The oil industry has been for many years, growing and innovating technology over time. Economic cost is the main driver for changes that occur in our industry and the need to overcome a variety of challenges from reservoir to production to have a profitable well. Saudi Aramco as one of the largest operators worldwide have several fields that run completely on artificial lift, mainly ESPs, to produce. These ESPs are known to be prone to wear and tear, requiring replacement every few years. Conventionally through the use of a workover rig, these ESP and upper completion are replaced every so often. In recent years, the decline of the oil prices worldwide has cited the need to reduce capital & operational expenses to maximize the profitability in our economic analysis.

Saudi Aramco, as a lead oil & gas operator is paving the way in alternative deployments method of ESP completion. This paper details Saudi Aramco’s successful deployment and qualification of a high rate, slim design alternative deployed ESP system. As part of the qualification criteria the system was successfully installed, removed and reinstalled three times over a six month period on slick-line.

Introduction

Saudi Aramco extensively uses ESPs as an artificial lift method for producing oil wells in its producing fields. The number of ESPs utilized in these fields has grown significantly and will continue to grow over the foreseeable future.

The most significant concerns of ESP installations are the high workover cost to replace defective ESPs. A conventional ESP replacement will require an average of 10 days rig intervention. When coupled with a high work over cost and subsequent deferred production, both due to dependence on available workover rig in the field, the conventional ESP intervention can lead to exceedingly high operating costs. Therefore, an alternative ESP deployment method is crucial to reduce intervention cost, minimize production delays, and reduce oil production cost per barrel (Nutter, 2017).

Slickline Rigless Deployed ESP technology greatly reduces the cost of operations by simplifying the process of installing and retrieving ESP systems. It is no longer necessary to consider an ESP as a part of the completion string that must be pulled whenever there is a need to intervene in the well or to replace an ESP.
component or system. Slickline Rigless Deployed ESP technology makes the retrieval and replacement of an ESP system a through tubing, intervention operation performed using conventional slickline processes and equipment. The technology was developed to be used in areas associated with high workover costs especially with high number of slickline units and operation available (Dinkins, 2008).

There are numerous benefits to be gleaned when ESPs can be replaced without a rig or hoist:

**Minimal Production Deferment**
When ESPs fail unexpectedly, an operator often has to wait for months for a rig to become available to replace the failed systems. This incurs significant production deferment. Secondary deferment is also incurred when rigs are distracted from oil generating drilling, workover and/or reservoir management activities. Slickline units may typically be sourced in days and ‘rigless’ interventions may be completed in hours.

**Reduced Operating Expenditure (OPEX)**
Slickline units are typically a small fraction of workover rig costs and interventions are much quicker. Elimination of ESP replacement workovers may also allow a reduction in rig count.

**Reduced HSE Exposure and Risk**
Light interventions utilizing Slickline are quicker, safer and involve fewer personnel than heavy workover operations. HSE exposure, risk and environmental footprint are thus reduced (Malone, 2017). If wellsite security is an issue reduced exposure time is also a significant benefit. Quick, light intervention activity can also have advantages in terms of the environmental impact.

**Production Optimization**
Slickline Rigless Deployed ESP technology provides an opportunity to replace systems before failure and maybe deploy elsewhere (plug-and-play) – a unique opportunity to optimize production. Often ESPs operate sub-optimally, outside of their ideal operating envelopes, but heavy workover replacement before failure cannot be justified.

**Intervention beneath the Docking Station**
When the ESP is riglessly retrieved, there is opportunity to run intervention tools through the Docking Station to service the reservoir and/or lower completion components.

Intervention activities might include:

- Re-perforation
- Production / Reservoir Logging
- Casing Caliper / CBL
- Coiled Tubing Stimulation
- Zonal Isolation / Shifting Sleeves etc.

**Technology Overview**
The Slickline Rigless Deployed ESP system consists of an Outer, Permanent Completion and a Through Tubing Retrievable Assembly. The Permanent Completion is deployed with the tubing string (run with rig) and is intended to remain in the well for an extended period (10 years plus). The Retrievable Assembly is designed to be removed and redeployed through tubing with conventional, light intervention slickline equipment.
Permanent Completion

The Permanent Completion is the landing string for the Retrievable Assembly (ESP system). It includes the male wet connector - Dock, the orientation system to align the male and female wet connectors, and the mechanical connection between the Retrievable Assembly and tubing string.

