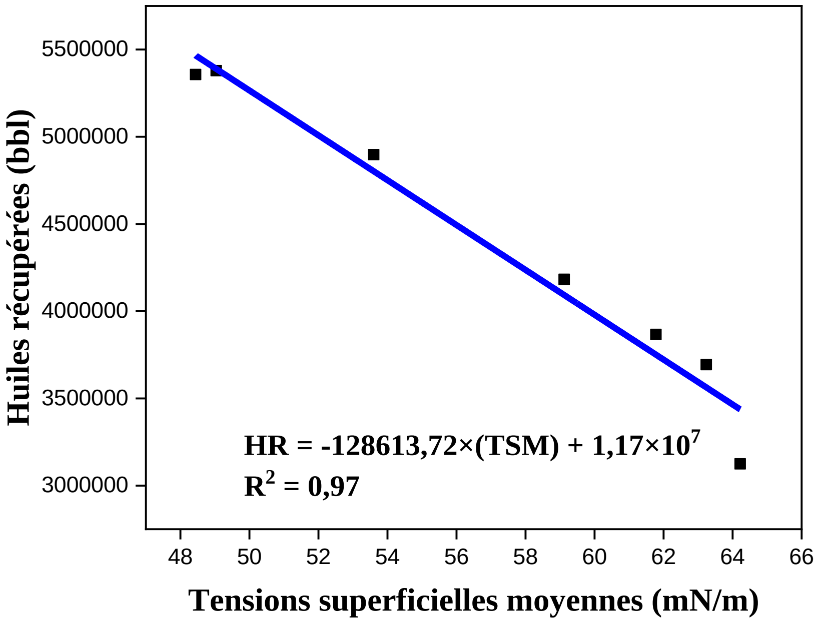

Figure 8: Regression line of enhanced oil recovery under the effect of the reduction of surface tensions by isolates

In this table, the quantities of recovered oils are obtained using the equation of the regression line. The quantities of oils recovered increase with the lowering of the surface tension. The very low surface tensions from the RPG14, RPG18, RPG20 isolates recovered enormous quantities of the oils that were retained in the EPPGs. In detention. This recovery performance is related to the activities of the isolates to produce biosurfactants that are highly compressive to surface tension (Plassard 2020). These biosurfactants reach the molecular level, binds to molecular bonds and inhibits cohesion (L. Nabzar 2011). This causes a release of the besieged oils at the molecular level. Some biosurfactant substances are not so effective at sufficiently releasing beleaguered oils like isolates (RPG11, RPG12, RPG13, RPG15, RPG16, RPG17, RPG19). This inefficiency is due to their low capacity to develop emulsifier, detergent and other activities (Bourneuf 2015). This inactivity is directly related to the source of collection and the composition of the isolates (Crini, Badot, and Montiel 2007).

Table 7: Results of oil recovery in the 2014-2023 EPOGs, under the influence of the surface tensions of the ten selected isolates.

	HR= -128613.72 (TSM)+1.17.107			
	Total quantity of crude oils: 102,400,296 bbl			
Isolates	Surface tension (mN/m)	Dissolved oils recovered (bbl/yrs	2014-2023 Recovered Oils (bbl/10 years)	Percentage of oils recovered (%)
RPG11	63,45	3.539.459,466	35.394.594,66	34,56
RPG12	65,84	3.232.072,6752	32.320.726,75	31,56
RPG13	57	4.369.017,96	43.690.179,6	42,66
RPG14	23,7	8.651.854,836	86.518.548,36	84,49
RPG15	38,1	6.799.817,268	67.998.172,68	66,40
RPG16	50,4	5.217.868,512	52.178.685,12	50,95
RPG17	57,1	4.356.156,588	43.561.565,88	42,54
RPG18	22,45	8.812.621,986	88.126.219,86	86,06
RPG19	52,2	4.986.401,4	49.864.014	48,69

RPG20	22,75	8.774.054,25	87.740.542,5	85,68

2-5- Total oil recovery by lowering the mean surface and interfacial tension in oil and gas produced water

