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Generating revenue from non-profitable targets. Successful Implementation of HiWAY & TSO fracture techniques in Shushufindi Field

Generando ingresos a partir de objetivos económicamente no rentables. Implementación exitosa de técnicas de fractura HiWAY & TSO en el Campo Shushufindi

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Abstract

The giant Shushufindi field, discovered in 1968, is located in the North-East of the Orient basin in Ecuador, neighboring Maranon and Putumayo basins in Peru and Colombia, respectively. The field belongs to Block 57, it started production in 1972 and is sparsely developed with 165 active wells. The production comes from two of the main cretaceous reservoirs: Ti and Ui, with Ts, Us and BT as secondary targets. The challenge to obtain incremental production from the main reservoirs becomes a tough task. The emphasis on producing from the secondary reservoirs turns into a crucial target for meeting the production expectations in the low production or abandoned wells. The main challenges in the secondary reservoirs are intermediate petrophysical properties, stratigraphic variability, low pay, lateral discontinuity, and shale intercalations. However, there is an important volume of recoverable volumes associated in these sands that makes them an attractive target for production enhancement. Performing conventional operation in secondary reservoirs has a wide margin of risk in terms of incremental production, where the average oil production is ~120 BOPD.

A strategy to improve conductivity in these marginal reservoirs is hydraulic fracturing. Induced fractures enhance permeability greatly by connecting pores together; with this, hydraulic fracturing becomes a critical technology to increase production. The effectiveness of hydraulic fracturing is determined by the propped conductivity and geometry, the fracture height, and half-length. Pad volume and proppant concentration also play an important role in the fracture-treatment design because they determine final propped fracture penetration and conductivity. A good understanding of the reservoir characteristics, together with a fit-to-purpose fracture design, led to a successful implementation of TSO and HiWAY fracture designs in the Shushufindi field, with outstanding results. During the 2018-2019 WO campaign, nine (9) well interventions involved hydraulic fracturing in secondary targets and two (2) in main targets. The execution of these jobs exceeded expectations generating oil production of 7000 BOPD (790 BOPD/well) after the jobs and revenue to the project, which translates to an estimated 6.9MM Bbls of recoverable reserves.

Keywords: Hydraulic Frack; Fracking; HiWAY; Conductivity; Productivity; Secondary Reservoirs; New Technology.

Resumen

El campo Shushufindi descubierto en 1968, está ubicado en el noreste de la cuenca Oriente en Ecuador, vecino a las cuencas de Marañón y Putumayo en Perú y Colombia, respectivamente. El campo pertenece al Bloque

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57, inició la producción en 1972 y está desarrollado con 165 pozos activos. La producción proviene de dos de los principales reservorios del Cretácico: Napo Ti y Ui, con Ts, Us y BT como objetivos secundarios. El desafío de obtener una producción incremental de los reservorios principales se convierte en una ardua tarea. El énfasis en la producción de los reservorios secundarios se convierte en un objetivo crucial para cumplir con las expectativas de producción en los pozos de baja producción o abandonados. Los principales desafíos en los reservorios secundarios son las bajas propiedades petrofísicas, la variabilidad estratigráfica, el bajo pago, la discontinuidad lateral y las intercalaciones de lutitas. Sin embargo, existe un volumen importante de reservas recuperables asociados en estas arenas que las convierte en un objetivo atractivo para la mejora de la producción. Realizar operaciones convencionales en reservorios secundarios tiene un amplio margen de riesgo en términos de producción incremental, donde la producción promedio de petróleo es de ~ 120 BOPD.

Una estrategia para mejorar la conductividad en estos reservorios marginales es la fracturación hidráulica. Las fracturas inducidas mejoran enormemente la permeabilidad al conectar los poros entre sí; con esto, la fracturación hidráulica se convierte en una tecnología crítica para incrementar la producción. La efectividad de la fracturación hidráulica está determinada por la conductividad y la geometría apuntalada, la altura de la fractura y su longitud. El volumen del tratamiento y la concentración de apuntalante también juegan un papel importante en el diseño de fracturas porque determinan la penetración y conductividad final. Una buena comprensión de las características del yacimiento, junto con un diseño de fractura adaptado al propósito, llevó a una implementación exitosa de los diseños de fractura TSO y HiWAY en el campo Shushufindi, con resultados sobresalientes. Durante la campaña WO 2018-2019, nueve (9) intervenciones de pozos involucraron fracturación hidráulica en objetivos secundarios y dos (2) en objetivos principales. La ejecución de estos trabajos superó las expectativas generando una producción de petróleo de 7000 BOPD (790 BOPD / pozo) luego de los trabajos e ingresos del proyecto, lo que se traduce en un estimado de 6,9MM Bbls de reservas recuperables.

Palabras clave: Fractura Hidráulica; HiWAY; Conductividad; Productividad; Reservorios Secundarios; Nueva Tecnología.

1. Introdution

The Shushufindi structure is an elongated asymmetric anticline located in the Block 57 of the Orient Basin in Ecuador, covering ~346.5 km^2. As of August 2019, the field produces about 54,500 BOPD with ~ 80% water cut (Figure 1) from the reservoirs Napo U, Napo T, and Basal Tena. The T sandstone of the Napo formation is continuous across the field, while U sandstone is stratigraphically compartmentalized. The drive mechanism is solution gas for both sands, with lateral aquifer support for U sandstone, and a stronger aquifer support in T sandstone.

Shushufindi is a brown field operated by Petroamazonas EP now E.P. Petroecuador (Ecuadorian NOC), where Consortium Shushufindi (a joint venture between Schlumberger and Tecpetrol) provides integrated services and performs activities for production incremental. A big part of these activities are the Workover operations. Being a brown field, the activities in Shushufindi to obtain incremental production as well as recoverable volumes from accustomed Workover operations (zone change, adding perforated intervals) become more challenging every day. The emphasis on producing from the secondary reservoirs turns into a crucial task for meeting the production expectations and generate revenue in the low production or abandoned wells.

The main challenges in the secondary reservoirs are the lack of water-oil contact, and intermediate petrophysical properties. These reservoirs present high stratigraphic variability reflected in the low net pay (5 to 15 ft), limited lateral continuity compared to the main reservoirs, and shale intercalations (*shaly* sands). However, there is an important volume of recoverable volumes associated with these sands, combined with low, or no, production from the main reservoirs due to various reasons; production decline, high water cut, or mechanical issues in the well, makes them an attractive target for Workover.

Performing conventional workovers in these wells has a wide margin of risk in terms of incremental production due to the sand characteristics and this is where hydraulic fracturing steps into the scenery as a game changer. Fractures (natural or induced) can enhance permeability of rocks greatly by connecting pores together; with this, hydraulic fracturing becomes an interesting technology that has evolved to a complex level and is critical to economical production of hydrocarbons in such wells.

The effectiveness of hydraulic fracturing is determined by the propped fracture conductivity and geometry – the propped fracture height and half length. (Economides et al., 1994). Pad volume and proppant concentration also play an important role in the fracture-treatment design because they determine final propped fracture penetration and conductivity. The propped fracture conductivity depends on the type of proppants, extent of permeability damage caused by fracture fluid residue and other factors (fluid viscosity, pumping schedule). The intrusion of a fracture from the pay zone into the formations lying above and below is another factor that affects the effectiveness of the treatment.