The Permanent Completion also provides the connection point to the ESP power cable, which runs to the surface on the outside of tubing (like a conventional ESP), ESP packer, penetrators are identical to the conventional ESP installation. There are no modifications required to the wellhead and penetrator for the permanent installation. Moreover, this rigless ESP deployment concept allows to install shallow depth SSSV, which must be installed for a well close to the populated area. Fluid enters Permanent Completion through a perforated intake into the tubing string from the annulus (like a conventional ESP). This system allows gas to be diverted to the annulus, reducing the amount of gas that must pass through the pump. The Permanent Completion is compatible with casing sizes of 7", 29 ppf and larger;

The Slickline Rigless Deployed ESP Permanent Completion-Dock has a number of unique features:

- The male wet connector is mounted in a ‘side pocket’, outside the main tubing bore.
The offset position of the connector makes the system far less susceptible to debris. The wet connector sits in a side pocket and has a protective cover that extends over the connector whenever the Retrievable Assembly is not in place.

The minimum ID through the Dock is 3.853", allowing unimpeded access to the lower completion and reservoir for workovers, re-entry and other intervention/remediation;

![Cross Section of Male Wet Mate](image)

**Retrievable Completion**

Once the Permanent Completion is installed with the production tubing string, the Retrievable Completion can be deployed. The Retrievable Completion deployment/retrieval is divided into four slick line runs:

The four run design philosophy has numerous advantages over a ‘one piece’ deployment:

**Length:** The length of each deployed assembly is short enough allows the use of a conventional 4.5" slickline lubricator for live-well deployment. Including the running string, the total length of each slick line run will fit inside a standard lubricator.

In addition, the short length of each assembly greatly reduces the likelihood of becoming stuck and increases the ability of the system to negotiate dog-legs.

**Weight:** The combination of the Slickline Rigless Deployed ESP Permanent Magnet Motor and the four-run configuration results in a maximum deployed weight of roughly 1800 lbs. depends on the pump design that has been selected. This weight can be easily handled by standard, 0.16" slick line on a standard slick line unit. This allows the use of readily available surface equipment, minimizes handling risk at the surface and allows for easy logistics when moving the equipment.

**Ability to retrieve:** Solids accumulation is to be expected in the tubing above an ESP system. The four runs configuration offers many advantages in retrieving the Slickline Rigless Deployed ESP system:

- The first slick line run (during retrieval of the system) pulls the tubing stop (2’ long, 40 lbs.). A slick line BHA with mechanical jar and weight bars applied enough pull force on this component to loosen any debris during removal.
  - The second slick line run pulls the tubing pack off (5’ long, 120 lbs.). Again, the slick line utilizing hydraulic jar was able to apply large over pull force on this component to be removed.
  - Finally, the pump and motor are pulled. By the time, they are removed the tubing has been ‘cleaned’ by the first two slick line runs.

**Logistics and reliability:** The short length/low weight of each assembly allows them to be delivered to the rig pre-assembled. The motor and protector arrive at the rig site already assembled, oil filled and ready to run in the well. Very little rig site assembly is required, minimizing lost rig time and the likelihood of human error.
Well Candidate Completion Design and Barriers Philosophy

Candidate well was selected for a trial test of Slickline Rigless Deployed ESP technology. The well was drilled and completed as a horizontal open-hole producer to a total depth of 9478’ MD / 5453’ TVD at 87° inclination. ESP was designed to produce between 3000 to 6000 BFPD according to data and production expectation.

Wellbore Design

- **Casing Size and weight:** 9 5/8”, 43.5 PPF
- **Openhole size:** 8.500”
- **Above the ESP Packer - Tubing size and weight:** 5-1/2”, 17 PPF
- **Below the ESP Packer - Tubing size and weight:** 4 1/2”, 12.6 PPF
- **Well inclination at ESP depth:** 39°°
Permanent Completion Schematic

Figure 4—Slickline Rigless Deployed ESP Permanent Completion Schematic

Retrievable Assembly ESP Schematic
**Well Barrier Philosophy**

During the rig operations of running in hole with the permanent completion, our barrier philosophy includes use of the kill fluid and a rig/workover BOP system, effectively representing ONE fluid barrier and ONE emergency barrier until we land the tubing hanger and set the production packer.

