Please fill in the name of the event you are preparing this manuscript for.	**2020 SPE/IADC Middle East Drilling Technology Conference and Exhibition**
Please fill in your 6-digit SPE manuscript number.	**SPE-202076-MS**
Please fill in your manuscript title.	**LEAN Rig-less And Explosiveness Abandoning In Morocco**

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Abstract

A 5-well rig-less & explosiveness abandonment campaign by 2 project partners operator and service provider was made a reality in Morocco whereby a novel method of cementing squeeze of perforations and an annular fill-up were established in one single operation.

This is called LEAN abandonment and the method was masterminded as a result of intense collaboration between both partners. The method is scale-able and has full merit to target existing legacy wells for abandonment in Morocco and world-wide where appropriate.

In this LEAN approach the tubing and annulus were communicating via SSD / non-explosive created tubing punch by holding backpressure on the annulus till perforations squeezed or pressure lock-up and subsequently immediately opening the annulus and releasing the annular pressure whilst continuing pumping and filling the annulus with some 800 m of cement creating the firm additional barrier.

Clinical planning by operator and service provider on a establishing a new abandonment process that is opening-up further in-country and beyond opportunities was the critical success factors in this work. It led to organic improvement on a well by well basis in the campaign, it resulted in safe and successful operations and achieving abandonment objectives cementing to surface in tubing and annulus.

LEAN Abandonment forms a paradigm shift. It may be different in different down-hole settings and there is no single solution however like in our case working a bottoms-up approach has resulted the lowest cost solution and having done so ways to improve overall safety and efficiency were identified. The use of non-explosive technology is a very good example.

1. Introduction

The operator is a MENA-focused, international oil and gas exploration, production, and development company with an significant number of inherited non-producing gas wells that were beyond their economic life.

The operator has high-margin producing assets in Morocco with long term, fixed-price gas contracts and their philosophy is focused on safely and cost effectively producing and developing their current resource base, as well as discovering new resource. The operator wanted to apply the same methodology to the wells to be abandoned in the country Gharb basin in line with their social responsibilities to the country and their shareholders and its implications for long term success. Since abandonment has proven to be a costly process, in particular with a drilling rig involved, the operator had contacted the service provider to implement a rig-less methodology for well abandonment.

Service provider conducts well testing and slick-line operations in Morocco and had previously implemented a 6 well rig-less abandonment campaign with Coiled Tubing of wells for a major operator in country Jordan. The Jordan campaign was with Coiled Tubing and this new application was completely rig-less and Coiled Tubing-less.

The justification for developing a brand-new concept furthering the efficiency and reducing the safety exposure of the abandonment process was strong for both companies and this formed the mutual driver for the abandonment journey that led to the development of the first Morocco LEAN abandonment campaign, outperforming all other campaigns in the area in time and cost.

2. Statement of abandonment scope

The objective of the 5 well abandonment campaign of gas wells was to demonstrate driving down the costs of abandonment whilst creating a set of best operational abandonment practices resulting in safe operations and sustainable abandonment integrity. The wells to be abandoned are in 2 categories i.e. wells with dual packer and wells with single packer:

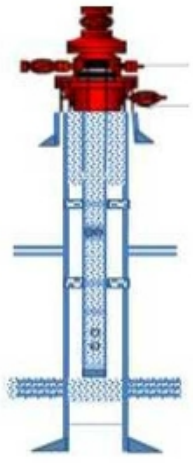


Fig 1: Wells with dual packer (CDG-10, ONZ-6, ADD-01)

Fig 2 : Wells with single packer (ONZ-4 , DRJ-06)

The target was to squeeze cement into the perforations of different formations, performing tubing punch above the upper packer for the case of wells with Dual Packer (3 wells) and open SSD valve for wells

with Single Packer (2 wells), circulating cement between in the tubing / casing annulus till cement at surface thereby completing the full abandonment operation with a solid cement column of at least 800 meters in both the tubing and 2 7/8" x 7" annular side.

3. Description and application of processes and equipment

This section will contain the workflow of the full project life cycle that took place between November 2018 and July 2019. The objective was to perform the campaign rig-less and explosive-less and the key enablers for this will be highlighted in his section.

Integrated project management approach

For this specific abandonment work-scope an integrated project management approach was chosen. The objective was to provide a total abandonment solution including the abandonment engineering, equipment and execution and handing-over a tested methodology that is sustainable for future operator and Moroccan abandonment operations. In this case the wealth of the experience of the operator staff was capitalized on for project optimization, risk validation and for execution support. The integrated project approach had the following key steps and activities:

1. **Project Initiation Statement** provided the relevant information related to the abandonment objectives, the scope (as provided in section 2 above), the key stakeholders and the proposed accountabilities and responsibilities of all participants. The service provider Project Manager sought alignment on all of these from operator and service provider senior management and a working visit from service provider to Morocco was performed in November 2018.

