

Research Article

Microbial Treatment of Oil and Gas Production Water in Petrochad's Mangara Field (Badila)

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Abstract

Microbial isolates RPG14, RPG18, and RPG20, selected after a screening test, were subjected to optimization of physicochemical and nutritional parameters. Subsequently, a 3-liter extraction for each culture medium was initiated. The optimal yields after 20 days of incubation were 68.62 g/l for RPG14, 60.42 g/l for RPG18, and 69.85 g/l for RPG20. Five graduated tubes, each containing 150 mL of oil and gas production water, were supplemented with 25, 30, and 50 mL of the supernatant from each isolate (RPG14, RPG18, and RPG20). The tubes were placed on a MPW-260RH centrifuge heater, running at 300 rpm for 15 minutes. Each centrifugation was performed at temperatures of 55 °C, 70 °C, and 75 °C. The tubes were then transferred to a mini-decanting unit (SIMOP 6016-SIM) for water separation, and the volume of oil in the tube was measured after 20, 40, and 60 minutes of decantation. The purification efficiency was calculated. The results indicated that biosurfactants could purify the oil and gas production water (EPP) up to 100%. However, the quantity of biosurfactants did not influence purification significantly. Notably, longer exposure time of biosurfactants in the EPP led to higher purification rates. The purified EPP were analyzed and found to comply with the IFC 2007, WHO, and FAO discharge standards.

Keywords

Production Water, Biosurfactants, Purification, Environment

1. Introduction

Excessive water production in the Petrochad field represents a significant challenge, primarily due to the entrainment of oil droplets and the solubility of oil in water [1]. This phenomenon not only hampers oil recovery but also leads to high treatment and disposal costs [2]. The oils remain in the

solution due to their high surface tension, with a substantial portion existing as fine droplets that form a stable inverse emulsion with water as the continuous phase [3, 4]. Despite various physicochemical treatments, these contaminated waters are typically discharged into the environment or buried in

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the subsurface, resulting in substantial and irreversible environmental damage. Biological treatment has emerged as a promising and effective approach to addressing this issue, with the potential to reduce surface tension and enhance oil separation [5]. This study aims to optimize the physical, chemical, and nutritional parameters of microbial isolates RPG14, RPG18, and RPG20, selected after a preliminary screening, to improve their ability to reduce the surface tension that keeps oils in solution. The goal is to enhance the production of biosurfactants, which will be added to crude production water under controlled temperature conditions to facilitate the release of remaining oil in solution.

2. Materials and Methods

2.1. Study Site Location

The Petrochad (Mangara) Limited field consists of two distinct sites: Mangara and Badila, located in the Doba basin, southern Chad, near the capital, N'Djamena. The field was first discovered in 1978 by the American company CONOCO and became operational in 2013 under Griffiths International Energy (GIE). The Badila field is situated in the Nya Pendé department at latitude 08°20' 25.25" North and longitude 16°19' 40.32" East, in southwestern Chad [6]. It lies approximately 430 km southwest of N'Djamena and 60 km from Moundou, the economic capital of Chad. The field is located within the Logone Oriental province, with Doba as the administrative center, and borders the Central African Republic (CAR) and Cameroon. The location of the Badila field, which houses all oil treatment and shipping facilities for the Mangara project, is shown in Figure 1.

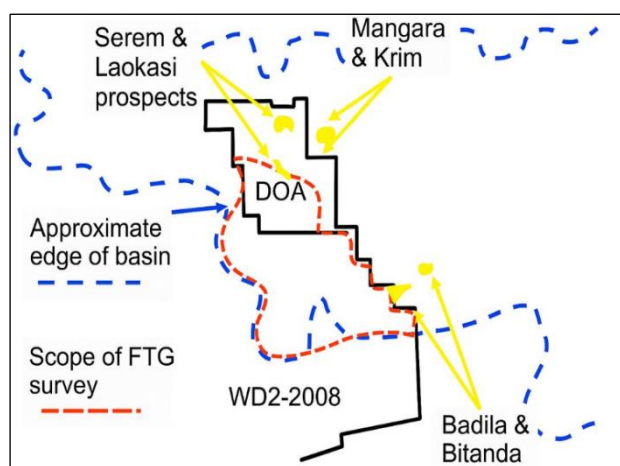


Figure 1. Study site map (Glencore, 2014).

