vol. 19, n.° 2, julio-diciembre de 2021
ISSN impreso: 1657-6527 • ISSN en línea: 2145-8502

FUENTES
EL REVENTÓN ENERGÉTICO

Pilot study for the Injection of Bactericides in Sands with Microbial Activity Problems in the Libertador Field, Block-57

Estudio piloto para la inyección de bactericidas en arenas con problemas de actividad microbiana en el Campo Libertador, Bloque-57

Hayliz Sánchez-Bernal[1]; Paola Pucha-Ortega[1]; Danilo Arcentales-Bastidas[1]; Rolando García-Villalva[1]; Kenny Escobar-Segovia[1*]; Jorge Lliguizaca-Dávila[1]; Fernando Sagnay-Sares[1]

[1] Escuela Superior Politécnica del Litoral, Red Internacional de Investigación de Actividades Hidrocarburíferas y Energéticas (RIIAHE), ESPOL, Campus Gustavo Galindo Km. 30.5 Vía Perimetral, P.O. Box 09-01-5863, Guayaquil, Ecuador

kescobar@espol.edu.ec

Recibido: 08 septiembre de 2021. Aceptado: 06 diciembre, 2021. Versión final: 21 diciembre, 2021

Abstract

Microbial activity can lead to problems such as corroded tubing, formation plugging, and decreased effective permeability, especially the sulfate-reducing bacteria that have the formation water as a medium that allows their proliferation. These adhere to the conductive channels of the producing sand and form biomass that restricts the flow of fluids. This work was carried out to design a non-reactive matrix stimulation by injecting biocides that clean the sand face to increase permeability, reduce formation damage, control corrosive environments, and increase daily oil production. By analyzing the total concentration of iron, sulfate, carbon dioxide, sulfide in gas and water, wells with microbial activity were identified, while the behavior of the bacteria was characterized by evaluating bacterial cultures and corrosion coupons. Using economic profitability criteria, the TTT A 011 and TAP 09 wells were selected as the most prospective in the Libertador field since, out of the 94 wells analyzed, they presented the highest index of microbial activity and recovery of oil barrels. The microbial activity in the wells of the Tetete station is more aggressive, since they reproduce in less time, clogging the porous channels at a faster rate. The THPS and GLH bactericides had better functionality against bacteria and the environment, so they were considered in this design of non-reactive matrix stimulation generating $907,976.10 as profit for the company in the 12-month projection.

Keywords: Sulfate-reducing bacteria; corrosion; non-reactive matrix stimulation; biocides.

Resumen

La actividad microbiana puede provocar problemas como la corrosión de las tuberías, el taponamiento en las formaciones y la disminución de la efectiva permeabilidad, especialmente las bacterias reductoras de sulfatos que se encuentran en el agua como medio de formación donde se permite su proliferación. Estas se adhieren a los canales conductores de la arena productora y forman una biomasa que restringe el flujo de fluidos. Este trabajo se llevó a cabo para diseñar una estimulación de matriz no reactiva mediante la inyección de biocidas que limpien la cara de la arena para aumentar la permeabilidad, reducir el daño de la formación, controlar los ambientes corrosivos y asi aumentar la producción diaria de petróleo. Mediante el análisis de la concentración total de hierro, sulfato, dióxido de carbono y sulfuro en el gas y el agua, se identificaron los pozos con actividad

ISSN impreso: 1657-6527, ISSN en línea: 2145-8502, **CC BY**

Forma de citar: Sánchez-Bernal, H., Pucha-Ortega, P., Arcentales-Bastidas, D., García-Villalva, R., Escobar-Segovia, K., Lliguizaca-Dávila, J., & Sagnay-Sares, F. (2021). Pilot study for the Injection of Bactericides in Sands with Microbial Activity Problems in the Libertador Field, Block-57. Revista Fuentes, El Reventón Energético, 19(2), 95–103. https://doi.org/10.18273/revfue.v19n2-2021007