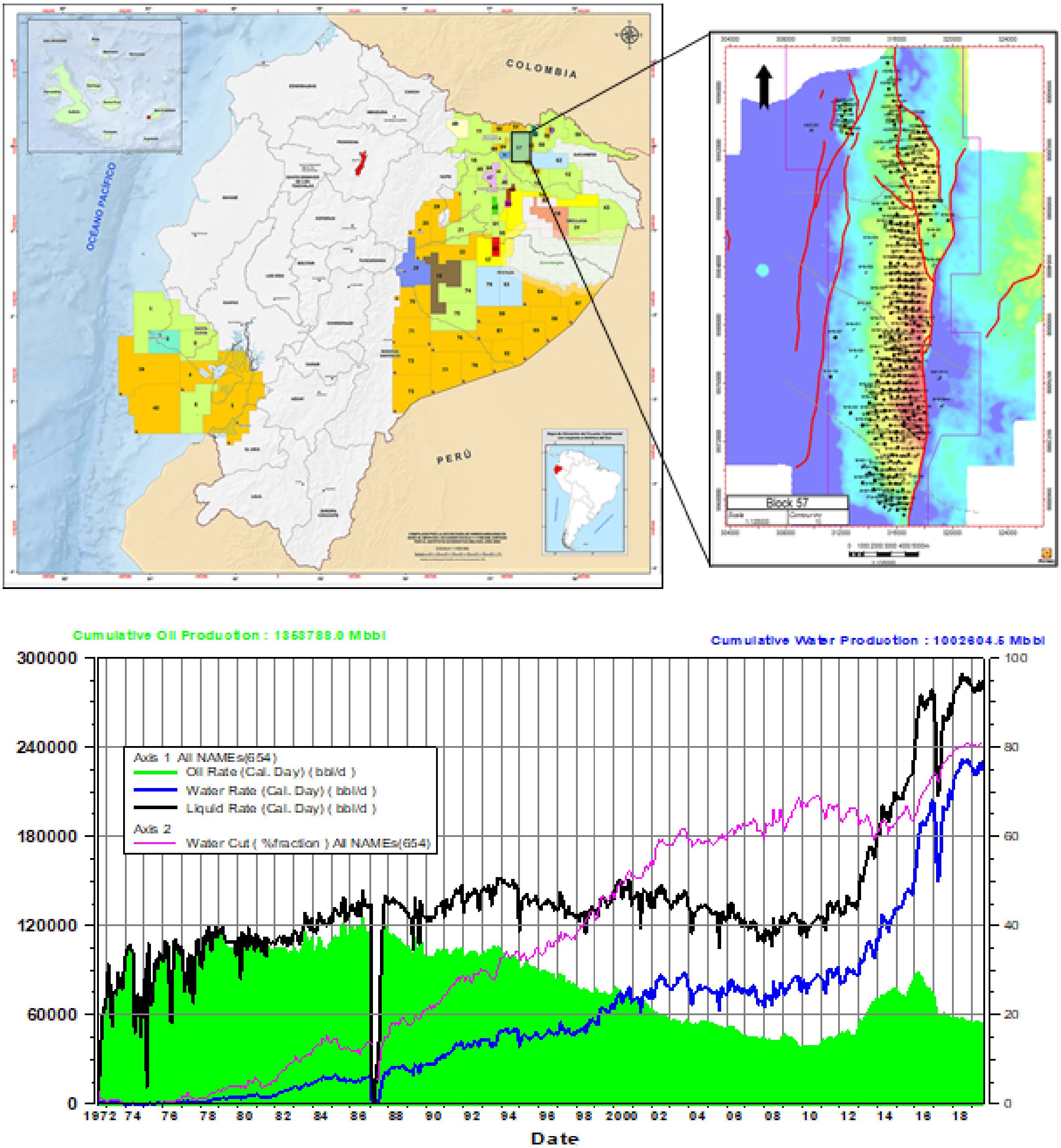


Figure 1. Location and production trend of the Shushufindi Field

Two fracturing techniques have been implemented in the Shushufindi field so far: TSO, and the new HiWAY technique, implemented during the 2018-2019 WO Campaign for the first time in the field's history (Oilfiel glossary). In a TSO fracture, the fluid will flow between the spaces left by the proppant distribution within the fracture, the residual gel will be eliminated carrying out some proppant and, in some cases, could block the sand face making ineffective the fracturing treatment, or even worse - the proppant will flow through the tubing and block the pipe in the hole, creating extra costs, increased operational time and - creating a new formation damage.

The implementation of the HiWAY fracturing technique has reached new limits, by using proppant continuous pulses delivering packages of proppant within the fracture, increasing the fracture length with a reduction in the pressure drop in the fracture and delivering increased production of hydrocarbon. By reducing the proppant flowback, the fracture conductivity is now independent of the quality of the proppant, because now the fluid flows through the proppant packages channels, extending infinite conductivity behavior to the tip of the fracture, while near-wellbore tail-in ensures connectivity to the wellbore.

2. Shushufindi Field

Shushufindi is a mature oilfield with a cumulative oil production of 1,352 MMSTB over a 47-year time span, having recovered approximately 32% of its estimated 4,200 MMSTB STOIIP. The field characterized by a low dip asymmetric anticline structure inversed faulted at its east flank; the field presents six main regions:

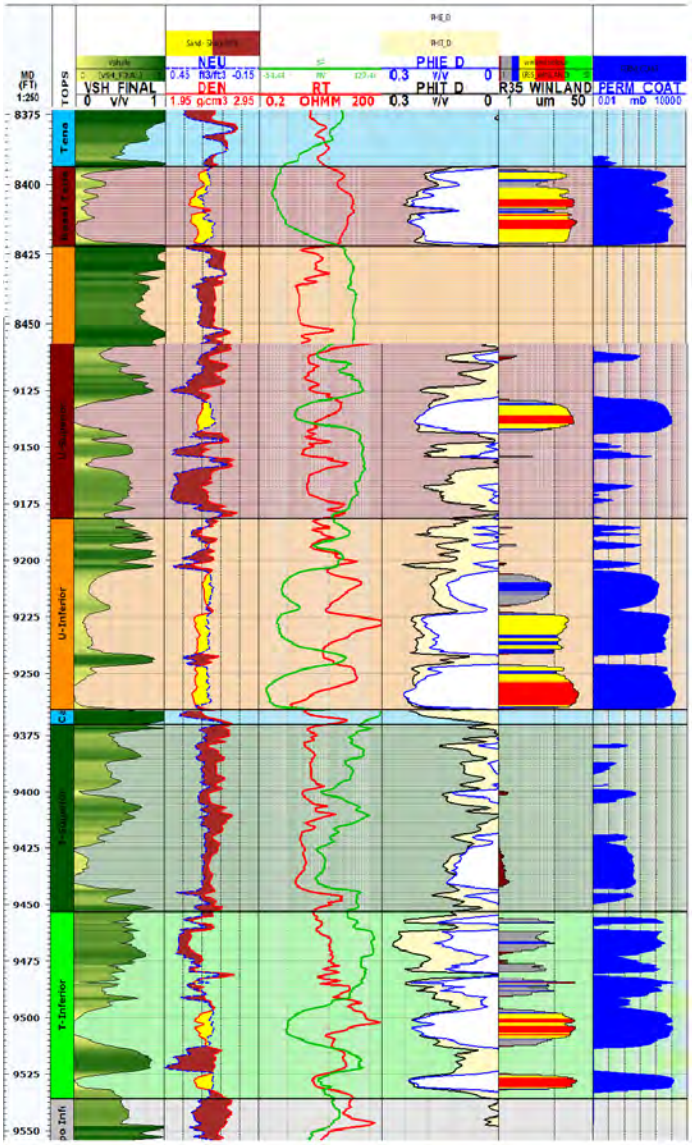


Figure 2. Common Well Type in the Shushufindi field

The Shushufindi field hosts Cretaceous clastic reservoirs with many opportunities remaining for increasing the production:

1) *Basal Tena (BT)*: is a partially developed reservoir. It is discontinuous and selectively completed in two regions of the field (SSFD North and Aguarico Volcanic).
2) *Upper U (Us):* is semi-massive sand and finely layered, partly completed (most by Hydraulic Fractures) over best facies only.
3) *Lower U (Ui)*: is massive sand, stratigraphically

discontinuous along the field with good petrophysical properties

4) *Upper T (Ts):* are thin isolated sands, scarcely completed over best facies
5) *Lower T (Ti):* is massive sand very continuous along the field with good aquifer support and good petrophysical properties. (Figure 2).

The importance of fracking in terms of production is the main key to reach and guarantee incremental rates from reservoirs that traditionally don't flow as expected with the petrophysical interpretation. For Us, Ts and Basal Tena (secondary targets), the current production rates expected without hydraulic fracturing range from 120 to 200 BOPD; through hydraulic fracturing, the rates obtained in these sands go up to 350-600 BOPD. The nature of these reservoirs, due to the lateral discontinuity and considerable shale content, decreases the petrophysical properties significantly, with this - constraining the flow rates and the potential that can offer the reservoirs. Through hydraulic fracturing, we are enhancing the connectivity between pores and layers; in petrophysical terms, we are connecting the zones with better permeability, leading to reach high flow rates in these under-exploited reservoirs. Furthermore, the layering in these reservoirs constrains the sands to layers of 5 to 15 ft separated by shales, creating local seals that ensure and allow the fracture can extend laterally more than vertically; an extended coverage is achieved mainly for the zone of interest, and more control and direction to the fracturepropagation is achieved. This layering can be one of the possible explanations to why the production of these layers comes with low water cut.

In some areas, the Us reservoir has good petrophysical properties; here, the effect of the fracture enhances the connectivity and removes the possible formation damage generated and carried since drilling operations or previous completion processes/well interventions.

2.1 Fracture design and technique selection

Tip Screen Out: improve the connectivity between the reservoir and the well, creating a highly conductive pack with conductivity higher than the conductivity of the reservoir.

HiWAY: improve the connectivity between the reservoir and the well, creating open channels inside the fracture, which enables substantially higher conductivity.

2.2 Description of Tip Screen Out technique

The design of hydraulic fracture jobs depends mainly on the characteristics of the reservoir, the formation permeability being the main design parameter. Post-fracture productivity is dominated in addition to permeability (k), due to fracture permeability (kf), effective fracture length (Xf) and fracture width (w) (Khristianovich et al. 1959). The four parameters serve to determine the objectives of the fracture design and the calculation of the dimensionless conductivity.

