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ENERGY EFFICIENCY AND SECONDARY RECOVERY: TWO MANAGEMENT OPTIONS FOR A MATURE FIELD IN ECUADOR

EFICIENCIA ENERGÉTICA Y RECUPERACIÓN SECUNDARIA: DOS OPCIONES DE GESTIÓN PARA UN YACIMIENTO MADURO DE ECUADOR

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Abstract

Strategies focused on solving the drawbacks of a mature field must consider production decline, which is paramount when considering future investments to maintain the field's competitiveness and profitability. B49 is an oil field with the typical problems of a mature field, management aimed at increasing the recovery factor and the implementation of an energy efficiency model were the axes to reduce OPEX and achieve a barrel with a production cost of 5.20 USD. The main objective of waterflooding in the field is to maximize oil recovery. Formation water from the north and south zones of B49 is used in waterflooding which increased the recovery factor from 21% to 26%.

In Ecuador, the associated gas is not fully exploited. For this reason, its flaring is an accepted practice; however, since 2009 the Ecuadorian State Oil Company has been implementing an ambitious Energy Efficiency program called Optimization of Electricity Generation and Energy Efficiency (OGE&EE for its acronym in Spanish), which is a comprehensive development of generation, distribution and transmission of electricity, as well as the development of facilities for the collection and transportation of associated gas.

OGE&EE consists of a group of projects, covering an area of 25,000 km^2, 17 oil blocks, 56 oil fields and more than 66 facilities, to date the program results are:

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- Installation of multiple generation plants with a combined capacity of 325MW, 95MW and can use associated gas as fuel.
- 200 km of electric energy transmission and distribution facilities.
- Installation of 17 km of gas pipelines out of a total of 100 km, upgrading of existing facilities by implementing waste heat recovery.
- The OGE&EE Program has also interconnected the oil industry's power grid to the national grid, which helps optimize national renewable energy (hydropower).

In 2015 the Ecuadorian oil company joined the World Bank initiative "Zero Routine Flaring by 2030", the Government of Ecuador also joined this initiative in 2018, and as part of PAM EP's Energy Efficiency program since 2015 it has been working to develop projects and financial solutions to increase power generation with associated gas and decrease gas flaring facilities (flare gas).
The production of 12 wells is used for electricity generation, the daily energy demand is an average of 3MW (72 MWh per day). B49's electricity generation meets the efficiency objectives by using gas in high efficiency generators to cover 100% of the energy needs; the field uses 194 MMcf of gas per year, stops emitting 20 MTon CO^2 eq/KWH and saves 420 M USD/year for unconsumed diesel. Problems such as pressure depletion in producing sands, water injection, BSW increase, gas availability, gas flaring limitation, pressure maintenance facilities and gas distribution are issues addressed in this research.

Keywords: Waterflooding, Mature fields, Energy Efficiency.

Resumen

Las estrategias enfocadas a solucionar los inconvenientes de un campo maduro deben contemplar la declinación de la producción, lo cual es primordial a la hora de considerar futuras inversiones para mantener la competitividad y rentabilidad del campo. B49 es un campo petrolífero con los problemas típicos de un campo maduro, la gestión orientada a aumentar el factor de recuperación y la implantación de un modelo de eficiencia energética fueron los ejes para reducir el OPEX y conseguir un barril con un coste de producción de 5,20 USD. El principal objetivo de la inyección de agua en el yacimiento es potenciar al máximo la recuperación de petróleo. El agua de formación de las zonas norte y sur de B49 se utiliza en la inyección de agua, lo que aumentó el factor de recuperación del 21% al 26%.

En Ecuador, el gas asociado no se explota en su totalidad. Por esta razón, su quema es una práctica aceptada; sin embargo, desde 2009 la Empresa Pública de Hidrocarburos del Ecuador viene implementando un ambicioso programa de Eficiencia Energética denominado Optimización de la Generación Eléctrica y Eficiencia Energética (OGE&EE), que consiste en un desarrollo integral de la generación, distribución y transmisión de energía eléctrica, así como el desarrollo de instalaciones para la recolección y transporte de gas asociado.

OGE&EE consiste en un grupo de proyectos, que cubren un área de 25.000 km2, 17 bloques petrolíferos, 56 campos petrolíferos y más de 66 instalaciones, hasta la fecha los resultados del programa son:

- Instalación de centrales de generación múltiple con una capacidad combinada de 325MW, 95MW y que pueden utilizar gas asociado como combustible.
- 200 km de instalaciones de transmisión y distribución de energía eléctrica.
- Instalación de 17 km de gasoductos de un total de 100 km, mejora de las instalaciones existentes mediante la implantación de la recuperación del calor residual.
- El Programa OGE&EE también ha interconectado la red eléctrica de la industria petrolera a la red nacional, lo que contribuye a optimizar la energía renovable nacional (hidroeléctrica).

En 2015 la petrolera ecuatoriana se adhirió a la iniciativa del Banco Mundial " Zero Routine Flaring by 2030", el Gobierno ecuatoriano también se adhirió a esta iniciativa en 2018, y como parte del programa de Eficiencia Energética de PAM EP desde 2015 trabaja en el desarrollo de proyectos y soluciones financieras para incrementar la generación de energía con gas asociado y disminuir las instalaciones de quema de gas (flare gas).