2. **Project Scoping Exercise & Project Award**. The former was performed with all stakeholders in the operator Morocco Head Quarters in Rabat. Service Provider abandonment experience and novel solutions were presented against the background of operator aspiration to change the landscape for abandonment. All participants felt the service provider experience could be transposed to a Moroccan environment with further optimization i.e. fully rig-less and coil-less. The operator goals for abandonment HSE, abandonment integrity, expected (minimum) job time, improvements and cost were clearly specified directed by operator Morocco leadership and were set as condition for participating in the tender. Service provider responded with proposal in Q4, 2018 for low cost abandonment being fully de-risked for operator. Following tender award this was signed-off with responsibilities and provisions of both companies clearly stipulated (Appendix 1). The main reason that a fixed lumpsum contract was selected above an incentive contract was because of the desire of both companies to set a transparent benchmark for abandonment work in Morocco.

3. **Integrated Project Management Plan** covered all the activities for both parties ; operator and service provider of the following management loop:

    a. **Contract Award & Project Initiation**: The project got live after the acceptance and sign-off

by operator of the contractual arrangements in December 2018.

b. **Planning**: The abandonment strategy for each individual well was set based on the well type (one or two packers) and the specific well conditions (Fig. 9). An Abandon the Well on paper was held with the staff involved in the future operations from operator and service provider in the offices in Rabat (April, 2019). A full risk assessment was compiled and all locations were visited by the Senior Stimulation Supervisor. Subsequently the detailed abandonment programs for all 5 wells were produced by operator Engineering Team, peer reviewed by both parties and approved as per individual companies' protocol in June 2019 prior to execution.

c. **Scheduling**: Crews, equipment and chemicals was scheduled from Abu Dhabi, Canada and several Middle Eastern Countries. In particular close liaison for visa and other immigration formalities for crews was required. Extensive training was given related to the special non-explosive cutting tool operations and techniques. The operator took on the full responsibility of arranging the in-country challenges in particular the permits and dealing with the local land-owners on which the well locations resided and the decommissioning of the protective cage. AlMansoori brought in the equipment from all external locations and close liaison with operator took place on this having the link with all local and governmental entities involved.

Fig. 3. All wells in Morocco are highly protected

d. **Executing** – The execution of the individual approved 5 wells abandonment programs took place in July, 2019 with a total campaign delivery time of 15 days and 10 days ahead of schedule. The project was managed on-site by an Stimulation Senior Supervisor reporting in to the service provider Integrated Abandonment Project Manager and to the operator Company Representative on site. The obtained key results and main lessons learnt are given in section 4.

e. **Monitor, control and project close**: An activity and time-based performance management system was adopted with daily reporting on progress and management of the risks. The aim was to perform each abandonment more efficient and therefore better than the last one. The side-note to make is that not all wells were like-for-like however there were many analogues. The target duration was 3 days maximum per well. An After-Action Review was held capturing all learnings (July, 2019) for future campaigns. A final follow-up visit

was performed towards year-end 2019, one year after the Project Initiation Meeting in order for service provider to seek client's reconfirmation about sustainable success in the abandonment project outcomes.

4. **Project Scope Change Management**. The campaign was executed almost flawlessly and those instances where the actual conditions - for example the injectivity into lower zone - deviated from the plan, the new way-forward was already described as part of the risk assessment and was fully absorbed in the plan. Therefore, there was no non-productive time "waiting on decision", the on-site team was fully empowered to make their "own" pre-approved decisions. Since this was a lumpsum project for a fixed scope there was an allowance made for non-explosive extra tubing punching runs to be conducted in emergency cases at a specified cost above the lumpsum.

Against the backdrop of the integrated project management approach a number of technical enablers are now described as they have valuable for the sharing of learnings to the wider SPE audience.

Abandonment design and barrier requirement

This campaign called for a full abandonment of the zones and the cementing up of the full annulus and the tubing with cement at surface for both.

Abandon the well on paper

The Abandon the Well on Paper outcome resulted in a validated risk assessment by all parties. The risks were inventorized and a mitigation plan was agreed mutually. Performing this upfront exercise helped the abandonment program preparation as the outcomes would be integrated in the abandonment program without further iteration between parties. The value created was that during the operations the executors knew exactly what to do in case of each risk materializing and therefore at any time felt fully empowered to move forward without delays. In particular in cementing operations, people need to feel confident that their decisions will be fully supported. In situations with a partly completed cement job any interruption in the process (e.g. due to waiting on higher level management decision) leads to risk that dictates major re-work resulting from the cement setting.