Dimensionless conductivity (CfD) is the relationship between the ability to flow through the fracture and the ability of the formation to feed the fracture:

$$C_{fD} = \frac{k_f w}{k\, x_f} \tag{1}$$

Using Prat's correlation, the post-fracture skin can be calculated (Figure 3). (Prat's 1961). Have developed correlations that enable the engineer to use Fcd to predict the benefits of the fracture stimulation, yielding a method that balances fracture half-length with fracture conductivity for stimulation design.

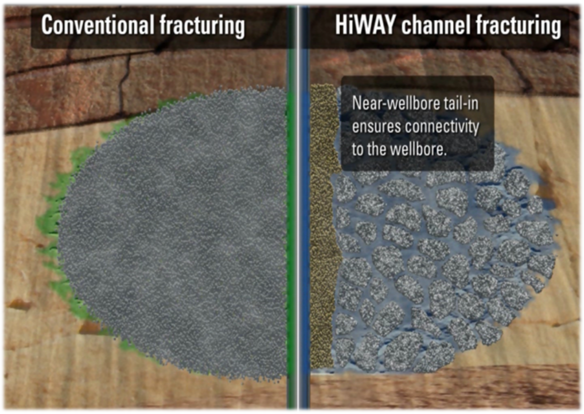
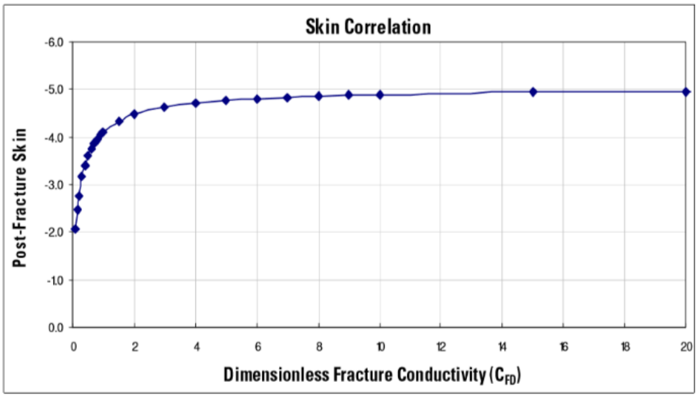


Figure 3. Correlation between post-fracture skin and dimensionless fracture conductivity (Prat's correlation)

The TSO technique consists in increasing the pumping time of the proppant generating a greater net pressure, and thus obtaining a greater fracture width, which in turn increases the dimensionless conductivity and improves post-fracture productivity when obtaining a smaller skin. Another way to improve the dimensionless conductivity is to increase the size of the proppant, with the aim of increasing the permeability of the fracture and thus - increasing the dimensionless conductivity.

2.3 Design of Tip Screen Out fractures in Shushufindi Field

In the Shushufindi field, the TSO technique was applied in the well Shushufindi-111D during the WO Campaign of 2018-2019, using as the main fracture design parameter the fracture width. Based on field experience, with a fracture width of at least 0.2 in, sufficient fracture conductivity can be guaranteed to overcome the damage and reach enough fracture conductivity. Another way to increase fracture conductivity is to increase the size of the proppant. However, due to field experience, when using proppant mesh sizes greater than 20/40, there is a high risk of premature sagging due to bridging of the proppant near the well. Below are the proposed pumping program and preliminary design parameters (Table 1).



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The material balance of the pumped fluids and proppant described below:

Fluid totals:
21840 [gal] of YF140HTD
3760 [gal] of WF140
Proppant Totals:
27400 [lb] of CarboLite 20/40

With these conditions, the simulated fracture geometry parameters are:

EOJ Hyd Height at Well	57.4 ft
Conductivity	5832 md.ft
Fcd	0.19
Fracture Half Length	168.7 ft

Table 1. Proposed pumping schedule for TSO fracture in well Shushufindi-111D - FracCADE software.

Job Description						
Step Name	**Pump Rate** (bbl/min)	**Fluid Name**	**Step Fluid Volume** (bbl)	**Gel Conc.** (lb/mgal)	**Prop. Type and Mesh**	**Prop. Conc.** (PPA)
Pad	20.0	YF140HTD	350	40.0		0.00
1.0 PPA	20.0	YF140HTD	24	40.0	CarboLite 20/40	1.00
2.0 PPA	20.0	YF140HTD	24	40.0	CarboLite 20/40	2.00
3.0 PPA	20.0	YF140HTD	28	40.0	CarboLite 20/40	3.00
4.0 PPA	20.0	YF140HTD	28	40.0	CarboLite 20/40	4.00
5.0 PPA	20.0	YF140HTD	27	40.0	CarboLite 20/40	5.00
6.0 PPA	20.0	YF140HTD	22	40.0	CarboLite 20/40	6.00
7.0 PPA	20.0	YF140HTD	17	40.0	CarboLite 20/40	7.00
Flush	20.0	WF140	81	40.0		0.00

2.5 Description of the Channel fracture technique

In a conventional fracture treatment (TSO), the operations are done by placing a proppant package, which means that the performance of the fracturing treatment depends essentially on the quality of the proppant used. Additionally, with the TSO technique increases the risk of the premature screen out. As the reservoirs have low pressure and high permeability, they tend to admit control fluids after the fracture. In case of the premature screen out, a lot of fluid must be used for cleaning, which adds very high costs to the job.

The channel fracture technique goes one step further. This is done by creating channels within the fracture, which allows hydraulics with a substantially higher conductivity for reservoir fluids compared to conventional fracture treatment. In a channel fracture, the proppant is placed heterogeneously in the form of “columns” surrounded by open channels. Therefore, in the channel fracture, the proppant serves not as a conductive means but as a support agent to prevent the closure of the fracture walls around the channels.

With a channel fracture, it is not only the improvement in fracture conductivity that contributes to the well’s productivity but also the following secondary advantages are added:

Longer average fracture length - open channels created within the fracture increase the conductivity of the fracture and improve the process of cleaning the fracture, allowing the residual gel to be easily removed from remote fracture areas, for example, near the tip.

Decrease in the probability of premature screen-out - this is mainly achieved by reducing the effective concentration of proppant due to pulses (proportion of proppant mass to volume of the fluid pumped in a proppant stage). Clean pulses can contribute to preventing the accumulation of proppant in the area near the well, which could otherwise lead to a screen-out near the well.

Decrease in the probability of return flow of the proppant - in a channel fracture, reservoir fluid flows, not through the proppant package (as in a conventional fracture), but through the channels. Therefore, the drag force exerted by the fluid on the proppant particles is reduced, which in turn reduces the probability of proppant flow.

Improvement of long-term performance - open channels, created within a channel fracture, are less prone to clogging either by scale or fine migration; therefore, they can maintain greater conductivity for longer periods.

2.6 Channel fracture technique applied in the Shushufindi field

The main objective for introducing the channel fracture technique in the Shushufindi field was to improve productivity by increasing fracture conductivity, reducing the risk of proppant production, and reducing the risk of premature screen-out, especially in the Ui formation that has very high permeabilities. The dimensionless fracture conductivity was used as the main parameter to determine if the fracture of the channel would improve the fracture geometry. The dimensionless conductivity that was obtained from the conventional fractured wells was compared with the dimensionless conductivity that would be obtained with the channel technique. The simulations indicated that the dimensionless conductivity obtained with the channel technique was on average 10 times higher than that obtained with a conventional fracture.

2.7 Design of Channel fracture

For the first Channel fracture job carried out in the well Shushufindi-192D, a PBU test was carried out before the fracture job and the permeability data of 10.6 mD was obtained.A dimensionless conductivity of at least 1 was required to achieve the production objectives in the well Shushufindi-192D, and with conventional techniques, it was not economically profitable to reach this value. Using the channel fracture technique due to the high conductivity of the fracture, a dimensionless conductivity of at least 2 could be achieved, according to the proposed design. Below is the proposed pumping program (Table 2) and preliminary design parameters.

The material balance of the pumped fluids and proppant is described below:
Fluid totals:

22173 [gal] of YF140HTD
3960 [gal] of WF140
Proppant Totals:
30800 [lb] of CarboLite 20/40

With these conditions, the simulated fracture geometry parameters are:

EOJ Hyd Height at Well	46.3 ft
HiWAY Conductivity	8956 md.ft
HiWAY Fcd	2.0
HiWAY Channeled Length	320.6 ft

2.8 Proppant Flow-back Advisor

When talking about fracture design, the post-fracture operations in the well play a significant role in the successfulness of the fracture job. At this point, it is important to mention the design of well start-up after the fracture job, using the Proppant Flow-back Advisor software.