La producción de 12 pozos se utiliza para la generación de electricidad; la demanda diaria de energía es de una media de 3 MW (72 MWh al día). La generación eléctrica de B49 cumple los objetivos de eficiencia al utilizar gas en generadores de alta eficiencia para cubrir el 100% de las necesidades energéticas; el yacimiento utiliza 194 MMcf de gas al año, deja de emitir 20 MTon CO2 eq/KWH y ahorra 420 M USD/año en gasóleo no consumido. En esta investigación se abordan problemas como el agotamiento de la presión en las arenas productoras, la inyección de agua, el aumento de BSW, la disponibilidad de gas, la limitación de la quema de gas, las instalaciones de mantenimiento de la presión y la distribución de gas.

Palabras clave: Inundación, Campos maduros, Eficiencia energética.

1. Introduction

This paper shares practical solutions implemented to face the challenging reality of operating a mature field. The exploitation of a mature field requires a complete capitalization of the knowledge of its wells, reservoir and facilities (Tournier et al. 2010), for this reason power generation with associated gas is presented as an option for integral optimization.

Currently most of the world's fields are mature or in close proximity and the current costs of WTI crude oil reduce the profitability of the projects, B49 has 35 producing wells, 3 injectors and 6 re-injectors.

Ecuador bases part of its economy on oil production and the demand for increased production is permanent. Optimization processes reduce costs and make it possible to better manage the negative effects of oil market volatility.

Using the associated gas from 12 wells with calorific value of 1560 btu/ft³ for electricity generation is an option that leads to a better use of gas that would otherwise be destined to be burned in burners, the energy mix of the B49 field is 100% gas-fired electricity generation.

Additionally, in the B49 the formation water and its utilization and in the secondary recovery system gives an added value to this fluid and turns it into a resource (Goudarzi et al, 2013).

Currently the global volume of emissions from gas flaring is 100 billion m³ per year (Ojijiagwo et al., 2016), and 140 billion m³ of gas are burned (Aregbe, 2017), with the Paris agreement there are several efforts to reduce emissions associated with gas flaring. Ecuador is among the nations that can achieve a reduction of NDC[1] from 5 to 20% (Farina, 2011), currently its total emissions reduction with gas flaring reduction is 8% (Elvidge et al., 2018), and the B49 adds to these objectives through an efficient use or resources.

2. Field management axis B49

The management model is the main strategy to reactivate a Mature Field, the approach and application will depend on the current operating situation, there is no single formula, and each field requires solutions adapted to its reality.

The strategies implemented reduced OPEX and resulted in a cost per barrel of 5.20 USD, which is a value that achieves a profitability margin. The strategy to improve the profitability of the B49 field is:

- Increased recovery factor
- Waterflooding
- Energy efficiency
- Power generation from associated gas.

3. Increase in the recovery factor

Due to the low productivity of the field (1078 bpd) there is a delicate economic balance, and fluctuations in the price of barrel of oil can compromise, this balance; however, operating costs are parameters that can be controlled.

3.1. Secondary recovery

The B49 field has an area of 61,100 hectares and is located in the NW sector of the Basin of the Ecuadorian East, Napo sub-basin. Exploitation of the northern zone began in 1973, and 15 vertical wells were drilled. Peak production in the northern zone was reached in 1990 with a production of 1625 bpd. Daily production for 2001 was reduced to 156 bpd.

Secondary recovery of the Basal Tena reservoir began in 2003, nowadays the wells that inject in Basal Tena are: BN01, BN 07, BN 15, of which the first two are gas injectors and the last one is water injector. Wells BN10 and BN 18 are used as re-injector wells of water to sandstone. Figure 1 shows the distribution of the wells.

