WELL TESTING OPERATIONS IN WINTERSHALL'S VACA MUERTA OPERATED FIELDS

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RESUMEN

Operaciones de Ensayo de Pozo en los Campos de Vaca Muerta Operados por Wintershall
En enero de 2014 Wintershall Energía S.A. adquirió la operación de la concesión Aguada Federal, ubicada en el centro de la cuenca neuquina con un área de 97 km^2, con el fin de realizar un plan multi etapa de estudio de prospectos en Vaca Muerta. Inicialmente dos pozos verticales fueron perforados, completados y ensayados, con el objetivo de adquirir un completo paquete de datos geológicos, de reservorio y producción, para identificar las zonas de mejor productividad. Seguidamente, se realizaron cuatro pozos horizontales, los cuales se encuentran actualmente en ensayo extendido de producción. El resultado obtenido en estas dos primeras etapas permitirá diseñar la posterior campaña de perforación para el desarrollo del bloque.
Dentro de este contexto, resulta fundamental contar con una apropiada estrategia del ensayo de producción para poder garantizar precisión en los modelos de reservorio. Para ello se ha diseñado un programa exhaustivo de adquisición de datos con la premisa fundamental de asegurar fluencia continua, evitando así un posible daño al sistema fractura-reservorio e interferencias en el análisis de datos.
Considerando la ausencia de instalaciones existentes, el corto tiempo de ensayo, el número limitado de pozos y el volumen de producción diaria, una planta temporal con un tamaño intermedio entre un set de ensayo de pozos tradicional y una planta fija de producción temprana, resultó el mejor enfoque para las instalaciones. El diseño de esta planta, denominada Planta de Ensayo Extendido de Pozos, o EWT por sus siglas en inglés, fue basado en la combinación de equipamiento tanto propio como rentado, con el fin de asegurar flexibilidad y minimizar la exposición de capital.
El concepto de procesamiento consiste en dos separadores trifásicos que descargan a un parque de piletas que provee tiempo de residencia para la separación de fases, medición y almacenamiento de líquidos. Dado que no existen ni ductos ni plantas de tratamiento cercanos, el gas se ventea en locación y los líquidos se conducen por camión a plantas de tratamiento o disposición final.
En línea con el desafío de mantener los pozos en fluencia continua, se han desarrollado e implementado distintas estrategias de control de las dificultades asociadas al proceso, como emulsiones estables, deposición de parafina y restricciones logísticas.
En resumen, este trabajo intenta describir como la planta EWT de Aguada Federal demostró ser más que una simple instalación temporal, permitiendo obtener datos de producción de alta calidad de los pozos, cumpliendo además todos los requerimientos logísticos y de HSE.

BACKGROUND

The Aguada Federal exploitation concession is located in the central Neuquén basin, Argentina. Wintershall is the operator with a 90% share, while our partner Gas y Petroleo del

Neuquén (GyP), has the remaining 10% share.

The block is 97 km². The target zone is the Vaca Muerta shale oil play at a depth range of 2,700 – 3,000 m. The concession is covered by a recent 3D seismic survey and in additionthree vertical wells have proven oil flow.

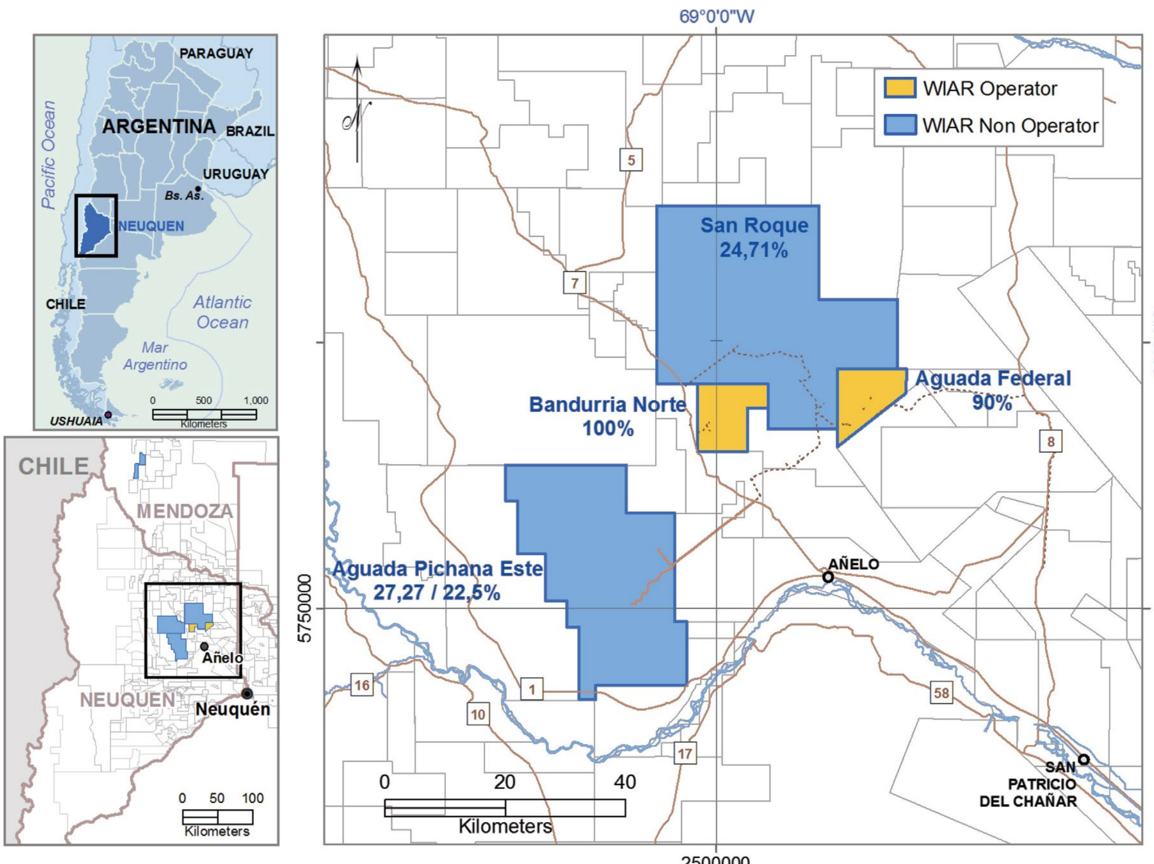

Figure 1. Aguada Federal block location

The development concept of the Vaca Muerta play is planned with a multi-stage approach, divided into four phases, as shown in the diagram of the Figure 2.