2.2. Sampling

A total of thirty-seven (37) samples of oil and gas production water (EPP) and sediment were collected between May

and June 2022. Sampling was carried out using a sterilized spatula, and all tools were disinfected by flaming with 90% ethyl alcohol to avoid contamination. The samples were transferred into sterile plastic containers for further analysis.

2.3. Culturing and Isolation

Haloanaerobium isolates were obtained using the protocol adapted from Ozcan et al. [7]. The process involved an initial enrichment step where 10 mL of production water was added to 90 mL of Sehgal-Gibbons (SG) liquid medium in a 250 mL Erlenmeyer flask. The mixture was stirred for 30 minutes to ensure proper dispersion of particles and incubated at 37 °C for 15 days. Serial dilutions of the culture (from 10⁻¹ to 10⁻³) were made, and 100 µL of each dilution was plated onto solid SG medium. The plates were incubated at 37 °C for 15-20 days in sealed plastic bags to prevent desiccation and salt crystallization [7].

2.4. Purification and Storage of Isolates

The isolates were purified by subculturing well-separated colonies on solid SG medium. After purification, each isolate was assigned a unique code starting with "RPG," followed by a distinct number. The isolates were preserved by two methods: short-term storage on slants at 4 °C with subculturing every 3 to 6 months, and long-term storage in sterile 1.5 mL Eppendorf microtubes with 20% glycerol, stored at -10 °C [8].

2.5. Screening of Biosurfactant-Producing Isolates

Ten isolates (RPG11, RPG12, RPG13, RPG14, RPG15, RPG16, RPG17, RPG18, RPG19, RPG20) were selected from various sampling sites for biosurfactant screening. The screening was carried out using four methods: drop collapse assay, oil spreading assay, emulsion stability (ES%) test, and surface tension measurement [9, 10]. All tests were performed in triplicate.

2.5.1. Drop Collapse Assay

The drop collapse assay was used to assess oil droplet destabilization by surfactants. A 96-well microplate was used, with each well containing 100 µL of various oils (sunflower oil, olive oil, mineral oil, car engine oil, and diesel) [9]. After equilibrating the oils at room temperature for 1 hour, 10 µL of the culture from each isolate was added to each well, and the droplet's collapse was observed after 1 minute using a binocular magnifier. The presence of biosurfactants was indicated by the spread of the oil droplet [10].

2.5.2. Oil Dispersion Assay

In this assay, 50 mL of synthetic seawater was added to a glass Petri dish (90 × 15 mm), followed by 20 µL of crude oil or mineral oil to form a thin layer on the water's surface [11].

A 10 μ L culture sample was added, and dispersion was observed. Each test was performed in triplicate.

2.5.3. Emulsification Test

A 2 mL culture was mixed with 2 mL of diesel in a 15 $\times$ 125 mm test tube. The mixture was agitated for 4 minutes and left to settle. The emulsion volume (EV%) and emulsion stability (ES%) were calculated, with ES% defined as the percentage of the initial emulsion volume retained after 24 hours [12].

2.5.4. Surface and Interfacial Tension Measurement

The surface tension of the supernatant (free of bacterial cells) was measured using a TD1C LAUDA tensiometer. The measurements, taken at 24-hour intervals, were repeated three times to calculate the average surface tension value [13].

2.6. Optimization of Physicochemical Conditions

The production of biosurfactants is influenced by several physicochemical factors, including temperature, pH, agitation speed, and salinity (NaCl and $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$) [14]. Optimization studies were conducted to determine the ideal conditions for biosurfactant production.

2.6.1. Effect of pH

The effect of pH on biosurfactant production was tested at pH values of 6, 6.5, 7, 7.5, and 8. The cultures were incubated at 37 $^{\circ}\text{C}$ with agitation at 120 rpm for 13 days.

2.6.2. Effect of Temperature

Temperature conditions of 27 $^{\circ}\text{C}$, 30 $^{\circ}\text{C}$, 37 $^{\circ}\text{C}$, 40 $^{\circ}\text{C}$, and 45 $^{\circ}\text{C}$ were tested to identify the optimal temperature for biosurfactant production under optimized pH and agitation conditions.