The major inputs for the calculations of the recommended flowrate to assure the proppant stability in the reservoir and thus – the fracture effectiveness itself, are as follows:

- Fractured interval, number of perforations that receive fluid
- Reservoir and rock properties (Young module, fracture closing pressure, temperature)
- Fracture properties (fracture width, fracture permeability)
- Fracture fluid properties to generate Cleanup Graph (gel viscosity)
- Formation fluid properties to generate Production Graph (oil viscosity, volumetric factor)

The output of the software is given in the form of graphs (Figure 4) and shows the maximum admissible flow rates, in order to avoid that the fracture and the proppant become unstable and to flow into the well. The two major fazes are considered: well cleanup (the phase until the pumped gel and fracture fluid is recovered) and well production (the phase of production itself after the fracture job).

Table 2. Channel fracture pumping schedule, well Shushufindi-192D

Job Description									
Step Name	**Pump Rate** (bbl/min)	**Fluid Name**	**Step Fluid Volume** (gal)	**Gel Conc.** (lb/mgal)	**Prop. Type and Mesh**	**Prop. Conc.** (PPA)	**Prop Pulse** (second)	**Clean Pulse** (second)	**Cycle**
Pad	20.0	YF140HTD	7560	40.0		0.0	0.0	540.0	0
1.0 PPA	20.0	YF140HTD	2193	40.0	CarboLite 20/40	1.0	10.0	10.0	8
2.0 PPA	20.0	YF140HTD	2150	40.0	CarboLite 20/40	2.0	10.0	10.0	8
3.0 PPA	20.0	YF140HTD	2374	40.0	CarboLite 20/40	3.0	10.0	10.0	9
4.0 PPA	20.0	YF140HTD	2851	40.0	CarboLite 20/40	4.0	10.0	10.0	11
6.0 PPA	20.0	YF140HTD	2509	40.0	CarboLite 20/40	6.0	10.0	10.0	10
8.0 PPA	20.0	YF140HTD	1706	40.0	CarboLite 20/40	8.0	10.0	10.0	7
TAIL IN	20.0	YF140HTD	830	40.0	CarboLite 20/40	8.0	80.0	0.0	0
Flush	20.0	WF140	3960	40.0		0.0	0.0	282.8	0

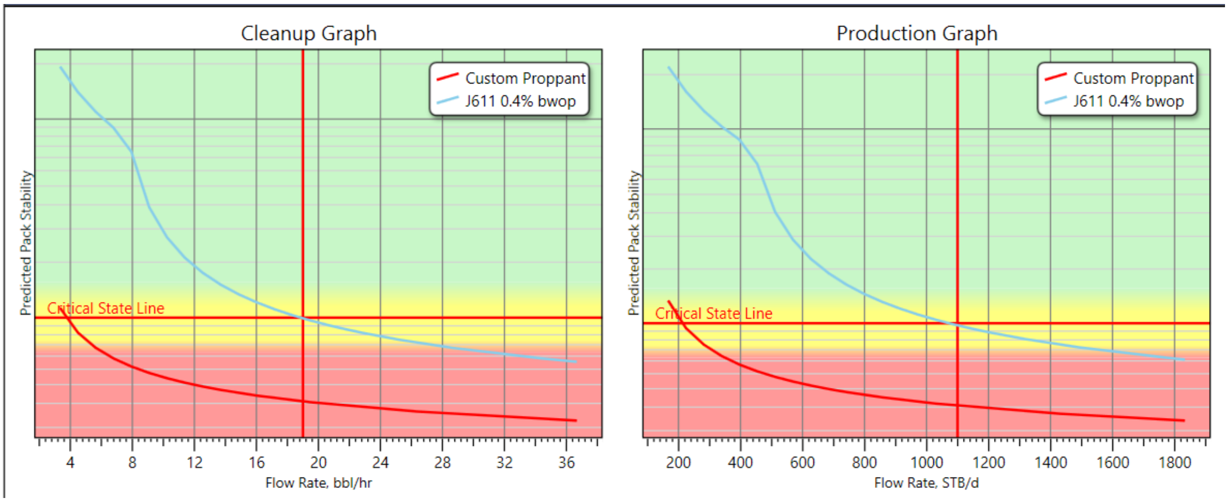


Figure 5. Proppant Flow-back Advisor software output graphs

2.9 Execution during WO campaign 2018-2019 TSO fracture execution and geometry

The TSO fracture discussed above was performed in the temporary abandoned well Shushufindi-111D. This well was inactive due to the difficulty of recovering various tools stuck in the lower part of the well (Appendix 1). These tools were blocking the main sands Ui and Ti, which had good potential but were unreachable. An opportunity was identified in the upper, unblocked part of the well, in secondary sand BT (Figure 5, Table 3) to increase.

The TSO fracture operation was carried out as per the proposed design without operational problems. A bottom hole sensor information was available in this fracture operation (Figure 6). With the bottom hole sensors data, the net pressure was analyzed, obtaining the following results:

Table 3. Petrophysical properties of the BT sand, well Shushufindi-111D

Sand	Phie avg [%]	Kabs [mD]	Sw_avg [%]
Basal Tena	13 - 19	50	30

- The first slope of 0.04 indicates that the fracture grows in T-shape
- The second slope indicates growth in length and growth in controlled height (PKN & HG)
- The third slope of 0.19 indicates growth in fracture length (PKN).
- The last slope of 1.22 indicates that the fracture the field production.

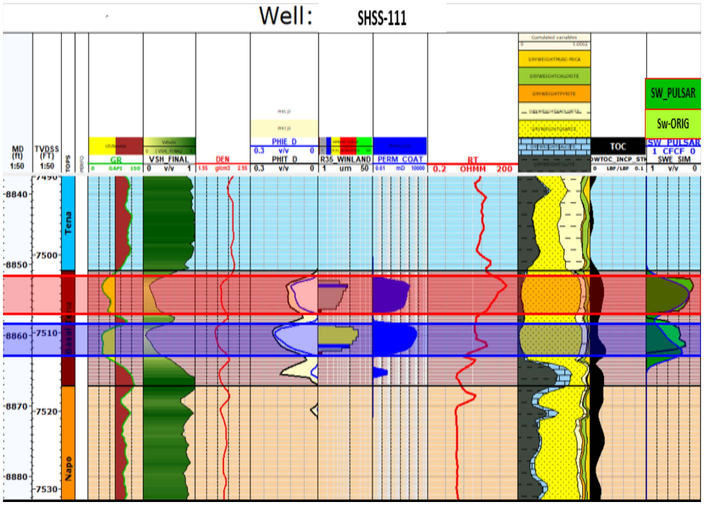
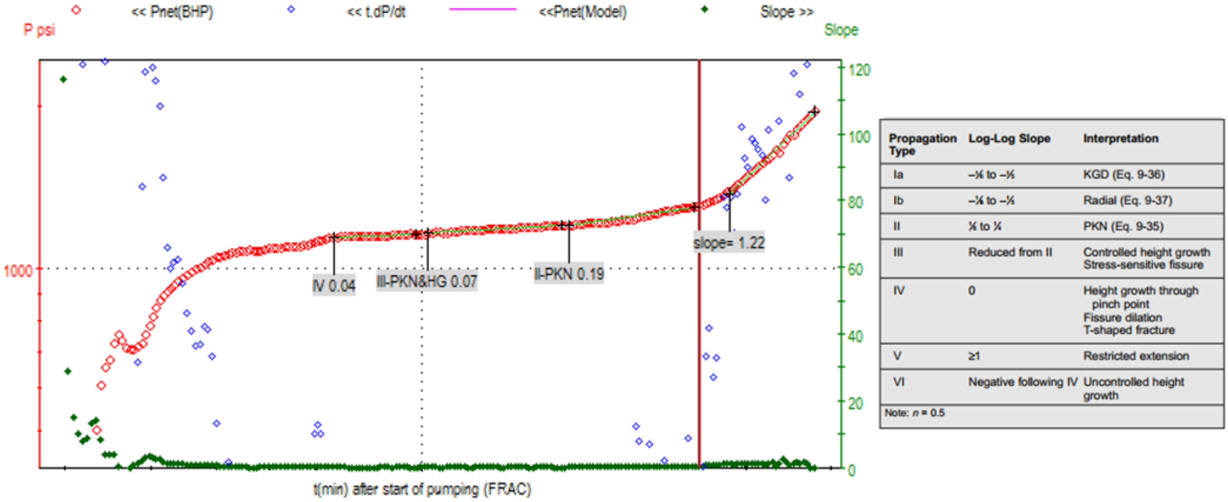


Figure 6. Petrophysical properties of the BT sand, well Shushufindi-111D

The fracture geometry obtained with the pressure match in the software FracCADE (Figure 7, Figure 8) using the bottom hole information is the following:

EOJ Hyd Height at Well	60.6 ft
Conductivity	5398 md.ft
Fcd	0.2
Fracture Half Length	164.7 ft

After performing the TSO fracture job, reaching a pressure of 5136 psi, and pumping about 28862 lbs of proppant (Figure 9, Table 4), the well Shushufindi-111D started with a production of almost 600 BOPD and 35% of water cut. It is important to mention that this is the incremental production, as the well was producing 0 BOPD and was abandoned before the intervention.