<table>
<thead>
<tr>
<th>Description</th>
<th>Length feet</th>
<th>Max O.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tubing Stop 4.0&quot; GS Profile</td>
<td>1.17</td>
<td>3.72</td>
</tr>
<tr>
<td>Tubing Packoff 4.0&quot; GS x 2 7/8&quot; 10md NU box</td>
<td>2.83</td>
<td>3.72</td>
</tr>
<tr>
<td>Standing Valve 2 7/8&quot; 10md NU pin x pin</td>
<td>0.92</td>
<td>3.72</td>
</tr>
<tr>
<td>Stinger with spacer pipe 2 7/8&quot; 10md NU box</td>
<td>1.33</td>
<td>3.72</td>
</tr>
<tr>
<td>PBR 4.0&quot; GS x 2 7/8 10md NU box</td>
<td>2.10</td>
<td>3.72</td>
</tr>
<tr>
<td>Crossover 2 7/8 10 rnd NU pin x 2 3/8 EUE pin</td>
<td>0.50</td>
<td>3.72</td>
</tr>
<tr>
<td>Ported Pump Head 400 PMSXD 179 P60H6 ESP Intake FPXINT</td>
<td>58.5</td>
<td>3.80</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>3.80</td>
</tr>
<tr>
<td>Upper Mating Unit</td>
<td>0.42</td>
<td>3.75</td>
</tr>
<tr>
<td>Lower Mating Unit</td>
<td>1.25</td>
<td>3.75</td>
</tr>
<tr>
<td>Upper Seal Section (protector)</td>
<td>6.10</td>
<td>3.80</td>
</tr>
<tr>
<td>Lower Seal Section (protector)</td>
<td>6.10</td>
<td>3.80</td>
</tr>
<tr>
<td>Permanent Magnet Motor AccessESP 250 HP 3600 RPM 4 pole</td>
<td>17.05</td>
<td>3.75</td>
</tr>
<tr>
<td>ESP Gauge</td>
<td>3.38</td>
<td>3.75</td>
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<tr>
<td>Plug Head Assembly c/w female wet connect</td>
<td>11.40</td>
<td>3.75</td>
</tr>
<tr>
<td>Motor Guide</td>
<td>0.25</td>
<td>3.75</td>
</tr>
</tbody>
</table>
Following the permanent completion installation and during the operation to nipple down the rig BOP and nipple up the Christmas Tree, our barrier philosophy includes use of two mechanical barriers, effectively setting slickline bi-directional sealing plugs; one to be set in a deep-set landing nipple, and one back-pressure valve to be set in the tubing hanger to isolate tubing. Use of already set production packer and Tubing Hanger allow maintaining two mechanical barriers as related to the Annulus ‘A’ (production packer plus tubing hanger seals). Please note that during rigless ESP interventions both production packer and tubing hanger remain in place.

During the sequential rigless slickline interventions to deploy/replace the retrievable ESP four short assemblies in live well environment, our barrier philosophy includes using conventional 4.50” slickline lubricators, slickline BOP pressure control equipment and the Christmas Tree valves, that effectively representing two mechanical barriers with the option of adding contingency fluid barrier by utilizing a pump in sub is usually located above the slickline BOP. This allows the system to be deployed into a ‘live well’ without adding expensive and complex completion hardware such as downhole annular flow control valve or a reservoir isolation valve and its associated multiple control lines run from surface.

**Technology Evaluation Plan and Success Criteria**

An evaluation plan was developed for the Slickline Rigless Deployed ESP trial test in order to decide the success criteria prior to start the trial test program. The main objective of the trial test program was to prove the concept of rigless ESP deployment method. Retrievable ESP assembly was planned to be pulled and rerun back to the same well using slick line unit three times during the trial test period. The main purpose is to test and monitor side pocket wet connector electrical system integrity.

The first replacement intervention was planned to be performed during run in hole with the permanent completion with the rig at 800ft below the rotary. The ESP wet mate connector will be disconnected and reconnected to the Dock using slick-line unit.