1 The greenhouse gas reduction targets presented by countries in their nationally determined contributions (NDC).

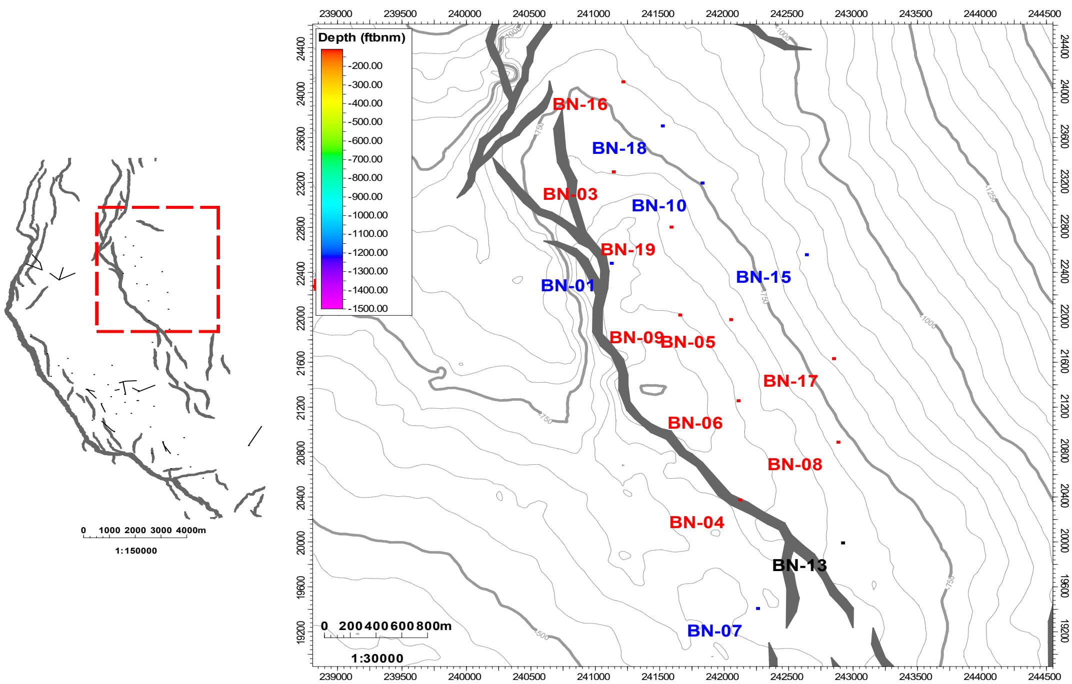

Figure 1. Well distribution, B49 Field.

3.2. Drainage mechanism

The drainage mechanism of the identified reservoir is by gas layer and gas in solution. Figure 2, shows a structural map of the Tena Base and a structural section that identifies an asymmetric anticline governed by faults.

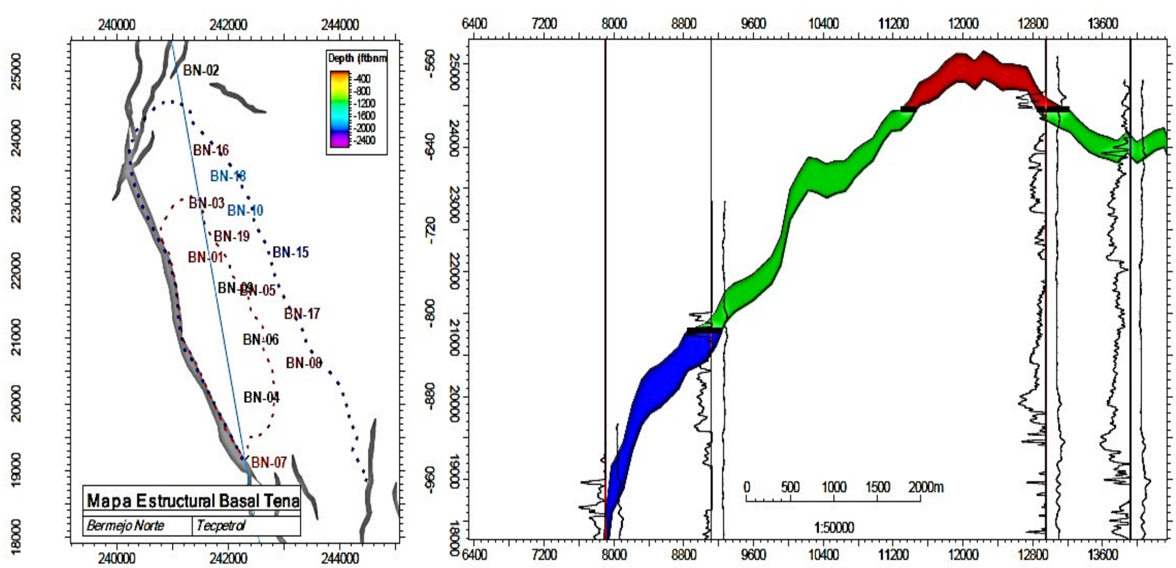

Figure 2. Structural map, B49's North Zone.

3.3. Gas injection - wells BN01 and BN07

Since June 2016 the wells are closed due to the lack of gas, this fact is due to normal conditions of production decline. The accumulated gas injection is 6697 MMcf (BN01 since December 2003 to April 2016) and 1045 MMcf (BN07 since March 2008 to April 2016), the detail of gas pressure and gas injection is exposed in Figure 3.