2.6.3. Effect of Agitation

Agitation speed was tested at 50, 100, and 150 rpm to determine the best conditions for biosurfactant production, with temperature and pH kept constant.

2.6.4. Effect of NaCl

The effect of NaCl concentration on biosurfactant production was studied at concentrations of 8%, 15%, 20%, 25%, and 30%, with optimized temperature, pH, and agitation conditions.

2.6.5. Effect of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$

Various concentrations of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ (0.005M, 0.01M, 0.05M, 0.1M, 0.2M, and 0.3M) were tested to optimize biosurfactant production under the previously determined optimal conditions.

2.7. Optimization of Nutritional Conditions

The impact of different nutritional sources was also investigated to improve biosurfactant production.

2.7.1. Effect of Carbon Source

Cultures were performed in SG liquid medium with various carbon sources, including glucose, lactose, starch, and sodium citrate at 4 g/l, along with gasoil and glycerol (4% v/v).

2.7.2. Effect of Nitrogen Source

Different nitrogen sources (sodium nitrate, ammonium sulfate, yeast extract, and urea) were tested at 7 g/l to optimize biosurfactant production.

2.8. Measurement of Parameters

After 13 days of incubation, cultures were centrifuged at 8000 $\times$ g for 30 minutes at 4 $^{\circ}\text{C}$. Supernatants were collected, and surface tension was measured with a tensiometer. The reduction in surface tension was calculated using the following formula:

$$\% \text{RTS} = [1 - (\text{TS}_{\text{after}} / \text{TS}_{\text{before}})] \times 100 \quad [15]$$

Where $\text{TS}_{\text{before}}$ is the surface tension before inoculation, and TS_{after} is the surface tension after inoculation.

2.9. Biosurfactant Extraction

Biosurfactant extraction was performed using the method described by Smyth et al. [16], which involved centrifugation, acidification with HCl (4.8 N) to pH 4, followed by extraction with ethyl acetate (v/v). The organic phase was dried using magnesium sulfate (0.1 g per 100 mL solvent) and evaporated using a rotary evaporator (BUCHER R-114) at 45 $^{\circ}\text{C}$.

2.10. Purification Efficiency of Production Water and Oil Extraction and Analysis of Decanted Water

Five graduated tubes, each containing 150 mL of oil and gas production water, were supplemented with 25, 30, and 50 mL of supernatant from RPG14, RPG18, and RPG20 isolates. The tubes were placed on a MPW-260RH electric centrifuge, rotating at 300 rpm for 15 minutes. The centrifugation was carried out at 55 $^{\circ}\text{C}$, 70 $^{\circ}\text{C}$, and 75 $^{\circ}\text{C}$. The volume of oil in each tube was measured after 20, 40, and 60 minutes of decantation. Purification rates were calculated using the formula:

$$\text{Purification Rate (\%)} = [1 - (\text{Voil} / \text{Vtotal})] \times 100 \quad [17]$$

Where Voil is the oil volume measured after decantation and Vtotal is the total volume of crude production water be-

fore decantation.

The oil extracted from the decanted water was stored at 4 °C and analysed using spectrometry as describe by Maryutina, & Soin [18]. Physicochemical parameters of the samples were analysed, including pH and electrical conductivity using a

HANNA multiparameter meter [19]. Ions such as sodium, potassium, magnesium, sulfate, chloride, ammonium, total hydrocarbons, phenol, barium, and manganese were analysed using flame spectrometry and DR 2400 spectrophotometry [20].

3. Results and Discussion

3.1. Optimization of Physicochemical Parameters

Table 1. Physicochemical Parameter Optimization for Biosurfactant Production by RPG14, RPG18, and RPG20 Isolates.

Culture Condition	Culture Conditions (Before Optimization)	RPG14 (After Optimization)	RPG18 (After Optimization)	RPG20 (After Optimization)
Mineral Salts	NaCl (250 g/l), MgSO ₄ · 7H ₂ O (200 g/l)	NaCl (150 g/l), MgSO ₄ (0.009 M)	NaCl (250 g/l), MgSO ₄ (0.09 M)	NaCl (200 g/l), MgSO ₄ (0.05 M)
pH	7.2	7.5	8.0	8.0
Agitation (rpm)	120	150	150	100
Temperature (°C)	37	50	55	45
Surface Tension (mN/m)	RPG14 (23.7), RPG18 (22.45), RPG20 (22.75)	18.92 ± 0.2	10.68 ± 0.6	7.77 ± 0.6
% Surface Tension Reduction (RTS)	RPG14 (57.65%), RPG18 (59.89%), RPG20 (59.35%)	70.5 ± 0.6	71.02 ± 0.1	71.03 ± 0.01