microbiana, mientras que el comportamiento de las bacterias se caracterizó mediante la evaluación de cultivos bacterianos y cupones de corrosión. Utilizando criterios de rentabilidad económica, se seleccionaron los pozos TTT A 011 y TAP 09 como los más prospectivos del campo Libertador, ya que, de los 94 pozos analizados, estos presentaron el mayor índice de actividad microbiana y de recuperación de barriles de petróleo. La actividad microbiana en los pozos de la estación Tetete es más agresiva, puesto que se reproducen en menos tiempo, obstruyendo los canales porosos a mayor velocidad. Los bactericidas THPS y GLH tuvieron mejor funcionalidad contra las bacterias y el medio ambiente, por lo que fueron considerados en este diseño de estimulación de matriz no reactiva generando 907.976,10 dólares como ganancia para la empresa en la proyección de 12 meses.

Palabras clave: Bacterias reductoras de sulfato; corrosión; estimulación de matriz no reactiva; biocidas.

1. Introduction

The Ecuadorian oil industry has been operating for more than 90 years, so its fields which are already mature present high-water cuts. Nevertheless, the implementation of prevention methods and timely identification of operational problems enables hydrocarbon sustainability.

For more than forty years Ecuador has been exploiting hydrocarbons in environmentally sensitive areas due to the large hydrocarbon reservoirs are in the area comprising the great tropical rain forest of the Amazon, in the Amazon Basin (Erazo-Bone, Chuchuca-Aguilar, & Escobar-Segovia, 2016). According to information from Petroamazonas EP in 2019, the Libertador field has average basic sediment and water of 90%, being the formation water the instrument of survival for microorganisms whose proliferation is associated with the decrease in production due to their metabolic process of reduction (Petroamazonas EP, 2019). Although there are simulation studies and in turn the use of statistical tools (Escobar-Segovia, Erazo-Bone, Chuchuca-Aguilar, Murillo, & Solorzano, 2019), and the design of experiments (Erazo-Bone et al., 2019) for finding better production zones, it is also important to analyze the causes and effects microbiological induced corrosion (MIC) (Sooknah, Papavinasam, & Revie, 2007) to determine solutions for an optimal oil management production.

The oil reservoirs are an optimal habitat for the microorganisms (Pannekens, Kroll, Müller, Mbow, & Meckenstock, 2019), their proliferation especially occurs in the formation water, which according to Monroy, due to its chemical composition has sulfates, which serve as food for the bacteria that upon interacting with the surface and carrying out their metabolic activity decompose or reduce the sulfate (SO_4) to sulfide (H_2S). (Monroy, 2014)

Several studies regarding MIC effects and causes have been performed, from the monitor and control the bacteria proliferation in oilfield water systems (Senthilmurugan, Radhakrishnan, Poulsen, Tang, & AlSaber, 2021), to show the operational problems of electrical submersible pumps mainly (Adams, 2010).

On the other hand, microbes produce organic matter that adheres to the pores of the sand-producing zone and decreases effective permeability. The biomass or organic matter formed in these conductive channels of formation fluids not only protects the microorganisms but also becomes a reproductive ecosystem strengthened by continuous metabolic action. (Augustinovic et al., 2012)

Based on the article by (Rincon, McKee, Tarazon, & Guevara, 2004), it is evident that these solid accumulations contribute to preferential water mobility, thus increasing water cut-off. Illustration 1 below shows how biomass is formed when in contact with metals or rock.

The dissimilatory action of the sulfate cation by microbial action is evidenced in the producing sand by the high concentrations of H_2S, CO_2, and Fe since these generate reactions that contribute to corrosion problems. Therefore, if in the physicochemical analysis of the formation water these factors are not within the allowed ranges of each station, bacterial cultures should be performed to determine the speed and time of propagation and validate this information with corrosion coupons. In such a way that it is possible to correctly describe and delimit the problem of microorganisms in the producing formation of each well.