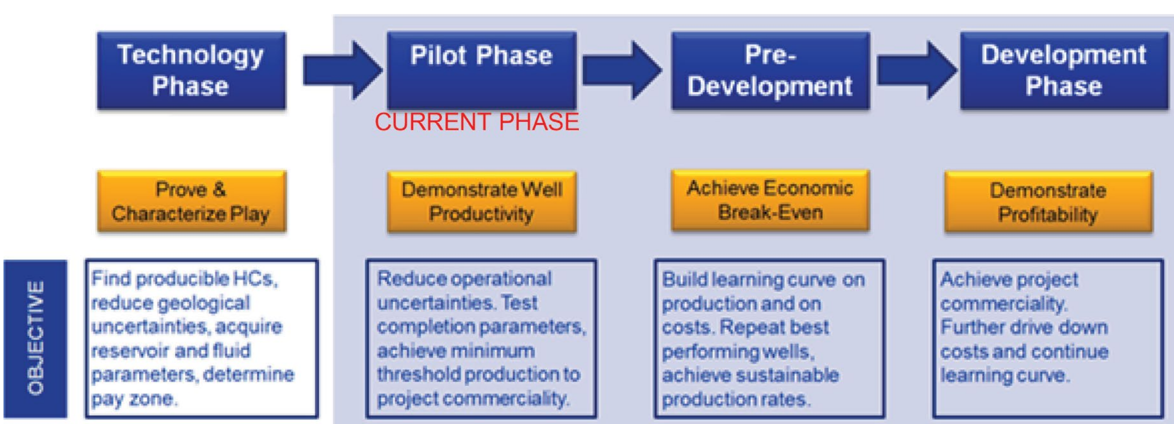

Figure 2. Project phases

Technology phase was successfully completed and consisted of drilling vertical wells with two main objectives. Firstly, acquiring an extensive set of geologic and reservoir-specific data to optimally design and place hydraulic fracture stages along the vertical profile and secondly, a long-term production test was performed in order to gain insight into the production characteristics.

The aim of the Pilot phase is to appraise the previously proven shale play by means of optimization of drilling, completion and production testing parameters and to understand their impact on production results. During this phase, four horizontal wells were drilled and completedon the PAD-1 location. Micro seismic surveys in association with tracers, PLT and fiber optics helped to determine optimal well and frac cluster spacing. All four wells are currently being tested through the Extended Well Testing plant.

Anotherfundamental factor for successfully development of anyshale play is to reduce operational costs by increasing efficiency, mainly driven bycost reductions in drilling and completion. Wintershall has therefore defined a Pre-Development phase to follow the Pilot phase to reach an economical break-even through cost optimization and production increase by quasi-factory style drilling and completion operations. Project economics will be continuously monitored and compared with the play-specific profitability benchmarks prior to the decision to launch a profitable full field development.

OBJECTIVE OF THE WELL TESTING FACILITIES

The main objective of the EWT plant is to measure and record production data needed to fulfill the requirements for the Pilot Phase as described above. One of the main drivers to achieve this is the importance of avoiding unnecessary well shut-ins during the well testing duration. Rate transient analyses performed using production data from the technology phase show that, in general, productivity index is lower when the well is put back in production after a shut-in, probably due to a negative impact of surface maneuvers on fracture conductivity. Thus, the EWT plant is designed and operated to ensure continuous and steady flow from the wells. Among others, the acquired data is used for the following purposes:

- Input for reservoir calculations and models to predict production behavior
- Define the best choke management strategy
- Feedback on well stimulation strategy
- Artificial lift system selection and design
- Perform production balances and reporting to authorities
- Fluid treatment and delivery/disposal

Well Testing data measurement, logging and reporting

The following data needs to be measured and recorded throughout the well testing period:

a. Well Testing data

Group	Parameter	Acronym	Unit	Measured by	Frequency
Pressure and temperature	Bottomhole Pressure	BHP	psi	Downhole sensor wired to surface	hourly
	Bottomhole Temperature	BHT	°C		
	Wellhead Pressure	WHP	psi	Wireless Transmitter	
	Wellhead Temperature	WHT	°C		
	Line Pressure	LP	psi		
	Line Temperature	LT	°C		
Flowrates	Gas rate	Qg	m3/d	Orifice plate flowmeter	hourly
	Oil rate	Qo	m3/d	Flowmeters / Tank level	
	Water rate	Qw	m3/d		
Oil Quality	Salinity		ppm	AgNO3 Titration	daily
	Density		g/cm3 / °API	Densimeter	
	Basic sediment and water	BS&W	%	Centrifugation	
Water Quality	Salinity		ppm	AgNO3 Titration	daily
	Density		g/cm3	Densimeter	
	pH			pH meter	
Gas Quality	Specific Gravity	SG		SGM	daily

Table 1. Well testing parameters summary

Bottomhole pressure and temperature are measured by a sensor inserted in a mandrel above the production packer in each well. The sensor is wired to an acquisition unit installed at the wellhead. From there, the data is transmitted to the data acquisition system. Surface pressure and temperature parameters are measured by standard wireless transmitters.