Propagation Type	Log-Log Slope	Interpretation
Ia	–⅙ to –⅛	KGD (Eq. 9-36)
Ib	–⅛ to –⅕	Radial (Eq. 9-37)
II	⅛ to ¼	PKN (Eq. 9-35)
III	Reduced from II	Controlled height growth Stress-sensitive fissure
IV	0	Height growth through pinch point Fissure dilation T-shaped fracture
V	≥1	Restricted extension
VI	Negative following IV	Uncontrolled height growth

Note: n = 0.5

Figure 7. Net pressure of the fracture job in the well Shushufindi-111D, obtained from bottom hole sensor data

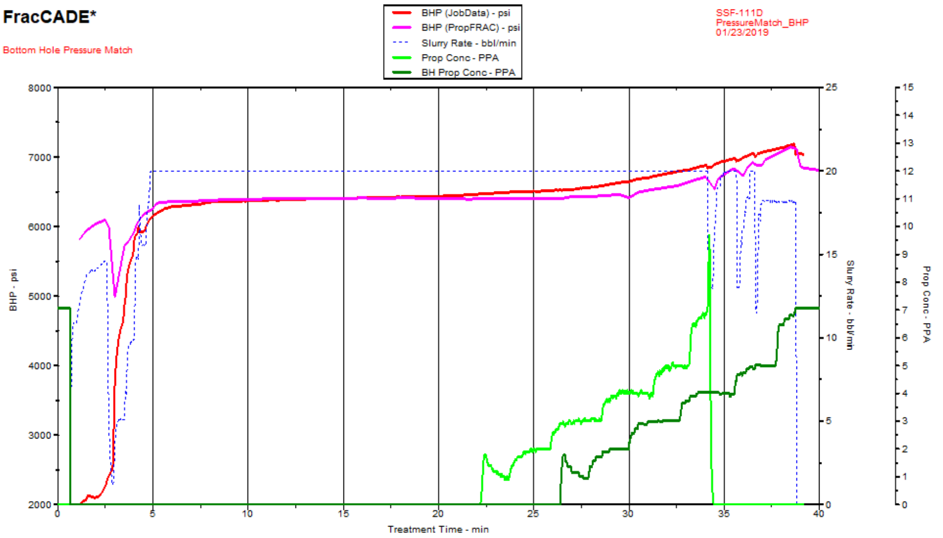


Figure 8. Pressure match of bottom hole real data and FracCADE simulation

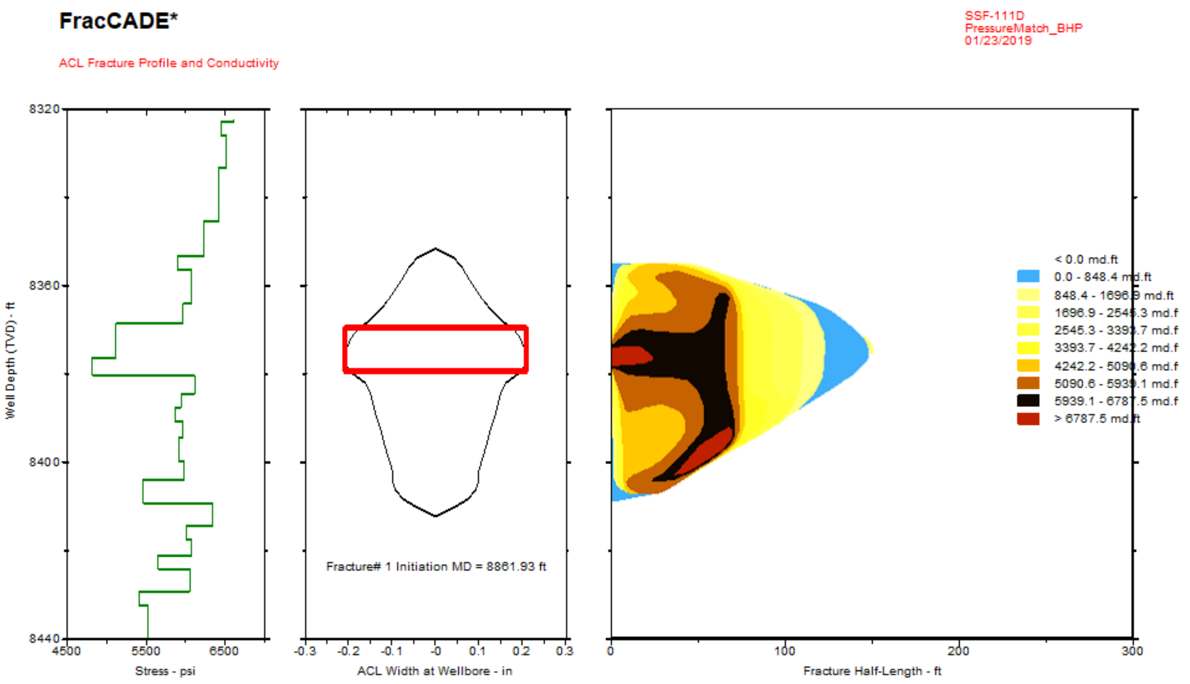


Figure 9. Fracture profile and proppant distribution for the well Shushufindi-111D

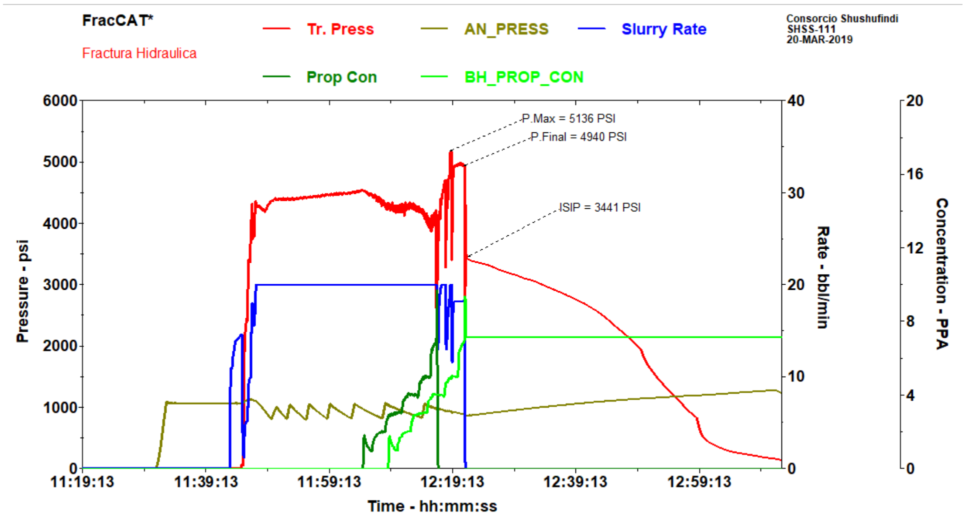


Figure 10. Fracture job performed in the sand BT of the well Shushufindi-111D

Table 4. Pumped volumes and job parameters for the TSO fracture operation in the well Shushufindi-111D

Job Volumes and Parameters					
Slurry (bbl)	**Pump Time** (min)	**WF140 Volume** (gal)	**YF140HTD Volume** (gal)	**Carbolite 20/40 Volume** (lb)	**Max Treating Pressure** (psi)
615	36.2	3318	25410	29072	5136

The production profile of the well after the performed fracture job is shown in the Figure 10 and the IPR curve in Figure 11.

2.10 Channel fracture execution and geometry

The first well in the SSFD field to perform the channel fracture (HiWAY) was the well Shushufindi-192D.

The operations performed in this well were a clear example of excellence in operations. Before the WO intervention, the well was producing about 110 BOPD from Ui sandstone. During the WO operation, the well was perforated in secondary Ts sand and evaluated there. The PBU test results (Figure 12) confirmed the severe formation damage (S=25.8) and the need to improve the conductivity in the reservoir.