Risk Management (operational execution phase)

The key risks related to the operational phase were identified and crews were trained in the mitigation when encountered.

Fig. 4. Risk Management (based on all wells)

Equipment on site lay-out and set-up

The equipment set-up could be kept LEAN and involved the following key equipment packages:

- **Intervention**: Slick-line package with crane support and novel tubing hole punching capability
- **Pumping**: Batch mixer, cementing pump, tanks and accessories
- **Downstream:** Return fluid tanks and flare stack

The equipment lay-out on site is represented below:

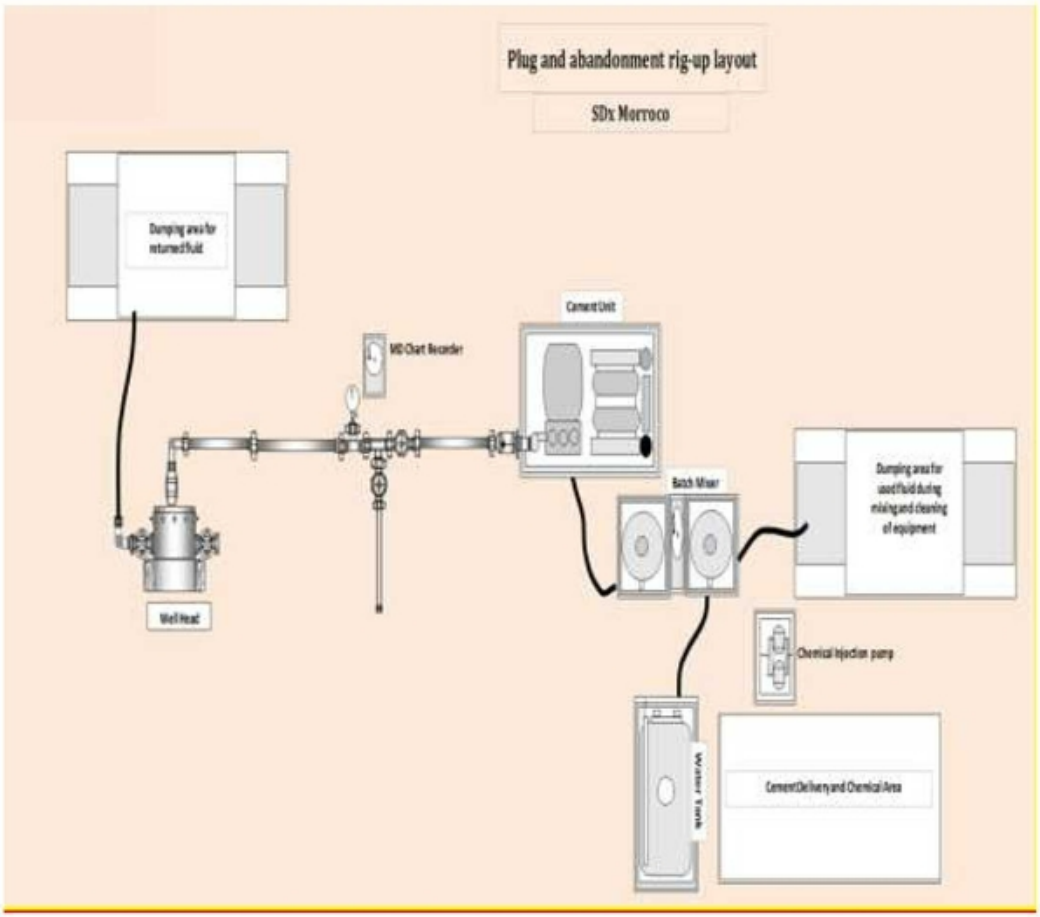


Fig 5. Equipment lay-out

The best impression of the wellhead set-up is provided by the photos taking during the execution below:

Fig 6. Wellhead set-up Intervention **Fig 7. Wellhead set-up circulating, cementing, flaring**

The surface equipment package comprised routine equipment and this set-up is easy to replicate.

Slickline Punching Equipment

Based on the many risks identified with the use of explosives related to a tubing punch in case no natural circulation could be achieved through the sliding side doors, service provider opted as a precaution to mobilize and run if needed the combination of a remote firing mechanism (RFM) with a perforating torch cutter (PCT). This is a non-explosive solution which can be deployed on slickline. It added as such a non-hazardous operation to the program. The PTC relies on perforating through a patented nozzle by means of a bespoke highly energized plasma caused by a mixture of various powdered metals.

Hence there was an active rig-less explosive-less solution for this abandonment scope. The benefits of the non-explosive solutions are: (1) eliminating the use of hazardous and explosive material, (2) to ease of logistics cross and inter regions, and finally (3) eliminating the need of permits usually associated with explosive licenses, and the different requirement needed by different regions.