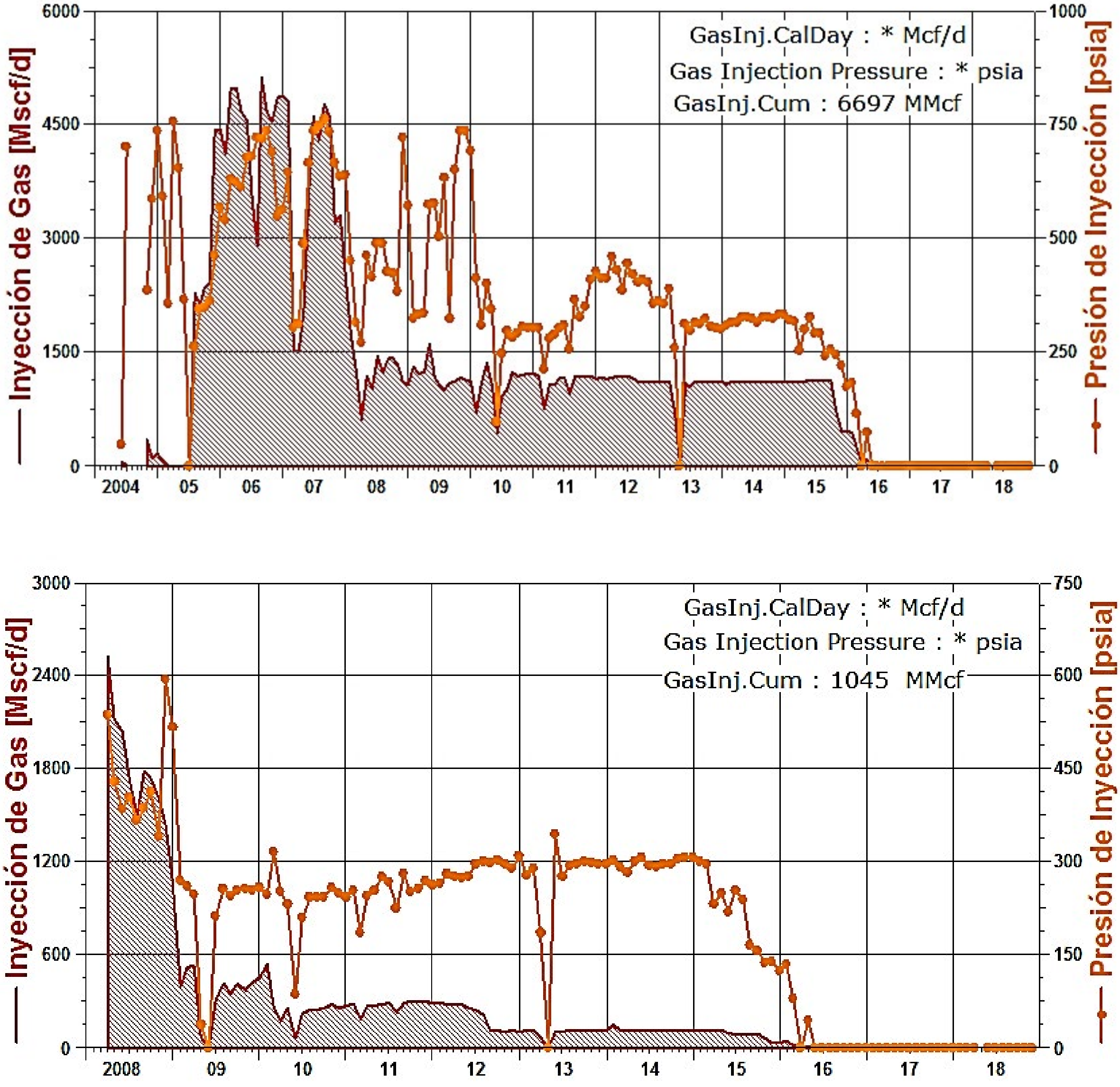

Figure 3. Secondary recovery gas pressure and injection.

3.4. Water injection

The average daily water injection in the month of July 2020 was 2314 bapd at 1428 psi and a cumulative 13.06 MMbls, the last 15 years of fluid injected and pressure are indicated in Figure 4.

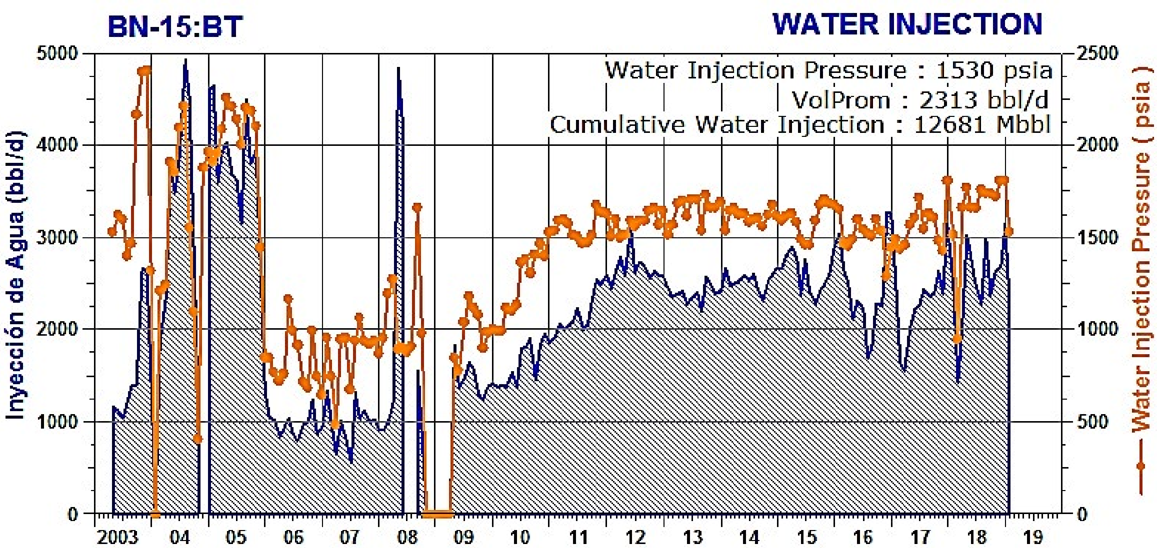

Figure 4. Water pressure and injection of secondary recovery, north zone.

3.5. Influenced wells

Figure 5, shows the influence of BN15 injection in wells: BN 3, BN 19, BN 5, BN 17 and BN 8, which show an increase in both their flow rate and water cut; their production is only possible by maintaining water injection.

