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Continuous Pumping, Multistage, Hydraulic Fracturing in Kitina Field, Offshore Congo, West Africa

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Abstract

Many West Africa offshore fields are maturing and operators are completing secondary targets in their wells to maintain the economic operation of their valuable assets. Large quantities of reserves can be found in low permeability, consolidated, formations and new techniques are being investigated to improve the economic return of completing these formations.

The Kitina Field, offshore from Pointe Noire, Congo, is one such field. Deeper sands have been produced to economic depletion and the operator is looking for alternative production intervals.

The targeted reservoir is the 3A Sand at approximately 2200 meters TVD. The reservoir is a very heterogeneous lithology with varying quantities of siltstone, sandstone and calcite. The intervals of better porosity show a decrease in clay content, but the good “sands” can be either dominated by quartz or calcite with substantial variations with each meter of height.

Three candidate wells were selected for placing multiple propped fractures using a technique that has been used for six years in North America. This technique utilizes a series of mechanical packers and frac ports that are sequentially shifted “on the fly” allowing continuous placement of more than one hydraulic propped fracture without shutting down the pumping equipment.

During April to June of 2007, eight hydraulic propped fractures were placed in three re-completed, cased-hole wells in the Kitina Field with very encouraging production increases. During the first 90 days of post fracturing production, a production increase of 200% was achieved.

This paper will discuss the steps that were taken to place these propped fractures from an ocean going tender barge using skid equipment and recommendations for the future applications of this stimulation technique.

Introduction

The Kitina Marine offshore field was discovered in 1991 and put on production in November 1997. Originally, the field development considered the three deeper intervals:

- 2A – Limestone,
- 1A – Sand with carbonate cementing,
- 1B – Limestone.

The three reservoirs were developed via a peripheral water injection scheme and a crestal gas injection displacement process. After a quite significant initial rate (around 50,000 BOPD), the field declined quite rapidly. The recovery factors vary between 15% of the 1B reservoir to aroud 25-30% of the 1A and 2A reservoirs.
The platform has gas lift installed on some of the completions and others produce in natural flow. Production of the platform was 7,000 BOPD prior to the fracture stimulation.

The 3A Sandstone reservoir was initially completed in natural depletion between the end of 2005 and august 2006 via the recompletion of three deeper wells into this shallower and low permeability reservoir (gas lifted wells). The formation permeability to oil is in the range of 2-7 mD. Due to the low permeabilities, during the first year of production, the reservoir 3A oil production potential has been of around 800 BOPD. Their steady-state production was:

- KTM W6 ST – 160 BOPD
- KTM 107 – 130 BOPD
- KTM 111 – 300 BOPD

Level 3A in Kitina field had progressively declining production heading to a marginal-economic scenario. A study was carried out by Eni Congo and Eni E&P with the final objective of re-establishing the reservoir 3A production to a viable economic level (more than 1500 BOPD) without drilling new wells or performing heavy workover operations. Because of the low rates of the three wells producing from the 3A Sand, this target could have been achieved only with a massive hydraulic fracturing operation on all the wells. Therefore the three wells were selected to be treated. Secondly, this was considered an attractive situation for testing new technologies and techniques to build a learning curve applicable in other similar situations opening a wide scenario for further applications in other low permeability reservoir of the Congo Basin. For this reason, different technologies were evaluated and eventually the Continuous Pumping Multi-Stage System (CPMSS) technique was selected.

The CPMSS allows pumping multiple hydraulic fracturing treatments without the need of intermediate operation such as bridge plugs or proppant plugs (run in hole, set, retrieve, and mill or clean) and perforate each interval with multiple TCP or wire-line operations. The CPMSS hardware is a permanent bottomhole assembly that is run and set into the hole after all the interval requiring fracturing treatment has been perforated. This peculiarity allows the placement in the formation of multiple treatments with a continuous pumping operation; the limiting factor is represented by the amount of proppant that can be stored in the silos (or equivalent storage system) and the amount of fluid available.

In conclusion it is possible to pump all the treatments planned in each well in just a few hours which is a substantial time savings. This has the potential to become a remarkable advantage in offshore operation with the rig on location.