The solution is well tested with a strong track global track record and an operating process that reduces the risk of failures. A photo of the PTC is provided in Appendix 2.

The RFM/PTC did not get deployed as a single run but was part of a fully integrated abandonment process. Therefore, it was possible to properly design the downhole torch head to achieve the desired environment which will cater for a hole size for future successful pumping operations.

Very detailed training which was provided by the Equipment Provider. This ensured that engineers were trained specifically focusing on operating the tool within the proper envelope. All jobs were successfully delivered.

The RFM proved a unique feature of the capability and instrumental for the successful job.

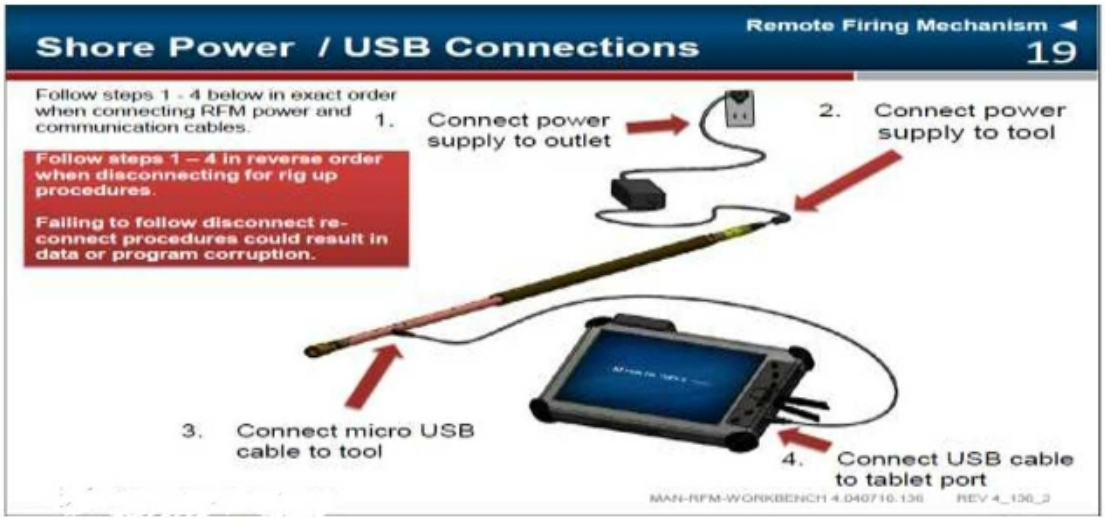


Fig. 8. Set-up of the Remote Firing Mechanism

Outline of operational execution

In order to get a good overview an example is given for a specific application in the campaign which is a well with 2 packers. The well has two perforated intervals, two packers and an SSD located between the two packers and there is no SSD above the top packer. Drawing is in Appendix 3.

In the wells many uncertainties existed related to achieving a successful abandonment as per required specifications like injectivity profile, ability to kill the well, ability to squeeze the minimum cement volume in the bottom zone and in the zone above, maintaining a column of cement in tubing and annulus a detailed procedure with all "what-if-scenario" was developed during the abandon the well on paper, flow-charted during the program preparation and extensive training and rehearsing with the operations team on site took place as the abandonment was meant to be a one stage process. The ideal cementing scenario of a one stage process for which the team has to set themselves up properly was as follows:

1. With annulus closed at well-head and the SSD between the two packers closed and a hole perforated above the upper packer a volume of 10 barrels of cement was squeezed in the bottom zone (the criteria was 10 bbl. squeezed or pressure lock-up).
2. The annulus, upon achieving (1) above, was opened and pumping of cement continued until cement returns at the wellhead.

From the below flowchart it can be seen that there were many possibilities. The bottom line was to have a firm basis in the well with a cemented-off perforation (or zero injectivity) and an annular space full with cement and same for tubing with cement evident in the wellhead. This can be achieved in either one or two steps. The other end of the risk spectrum was that a filled string with cement and no circulation in annulus must be avoided in circumstance.