Although the microbial problem promotes water production and corrosion, Block 57 is economically profitable due to its oil input of 12,780 BBL/D. (Petroamazonas EP, 2019); which can increase in case of cleaning the organic matter produced by sulfate-reducing bacteria (SRB) that clog the pores of the producing sand.

Nowadays, the use of specialized chemicals in the treatment of SRB contributes to the control of bacterial proliferation; since these chemicals, generally, biocides, work on the production pipeline; avoiding biocorrosion, and on the well, controlling bacterial activity (Jaimes, Villar, Escobar, & Acevedo, 2014). Among the biocides used in the field, Glutaraldehyde (GLH) and Tetrakis Hydroxymethyl Phosphonium Sulfate (THPS) stand out, which disrupts the cell wall and blocks the biochemical reaction essential for the life of SRB bacteria, respectively. (Figueroa De Gil et al., 2012)

Islas on 1991, emphasized the importance of knowing the surface tension, wettability, and capillarity of formation for the success of a non-reactive matrix stimulation since the reaction of certain chemicals used in this treatment can affect the properties of the rock and act negatively on the formation damage. (Islas, 1991)

This project proposes a methodology that directly attacks SRB bacteria within the formation based on non-reactive matrix stimulation and the injection of GLH and THPS biocides that will allow cleaning clogged pores, increase permeability, and decrease formation damage. In addition, the economic profitability of the project in the selected wells is considered through a cash flow and an estimate of the recovery in barrels after treatment.

2. Methodology

A methodology based on four phases was implemented, where previously wells were not influenced by secondary recovery, and wells with more information from the physical-chemical analysis of the formation water were considered.

In phase 1, the wells with microbial activity problems of the seven stations under study are discretized, by analyzing the total concentration of iron (Fe), carbon dioxide (CO_2), sulfate (SO_4), sulfur in gas and water that are fundamental physicochemical parameters (ff-qq) to measure bacterial proliferation and life.

The histories of discontinuous cultures of bacteria are analyzed using the bacterial growth curve that allows establishing the growth rate of the cells, thus identifying the station with the shortest doubling time for new cells. For this, the slope of the line of the logarithmic growth phase is used, which is proportional to the concentration of cells in the system and a proportionality μ factor expressed by the following equation.

$$\frac{dX}{dt} = \mu X \tag{1}$$

Where:

μ is the specific growth rate [h^{-1}]
X is the cell concentration [mg/cm]^3
t is the incubation time [h]

Integrating equation 1, the concentration of the cells is obtained at any instant of time.

$$X_t = X_o e^{\mu t} \tag{2}$$

Where:

X_t is the cell concentration at time zero
X_o is the cell concentration at time t

Employing Malthus's Law, which allows the second equation to be linearized, the growth kinetics are obtained, that is, the growth rate of the biomass.

$$l\,n\,X_t = lnX_o + \mu t \tag{3}$$

Equation 3 represents the linearized exponential growth phase seen in the graph form where, through the slope, the specific growth is obtained. From equation 2.3, we can find the equation shown below, which allows us to represent the growth rate as a function of the doubling time, that is, the time it takes for a cell to divide.

$$\mu = \frac{l\,n\,X_t - lnX_o}{t} \tag{4}$$

Considering t = td and Xt = 2Xo, we have the summarized equation for the doubling time of the cells.

$$\mu = \frac{0,693}{td} \tag{5}$$

Where:

td is the doubling time [h]
μ is the growth rate [h^{-1}]

This exponential growth decreases once the substrate has been consumed and toxic by-products have been generated that accumulate, causing a deviation of the specific speed for its maximum value, reducing cell growth in the long term, thus ending the exponential phase, and starting the stationary phase in a discontinuous culture.

To finish the first phase, the rate at which corrosion occurs in the production pipes of the stations and sands previously discretized through the corrosion coupons is analyzed. In phase 2, we proceed to select the wells that present the best production recovery projection of the producing sand, by analyzing the production behavior, workover histories, and relevant events during the active life of the well.