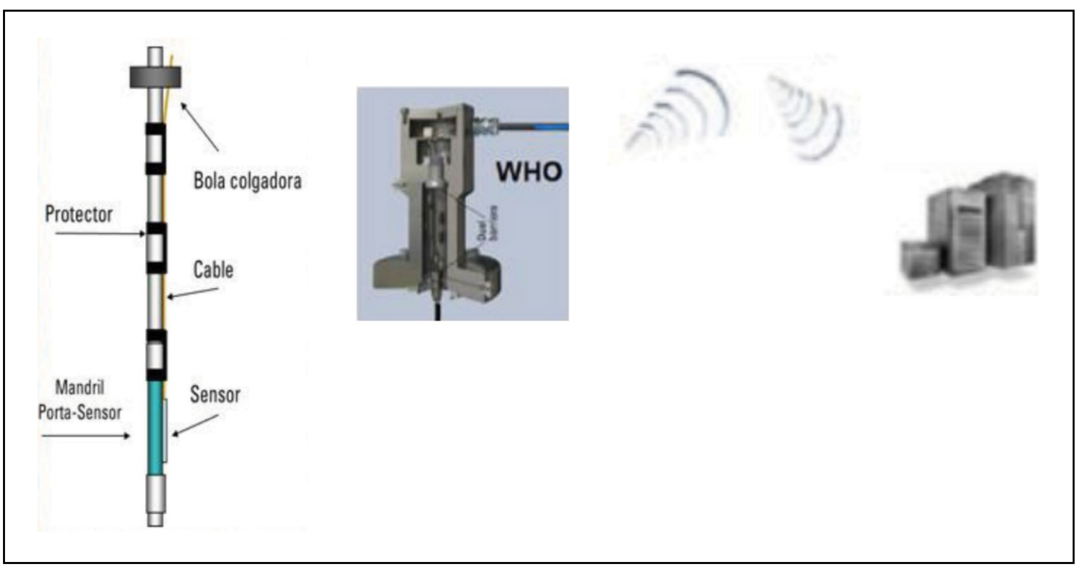

Figure 3. Bottom-hole data acquisition scheme

Gas flowrate is measured by an orifice plate gas meter. Direct liquid rate values from the separators' oil and water flowmeters are not reliable due to presence of an emulsion, so flowrates are compared to tank level measurements.These parameters can then be plotted to monitor well behavior and, if necessary, to take actions to optimize production and maintain well stability. This would generate the best possible datasets for the subsurface studies.

Fluid quality parameters are determined onsite in the well testing lab and can be used to monitor and adjust the fluid treatment process.

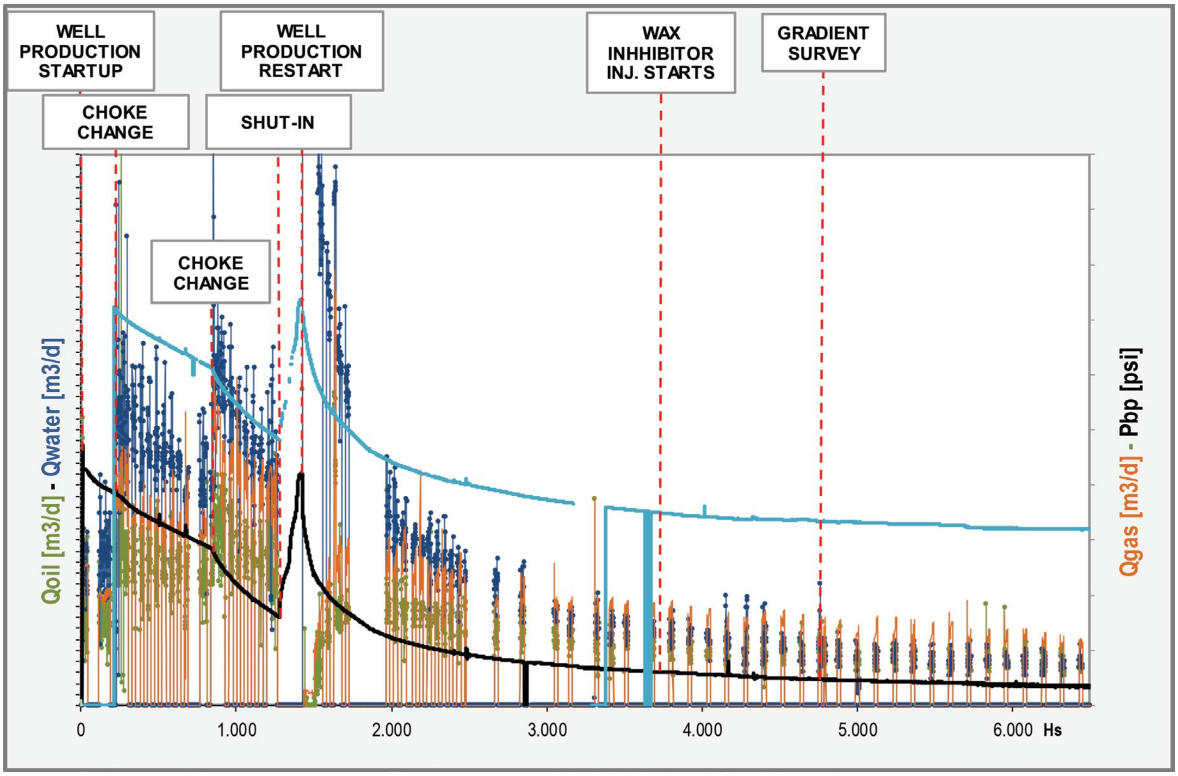

Figure 4. Well testing plot

b. External lab analyses

More comprehensive fluid analyses for each well are performed monthly by an external lab.

Group	Parameter	Measured by	Frequency
Lab Analysis	Water physiochemical analysis (complete)	External Lab - sampling onsite	monthly
	Oil physiochemical analysis and distilation curve		
	Oil cromatography		
	Gas cromatography		
	Frac Tracers		fix schedule

Table 2. Lab analyses summary

During hydraulic stimulation tracers are injected along with the fluid. Oil and water samples are regularly taken to study each frac's contribution to the overall well production and any interference among adjacent wells.

Reservoir Engineering Analyses

The above described production data set gathered by the EWT plant is used as an input for various RE workflows. The data needs to be as precise and reliable as possible in order to produce quality studies and models from these workflows. Thus, flow assurance is mandatory. Optimizing the interwell spacing in both a horizontal and vertical sense is critical to determining an ideal multi-well program. Maintaining quality, consistent production in the pilot program is essential to achieve these results.

Fluids logistic requirements and constraints

Aguada Federal has no legacyinfrastructure from conventional oil and gas exploitation. No nearby treatment plant is available for oil and gas delivery, turning fluid logistics into a majorchallenge for the WT strategy.