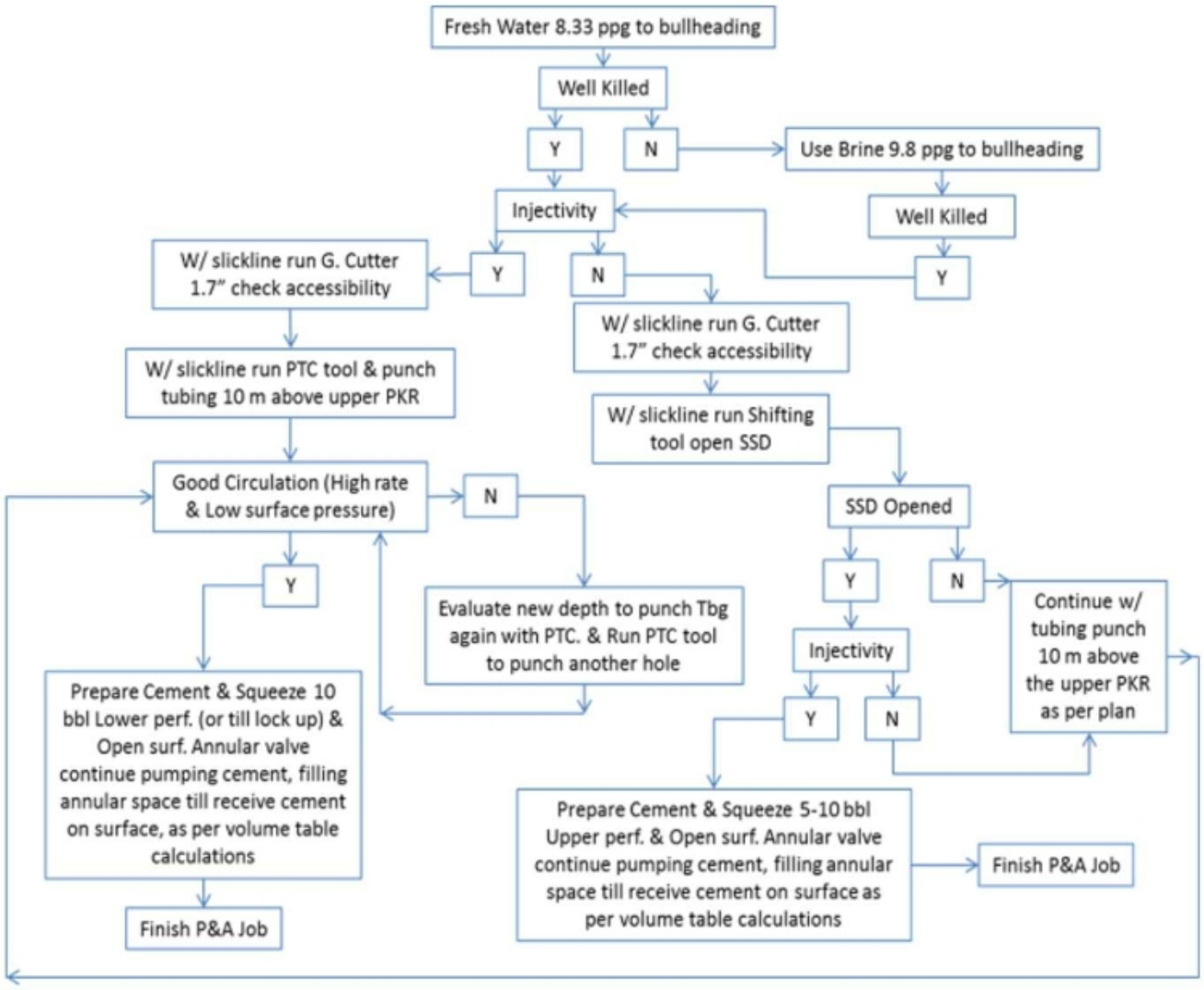


Fig 9: Decision making flowchart for the cementing process logic

4. Results and lessons learnt

Well conditions

#	Requirement	ADD-1	ONZ-4	ONZ-6	CGD-10	DRJ-6
1	Sustainable Annulus Pressure (A/B/C annulus)	220 Psi / 0 / 0	0 Psi/ 0 / 0	0 Psi/ 0 / 0	0 Psi / 0 / 0	0 Psi / 0 / 0
2	Other known well head integrity problems (Y/N)	N	N	N	N	N
3	Injectivity in the zone to be abandoned (Y/N, if yes x bpm @ y psi)	NA Injectivity test to be done by contractor prior to pumping	NA Injectivity test to be done by contractor prior to pumping	NA Injectivity test to be done by contractor prior to pumping	5 bpm@ 1100 psi	NA Injectivity test to be done by contractor prior to pumping
4	Bottom hole pressure (psi)	~ 1352 Psi (Calculated from WHP using the gas gradient 0.12 psi/ft)	~1038 Psi same	~1327 Psi same	~1064 Psi same	~614 Psi same
5	Bottom hole temperature (deg C)	42.8 deg C @ 969m (Hoot top perf)	42°C @ 920 m	40.6 deg C @813m (Lower N'zala)	46.1 deg C @ 897m (Guebass)	52.8 deg C @ 1,044m (Main Guebass)
6	Fracture gradient (psi /ft)	NA	NA	NA	NA	NA
7	Fluid content tubing and gradient	Full with methane 0.12 psi/ft	Full with methane 0.12 psi/ft	full with reservoir water	Full with methane 0.12 psi/ft	Full with methane 0.12 psi/ft
8	Fluid content annulus and gradient	Water and inhibitor SG=1.15	Water and inhibitor SG=1.15	Water and inhibitor SG=1.15	Water and inhibitor SG=1.15	Water and inhibitor SG=1.15
9	SSD operable (y/n)	Y	Y	Y	Y	Y
10	Connection of X-Tree to rig-up w/line lubricator	2 7/8'' EUE Box 2-9/16" 5k x 6-1/2" Bowen Crossover	2 7/8'' EUE Box 2-9/16" 5k x 6-1/2" Bowen Crossover	2 7/8'' EUE Box 2-9/16" 5k x 6-1/2" Bowen Crossover	2 7/8'' EUE Box 2-9/16" 5k x 6-1/2" Bowen Crossover	2 7/8'' EUE Box 2-9/16" 5k x 6-1/2" Bowen Crossover
11	Any known fish / obstruction in the tubing (y/n)	N	N	N	N	N
12	Accessibility of the well site (Good / poor)	Good	Good	Poor in winter time (Muddy)	Good	Good