Table 1 presents a summary of the optimization of the physicochemical parameters for biosurfactant production by isolates RPG14, RPG18, and RPG20. Parameters such as pH, temperature, agitation speed, and mineral salts showed significant reductions in surface tension, resulting in high percentages of reduction. These parameters are crucial for the yield and characteristics of the biosurfactants. High yields of biosurfactants were obtained after optimizing parameters like temperature (45, 50, and 55 °C), pH (7.5 and 8), aeration, and agitation speeds (100 to 150 rpm). Previous studies have shown that optimal biosurfactant production typically occurs at temperatures between 25 and 30 °C [21-24]. Our results are consistent with those of Shi et al. [25] who suggested that the best biosurfactant production occurs at a pH of 8. The highest biosurfactant yield, 45.5 g/l, was achieved when the airflow rate was 1 v/v, and the dissolved oxygen concentration was maintained at 50% saturation [26-28].

3.2. Optimization of Nutritional Parameters

Table 2 provides a summary of the optimization of nutri-

tional parameters for biosurfactant production by RPG14, RPG18, and RPG20 isolates. The composition and emulsifying activity of the biosurfactants are not only dependent on the producing strain but also on the culture conditions, including the type of carbon and nitrogen sources, as well as the C:N ratio [27-30]. The quality and quantity of biosurfactants produced are significantly influenced by the carbon sources used. Gasoil (5%), sodium citrate (5.5%), and glycerol (5.5%) resulted in very low surface tensions with high reduction percentages. Different nitrogen sources were used, with yeast extract (5.5%), urea (5.5%), and ammonium sulfate (5%) showing the most significant results for biosurfactant production. These results enabled surface tension reductions of more than 70%, which was substantially lower compared to pre-optimization levels. Among the nitrogen sources, yeast extract proved to be the most effective medium for biosurfactant production, showing a reduction of over 80%. Saline culture sources were found to be the best producers of biosurfactants, providing increased resistance to degradation [31, 32].

Table 2. Nutritional Parameter Optimization for Biosurfactant Production by RPG14, RPG18, and RPG20 Isolates.

Culture Condition	Culture Conditions (Before Optimization)	Culture Conditions (After Optimization) RPG14	Culture Conditions (After Optimization) RPG18	Culture Conditions (After Optimization) RPG20
Carbon Source	Sodium Citrate = 3 g/l	Diesel = 5%	Sodium Citrate = 5.5%, Glycerol = 5.5%	Diesel = 5%, Sodium Citrate = 5.5%, Glycerol = 5.5%
	TSRPG14 = 23.7	TS = 6.24 ± 0.6	TS = 9.35 ± 0.6	TS = 5.72 ± 0.6
TS (mN/m)	TSRPG18 = 22.45	TS = 9.35 ± 0.6	TS = 6.89 ± 0.6	TS = 6.89 ± 0.5
	TSRPG20 = 22.75	TS = 9.35 ± 0.6	TS = 6.89 ± 0.6	TS = 10.06 ± 0.6
% RTS	%RTSRPG14 = 57.65	%RTS = 70.29 ± 0.6	%RTS = 71.67 ± 0.6	%RTS = 69.92 ± 0.6
	%RTSRPG18 = 59.89	%RTS = 71.67 ± 0.6	%RTS = 71.67 ± 0.6	%RTS = 70.03 ± 0.6
	%RTSRPG20 = 59.35	%RTS = 69.92 ± 0.6	%RTS = 70.03 ± 0.6	%RTS = 70 ± 0.6
Nitrogen Source	Yeast Extract = 8.5%	Yeast Extract = 5.5%, Urea = 5.5%, (NH ₄) ₂ SO ₄ = 5%	Yeast Extract = 4.5%, Urea = 4.5%, (NH ₄) ₂ SO ₄ = 5.5%	Yeast Extract = 4.5%, Urea = 4.5%, (NH ₄) ₂ SO ₄ = 5.5%
	TSRPG14 = 23.7	TS = 6.50 ± 0.6	TS = 7.35 ± 0.6	TS = 5.93 ± 0.5
TS (mN/m)	TSRPG18 = 22.45	TS = 2.22 ± 0.5	TS = 4.25 ± 0.5	TS = 6.89 ± 0.5
	TSRPG20 = 22.75	TS = 2.45 ± 0.5	TS = 2.95 ± 0.5	TS = 10.06 ± 0.5
% RTS	%RTSRPG14 = 57.65	%RTS = 80.30 ± 0.5	%RTS = 76.29 ± 0.5	%RTS = 74.69 ± 0.5
	%RTSRPG18 = 59.89	%RTS = 91.29 ± 0.5	%RTS = 85.34 ± 0.5	%RTS = 80.86 ± 0.6
	%RTSRPG20 = 59.35	%RTS = 88.39 ± 0.5	%RTS = 86.65 ± 0.5	%RTS = 68.57 ± 0.5