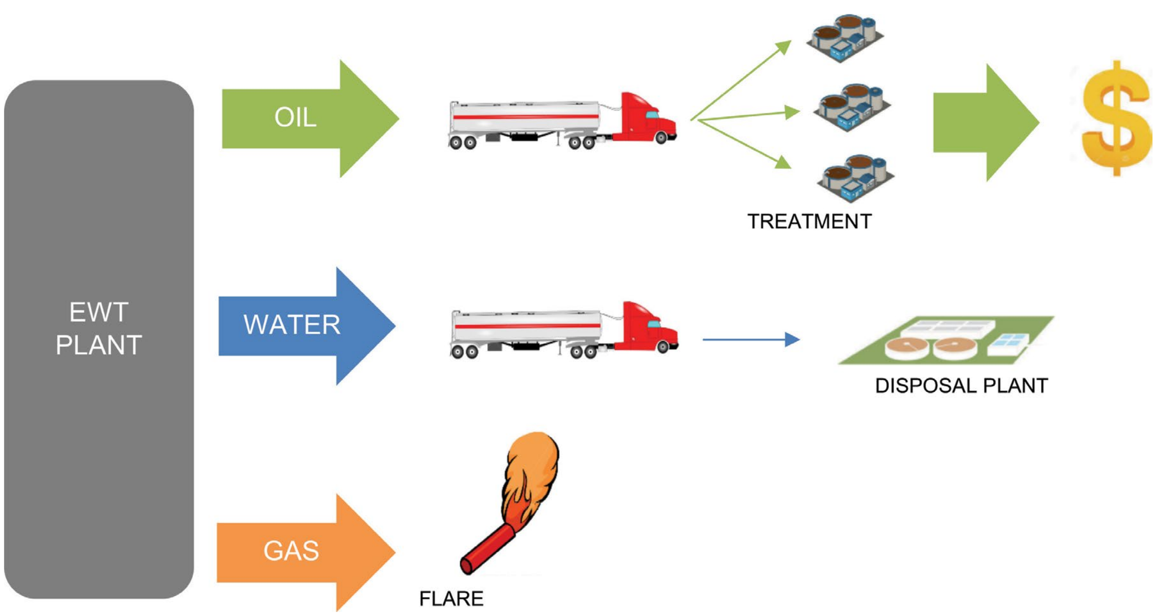

Figure 5. Fluids logistics

Oil and water are loaded into 30 cubic meter tankers atthe truck loading station.

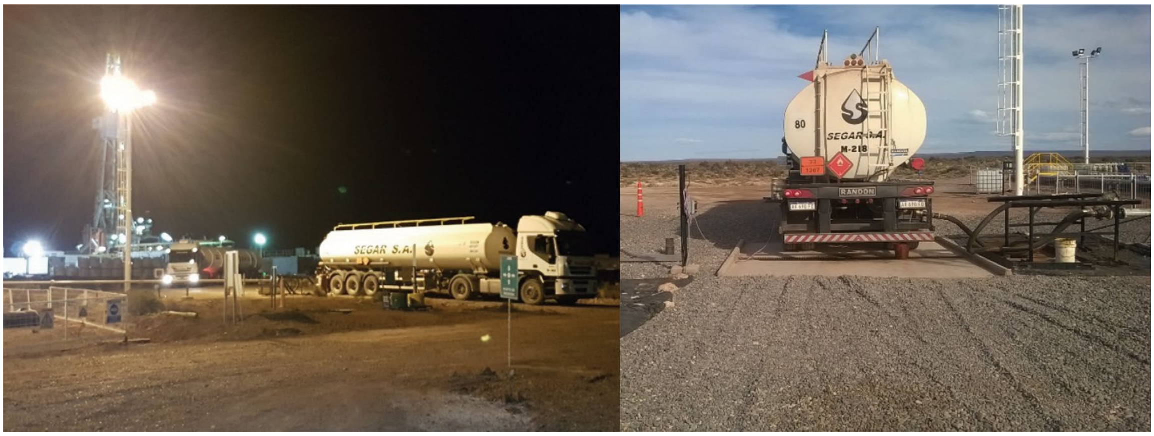

Figure 6. Truck loading station

The main issues regarding this kind of logistic,vary from potential road blocks due to strikes, adverse weather conditionsand to temporary unavailability of treatment plant capacity. Therefore, additional storage capacity had to be installedto keep wellscontinually flowing under stable conditions.

Oil is sent to different third-party plants for treatment and commercialization. This multi-plant strategy has the following advantages:

- Ensures reception availability
- Allows flexibility in terms of oil specifications
- Optimization of logistics

The main challenges associated with this strategy are:

- Different oil specificationsforeach plant.
- Different time windows to receive oil
- Long distances between plants, making it difficult to reschedule trips to an alternative plant if the truck is already in transit.

Dedicated personnel oversee fluid logistics to ensure continuous oil delivery and avoid well testing shut-down.

Since a disposal well is not available for this phase, water isdelivered to authorized treatment and disposal plants.

EXTENDED WELL TESTING PLANT

Process and equipment description

The production philosophy considers the use of two separators to handle the production of the wells; one for single well testing and the secondfor general production. Well production is switched at a field manifold.

The EWT plantisdivided intofive sections (see Fig. 7):