Fig 10: Well conditions prior to abandonment

Operational results

The field obtained results for the consecutive jobs are provided in the table. These jobs were executed on a back-to-back basis as one campaign led by the service provider stimulation supervisor, overseen and witnessed by company production manager and according to detailed work instructions. Each activity had a detailed tool-box talk, pre-job meeting and a risk assessment with what-if-scenario specified. In particular the sensitive of the success of the operational abandonment execution in light of the established injectivity was carefully addressed and discussed with all involved prior to each operation. All jobs were executed without safety incidents, road traffic incidents, oil spills and environmental impact incidents.

Key results observed are that wells had acceptable to good injectivity rates which is an instrumental contributor for successful cement squeezing, wells were successfully cemented both sides either in 2 stages but mostly in one stage both tubing and annulus. The overall improvement trend in job duration is notable as a function of time and position in the campaign.

Well Name	Type	Duration Job including R/U and R/D (days)	Mob / Demob (days)	Injectivity rate (bbl / min)	Cement Stages
CDG-10	2 Packers	5	2	>5	2
ONZ-06	2 Packers	3.5	1.5	1 - 2.5	1
ADD-01	2 Packers	2	1	1 - 4.5	1
ONZ-04	1 Packer	2	1	1 - 4.5	1
DRJ-06	1 Packer	2.5	1.5	N/A (FWG plug @R Nipple)	1

Fig 11 : Field results for the 5 wells that were abandoned

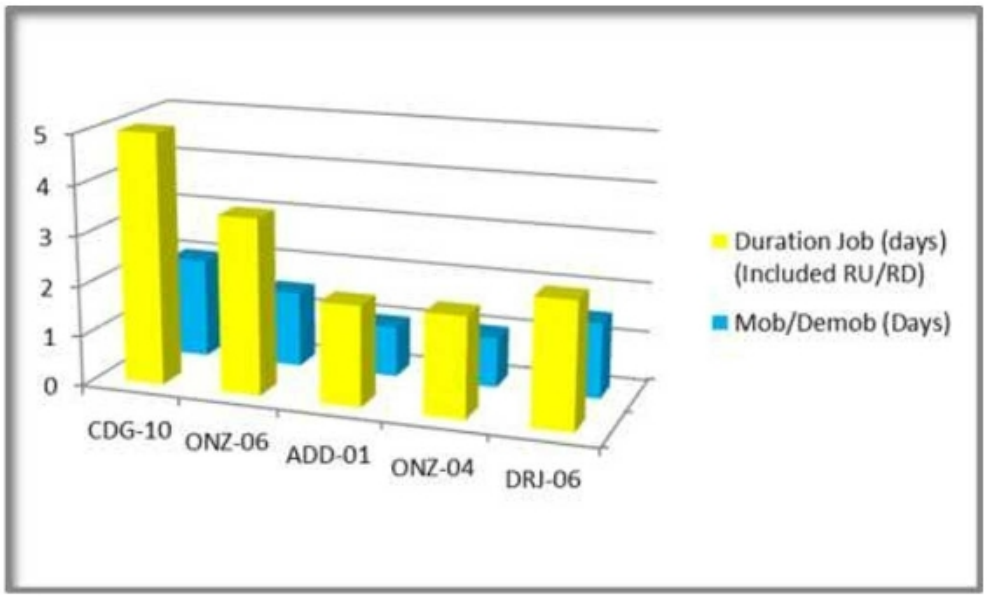


Fig. 12: Improvement potential demonstrated by working in a campaign

Fig 13, 14, 15 : Fully cemented tubing side as a result of hard work by the cementing team

The LEAN approach

In particular the results related to the envisaged the paradigm shifts were successful. In all the wells the full spectrum of abandonment operations was successfully supported by:

- Slick-line crane supported
- MRF/PTC, with slickline crews who became experts in its deployment and no misfires took place.
- A basic surface equipment set-up with a simple flare-set-up (no flow back package was needed as the wells were killed by successfully bull-heading as the first step).