In phase 3, the non-reactive matrix stimulation is designed specifying three pumping stages: pre-flow, main treatment, and displacement is the selection of chemicals and their dosage, the most characteristic of this research. This, because GLH and THPS and eco-friendly biocidal chemicals are used for the main stimulation treatment.

Although in the field it is common to use admission or injection tests to find pressures and charges before fracturing the formation, in this case, they were determined using petrophysical data and workover histories of the wells selected using the following equations.

- Fracture pressure

$$Pf = Gf * D \quad (6)$$

- Maximum surface injection pressure (*Ps max*)

$$Ps\,máx < Pf - 0,433 * D * \rho_f \quad (7)$$

- Maximum injection rate (Qi max)

$$qi\,max = \frac{4.917x10^{-6}\,x\,kf\,x\,hf\,x\left(Pwf - Pws\right)}{\mu\,x\ln\left(re/rw\right)} \quad (8)$$

To calculate the fluid volume, the penetration radius of the main fluid is estimated depending on the formation damage; this value ranges from two feet if the damage is shallow to five feet if the damage is deep. Once this value is determined, we proceed to calculate the volume through (9).

Volume of stimulation fluid Vf [gal]

$$Vf = 23.5\,x\,\varnothing\,x\,hf\,x\left(r^2x - r^2w\right) \quad (9)$$

Where:

Pf is the fracture pressure of the formation [psi]
Gf is the fracture gradient of the formation [psi/ft]
D is the depth of the upper top of sand [ft]
ρ_f is the fluid density [g/cc]
kf is the formation permeability [mD]
hf is the thickness of the sand [ft]
Pwf is the flowing bottom pressure [psi]
Pws is the static bottom pressure [psi]
μf is the viscosity of the treatment fluid [cP]
r_e is the drainage radius of the well [ft]
r_w is the radius of the hole [ft]
$\varnothing$ is the porosity of the sand [fraction]

Finally, in phase 4 a one-year economic projection is made to represent the sustainability of the project establishing a standard value of $15 in the marginal profit per barrel, defining as daily production of the first month the production differential between 2013 and 2020, and considering in the production of the following month a decrease of 10% of the previous production due to the probability of occurrence of events that affect production.

3. Analysis of Results

In the first phase, it was found that the sulfate concentration at the Tetete and Tapi stations presented values of 400 and 250 ppm, respectively, high reference levels concerning the other four stations, already inducing a problem of microbial activity at a higher level.

The histograms of the five physicochemical parameters at the seven stations revealed that at the Tetete station, well TTT A 011 presented a sulfate concentration above the reference level in 90% of the data collection, as shown in Fig. 1. After performing this analysis in all the stations, the wells with the highest index of microbial activity in their physicochemical histories were determined and are presented in Table 1.