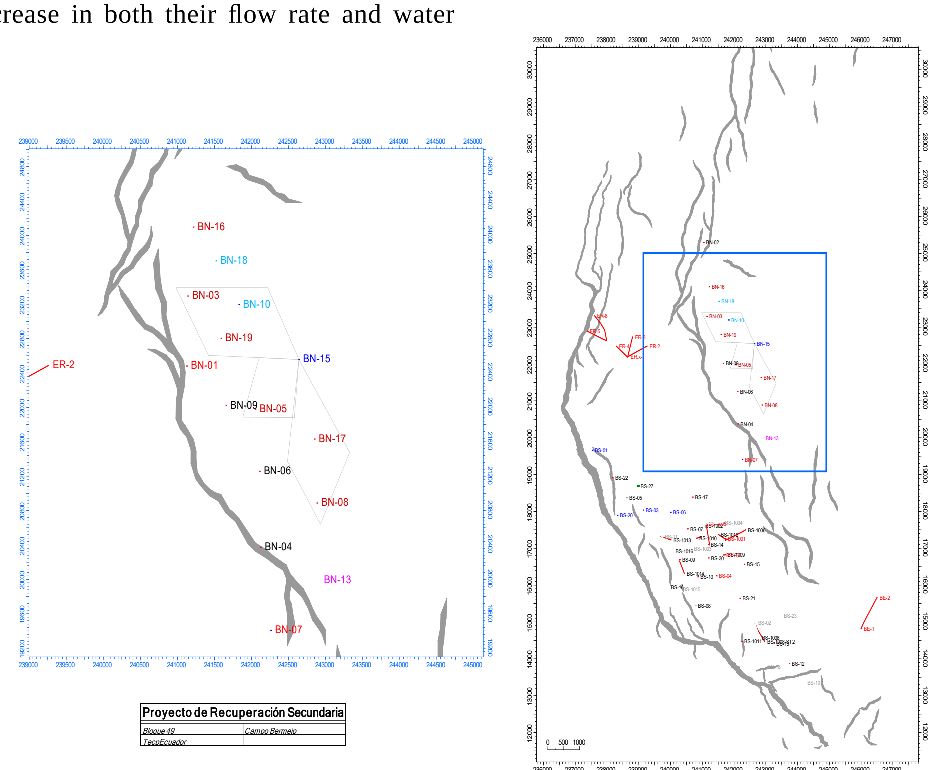

Figure 5. North Zone secondary recovery.

3.6. Injection monitoring and response in production wells

Mature Fields require efficient production monitoring to optimize production. Monitoring allows evaluating the performance of injector wells and producer wells associated with secondary recovery (Tournier et al. 2010). Each quadrant shows distinct behavior that helps characterize injection and production. High water cut has a negative effect on production stages (Afi et al., 2017), the %BSW of the field is 90%.

3.7. Production related to secondary recovery

The production increase by secondary recovery is 1415 [Mstb] until July 2020. Actual production in the North Zone as of July 2020, is 144 [bppd] versus 28 [bppd] from the base curve, which would be the case of production without water injection. The fluid handled is 1768 [bfpd] with a BSW of 90.72% which for more than 10 years of production by secondary recovery is a low value. Graph 6 shows the injection and production of the North Zone.

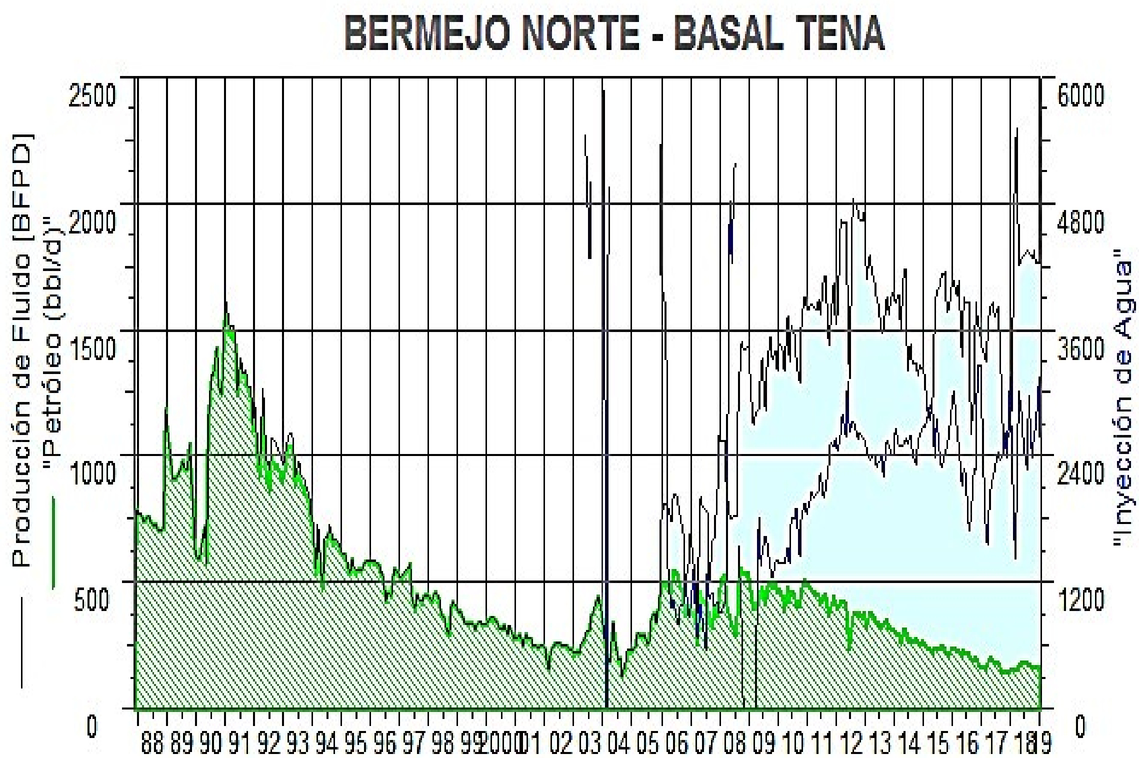

Figure 6. Oil and water production of the north Zone of B49.