Fig 16, 17, 18
Simple surface set-up, minimum flaring because bull-heading is the base case and the MRF/PTC experts demonstrated their skills in non-explosive cutting

Operational lessons learnt

1. All jobs were executed fully in-line with the safe standard operating procedures of the service providers and the operator. Communication was excellent between all parties in both field and office with key focus on personnel safety. Excellent HSE performance was achieved by having no incident at all.
2. All wells could be killed by bull-heading operations using fresh water only which was a big advantage.
3. Fresh water tankers on locations provided excellent support to the operations for quick and easy mobilization / demobilization and connections.
4. The MRF/PTC torch creating one single hole of around 1.2 square inch demonstrated that the surface pressure can be safely managed to perform the cementing job without compromising the success of the cementing job.
5. The use of a slick line unit is preferred over an E-line and coil-tubing for cost reasons.
6. A well by well improvement in operational activities was delivered till a 3-day total job duration was consolidated including the rigging-up and down.
7. In order to reduce the job time and avoid gas at surface (and flaring) the first attempt always was made to bullhead the gas back in the formation.
8. Facilities to burn and flare the gas were in place. This added 2 extra hours to the operations hence was avoided wherever possible.
9. The set-up of the flare stack and the pit was designed such that it was able to handle the return without the use of a full flow-back package.
10. A solid risk assessment with mitigation scenario proved very successful in an environment with a huge number or outcomes and empowering the operations teams to execute in line with these outcomes.

5. Conclusions

Rig less abandonment was successfully executed in this 5-well project. This approach is a good demonstrator for future abandonment projects of similar wells in Morocco. The operator as such has led a change procedure that is scalable and has both regional and global potential knowing the global abandonment liability is huge.

The LEAN approach whereby a crane, slick-line, batch-mixer and a high-pressure cement pump-truck was used instead of a rig, no completion was recovered, barrier requirements were fulfilled and explosiveness punching technology was used, led to the shortest well duration with the lowest costs. The campaign itself also showed an intrinsic improvement value on a well after well basis.

A paradigm shift was created by this new LEAN abandonment approach, developed by brainstorming, presenting and accepting the novel ideas as an in-depth collaborative effort from operator and service provider, and running them through a risk managed approach. It constitutes a shift from the conventional drilling environment to a well services environment which by nature is a lower cost environment with the required resources more readily available and to be mobilized faster.

6. Acknowledgements

The authors of this paper thank their respective company management for the opportunity given to operate in such an entrepreneurial way whereby a new way of working in abandonment could be successfully demonstrated.

7. Appendices

Appendix 1

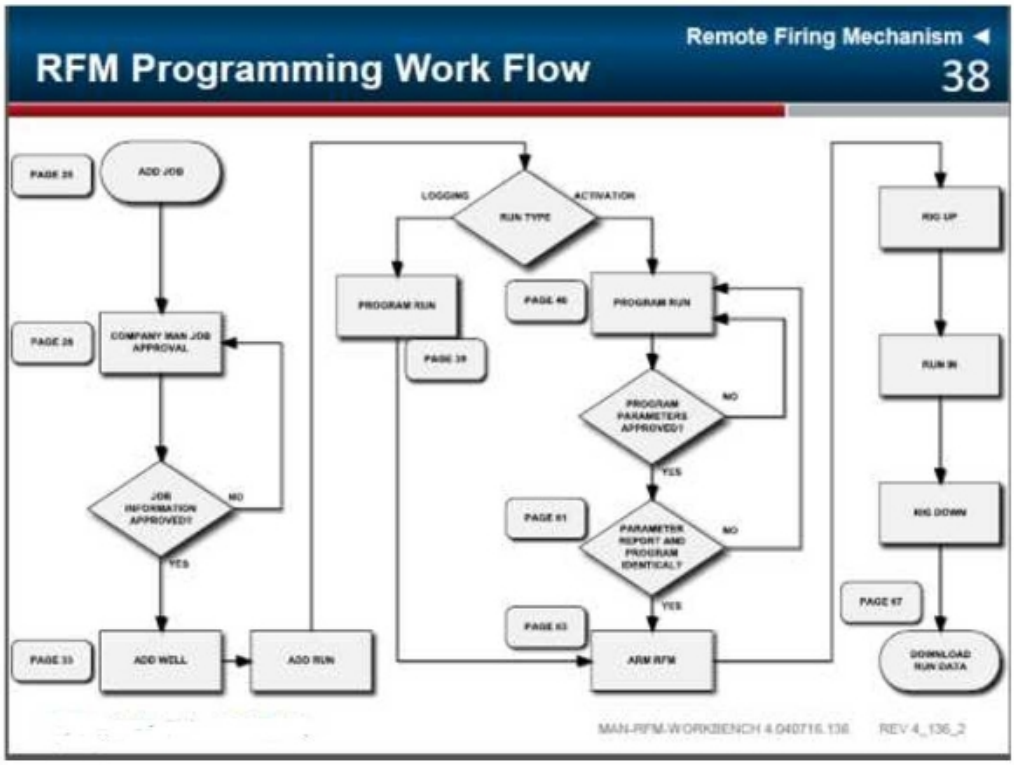
Item	Equipment Services Provided By Service Provider
1	Batch Mixer
2	Triplex Pump
3	Pipe Basket (include 150 ft pipes and cement houses)
4	Chemical Basket (cementing chemicals)
5	Cement Class G in bags with proper straps for cutting on top of the batch mixer
6	Water Tank for kill the well, mixing cement, cleaning equipment
7	(2) Acid Transfer Pump (double diaphragm 2")
8	Slickline Unit (already existing in Morocco)
9	PTC and SSD Shifting tools