TS= Surface Tension

RTS= Surface Tension Reduction (RTS)

3.3. Biosurfactant Extraction from RPG14, RPG18, and RPG20 Isolates

After optimizing the conditions for biosurfactant production, including physicochemical (temperature, pH, agitation, NaCl, and MgSO₄ 7H₂O) and nutritional (carbon and nitrogen sources) parameters, 3 liters of culture medium were extracted under optimal conditions for each isolate. The goal was to recover the highest possible quantity of biosurfactants. Various incubation periods were tested, and biosurfactant extraction was performed after 20 days of incubation. The extract was then concentrated by complete evaporation. The biosurfactant yield for RPG14, RPG18, and RPG20 was 68.62 g/l, 60.42 g/l, and 69.85 g/l, respectively. After 20 days, biosurfactant production significantly decreased. Similar studies have shown that 20 days of incubation can yield excellent results [31-33]. Beyond this period, microbial activity and biosurfactant production become considerably weaker [34].

3.4. Purification Rate of EPPG Under the Influence of Biosurfactants and Temperature Variation

Table 3 presents the results of tests conducted on EPPG

from Badila, with oil in solution at a density of 38 °API. Different concentrations of biosurfactants were tested under varying temperatures to determine the purification rate after 20, 40, and 60 minutes. The results show a clear influence of the biosurfactants, especially with variations in temperature, on the decantation time of oil and gas production water. A longer retention time leads to higher purification efficiency, consistent with previous studies showing that longer exposure of biosurfactants in the solution improves separation [35-37].

Table 3. Results of Optimal Biosurfactant Extraction from RPG14, RPG18, and RPG20 Isolates at Different Incubation Periods.

Incubation (Days)	RPG14 (g/l)	RPG18 (g/l)	RPG20 (g/l)
15	46.32	45.80	46.20
20	68.62	60.42	69.85
25	57.65	57.12	57.25
30	48.23	47.68	48.75

3.4.1. Purification by RPG14 Biosurfactants

Table 4 shows the results of the purification experiments on

oil and gas production water from Petrochad (Mangara) Limited at Badila, using RPG14 biosurfactant. The purification rate increased with time, and the oil volume decreased significantly. The quantity of biosurfactant did not influence the separation, but the temperature had a notable effect, especially at higher temperatures (75 °C).

Table 4. The purification tests carried out on the oil and gas production water by the RPG14 isolate.

Temperature (°C)	RPG14 isolate (mg/l)	Water Purification Rate		
		20 min	40 min	60 min
55	50	94%	98%	99%
55	25	96%	98%	100%
70	50	97%	99%	100%
70	25	97%	99%	100%
75	30	98%	99%	100%

3.4.2. Purification by RPG18 Biosurfactants

Table 5 shows the results of purification trials using RPG18 biosurfactants. Similar to RPG14, temperature variations significantly impacted the decantation time and purification efficiency. The concentration of biosurfactants did not have a significant effect, but higher temperatures (75 °C) enhanced the separation over time.

Table 5. Results of the purification tests carried out on the oil and gas production water by the RPG18 isolate.