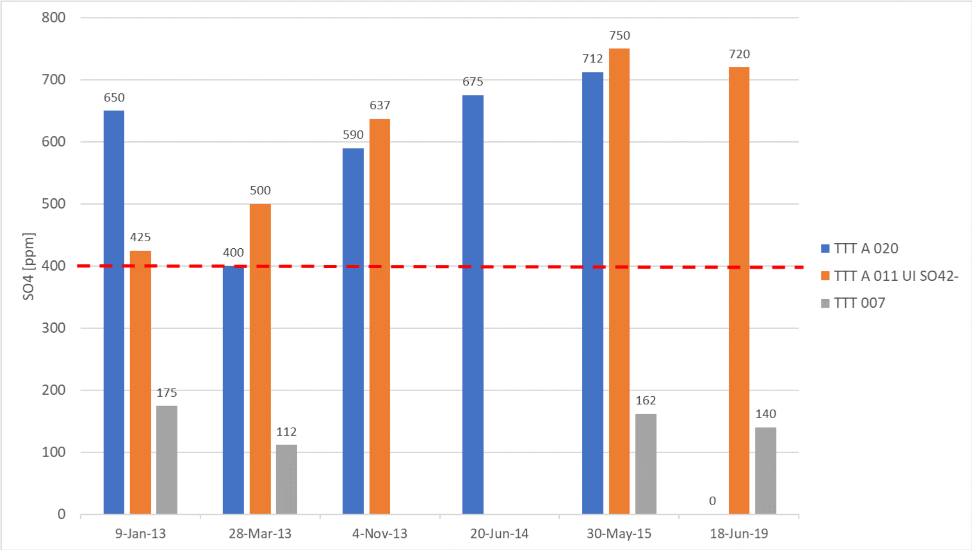

Figure 1. History of sulfate concentration in Tetete station wells.

Table 1. Summary of wells with the highest microbial activity indexes.

Nº	Station	Well	Sand
1	Tetete	TTT A011	Ui
2		TTT A007	Ui
3	Tapi	TAP 001	Ti
4		TAP A008	Ui
5		TAP B009	Ti
6	Frontera	FR B 04	Ti
7		FRN 05 RI	Ti
8	Atacapi	ATC B 011	Ti
9	Pichincha	PCH 09	Ts+Ti
10		PCH 07	Ti

From the analysis of the bacterial growth curves, it was determined that the Tetete station (Figure 2) shows a greater aggressiveness of bacterial proliferation since the bacteria proliferated more rapidly. Quantitatively, the cells grew at 2.85 col/L*days, so that in approximately 5 hours the number of initial bacteria doubled with a growth rate of new cells of 4.12 col/ L*days.

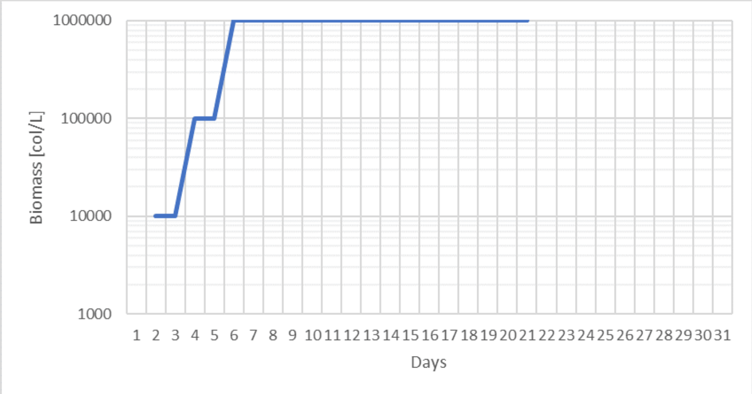

Figure 2. Bacterial growth curves on the tank from Tetete station.

Table 2 shows the summary of the bacterial growth curves of the five stations analyzed, in addition to the fact that using the corrosion coupons the Atacapi and Pichincha stations were discarded since they did not present significant variation to the bacteria cultures. Therefore, it is concluded that they are stations that present a correct control of bacterial activity.

In phase two, the most economically prospective wells were TTT A011 and TAP 09, since when analyzing the production history between 2013 and 2020, an optimal recovery profile of the lower U (Ui) producing sand was presented for both wells (Figure 3 and 4).

Table 2. Results of the growth curves of bacteria.

Station	Duplication time td [days]	Duplication time td [hours]	Growth speed [1/days]
Tetete	0.24	5.76	4.12
Tapi	0.30	7.20	3.32
Frontera	0.30	7.20	3.32