i. Wellheads

ii. Field Manifold

iii. Production and testing area

iv. Truck loading area

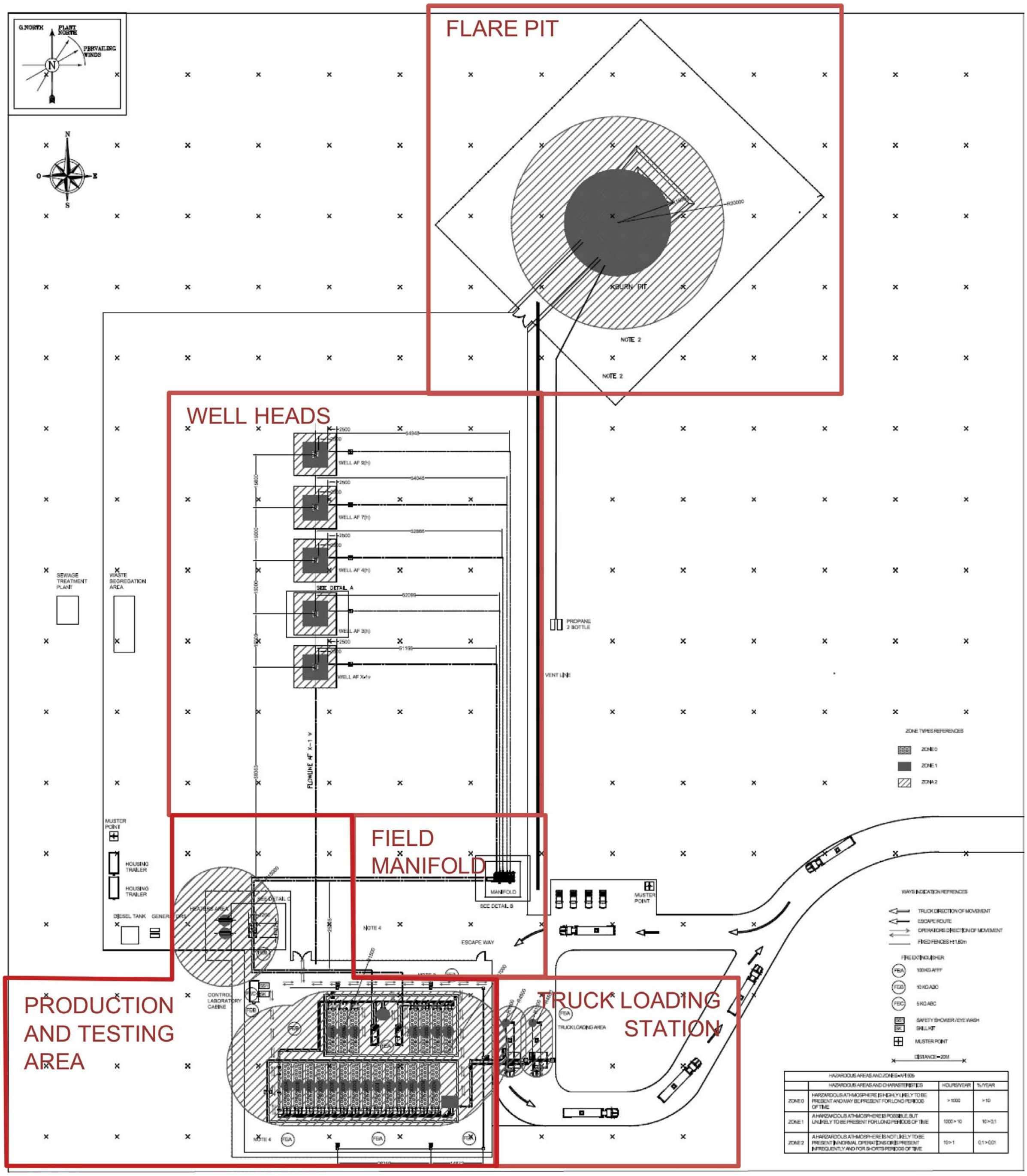

Figure 7. Location layout

Wellheads

To avoid well shut-in during choke changes or regular inspections, the Xmas-Tree configuration (see Fig. 8) consists of two production branches, themain and secondarybranch.

The well normally flows through the main branch, which has a surface safety valve (SSV) installed to prevent overpressure in the low-pressure rating flowline, downstream of the choke.It isflowed through the secondary branch only during maintenance or choke inspections of the main branch. Wellhead pressure and temperature transmitters are installed in the Xmas tree.

Downstream of the Xmas Tree both branches converge in the low-pressure data header, where line pressure and temperature are measured and transmitted. Sampling and chemical injection points are also available. A single flowline connects the data header to the field manifold.

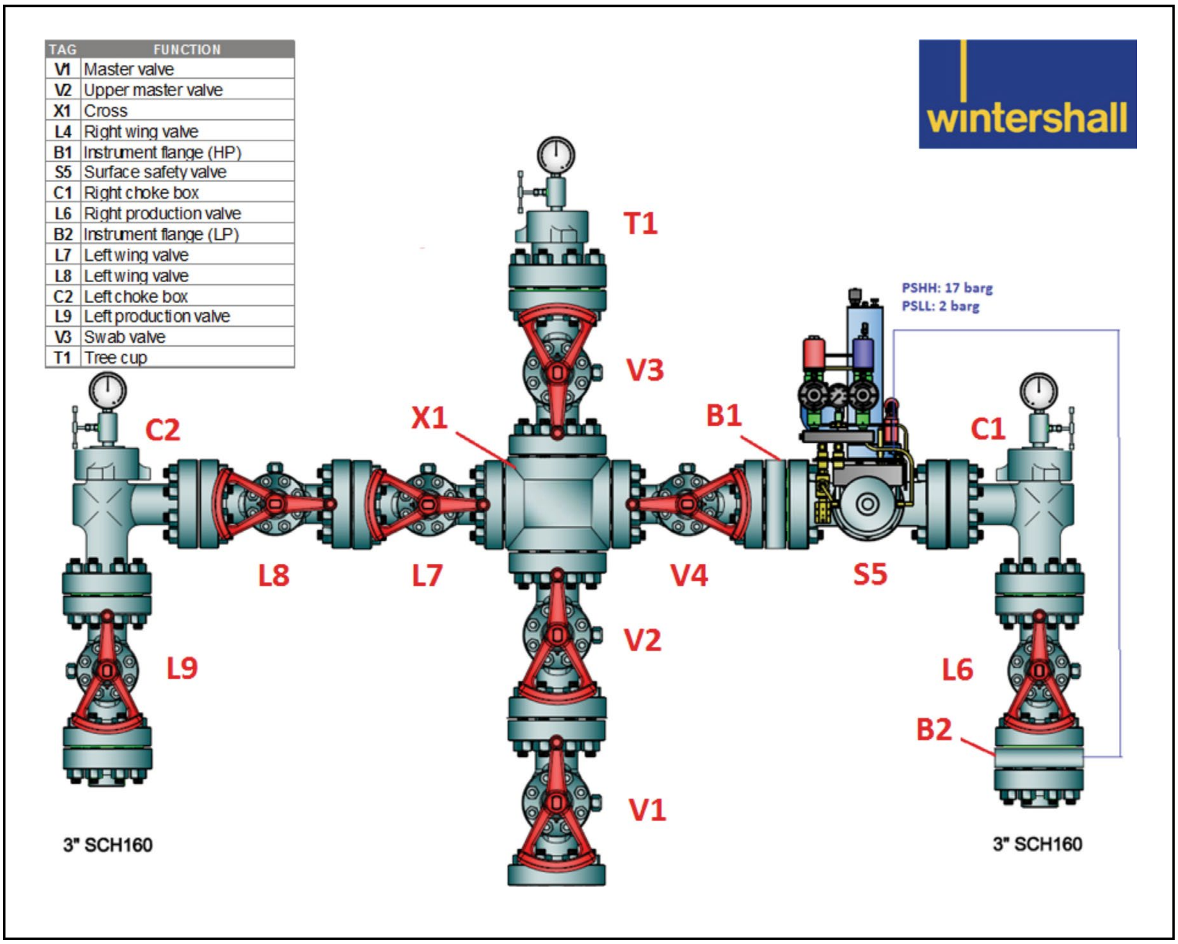

Figure 8. Xmas Tree configuration

Field Manifold

Each well is connected to thefield manifold through a dedicated flowline. By means of operating manual gate valves, each well's gross production can be derivedfrom either production or testing. Demulsifier is injected in both, production and testing outlets, to enhance phase separation efficiency.