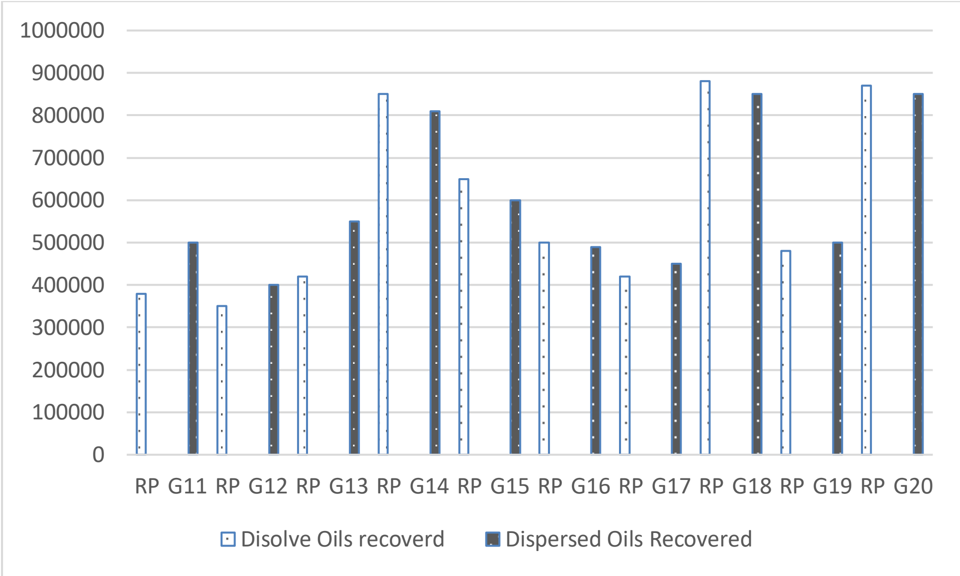

Figure 9: Illustration of the recovery of dispersed and solution oils under the action of isolates.

2-6- Comparative evaluation of the capacity of demulsifiers and bio emulsifiers to reduce surface tensions.

To establish the recovery efficiency of biological demulsifiers, a comparison was made between the surface tensions measured by the chemical demulsifiers, those of the ten isolates and then the three best isolates (Table 11). In view of this table, the difference in the average surface tensions emitted by demulsifiers of chemicals and biodemulsifiers of seven isolates (RPG11, RPG12, RPG13, RPG15, RPG16, RPG17, RPG19) is not significant. Consequently, the difference in the quantities of oil recovered is not as significant. While the average of the three isolates (RPG14, RPG18 and RPG20) is relatively low and therefore a significant number of oils have been released. This comparison relates to the ability of chemical or biological demulsifiers to reduce surface tensions in EPPGs. Biodemulsifiers reduce surface tensions much more than chemical demulsifiers (Roussos 1963).

Table 11: Comparative results of the capacity of oil recovery by average surface tensions produced by demulsifiers and biodemulsifiers.

Parameters	HR= -128613.72 (TSM)+1.17.107 Total quantity of crude oils: 102,400,296		
Surface tension (mN/m)	Oils recovered (bbl/years)	2014-2023 Recovered Oils (bbl/10 years)	Percentage of oils recovered (%)
TMS 2014-2023 CPU exit(51.02)	5.138.128,06	51.381.280,06	50,17
MSDs per 10 RPG11-20 isolates (44.7)	5.950.966,716	59.509.667,16	58,11
TMS for the top 03 RPG isolates14,18,20 (22,97)	8.745.742,852	87.457.428,52	85,40

Figure 10 illustrates the main differences between the average surface tensions from demulsifiers and biodemulsifiers.

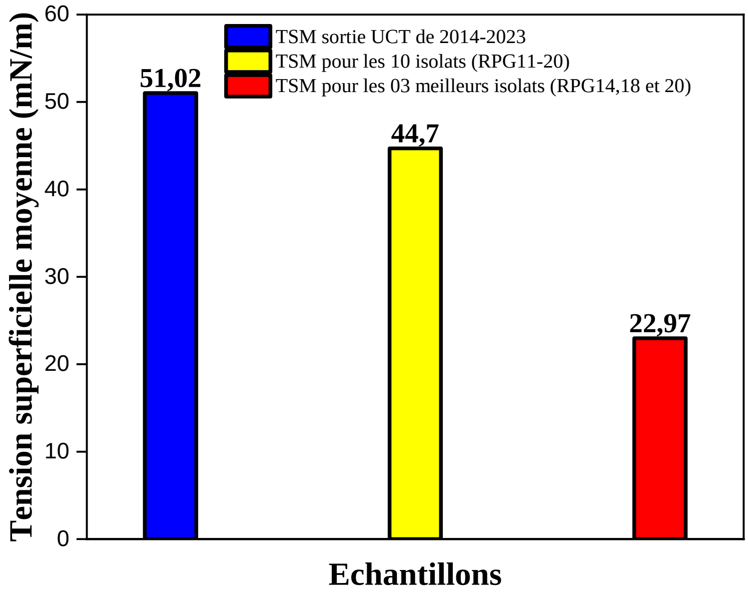

Figure 10: Comparative profile of the surface tension reduction capacity of demulsifiers and

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Conclusions

During the ten years of surface oil treatment using chemical demulsifiers, the recovery rate rarely exceeds 50%. All ten isolates obtained in a screening assay were active. The three isolates RPG14, RPG18 and RPG20 stood out and produced biosurfactants generating low surface tensions of 23.7, 22.45 and 22.75 mN/m, respectively. These low surface tensions led to the release of a significant amount of the dispersed oils and generated bacterial flocs to release the oils in solution. Microbial activities have doubled the recovery rate compared to chemical demulsifier activities over the ten years of surface oil recovery. The regression lines of recovered oils illustrated the trends of this recovery.

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