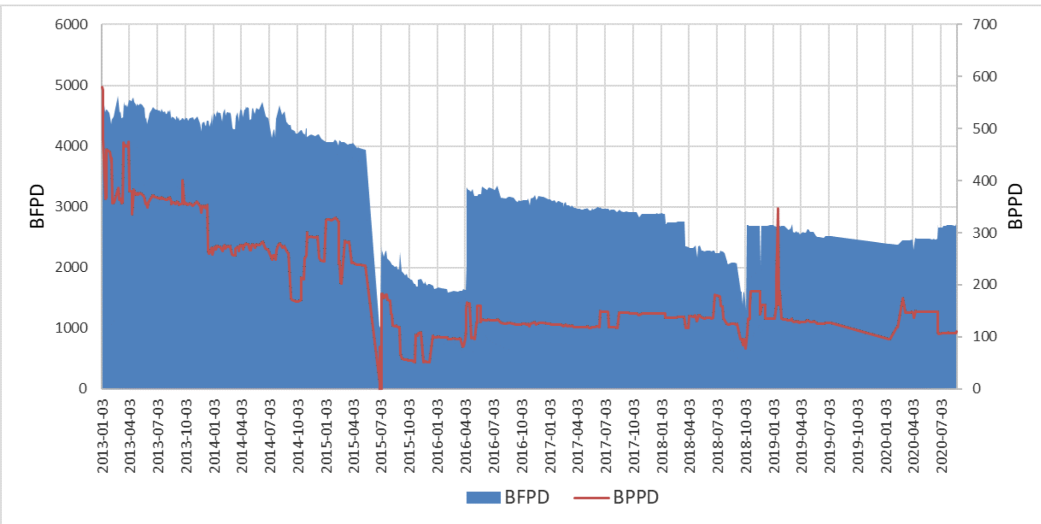

Figure 3. Production history from TTT A011 well (Sand Ui: 2013-2020).

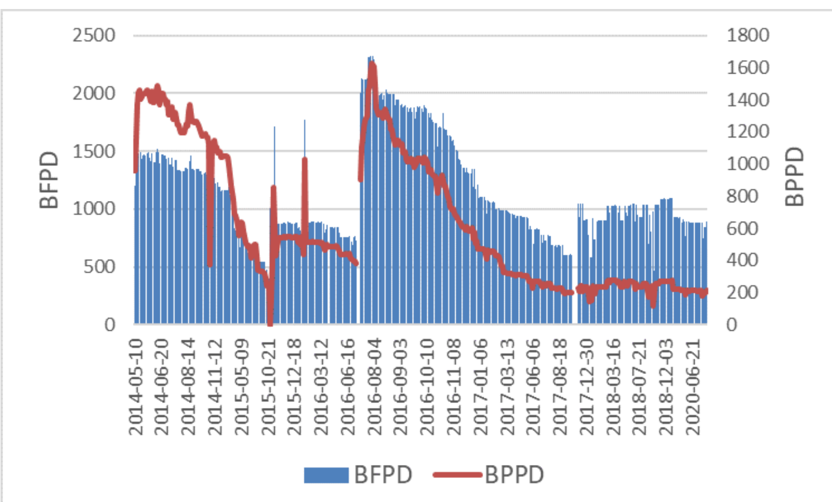

Figure 4. Production history from TAP 09 well (Sand Ti: 2014-2016 and Sand Ui: 2016-2020).

For phase 3, the bactericides injection design directly into the sand face has considered 3 stages, the first is the pre-flow, the second is the main treatment, and finally the over-displacement stage.

In the pre-flow stage, an organic stripper or inorganic acids that do not interact with the producing sandstone are used and act mainly in the production pipeline. For the main treatment, the use of two biocides, GLH and THPS, is proposed. They were already used in the Libertador field in chemical treatments of the bottom of the well such as continuous injection and batch injection. In addition, they have already been analyzed employing compatibility tests.

In the over-displacement stage, the use of an organic, diesel, or nitrogen remover was proposed to displace the spent biocides at the end of the treatment. In addition to this, it is recommended to maintain bacterial proliferation control through batch injection of biocides and surfactants, depending on the formation need, to maintain the benefits and extend the treatment. The operational parameters for the THPS injection were estimated as follows:

Table 3. Maximum injection pressure for THPS biocide.