Production and testing area

General gross production flows from the field manifold through the production heater and then to a three-phase separator. In line with the flow assurance driver, the oil and water streams flow separately to the storage tanks, which provide 48-hours storage capacity and time to allow further phase separation to meet oil treatment plants input restrictions in terms of salinity and water content. Water and oil are then pumped from the tanks to tanker trucks to deliver them to the different treatment plants.

Gross production from the well that is selected to be tested flows from the field manifold through the testing heaterand then to another three-phase separator. The oil and water streams are directed separately to the testing tanks. Tank levels are measured hourly to calculate oil and water production. Once the test has been completed, oil and water are pumped separately to the storage tanks through the two pneumatic transfer pumps.

The data acquisition system is installed in the control cabin and retrieves the wireless signals from all the sensors installed in the process. The data is logged and plotted for operation surveillance.

Figure 9. Data header (top left), field manifold (top right), heaters (bottom left) and separator (bottom right).

Onsite Lab performs the oil, water and gas quality analyses described above.

Truck loading area

This area has two loading stations to provide simultaneous loading of two tankers to comply with logistic requirements. Three pneumatic load pumpsare used –two for the simultaneous loading process and the third as a back-up. The inlet and outlet pump manifolds allow water and oil to be pumped to any of the two loading stations or the process inlet through a reprocessing pipeline. Oil and water are pumped through separate pipelines to avoid cross-contamination that may lead to a bottleneck in flow assurance due to truck rejections.

Gas samples are taken monthly from the gas outlet of both separators to analyze its properties and composition. This information is sent to the local authorities.

Figure 10. Loading station (top left), loading pumps (top right), data acquisition room (bottom left) and storage tanks (bottom right).

Process safety philosophy

Safety is a top priority in Wintershall operations. Thus, even for temporary installations, plant design meets rigorous standards. In this EWT plant two main safety devices are in place:

Emergency shut down system (ESD): Each well is equipped with a surface safety valve (SSV) placed on the main branch of the production tree (see Figs. 8 & 11). These valves are fail-close hydraulically actuated gate valves, driven by a controller that receives two different inputs to close the valve:

a- A sensing line connected to the flowline downstream the choke box that feeds high and low-pressure pilots to protect the well flowline in case of overpressure and avoid a leak in case of a pipe rupture.

b- Pushing one of the four ESD buttons available in strategic points of the EWT plant.

Restriction orifices (RO) are installed in each liquid outlet of both separators, aiming to limit the gas flowrate to the storage tanks in case of a gas break-through. Considering the gas inside the tanks is vented, a higher than expected rate vented could be hazardous. The RO diameter is designed considering the plant layout (ex-zones) and maximum separator working pressure.

Figure 11. Restriction orifice (top left), SSV (bottom left) and ESD switch (right).

EXTENDED WELL TESTING CHALLENGES

Critical operations

The operations strategy implies that the service company personnel needs to operate both own and Wintershall equipment. Therefore, critical task procedures were developed and operators were trained on them.

Choke inspection/change: In normal well testing services, a choke manifold is installed downstream of the well tree to control the production rate. As a result of technical and economic optimization, the well tree is used for the choke management. This means that, to ensure continuous flow while the choke in the main branch is being inspected or changed, the well will be flowing through the secondarybranch, which has no SSV. Therefore, the well will not be shut-in automatically in case of an overpressure or ESD activation. Thus, a detailed procedure is in place to ensure that there is always an operator monitoring the line pressure and ready to close the upper master valve in case there is a requirement to shut-in the well.

Truck loading and fluids transportation: While oil and water is generallytransported through pipelines for developed fields, during the pilot phase the construction of these pipelines is cost prohibitive. Thus, liquid fluids are loaded and delivered to treatment plants in tankers. This implies a series of safety risks that need to be mitigated, such as truck drivers falling from the top of the tanker, fire caused by static charge on the truck, spills, etc. Mitigation measures include, but are not limited to: loading procedures and tanker check-lists, harness and life line to access the top of the tanker, a grounding system with a faulty connection indicator and regular inspections and audits to operations and the transportation service company.

Tank level measurement: Although this is a common task in well testing operations, the number of tanks in this plant is considerably greater. To optimize time and avoid tripping hazards, a system of runways and railings (see Fig. 12) has been designed to connect the roof of all tanks, so operators can measure levels of them without having to go up and down the stairs for each tank.

Figure 12. Tanks runways and railings

Daily production data vs Testing data

As it was stated at the beginning of the document, the main objective of the EWT plant is to gather a single well testing data package to be used in the studies mentioned above. However, as in every oil field, production allocation and balance needs to be performed to compute daily production and match it with deliveries and sales. This implies a set of measurements and calculations that in developed fields are carried out by dedicated software and personnel, but are not usual for well testing operators.

Therefore, a special software tool was developed to help operators and supervisors perform, store and report daily production, well production allocation and monthly balances.

Oil-Water Emulsion

During the well testing of the Technology Phase, one of the most challenging difficulties encountered was due to the oil-water emulsion, generated by the pressure drop at the choke. This emulsion was surprisingly stable due to fluids composition, presence of solid wax and interference of wax dispersants and inhibitors. There are two main difficulties derived from the presence of emulsion that may compromise oil deliverability and thus flow assurance:

a. Higher water content in oil, generating a lack of precision in measuring oil and water flowrates, even if they are inferred by tank level variations in time, as the emulsion forms a layer at the oil/water interface, making it difficult to determine the interface level.

b. Production water salinity is around 130.000 ppm, so if oil is delivered with a 1% water

Figure 13. Technology phase salinity and BS&W evolution

content, its salinity will be 1300 ppm, much higher than the maximum acceptablelimit of 100 ppm to be on spec.

Although the EWT plant is much simpler than a crude oil treatment plant, an emulsion control strategy had to be developed, which consisted of three different methods:

Emulsion breaker injection

During the technology phase several products were tested, at different concentrations, and at different injection points along the process. BS&W and oil salinity were measured at different points of the process and then plotted (see Fig. 13) to monitor breakers efficiency.

These are the most relevant results identified during the test:

- Both higher and lower than optimal product concentration leads to higher water content in oil. Therefore, a narrow control over dosing rate needs to be assured.
- In the separator, mostly free water is eliminated from the stream. Thus, the emulsion break process in the oil phase occurs mainly in the storage tanks due to a much higher residence time.
- Some products showed a retarded effect, generating a higher BS&W in the separator, but then reducing it dramatically in the stock tanks after some residence time.
- Field tests showed quite different results from lab tests, due to the inability to reproduce the process conditions in the lab.
- Product 2 from supplier B showed to be the most efficient and was selected for the pilot phase. However, average salinity values averaged 1000 ppm, still quite high for some delivery points.