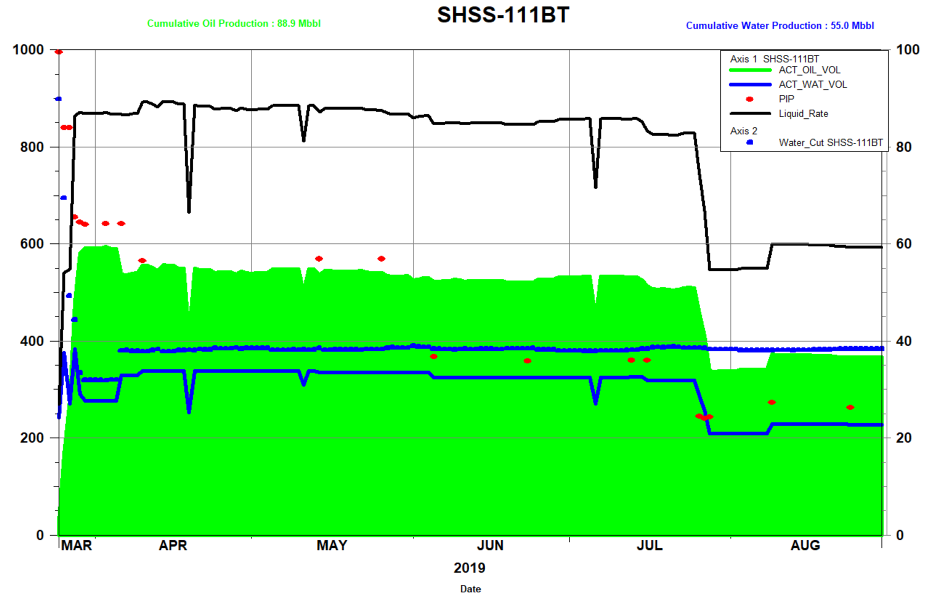


Figure 11. Production trend for the well Shushufindi-111D, sand BT, after WO

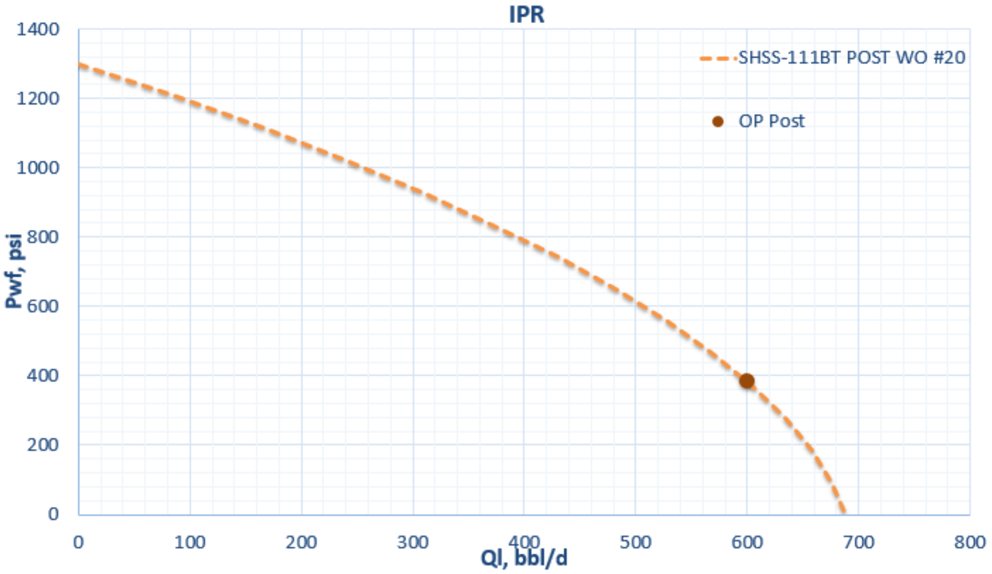


Figure 12. IPR curve in the well Shushufindi-111D, sand BT, after WO

The petrophysical interpretation for the Ts sand (Figure 13, Table 5) shows about 10 ft of intermediate quality sand, with average permeability of about 10-12 mD and maximum porosity of 15% (in the lower part of the sand), with an average of 13%.

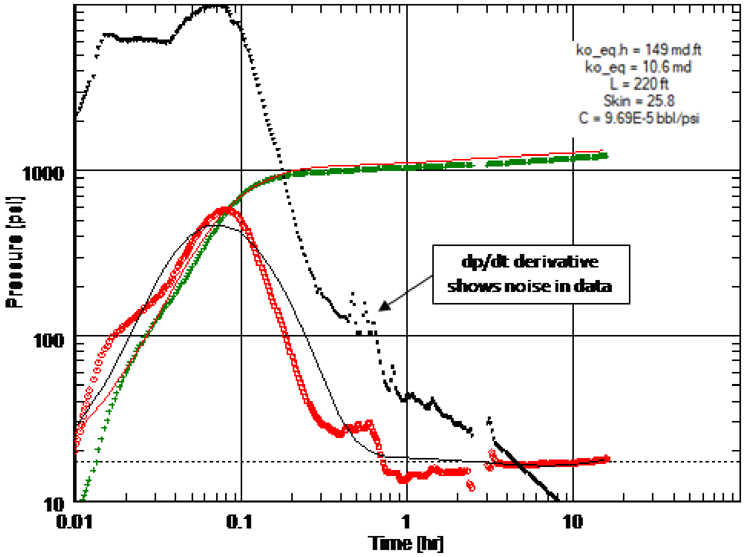


Figure 13. Pressure Build-Up test before fracture in the well Shushufindi-192D, sand Ts.

Table 5. Petrophysical properties of Ts sand, well Shushufindi-192D

Sand	Phie avg [%]	Kabs [mD]	Sw_avg [%]
Ts	13	10.6	19

The Channel fracture operation was carried out as per the proposed design, without any operational problems. According to the pressure match (Figure 14), the following fracture geometry was obtained:

EOJ Hyd Height at Well	45.5 ft
HiWAY Conductivity	9282 md.ft
HiWAY Fcd	2.4
HiWAY Channeled Length	303.9 ft
Propped Fracture Half-Length	322.4 ft

The operation reached a maximum pressure of 5175 psi with 34367 lbs of proppant pumped into the formation (Figure 15, Table 6). The channel fracture operation was carried out as per the proposed design without operational problems.

The results and effectiveness of the performed job can be clearly seen when comparing the two PBU tests – before and after the fracture job (Figure 17). A significant reduction in the value of skin was achieved, the PBU test showing skin of -2.73 after the performed HiWAY fracture. Also, a typical fracture behavior can be observed on the PBU test log-log plot (1/4 slope).

The well Shushufindi-192D reached a peak production of more than 600 BOPD with only 3% water cut after the performed fracture (Figure 18). The increase in the well's potential is shown in the IPR graph (Figure 19).

The results and effectiveness of the performed job can be clearly seen when comparing the two PBU tests – before and after the fracture job (Figure 17). A significant reduction in the value of skin was achieved, the PBU test showing skin of -2.73 after the performed HiWAY fracture. Also, a typical fracture behavior can be observed on the PBU test log-log plot (1/4 slope) (Warpinski, N.R, 1985).

The well Shushufindi-192D reached a peak production of more than 600 BOPD with only 3% water cut after the performed fracture (Figure 18). The increase in the well's potential is shown in the IPR graph (Figure 19).

The fracture geometry can be observed in the Figure 16.