Temperature (°C)	RPG18 isolate (mg/l)	Water Purification Rate		
		20 min	40 min	60 min
55	50	95%	98%	94%
55	25	96%	98%	99%
70	50	99%	99%	99%
70	25	99%	98%	99%
75	30	95%	99%	100%

3.4.3. Purification by RPG20 Biosurfactants

Table 6 highlights the purification results using RPG20 biosurfactants. Similar trends were observed, with temperature having a stronger effect than biosurfactant concentration on the purification efficiency. At 75 °C, a significant improvement in the purification rate was observed after 60 minutes of retention.

Table 6. Results of the purification tests carried out on the oil and gas production water by the RPG20 isolate.

Temperature (°C)	RPG20 isolate (mg/l)	Water Purification Rate (%)		
		20 min	40 min	60 min
55	50	38%	85%	99%
55	25	35%	80%	99%
70	50	94%	95%	97%
70	25	91%	92%	100%
75	30	94%	95%	100%

Purification of Oil and Gas Production Water Using RPG Biosurfactants: A Comparative Study

The purification efficiency of biosurfactants RPG14, RPG18, and RPG20 in oil and gas production water from Petrochad (Mangara) Limited, Badila, was evaluated in this study. The key focus was on the impact of biosurfactant concentration and temperature on the purification process, with significant findings reported in Tables 4, 5, and 6. The results showed that the purification rate of oil and gas production water improved with time for all three biosurfactants. RPG14 demonstrated near-perfect purification rates (99% and 100%) at temperatures of 55 °C to 75 °C after 60 minutes of retention. Notably, the biosurfactant concentration did not significantly influence purification, but higher temperatures (70 °C and 75 °C) considerably enhanced the purification efficiency. At 75 °C, RPG14 achieved a purification rate of 100% after 60 minutes, indicating the importance of temperature in the purification process [38] (Borys & Wojciechowski, 2020). Similarly, RPG18 biosurfactant exhibited comparable trends, with the purification rate nearing 100% at higher temperatures, particularly at 75 °C [39]. This biosurfactant also showed minimal impact of concentration on the separation process, with the highest efficiency reached after 60 minutes of exposure at elevated temperatures. RPG20 biosurfactant exhibited a more gradual improvement in purification, with a significant increase at 75 °C after 60 minutes. Even at lower temperatures (55 °C), RPG20 achieved high purification rates (99%) after 60 minutes, similar to the other isolates, highlighting temperature as the dominant factor in purification efficiency [40]. In definitive, the study confirmed that the temperature had a pronounced effect on the biosurfactants' ability to purify oil and gas production water, especially at higher temperatures (70 °C and 75 °C), while the biosurfactant concentration showed minimal impact. This suggests that optimization of temperature is key to improving the efficiency of biosurfactant-based purification systems in the petroleum industry.

3.5. Physicochemical Quality of EPPG After Biosurfactant Treatment

Before the biosurfactant treatment, the EPPG samples were subjected to a physicochemical analysis. The post-treatment analysis showed a drastic reduction in the concentrations of oils and metals after the mixing of EPPG with RPG14, RPG18, and RPG20 isolates (Figure 2).

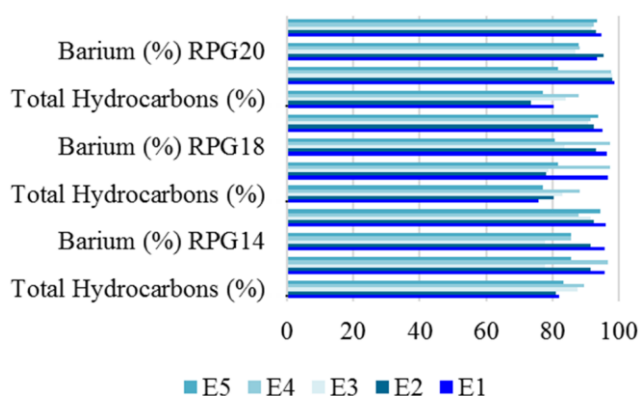


Figure 2. Reduction rate of oil concentrations in EPPG after decantation by the isolates.

The reduction was significant across all parameters, with hydrocarbons showing the least reduction compared to other elements like manganese, barium, and phenol. The reduction in hydrocarbons was less pronounced, which can be attributed to the shorter exposure time of biosurfactants in the EPPG [41]. However, the reduction of other contaminants, like barium, significantly decreased the potential for scale formation [42, 43].