Water injection began in May 2003 and the increase in production is evident in October 2004. This is interpreted knowing the low pressures of Basal Tena, in a time of filling the layer during 1 year and 5 months. In this period of time the gas that was free in the reservoir gradually became pressurized which caused the gas to be back in solution in the oil. In November 2005, water broke into the wells, increasing the BSW since then. Oil and BSW increased due to the energy the reservoir has acquired from water injection.

Fluid production peaked in august 2012 at 2009 [bfpd]; since that peak there has been a decline in well contribution due to operational issues. Waterflooding increased the recovery factor from 21% to 26%.

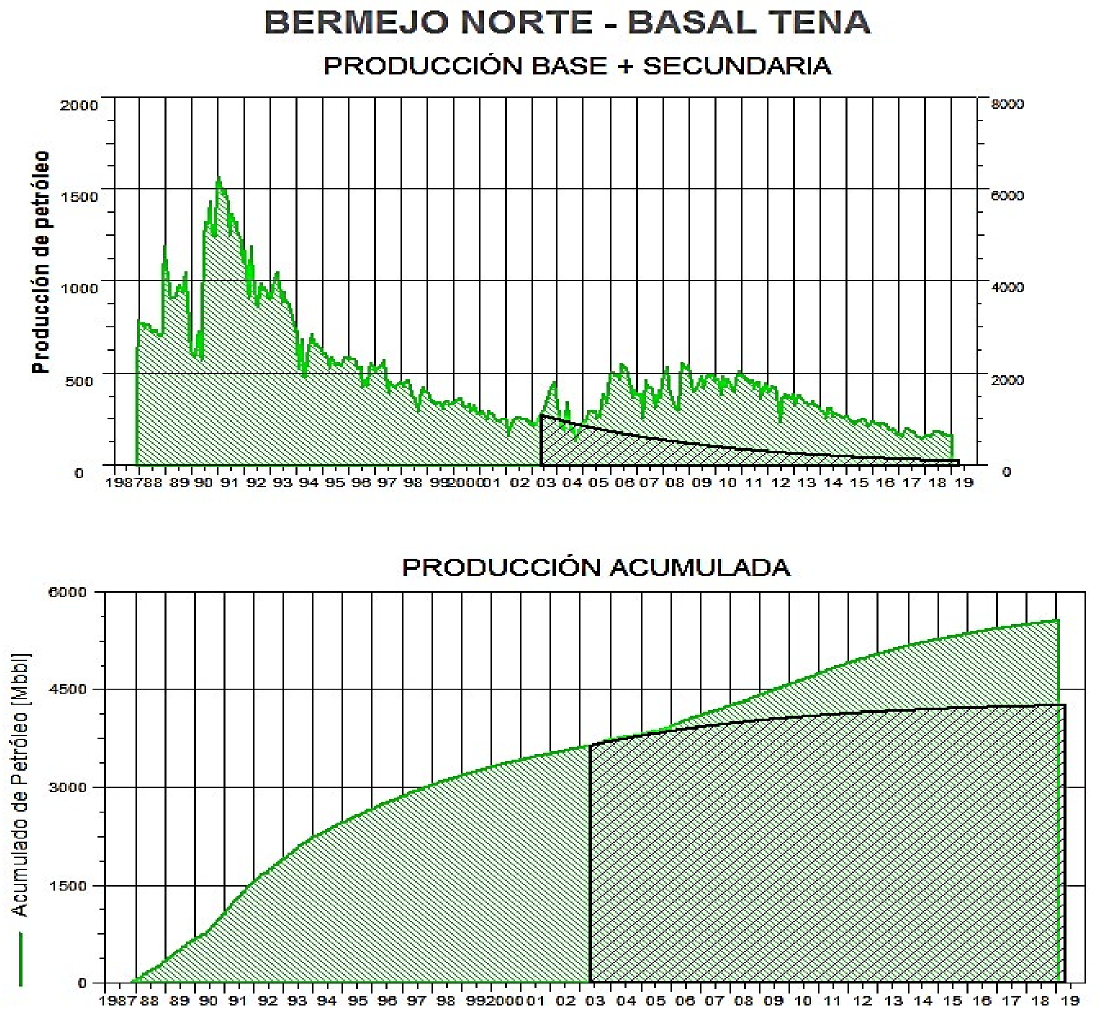

Figure 7. Oil production, north zone of B49.

The base curve indicates the behavior of the North Zone without water injection. The actual incremental achieved shows that the cumulative expected without secondary recovery was exceeded in February 2008, which indicates that the recovery factor improved, as shown in the curves in Figure 7.