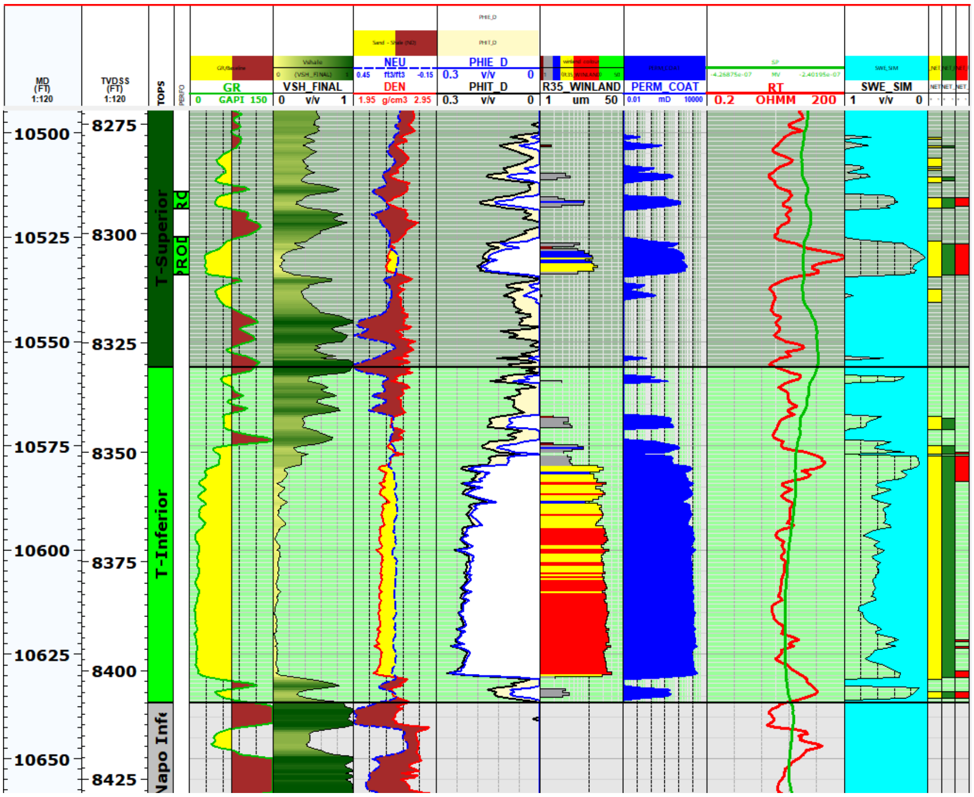


Figure 14. Petrophysical properties of Ts sand, well Shushufindi-192D

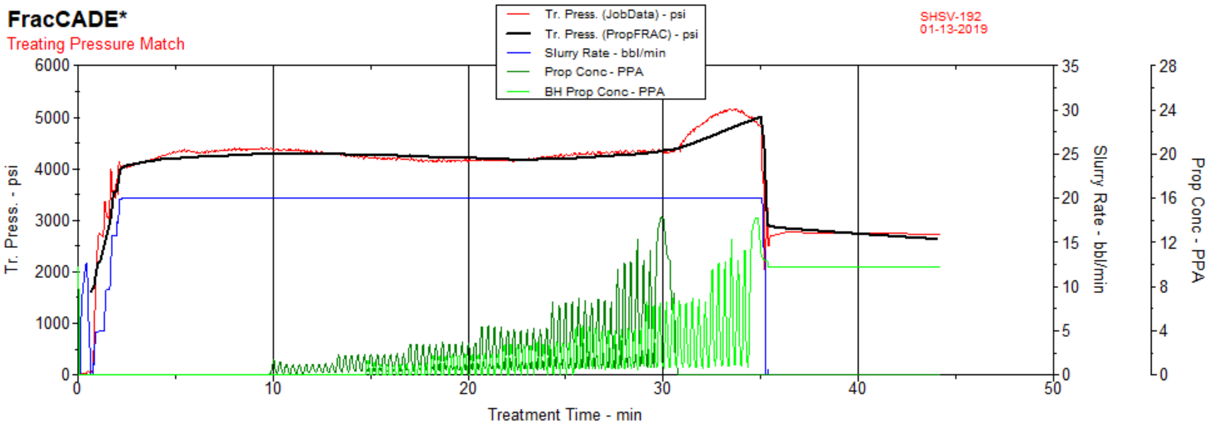


Figure 15. Pressure match of treating pressure and FracCADE simulation.

Table 6. Pumped volumes and job parameters for the HiWAY fracture in the well Shushufindi-192D

Job Volumes and Parameters					
Slurry (bbl)	**Pump Time** (min)	**WF140 Volume** (gal)	**YF140HTD Volume** (gal)	**Carbolite 20/40 Volume** (lb)	**Max Treating Pressure** (psi)
678.4	35.3	3864	23112	34678	5157

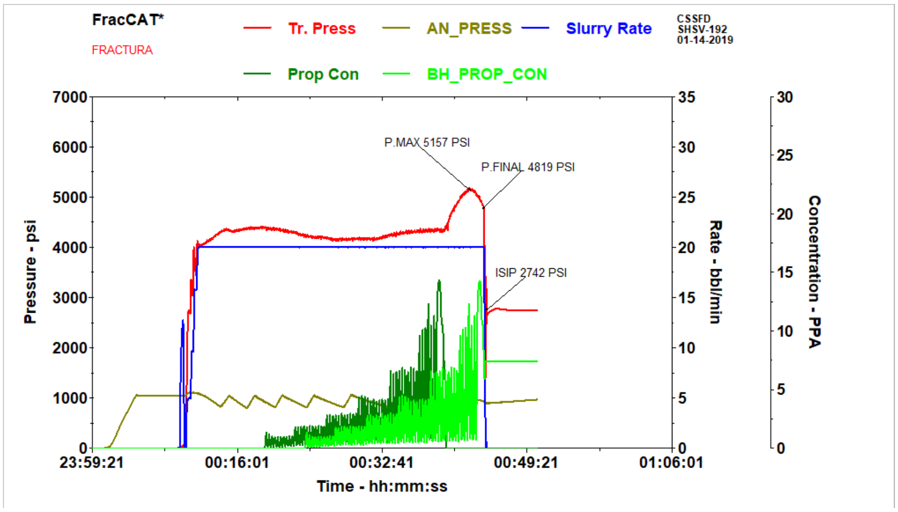


Figure 16. HiWAY fracture performed in the sand Ts, well Shushufindi-192D

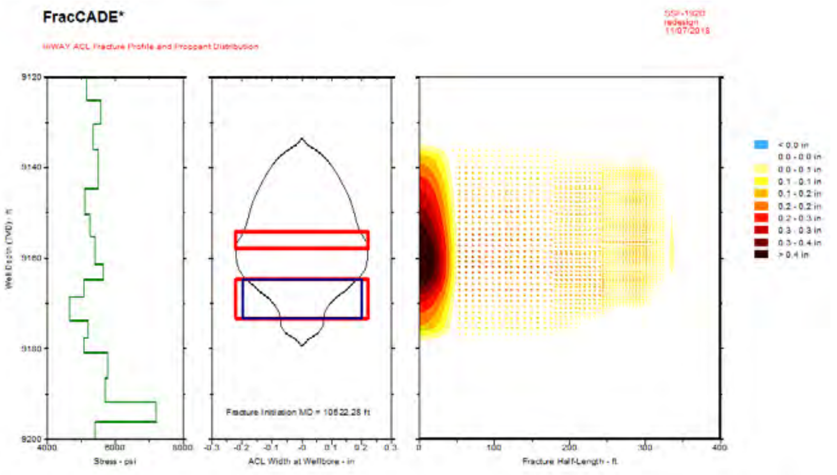


Figure 17. Fracture profile and proppant distribution for the well Shushufindi-192D, sand Ts

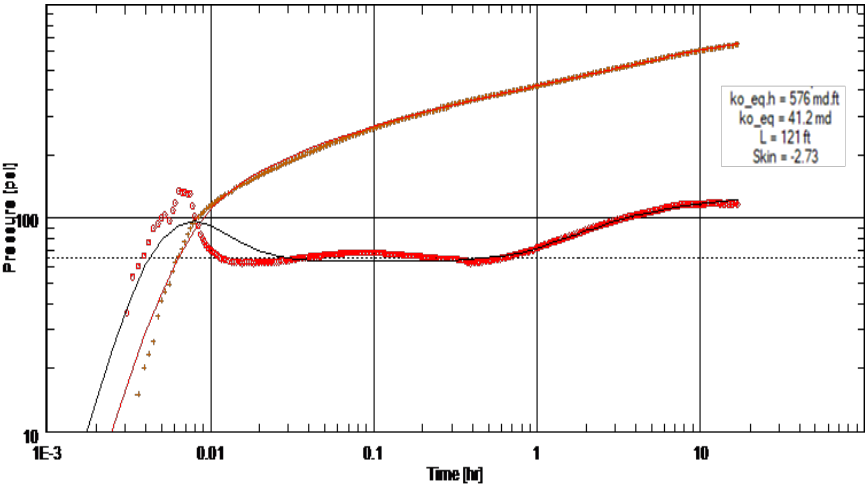


Figure 18. Figure 18. PBU test after the HiWAY fracture, well Shushufindi-192D, sand Ts

Performing a WO campaign is a challenging task, especially in a brownfield with aging facilities and wells with integrity issues. Selecting the best candidates to meet the incremental production adds to the challenge and selecting the candidates to perform hydraulic fracturing can only be done with the appliance of the lessons learned and the fine-tuning of the fracture design based on these lessons.

Several wells have been evaluated for 2018-2019 WO campaign in the Shushufindi field; the best candidates to perform hydraulic fracturing were mainly abandoned wells, wells with the main sands almost depleted or with a high water cut and wells with operative restrictions (integrity problems). Of these, 9 wells have been chosen for hydraulic fracturing implementation, five of which - for HiWAY fracturing.