The purification efficiency of biosurfactants RPG14, RPG18, and RPG20 in oil and gas production water from Petrochad (Mangara) Limited, Badila, was evaluated in this study. The key focus was on the impact of biosurfactant concentration and temperature on the purification process, with significant findings reported in Tables 4, 5, and 6. The results showed that the purification rate of oil and gas production water improved with time for all three biosurfactants. RPG14 demonstrated near-perfect purification rates (99% and 100%) at temperatures of 55 °C to 75 °C after 60 minutes of retention. Notably, the biosurfactant concentration did not significantly influence purification, but higher temperatures (70 °C and 75 °C) considerably enhanced the purification effi-

ciency. At 75 °C, RPG14 achieved a purification rate of 100% after 60 minutes, indicating the importance of temperature in the purification process [38]. Similarly, RPG18 biosurfactant exhibited comparable trends, with the purification rate nearing 100% at higher temperatures, particularly at 75 °C [39]. This biosurfactant also showed minimal impact of concentration on the separation process, with the highest efficiency reached after 60 minutes of exposure at elevated temperatures. RPG20 biosurfactant exhibited a more gradual improvement in purification, with a significant increase at 75 °C after 60 minutes. Even at lower temperatures (55 °C), RPG20 achieved high purification rates (99%) after 60 minutes, like the other isolates, highlighting temperature as the dominant factor in purification efficiency [40]. The study confirmed that the temperature had a pronounced effect on the biosurfactants' ability to purify oil and gas production water, especially at higher temperatures (70 °C and 75 °C), while the biosurfactant concentration showed minimal impact. This suggests that optimization of temperature is key to improving the efficiency of biosurfactant-based purification systems in the petroleum industry.

3.6. Quality of EPPG After Treatment by Biosurfactants

After treatment with the RPG14, RPG18, and RPG20 biosurfactants, the EPPG in the lower part of the tubes were collected, analyzed, and compared to international discharge standards for oil and gas production water. The results showed that, in all cases, the treated EPPG met the discharge standards, except for manganese in some cases, which slightly exceeded the WHO limit. These findings support the idea that biosurfactants can significantly reduce the contaminants in production water, making them suitable for discharge under specific environmental guidelines.

3.6.1. Quality of EPPG After Treatment by RPG14

Table 7 presents the comparison of the physicochemical quality of EPPG after treatment by RPG14 with the discharge standards of IFC 2007, WHO, and FAO. Hydrocarbon concentrations were found to be below the quantification limits, and phenol concentrations in tubes 1 and 2 were below the WHO and FAO guidelines. However, manganese levels were slightly above the WHO standard for drinking water. The treated EPPG meets the IFC 2007 and FAO discharge standards, making it suitable for agricultural irrigation.

Table 7. Comparison to Discharge Standards After Decantation of EPPG by RPG14.

Parameter (mg/l)	Tube 1	Tube 2	Tube 3	IFC 2007	WHO	FAO
Hydrocarbons	5.23	6.67	4.67	≤10	15	15
Phenols	0.09	0.20	0.40	0.5	0.3	0.3

Parameter (mg/l)	Tube 1	Tube 2	Tube 3	IFC 2007	WHO	FAO
Barium	0.09	0.20	0.40	≤0.7	0.7	0.7
Manganese	0.13	0.26	0.22	0.5	0.1	<2

3.6.2. Quality of EPPG After Action of RPG18 Isolate

The results of the analyses and the standards used are summarized in Table 8, which presents the quality of EPPG after the action of RPG18 isolate and compares them to the discharge standards. The measured concentrations of total

hydrocarbons, phenol, and barium in the water extracted from the tubes are all below the discharge standards (quantification limit). However, the manganese concentrations are slightly higher than the WHO guidelines; nevertheless, they comply with the IFC2007 and FAO standards.

Table 8. Comparison to Discharge Standards After Decantation of EPPG by RPG18.

Parameter (mg/l)	Tube 1	Tube 2	Tube 3	IFC 2007	WHO	FAO
Hydrocarbons	7,23	6,11	5,45	10	15	15
Phenols	0,07	0,5	0,4	0,5	0,3	0,3
Barium	0,08	0,16	0,31	≤ 0,7	0,7	0,7
Manganese	0,16	0,26	0,23	0,5	0,1	< 2

3.6.3. Quality of EPPG After Action of RPG20 Isolate

The results presented in Table 9 are enlightening. The same observation was made for the RPG20 isolate, where manga-

nese was not fully consumed according to the WHO standards. However, all other concentrations comply with the discharge standards.