4. Energy efficiency

Energy efficiency is part of a comprehensive vision of resource use that is currently transforming the productive sector (Madueme, 2010). The oil industry could not be oblivious to this revolution, it is the perfect opportunity to contribute to the challenges of climate change and encourage savings that would otherwise be destined to the payment of fuels to power generators. The use of gas is part of the energy transition process (Gervet,2007), in recent years it has become clear that gas is the most environmentally friendly hydrocarbon (Emam, 2015) and it is an abundant resource in the Basin of the Ecuadorian East.

4.1. Power generation in the initial stage of field development

The daily energy demand to cover the operational needs of the field is approximately 3 MWH; in the initial stage of development of the field and due to its remote location, the alternative of interconnection to the Amazon district power grid was not viable and diesel generators became the generation choice. Investments to cover the energy demand is an item that limits the competitiveness of crude oil. The details of generation are shown in Table 1.

Table 1. Electric generation in the initial stage of B49 field development.

Annual energy consumption MM kWH	Nº Diesel generators	Diesel generator consumption (MM gallon/year)	Diesel cost millions of USD/ year	Emission M Ton CO2/year
25	16	2.0	0.42[2]	20

4.2. Associated gas

The B49 field has a production of 1455 Mcf/day, initially the gas was flared, however, facilities were developed for gas utilization. The field has 12 wells that meet the technical parameters for its production to be used for electricity generation. Figure 8 shows a diagram of gas-fired power generation in the field.

- Production, there is a lower investment in facilities when selecting gas wells (Sangsaraki & Anajafi, 2015), in this case the gas with this characteristic comes from the wells located in the North zone (1 well), South (6 wells) and El Rayo (5 wells).
- Compression, maintaining pressure in the system is key for the correct operation of the equipment (Zadakbar,2008), the optimum pressure is 120 – 130 psi, the generators were proven to work down to a minimum of 25 psi. The BGC mechanism adapted to Bean Pumps is used for gas compression of 7 wells. The well BS04 has dual compression supported by BGC and a FRICK compressor which increases the pressure of the whole system. Due to the decline in gas production the pressure decreased in the last years, this drawback was solved by injecting directly to the system 4 wells with a high production rate which increased the pressure with a successful result. The water plant monitors and controls the gas pressure as it is the most critical point in the field's generation and production system.
- Distribution, the gas is transported in a 70 km pipeline, the design makes considerations on hydrocarbon transport to optimize the gas displacement (Ríos-Mercado, & Borraz-Sánchez, 2014), the same that covers the North, South, Water Plant, El Rayo and South 14 stations.
- Generation, there are 14 generators distributed throughout the field which support the ESPs and 8 gas engines that support the Beam Pump lifting system, which together support the demand of 3 MWH per day.

4.3. Gas flaring reduction

The use of associated gas has an impact on the economy, society, and the environment, in this particular case it has two positive points:

- **Maintaining** diesel-based generation means having the emissions from the generators plus the associated emissions from the daily flaring of the gas produced. The combustion of diesel engines has a higher contribution of particulate matter and NOx. Gas emits 0.64 Kg CO2/KWh versus 0.81 Kg CO2/KWh for diesel, which makes gas a more environmentally friendly option.
- **Implementing** electricity generation using the gas produced in the field reduces by 20 Mton CO2 per year.