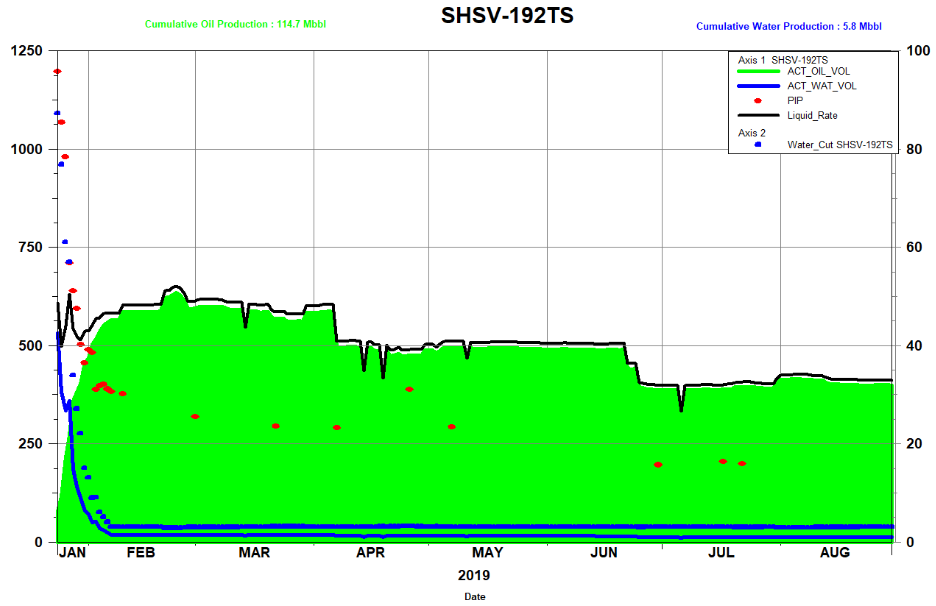


Figure 19. Production trend for the well Shushufindi-192D, sand Ts

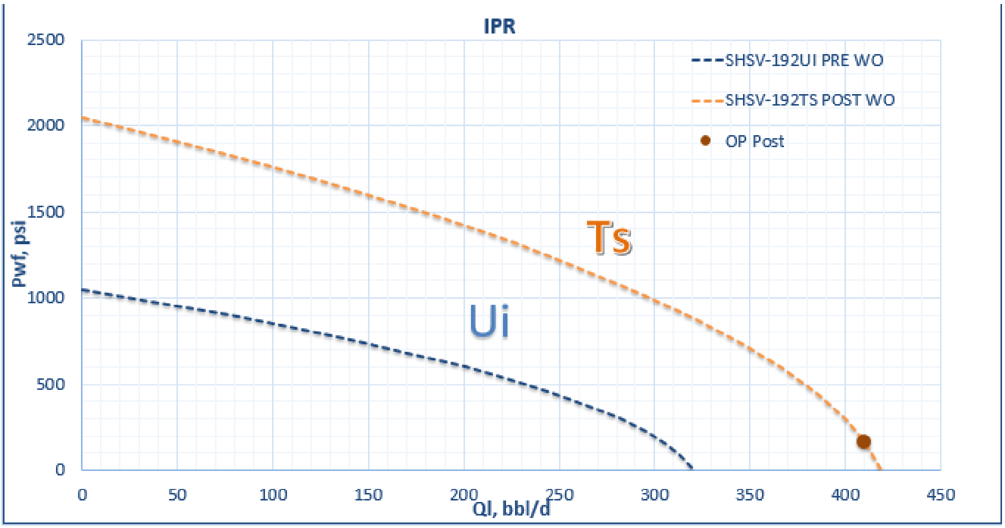


Figure 20. IPR comparison before WO (sand Ui) and after WO and fracture (sand Ts), well Shushufindi-192D

The campaign resulted into a significant oil production of +/- 7000 BOPD (790 BOPD/well) after the jobs and thus, revenue to the project, which translates to an estimated 6.9MM Bbls of incremental recoverable reserves (Table 7).

Figure 20 shows the evolution of the fracture jobs in the SSFD field since 2012 to 2019 and their performance in terms of post-job production. In blue are the conventional TSO fracture jobs performed until 2018 and in green – the HiWAY fracture jobs. It is clear the HiWAY technique has become a game-changer in the fracturing strategy of the field and has marked the beginning of a new era, especially for the secondary sands. Five channel fractures have been performed so far, summing a post-job production of +/- 4600 BOPD.

Table 7. Production data of the 9 wells fractured in the Shushufindi Field during the 2018-2019 WO Campaign

					Before WO			After WO				Fracture Geometry					
Well	Producing Sand Before WO	Producing Sand After WO	Objective	Frack Type	BFPD	BOPD	BSW	BFPD	BOPD	BSW	Reserves [Mbbls]	Cfd	Fcd [mD.ft]	Kf [mD]	Xf [ft]	W [inch]	K [mD]
SHS-087	Ti	Ui	FRACK Ui	HiWAY	2030	306	70	3880	1940	50	1680	6.52	2.5	2260000	160.1	1.063	398
SHS-199	Ui	Ui	FRACK Ui	HiWAY	160	138	14	1312	1010	23	328	7.25	3.3	2001000	185.5	1.967	317
SHS-119	Inactive	Us	FRACK Us	HiWAY	0	0	-	669	662	1	1256	5.26	10.1	2100000	120.6	1.227	100
SHSV-192	Ui	Ts	FRACK Us	HiWAY	236	179	24	603	585	3	404	6.51	2.4	2120000	322.4	1.55	134
AGRI-052	Ui	BT	FRACK BT	HiWAY	1840	92	95	478	454	5	922	5.29	3	2107000	1013	1.411	89
SHSI-164	Ui	Us	FRACK Us	TSO	0	0	-	928	668	28	826	3.5	0.86	189000	89.4	0.468	134
AGRI-051	Ui	BT	FRACK BT	TSO	3120	125	96	1058	635	40	450	2.9	0.1	190000	62.6	0.95	120
SHS-111	Inactive	BT	FRACK Bt	TSO	0	0	-	882	546	38	639	3.9	0.2	179500	60.6	0.203	208
SHSH-155	Ui	Us	FRACK Us	TSO	124	73	51	603	573	4	486	2.5	0.3	19200	107.5	0.254	147
									7073		6991						

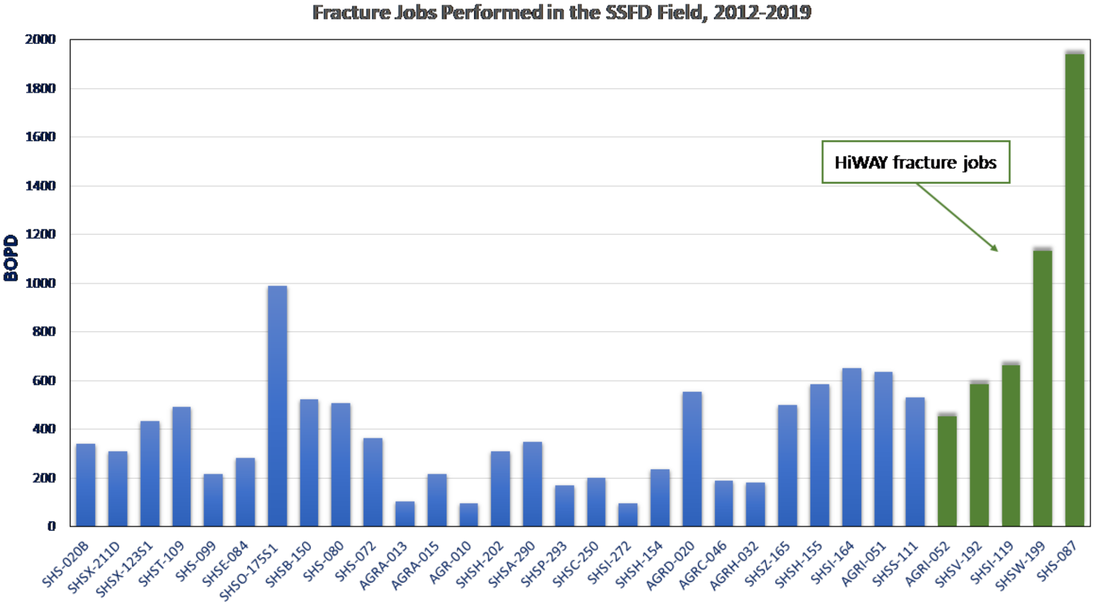


Figure 21. Fracture jobs performance, SSFD field between 2012-2019

3. Conclusions

For the past years, the only fracture technique that has been applied in the Shushufindi field was the TSO. The 2018-2019 WO Campaign and with it - the implementation for the first time of the HiWAY fracture has shown that the field still has good potential and the results of the WO operations have exceeded the expectations.

Secondary reservoirs with limited petrophysical properties are attractive targets for channel fracture jobs and in some cases – the only way to achieve economically profitable operations in these wells.

HiWAY fractures performed in the secondary reservoirs Us, Ts and BT have proven this theory.

The ongoing WO Campaign during 2018-2019 has brought significant oil production; the 9 fractured wells have provided +/- 7000 BOPD (790 BOPD/well) post-job production and an estimated of 6.9MM Bbls of additional recoverable volumes.

The HiWAY channel fracture technique is more effective than the TSO technique, as it can achieve greater dimensionless conductivity and, therefore, obtain greater post-fracture productivity.

As the wells have low reservoir pressure and high permeability, the reservoirs tend to admit control fluids after the fracture. In case of a premature screen out, a lot of fluid must be used for cleaning, which adds very high costs to the job. Due to this reason, it is advisable to use the channel fracture technique to avoid premature screen out.

4. Nomenclature

Ti	Lower T sand of the Napo formation in the Shushufindi field
Ui	Lower U sand of the Napo formation in the Shushufindi field
Ts	Upper T sand of the Napo formation in the Shushufindi field
Us	Upper U sand of the Napo formation in the Shushufindi field
BT	Basal Tena sand of the Tena formation in the Shushufindi field
TSO	Tip Screen-Out fracture technique
HiWAY	Channel fracture technique
WO	Workover intervention operation
SSFD	Acronym used for the Shushufindi field
K	Permeability
Kf	Fracture permeability
Xf	Effective fracture length
W	Fracture width
CfD	Dimensionless conductivity
PBU	Pressure Build-Up test
Fcd	Fracture conductivity

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FracCADE: Fracturing design and evaluation software www.slb.com/stimulation

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