Offshore Fracturing Challenges

The petroleum industry has made a well documented effort to improve the production of laminated pay intervals with the use of fracturing [2,8,9]. The large volume of data provides significant support for hydraulic propped fracturing to improve the well deliverability from laminated pay intervals by improving the poor vertical communication due to negligible vertical permeability.

The industry has also discussed, in much detail, the benefits of placing multiple fractures into a wellbore. These papers are usually discussing this application in horizontal wells where a single reservoir is drilled and stimulated multiple times from the same wellbore[3,6,10].

Hydraulic propped fracturing of consolidated formations is not new to West Africa reservoirs. During the early 1980's, hydraulic fracture stimulations had been performed in Gabon from a dedicated stimulation vessel. Both gelled water and gelled oils were used to place sieved sand and man-made proppants into laminated sandstone intervals in a large field of similar characteristics of the Kitina Field in Congo[4].

In 1991, three prop fractures were performed with good economic success in the Takula Field of Cabinda, Angola[1]. A detailed paper was written to discuss the philosophy and methodology of fracturing low permeability, thick, heterogeneous, offshore intervals in the N'Dola Field of Cabinda in the 1998 time frame. The authors describe their methods for placing multiple fractures into a well lithology that is similar to many fields in West Africa from Gabon to Angola.

The work in Cabinda has evolved into placing two or three hydraulic propped fractures into these slanted wellbores in the interest of connecting as much of the laminated pay as possible to the wellbore. A very large single fracture was not effective at growing through all the intervals of interest and then producing through bi-linear flow into a narrow contact area with the wellbore due the limited perforation interval required for fracture execution in deviated cased hole wells.

In late 2006 and early 2007 it was decided by the operator and partners of the Kitina Field of Congo to investigate propped fracturing several selected candidates from their existing wells. These candidate wells were cased and perforated. Some of the wells that were considered as candidates had continuous perforations over the entire interval and others had individual

A selected technique would have to isolate each interval and stimulate individual sands. One technique of interest that is being used in North America for vertical to horizontal wells also had the benefit of being a continuous pumping placement system [7,12]. This type of tool application had been successfully used for the first time offshore during late 2006/early 2007 in neighboring Gabon, West Africa and it was decided to use this technique on a few selected candidates in the Kitina Field.

Physical limitations of fracturing offshore

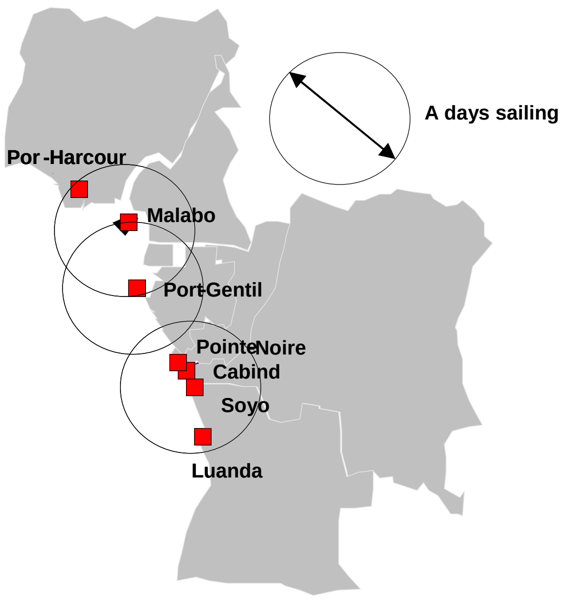
There are many limitations to fracturing offshore that may not be an issue on land. The following is a partial list:

- Space limitations
- Weight/area restrictions
- Flow back of hydrocarbons and solids
- Sea conditions
- Location / remoteness / access
- Available marine and stimulation equipment resources
- Mobilization expense for all rig and stimulation equipment
- Crane availability of the dock and the rig/platform
- High expense to re-mobilize to correct sanding issues

A dedicated stimulation vessel with an experienced crew always looks very attractive and it would be expected to be the most efficient approach, but in times of high utilization of oilfield service equipment, these vessels are in very high demand and there is a risk that they may not be available when the completion calls for them. The very large area of West Africa stretches the capabilities of the existing vessels that are in the theater of operations to reach a rig in a timely fashion. A vessel sailing from Nigeria will take 2.5-3 days to reach this rig work in Congo (See Figure 1). Each country is its own sovereign nation as well, so time must be allotted for customs clearance upon arrival and for departure from each country visited.