Well	Sand	Fracture pressure [psi]	Injection pressure [psi]	Maximum injection rate [BPM]
TTT A011	Ui	4000	1417	13
TAP 09	Ui	3500	1998	9

It is worth mentioning that first the THPS biocide is introduced to treat the organic matter and then the GLH to kill the bacterial cell wall. The following values shown in table 4 were obtained through equation 9:

Table 4. Solution volume.

Well	Sand	Fluid volume [gal]	Fluid volume [BBL]
TTT A011	Ui	1644.15	39
TAP 09	Ui	1644.15	39

Finally, the economic analysis revealed the sustainability of the project, since it is emphasized that the field operation is carried out in one day and, nevertheless, the benefits rebound for the estimated period of 12 months. Being the initial investment cost of $ 332,572.04 for two wells, considering a discount rate of 10%, it is in the second month where the investment cost is recovered, in such a way that benefits and profitable results are already obtained for the company as indicated in Figure 5.

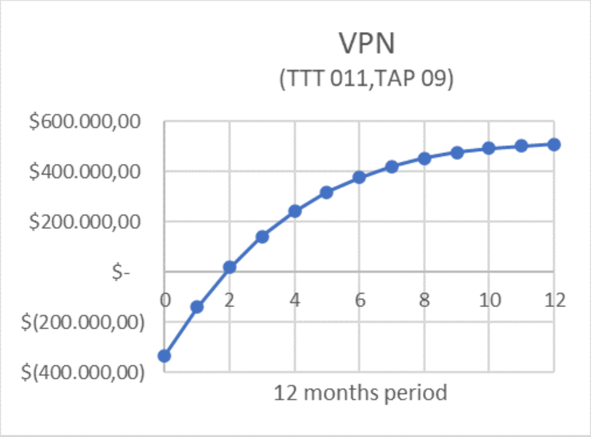

Figure 5. Net present value for a period of 12 months with 10% discount rate

4. Conclusions and Recommendations

Through the analysis of physicochemical parameters such as the concentration of total iron, carbon dioxide, sulfate, sulfur in gas and water, microbial activity was identified in 10 of the 94 analyzed wells.

The discontinuous cultures of SRB bacteria at the Tetete station reflected greater aggressiveness since it has a shorter doubling time and greater speed, that is, they proliferate faster in less time. From 10 wells with high rates of microbial activity, using the economic projection criterion, the TTT A 011 and TAP 09 wells were selected as candidates for the injection of bactericides in the sand face, in addition, that the sand with the highest bacterial proliferation. is the lower U (Ui).

Due to the degradation action of the non-toxic THPS bactericide, the aquatic life and natural salts of the formation water are conserved, reducing the long-term environmental impact, and creating savings in water treatment in the facilities.

The investment cost is recovered in approximately three months, leaving a net profit for the company of $ 907,976.10 and future savings in considerable repair and maintenance operations.

Representative core testing is recommended to analyze formation fluid compatibility and efficiency with chemicals to be used in core testing and with formation water samples directly from the wellhead to verify biocide efficiency on bacteria. Moreover, for wells with secondary recovery influence, more physical-chemical parameters must be analyzed to correctly determine problem wells.

References

Adams, D. (2010). Microbiologically Influenced Corrosion of Electrical-Submersible- Pumping-System Components Associated With Acid-Producing Bacteria and Sulfate- Reducing Bacteria: Case Histories. *SPE Latin American and Caribbean Petroleum Engineering Conference.* Lima, Peru: Society of Petroleum Engineers (SPE). doi:https://doi.org/10.2118/136756-MS

Augustinovic, Z., Birketveit, Ø., Clements, K., Freeman, M., Gopi, S., Ishoey, T., . . . Sunde, E. (2012). Microbes—Oilfield Enemies or Allies? *Oilfield Review, 4*(2).