Item	Equipment Services Provided By Operator
1	Fresh Water & Killing Fluid (in case f. water is not enough to kill the well)
2	Haulage Water Tanks for Killing Fluid if needed
3	Site Management and Security. Site Lights, Forklift and Diesel for all quipment.
4	Transportation for equipment and personnel (mob/ demob.)
5	Customs Clearance Fees and Customs Clearance Arrangement
6	Food and Accommodation for personnel
7	Fresh Water Supply for Mixing Cement and for cleaning the equipment
8	Tubing Handling, Well Control Assurance, (include flow back package & H2S in case if needed).
9	Final Decommissioning of the site including civil work to be provided
10	Killing and circulating package including flow back personnel if needed. (Green Burner, Choke Manifold + Separator + Return Holding Tank)
11	Wellhead Services including inspection, management, and cutting for final decommissioning after completing the Plug and Abandonment
12	Disposal and handling of the fluid/cement returned to surface. Civil Work for installing a return pit or return tank if needed

Appendix 2

Outline Specific for Run PTC (Perforating Torch Cutter- using memory type activation)

1. Before 1 3/8" PTC operation we need to run G. Cutter with size 1.7" to depth below the cutting depth with 100 FT to confirm passing of PTC.
2. Slick –line should determine the fluid level, depend on the hydrostatic pressure, if any Pressure below 4000psi use torch only, if any Pressure above 4000 PSI use torch and extension.
3. Hold TBT (Safety Meeting) to discuss job procedures.
4. Rig up Slickline lubricator and PCE and test same.
5. Run in hole with PTC, then take correlation pass, and then stop below the cutting depth with 100 Ft.
   - First run (Logging run to record the required data Pressure, Temperature, and Tool Movement)
     a. Check the tool at surface (Bench Test)
     b. Program the tool to read every second (pressure, temperature and tool movement)
     c. Connect the tool string as
        - Memory section
        - Battery section
        - Bull plug
     d. RIH with max speed (100 ft/min)
     e. Stop at depth 500 m and record stationary stop
     f. Continue RIH , record stationary stop above Shooting depth
     g. Record stationary stop at cutting depth and below it
     h. POOH and record first station again (to be sure well stability no pressure drop)
     i. Continue POOH and R/D the tool string
     j. Download the data
     k. Second run (Activation Run)
   a. Perform a bench test for activation
   b. Program the tool depending on the following data:
      - Pressure range
      - Temperature range
      - Tool movement range
      - Time to activate
      - Thermal generator firing cycle
      - All safe shut down time
   c. Connect the tool string PTC (Size 1 3/8 "- Part no. PTC-1375-200) as following:
      - Memory section
      - Battery section
      - Integrated ISO and thermal generator sub and thermal generator
      - Extension (if needed)
      - Torch (PTC)
      - PBA
      - PBE
6. RIH till Shooting depth (once achieved the programmed factors activate time will start and firing cycle for thermal generator)
7. Wait at firing depth till all safe shut down time is over
8. Start normal circulation to the well to confirm the string perforation.
9. If yes go to the next step (POOH and R/D), if not run in hole again with PTC system.



Appendix 3

CGD -10 Well Completion diagram