Table 9. Comparison to Discharge Standards After Decantation of EPPG by RPG20.

Parameter (mg/l)	Tube 1	Tube 2	Tube 3	IFC 2007	WHO	FAO
Hydrocarbons	6.25	8.43	5.22	10	15	15
Phenols	0.03	0.04	0.4	0.5	0.3	0,3
Barium	0.83	0.44	1.45	≤ 0.7	0.7	0.7
Manganese	0.22	0.23	0.23	0.5	0.1	< 2

The results of the purification trials using RPG14, RPG18, and RPG20 biosurfactants demonstrate the significant potential of biosurfactants in mitigating the contamination of oil and gas production water. After treatment, the water quality in all cases met the discharge standards for hydrocarbons, phenols, and barium, which are critical pollutants in such waters [38]. These findings highlight the efficiency of biosurfactants in reducing these pollutants to acceptable levels, aligning with previous studies that reported similar results using other bi-

osurfactants in environmental cleanup applications [43].

Notably, manganese concentrations were slightly above the World Health Organization (WHO) guidelines in all three isolates, particularly in the RPG14 and RPG18 treatments. This is consistent with other studies where manganese levels were found to vary depending on the biosurfactant concentration and the treatment conditions [40]. While manganese levels exceeded the WHO limit for drinking water, they remained within the limits set by the IFC 2007 and FAO

standards for discharge, which are less stringent for irrigation and industrial applications [38]. This indicates that, while biosurfactants are effective in removing major contaminants, further optimization of treatment conditions may be necessary to fully meet the more stringent WHO guidelines for manganese.

The RPG20 isolate showed a similar pattern to RPG14 and RPG18 in reducing most contaminants, although it struggled to reduce manganese to acceptable levels. This suggests that different biosurfactants may have varying affinities for certain elements, which could influence their overall effectiveness in treatment [39]. Despite this, all three biosurfactants demonstrated their potential in producing EPPG with quality suitable for agricultural irrigation, as confirmed by the compliance with the IFC 2007 and FAO standards.

In conclusion, these results reinforce the promise of biosurfactants as an environmentally friendly and efficient method for treating oil and gas production water, though further research is needed to optimize conditions for complete manganese removal.

4. Conclusions

In this study, biosurfactants extracted from the optimization of physicochemical and nutritional parameters of RPG14, RPG18, and RPG20 isolates were used to purify oil and gas production water at the Petrochad (Mangara) Limited field. The optimal yield of biosurfactants for these three isolates was achieved after 20 days of incubation. The yields were 18.62 g/l for RPG14, 20.42 g/l for RPG18, and 19.85 g/l for RPG20. Each biosurfactant type was harvested and added to the production water, with varying temperatures applied to assess their efficacy. Significant reductions in total hydrocarbons, phenols, and heavy metals were observed, and these reductions were compared to the discharge standards. The results confirm the potential of biosurfactants to effectively purify production water by reducing hazardous contaminants, making it suitable for discharge within environmental guidelines.

Abbreviations

RPG14	Residual Petrol Gaz lot 14
RPG18	Residual Petrol Gaz lot 18
RPG20	Residual Petrol Gaz lot 20
EPPG	Eaux de Production Pétrolière et Gazière
TSRPG	Tension Superficielle Résiduel Pétrole Gaz

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Author Contributions

Brahim Bakimbil: Conceptualization, Data curation Funding acquisition, Investigation, Writing - original draft

Niraka Blaise: Formal Analysis, Data curation, Software, Validation, Visualization, Writing -original draft

Samba Koukouare Prosper: Investigation, Resources, Formal Analysis, Visualization

Fadimatou Hamadou: Investigation, Data curation Validation

Djoulde Darman Roger: Methodology, Project administration, Writing - review & editing, Supervision

Data Availability Statement

The data is available from the corresponding author upon reasonable request.

The data supporting the outcome of this research work has been reported in this manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



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able and adaptive food solutions for vulnerable communities in Sub-Saharan Africa.

Research Field

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