Erazo-Bone, R., Chuchuca-Aguilar, F., & Escobar-Segovia, K. (2016). New challenges in construction and production prediction using multilateral well to develop Ecuadorian oilfield in environmental sensitive areas. *Society of Petroleum Engineers - SPE Trinidad and Tobago Section Energy Resources Conference.* Port of Spain, Trinidad and Tobago: Society of Petroleum Engineers (SPE). doi:https://doi.org/10.2118/180810-MS

Erazo-Bone, R., Escobar-Segovia, K., Arcentales-Bastidas, D., Vargas-Gutiérrez, X., Arreaga-Arévalo, A., & Román-Aguilar, A. (2019). Optimization of the drilling parameters in low angle wells by the application of statistical analysis. *17th LACCEI International Multi-Conference for Engineering, Education, and Technology, LACCEI 2019.* Montego Bay: LACCEI. doi:htpp://10.18687/LACCEI2019.1.1.78

Escobar-Segovia, K., Erazo-Bone, R., Chuchuca-Aguilar, F., Murillo, Y., & Solorzano, F. (2019). Análisis multivariable para la selección de las mejores zonas productivas de la formación Santo Tomás, sección 68, campo Gustavo Galindo Velasco. *Fuentes el Reventon Energetico, 17*(1), 47-54. doi:http://dx.doi.org/10.18273/revfue.v17n1-2019005

Figueroa De Gil, Y., Bruzual, Y., López de Gómez, G., Rodriguez, C., Prin, J., & Bravo, N. (2012). Evaluación de la eficiencia de biocida como inhibidor de la corrosión inducida por microorganismos. *Revista Latinoamericana de Metalurgia y Materiales*, 8-11. Retrieved from http://www.rlmm.org/ojs/index.php/rlmm/article/view/397

Islas, C. (1991). *Manual de Estimulacion Matricial de Pozos Petroleros.* Colegio de Ingenieros Petroleros de México.

Jaimes, M. G., Villar, A., Escobar, M. A., & Acevedo, N. P. (2014). Conceptual Study and Experimental Protocol for the Selection and Evaluation of Matrix Stimulation Treatments with Biocides, Focused on H2S and Corrosion Control in Producer Wells of Fields Undergoing Secondary Recovery. *SPE Latin America and Caribbean Petroleum Engineering Conference.* Maracaibo, Venezuela: Society of Petroleum Engineers (SPE). doi:https://doi.org/10.2118/169449-MS

Monroy, Y. Y. (2014). *Bacterias sulfato reductoras.* Universidad Militar Nueva Granada. Retrieved from http://hdl.handle.net/10654/12039

Pannekens, M., Kroll, L., Müller, H., Mbow, F., & Meckenstock, R. U. (2019). Oil reservoirs, an exceptional habitat for microorganisms. *New Biotechnology, 49*, 1-9. doi:https://doi.org/10.1016/j.nbt.2018.11.006

Petroamazonas EP. (2019). *Diseñando el futuro de un campo maduro. Caso Libertador.* Retrieved from https://www.petroamazonas.gob.ec/wp-content/uploads/downloads/2019/05/06_Wilson-P_Fabian-G.pdf

Rincon, P. R., McKee, J. P., Tarazon, C. E., & Guevara, L. A. (2004). Biocide Stimulation in Oilwells for Downhole Corrosion Control and Increasing Production. In S. o. (SPE) (Ed.), *SPE International Symposium on Oilfield Corrosion.* doi:https://doi.org/10.2118/87562-MS

Senthilmurugan, B., Radhakrishnan, J. S., Poulsen, M., Tang, L., & AlSaber, S. (2021). Assessment of microbiologically influenced corrosion in oilfield water handling systems using molecular microbiology methods. *Upstream Oil and Gas Technology, 7*. doi:https://doi.org/10.1016/j.upstre.2021.100041

Sooknah, R., Papavinasam, S., & Revie, R. W. (2007). Monitoring Microbiologically Influenced Corrosion: A Review Of Techniques. *CORROSION 2007*. Nashville, Tennessee, EEUU: Society of Petroleum Engineers (SPE).