Heaters

Emulsion breaker efficiency is strongly dependent on fluid temperature, which means that during the cold seasons emulsion can become a severe issue. Thus, a heater was installed in each circuit to warm the fluids coming from the wells.

Due to some logistics delays, heaters were started up when the cold season had already started, so the effect could be easily detected, as it is shown in Fig. 14.

Main conclusions:

- Heaters managed to increase the fluid temperature over 10°C, enhancing the separation efficiency.

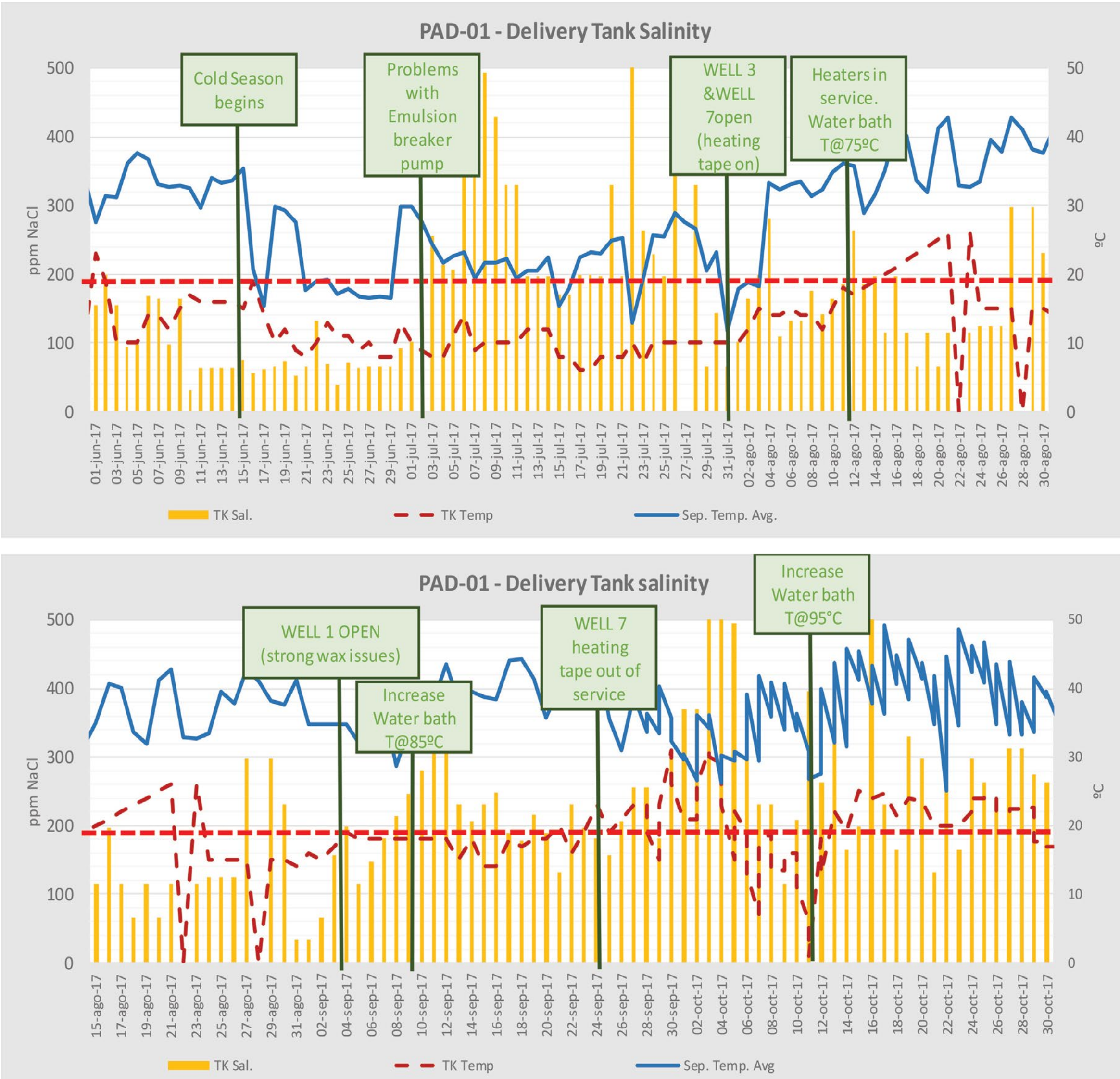

Figure 14. Pilot phase salinity and BS&W evolution

- Heating tape installed in two wells for wax control also helped to heat the fluid.
- Most of the time, salinity remained between 200 and 300 ppm during cold seasons and below 200 ppm during warm seasons.
- Presence of solid wax from Well 1 generated an immediate increase in BS&W and salinity.
- Process issues that generated an emulsion content increase could be somehow compensated by increasing heaters water bath.

Residence time

The effect of variations in residence time of the oil to be delivered is shown in Fig. 15. On

November 29th six tanks were removed from the facilities since they were no longer needed due to a decrease in production. In order to keep as much storage capacity as possible in case fluids delivery had to be interrupted, WT operators tried to keep the levels of the remaining tanks as low as possible. This resulted in a significant loss of residence time for the oil, which resulted in a salinity increase in oil deliveries. Once detected, a minimum of 24 hours residence time was set to allow emulsion to break inside tanks, managing to keep salinity below 200 ppm.