The second replacement intervention was planned to be performed after landing the tubing hanger and starting up the well for 8 hours to function test the ESP for a minimum of 8 hours before releasing the workover rig.

The third replacement was planned to be performed through a rigless intervention using slick-line unit. It is intended to prove the rigless deployment technique and reliability of both permanent and retrievable ESP completion equipment after 6 months of operations with potential debris or other downhole issues.

A total of minimum 180 days from first ESP Function Test define as part of trial test successful criteria in addition to safe rigless ESP deployment according to Saudi Aramco well control guideline.

**System Integration Test**

In order to ensure the compatibility of downhole component, a system integration test (SIT) was conducted at the vendor facilities. A minor modification on the 400 Series ESP bolt on discharge head, pumps housing, intake and upper housing of Seals were performed to ensure maximum system OD of 3.800 in. The SIT was successful. Each individual piece of equipment drifted 3.805 from head to base and when the equipment was made up into the full string to be run in hole each flanged interface passed through the 3.805 drift ring.

**Deployment Process and Operations Summary**

The retrievable ESP assembly and permanent completion were installed during the rig at the well location according to the workover program. ESP was pulled and rerun using slick-line unit smoothly. ESP was run together inside the permanent completion, and pulled once the system reached 800 ft. This to eliminate the requirement of unnecessary change of ESP seal. The seal cannot be rerun at deeper depth unless it will be redressed. The permanent completion Dock and retrievable assembly wet mate connectors maintained
a healthy electrical system integrity. During motor installation orientation of the plug arm for the annular port connection is necessary to set the assembly correctly and can be confirmed by electrical readings to the motor. Moreover, after completing the installation tubing isolation is tested by applying pressure where the pack-off and tubing stop combo will seal off the bottom part of the tubing completion. An issue that was faced during pack-off installation which will be shown during the final intervention performed riglessly. No major issue was observed during the first ESP pulling or running.

After installing the Tubing hanger and the Christmastree, the pump would not start. A series of troubleshooting techniques showed no success indicating the result of a mechanical problem and required the assembly to be retrieved. After retrieving the assembly it was found the motor shaft had recessed into the assembly 3 inches. A backup was used, due to solution limitation while rig is on location, and the assembly was re-installed successfully and working as intended. The damaged motor was sent for a tear down inspection for a complete analysis. The result was a modification to the motor assembly that was implemented in the final intervention. The ESP function test was performed after 58 hours from the first installation was completed. This was the total time required to perform the second intervention which included mobilization of both back-up equipment and slick-line unit from town. The ESP function test was successfully carried out for 9 hours then the workover was released.

ESP was commissioned after the reinstallation of surface flowlines to the plant and delivered the high flow rate design of over 4000 BFPD. It was running continuously for approximately 130 days prior the rigless third intervention.

As part of the technology trial success criteria, an rigless third intervention is required to evaluate both permanent and retrievable completion system after being operated and exposed to the reservoir environment. The ESP was pulled and rerun using slickline unit and 0.160" wire. Step by step procedures was reviewed by the team from all technical and safety perspectives.

A 90 ft 4-1/2" lubricator with 60 ft tower was utilized as part of slickline operations and safety requirements to pull and rerun ESP. There was no issue during the rigless third intervention. The job was completed within 90 hours, which includes the mobilization slickline and installation of tower. However, the main job to pull and run ESP can be achieved only less than 24 hours. During the retrieval process an operational challenge was met with the retrieval of the tubing pack-off. During the retrieval of the tubing pack-off difficulty was faced trying to unseat and retrieve the assembly. The force required to retrieve the assembly proved to be insufficient due initial installation process with the rig pointed out earlier. After running the tubing pack-off during rig installation pressure test was not passed and seal was damaged on retrieval. Afterwards, it was pulled and redressed and while installation excessive jarring was used a total of 40-50 attempts. This was likely the cause of difficulties faced during the retrieval of the assembly in the rigless operation. The slickline BHA was then redressed to increase weight bars and hydraulic jarring power. The assembly was then retrieved successfully with no issues.