2 Based on a diesel price of 2.10 USD $ / gallon

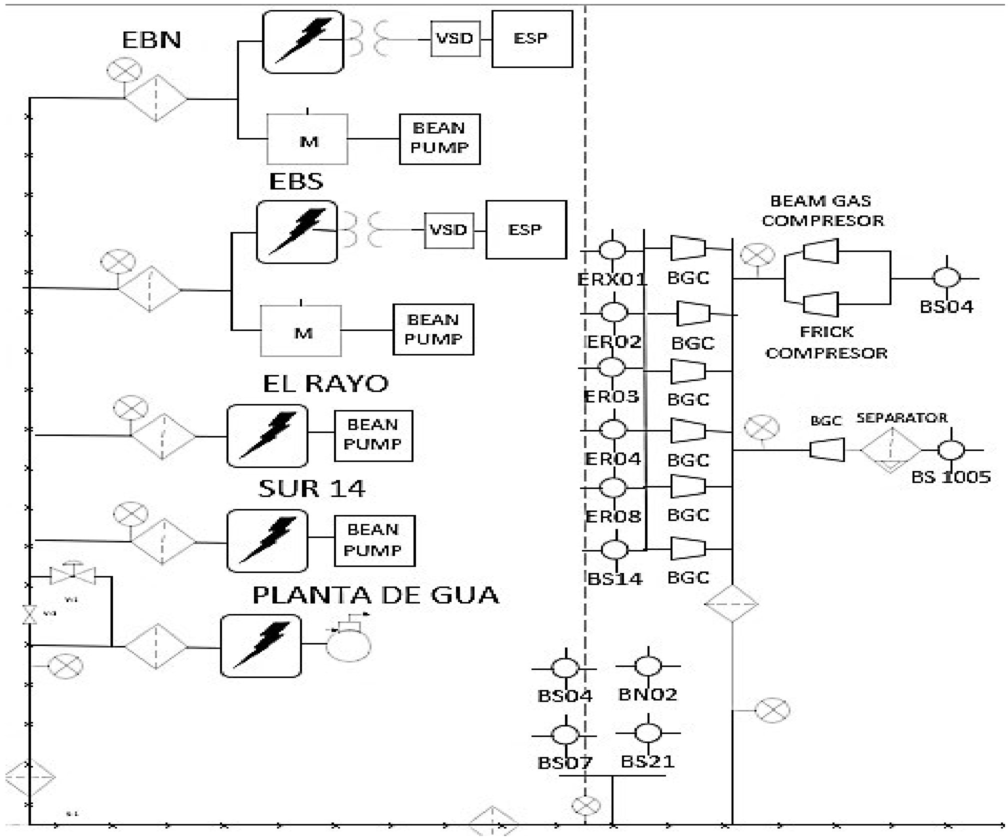

Figure 8. Schematic of power generation scheme using flared gas.

5. Conclusions

- The secondary recovery project using water and gas injection increased the recovery factor from 21% to 26%.
- Gas-fired power generation reduces the carbon footprint associated with each barrel of oil produced. The key to power generation is in the production, pressure maintenance and distribution of gas.
- B49 is an example of sustainability since it generates 100% of the energy demanded using the gas from 12 wells and is a model of optimization, management and cost reduction.

References

[1] Afi, F. N., Gunawan, H., Widiatmo, R., Waskito, L.B., Nugroho, P., Luthfan, M., Prayogo, R., & A, Suryana. (2017). How to Solve High Water Cut Well Problem in Mature Oil Field, Case Study: Application of Modified Completion Fluid Treatment in WW D-29, WW H-12, II A-22 Wells. *SPE/IATMI Asia Pacific Oil & Gas Conference and Exhibition, Jakarta, Indonesia*. https://doi.org/10.2118/187009-MS

[2] Aregbe, A. (2017). Natural Gas Flaring – Alternative Solutions. *World Journal of Engineering and Technology,* 5 (1). https://doi.org/10.4236/wjet.2017.51012

[3] Elvidge, C.D., Bazilian, M.D., Zhizhin, M., Ghosh, T., Baugh, K., & Hsu, F. (2018). The potential role of natural gas flaring in meeting greenhouse gas mitigation targets. *Energy Strategy Reviews*, 20, 156-162. https://doi.org/10.1016/j.esr.2017.12.012

[4] Emam, E.A. (2015). Gas Flaring in Industry: An Overview. *Petroleum & Coal, 57* (5), 532-555. https://www.vurup.sk/na_stiahnutie/gas-flaring-industry-overview/?tmstv=1692731316

[5] Farina, M. (2011). Flare Gas Reduction - Recent global trends and policy considerations. *GE Energy*. https://www.yumpu.com/en/document/read/5166624/flare-gas-reduction-ge-energy

[6] Gervet , B. (2007). Gas Flaring Emission Contributes to Global Warming. *Luleå University of Technology.* https://www.ltu.se/cms_fs/1.5035!/gas%20flaring%20report%20-%20final.pdf

[7] Goudarzi, Ali., Zhang, Hao., Varavei, Abdoljalil., Hu, Yunpeng., Delshad, Mojdeh., Bai, Baojun., & Sepehrnoori, Kamy. (2013). Water Management in Mature Oil Fields using Preformed Particle Gels. *SPE Western Regional & AAPG Pacific Section Meeting Joint Technical Conference, Monterey, California, USA*. https://doi.org/10.2118/165356-MS

[8] Madueme, S. (2010). Gas Flaring Activities of Major Oil Companies in Nigeria: An Economic Investigation. *International Journal of Engineering Science and Technology*, 2 (4), 610-617. https://www.researchgate.net/publication/50273834_Gas_Flaring_activities_of_major_oil_companies_in_Nigeria_An_economic_investigation

[9] Ojijiagwo, E., Odouza, C., & Emekwuru, N. (2016). Economics of Gas to Wire Technology Applied in Gas Flare Management. *Engineering Science and Technology, an International Journal*, 19 (4), 2109-2118. https://doi.org/10.1016/j.jestch.2016.09.012

[10] Ríos-Mercado, R.Z., & Borraz-Sánchez, C. (2014). Optimization problems in natural gas transportation systems: A state-of-the-art review. *Applied Energy*, 147 (1), 536-555. https://doi.org/10.1016/j.apenergy.2015.03.017

[11] Sangsaraki, M.E., & Anajafi, E. (2015). Design Criteria and Simulation of Flare Gas Recovery System. *International Conference on Chemical, Food and Environment Engineering.* https://pdf4pro.com/amp/view/design-criteria-and-simulation-of-flare-gas-recovery-system-510e64.html

[12] Tournier, E., Jaffres, B., Geoge, B., & Sabally, L. (2010). Production Monitoring and Optimization on A Mature Field. *Abu Dhabi International Petroleum Exhibition and Conference.* https://doi.org/10.2118/137969-MS

[13] Zadakbar, O., Vatani, A., & Karimpour, K. (2008). Flare Gas Recovery in Oil and Gas Refineries. *Oil & Gas Science and Technology - Revue d'IFP Energies nouvelles*, 63 (6), 705 – 711. https://doi.org/10.2516/ogst:2008023