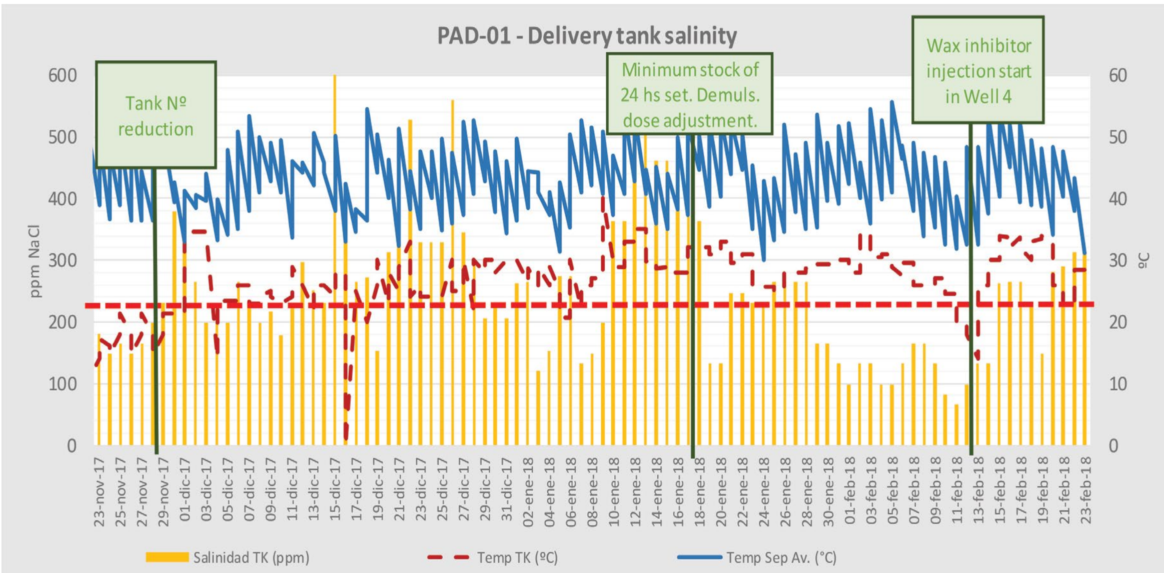

Figure 15. Effect of residence time

Solid wax precipitation

This is one of the most common issues in Vaca Muerta shale oil fields, and Aguada Federal is not the exception.Since the wax appearance temperature is around 32°C, wax became an issue when production declined and WHT decreased below the WAT. This would lead first to choke obstruction and finally to tubing blockage and the need for mechanical cleaning. As this challenge was already faced during the technology phase, some mitigation techniques and systems were considered for the pilot phase, such as downhole chemical injection, tubing heating tapes and insulating packer fluid. The detailed description, evaluation and results comparison of these methods is beyond the scope of this document and will be presented in a separate work.

RESULTS

After a year of continuous operations, Aguada Federal EWT plant is proving capable of meeting the expectations to achieve the objectives stated at the beginning of this document. A complete and high quality dataset is being delivered to stakeholders, mainly due to the capability of meeting flow assurance requirements.

During 2017 and after 9 months of operations, the total well shut-in time was 300 hours, representing 1,28 % of the total available flowing time. Themain causes identified are shown in Fig. 16.

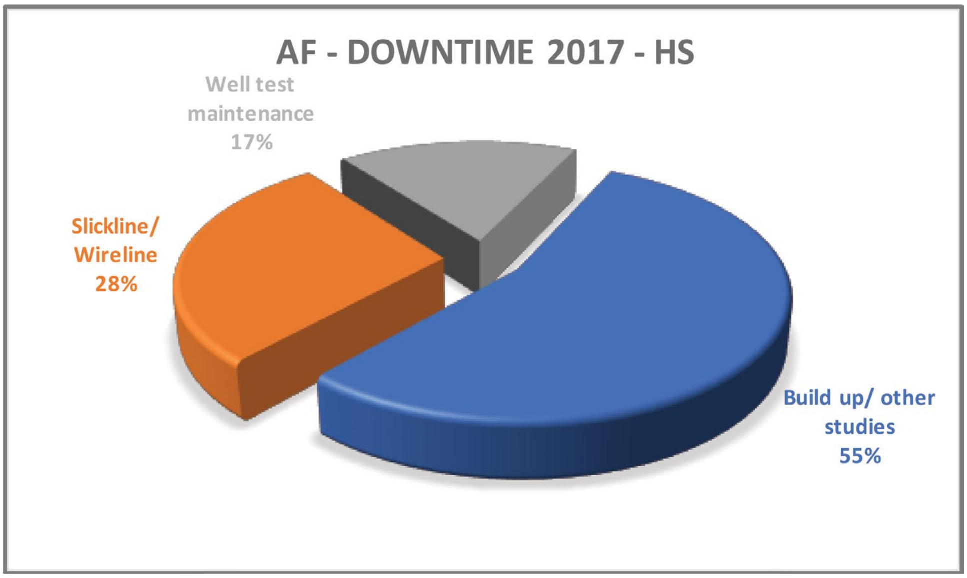

Figure 16. 2017 Downtime Causes distribution

As shown, more than half of the downtime was caused by external factors, such as anRE requirementto close wells to avoid water break through while stimulating nearby wells. Slickline interventions involving well shut-in were dewaxing operations, mainly in a vertical well with very low flowrates. No downtime was caused by logistics restrictions or plant operation requirements.

It is important to highlight that there was no plant shut-down during 2017, so downtime is only referring to single well shut-in.

CONCLUSIONS

One of the main drivers set to design and operate the Aguada Federal Extended Well Testing plant is that once each well is open to production, any unnecessary shut-in can be avoided in order to keep SRV integrity and generate smooth declination curves to feed engineering models. This flow assurance had to be achieved ensuring corporate HSE standards and minimizing costs. This implied several challenges both in the design and operation phases.

EWT plant design emulated a field battery with two separators, in which a single well can be tested while the other wells are kept flowing through a separate circuit, with enough storage capacity to cope with fluid deliverability restrictions. Choke management and inspection could also be performed without the need to shut-in the wells. Fluid logistics strategy proved to be 100% effective, since no downtime was attributed to deliverability restrictions.

Oil-water emulsion presented a continuous challenge during the whole testing period, increasing oil water and salinity content. This was successfully mitigated with both engineering design solutions, such as heaters, chemical injection and residence time, and operational procedures to optimize this emulsion control resources.

NOMENCLATURE

BHP: Bottomhole Pressure.
BHT: Bottomhole Temperature.
BS&W: Basic Sediment and Water.
ESD: Emergency Shut-down System.
EWT: Extended Well Testing.
GyP: Gas y Petróleo del Neuquén.
HSE: Health, Safety and Environment.
LP: Line Pressure.
LT: Line Temperature.
PLT: Production Logging Tool.
Qg: Gas Flowrate.
Qo: Oil Flowrate.
Qw: Water Flowrate.
RE: Reservoir Engineering.
RO: Restriction Orifices.
SG: Specific Gravity.
SRV: Stimulated Reservoir Volume.
SSV: Surface Safety Valve.
WHP: Wellhead Pressure.
WHT: Wellhead Temperature.

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