All ESP component were inspected once it was pulled to surface prior to being rerun in the well. Motor was replaced, the protector was also changed according to the recommendation from manufacture. A protector is intended to perform the valuable function to protect the motor from contamination by well fluids. It is impossible at the wells site to determine if all mechanical seals are intact and will seal, it is often difficult to determine if the thrust bearings have been damaged or destroyed and it is difficult to drain and refill protectors with complete confidence that all well fluids have been displaced and the protector is full of clean high dielectric strength motor oil. All triple tandem pumps were flushed with diesel before rerun back to the well. Also, since the rigless installation was in a time frame of six months after the rig deployment, a modification in design of the motor shaft’s retaining ring was completed. This modification ensured an increase in the ring’s reliability to hold the shaft above it and remove the issue of installation errors. In addition, a design modification was conducted on the tubing pack-off to improve quality and maintain a level acceptance as a third party item.
After the first run (motor and protector) connected to the downhole wet mate connector, an electrical system integrity was performed and measured at higher than 1 G ohm P-G and 7.7 ohms P-P balance, which ensured a healthy system. During the retrieval process of the tubing pack-off the first time difficulties were faced as mentioned above. The excessive jarring during installation, required a change of BHA to have additional weight and jarring force for the retrieval of the assembly. In the deployment phase, the installation of this assembly would follow the precautions of the vendor and using a maximum of 10 jarring attempts. The rest of downhole ESP equipment was run and set without any problem. Finally, ESP was function tested and delivered up to 5000 BFPD. Since the first installation, ESP has been run for more than 180 days. There were no failures or trip during the evaluation period related to ESP system.

Benefits
The overall system is uniquely positioned to be deployed with a slickline operations, through tubing and under live well intervention conditions to deliver the following benefits:

- ESP workover cost savings through slickline intervention instead of rig operation.
- Significantly minimized delayed production through live well intervention according to standard Saudi Aramco well control guideline.
- The plug-and-play design of the slickline deployed system eliminates the need to strip-out and hook-up surface flowlines during ESP intervention process.
- Allows for rapid intervention to changing reservoir conditions
- System compatibility to standard wellhead configuration and ESP surface equipment. No modification is required.
- Elimination for the requirement to kill the well to replace ESP which will minimize potential formation damage.
- Improved rig utilization through not having to perform unscheduled remediation and repair work.

Conclusion
The Slickline Rigless Deployed ESP Technology was installed and operated more than 180 days. During the evaluation period, the ESP system was pulled and reinstalled three times safely using conventional slick line unit in full compliance with the most rigorous well control guideline.

The Slickline Rigless Deployed ESP Technology proved the benefit of faster ESP change-out using rigless deployment method. ESP can be replaced within maximum 4 days which includes the mobilization of slickline unit and tower installation.

The Slickline Rigless Deployed ESP Technology proved significant cost savings up to 70% compared to utilization of a conventional rig. And provide a huge impact to reduce company lock potential.

The Slickline Rigless Deployed ESP Technology eliminates the requirement of wellhead modification, killing well and the need to strip-out and hook-up flowline prior replacing ESP similar to a conventional logging job.

The compatibility of permanent magnet motor to the existing variable speed drive (VSD) from various ESP vendor is a plus for offshore well. This will be a crucial cost savings as it eliminates the requirement to replace existing VSD in platform.

Recommendations
Several potential technologies implementation are recommended to further extend the applications of the Slickline Rigless Deployed ESP system to address the following challenges:
• **A conventional rig will be required whenever power cables fail:** Tubing Encapsulated Power Cable New Technology is being evaluated to enhance cables reliability and extend the permanent completion overall run life.

• **Rate delivered by the system is limited by the slim pump size:** Hybrid System is being developed to allow bigger and shorter pumps to be installed in bigger tubing sizes to deliver much higher rates up to 20,000 BFPD instead of current capacity of producing 6,000 BFPD, this solution will also help to reduce the limitation of the slickline lubricator lengths to further enhance both operation and safety aspects.

• **Short ESP run life in harsh environment such as high H2S and CO2:** A minor modification to the conventional ESP Dock that encases the Dock in a 12’ pup joint of 7 5/8” casing. By providing this external "shroud" the production fluid does not enter the annulus above the production packer that will be located below the Dock, extending ESP cable life by eliminating contact between the ESP cable and the corrosive production fluid.

References