The required frac equipment to perform this work would take up too much space on most, if not all rigs and platforms of the industry, hence that is eliminated as an option. Placing skid equipment on the deck of a service vessel was evaluated and it is a relatively common practice[5] that is occurring in many marine operation areas. Just as stimulation vessels are in high demand, so are service vessels. A large fracturing treatment would require a large service vessel of 600 m^2 deck space or larger. Sub systems of the vessel are used for air transfer of proppant. Below deck pumps and tanks are used for mix water and mixed gel storage. Therefore, the selection of the vessel and the access for cleaning these tanks and lines would be critical.

Figure 1 – Sailing time West Africa



Another option that was considered and chosen to pursue was to place the skids on the deck area of the large platform tender rig support barge, the Barracuda. (**Figure 2**). The rig-up is comfortably placed on ~1200 m^2 of open deck space. All the equipment on the single level of the deck was adequate to perform the stimulation treatments except the additional use of 1500 bbls (240 m^3) of the tender pit systems located directly below the blender system that held additional quantities of pre-blended gel.

The selection of the Barracuda (See Schematic 1 below) as the work platform and the use of skids then will put certain criteria in motion of the abilities and the limitations that control the execution of the fracture stimulation. A fracture design and sequence of operations must then be built around the given set of equipment, capabilities and available crew.

The major reasons for selecting the skids on the floating barge were:

- Captive pumping package that would be available as soon as the rig was ready for stimulation.
- Up front costs of the skid equipment is lower than using a dedicated stimulation vessel.
- The anchored and moored barge reduces risk of a weather interruption when pumping is initiated.
- Unavailability of either a dedicated stimulation or service vessel.

Figure 2 – Frac Equipment on Barracuda Tender Barge

This rig-up on the Barracuda gave us the capability of having access to 2,500 bbls (400 m^3) of gelled fluid, 150,000 pounds of proppant in two gravity silos feeding the blender and another 100,000 pounds pneumatically delivered (depending on timely transfer) to the gravity silo. 5,600 HHP of four fracturing skid pump were rigged up and available for these treatments planned to be pumped at 20-30 barrels per minute. A freshwater based, batch mixed fluid was utilized with this volume of fluid storage.

Fracturing Application to Kitina Field

There has been a search ongoing for decades to improve the efficiency of fracturing horizontal wells ever since it has been identified that horizontal well production can be improved by fracture stimulation [11,13]. One of the last approaches that have been developed was to use a system that becomes a permanent completion liner. This system is a series of external, mechanical element packers that can be screwed to the deployed liner in stategic places for isolation. Between each of the packers is a sliding sleeve referred to as a frac port. The use of the packers allows the wellbore to be segmented into selected areas for stimulation. Packers of a specified size can be used in either cased hole to straddle perforations or in open hole wellbores to segment that type of completion.

The method of selectively opening the frac port is to drop progressively larger diameter ceramic balls that land on a beveled seat below each of the ports. The seating ball allows sufficient pressure to be applied to create a down force that will shift the sleeve to the open position while isolating the previously placed fractures of the ports at deeper depths.

There are several theoretical benefits of using this continuous pumping, multi-stage system. Many of these have been realized on land operations and our attempt was to carry these benefits to a marine well. Some of them are:

- With adequate bulk capacity, all stimulation can be done in hours instead of weeks
- Quicker fluid recovery due to the short time for the injection process
- Reducing rig costs may encourage additional fracturing treatments for enhanced stimulation of the well
- The sliding sleeves will allow interval isolation at a later date

The technique has been previously applied for the first time on a marine well in Gabon, six months previously. The four wells were that fractured in Gabon, were three open-hole completions and one cased-hole completion.

Fracturing Execution of Offshore Kitina Fractures
Kitina Marine W6 ST

The first candidate well was KTM W6 ST. This well has 7" 29 ppf L-80 cemented liner run from 1,600 – 3,110m. The well was a re-completion from a lower interval. The intervals of interest for fracturing were in the 3A Sandstone. These perforations had been placed on gas-lift production in August of 2006 until the time of the workover to fracture the perforations in April 2007.

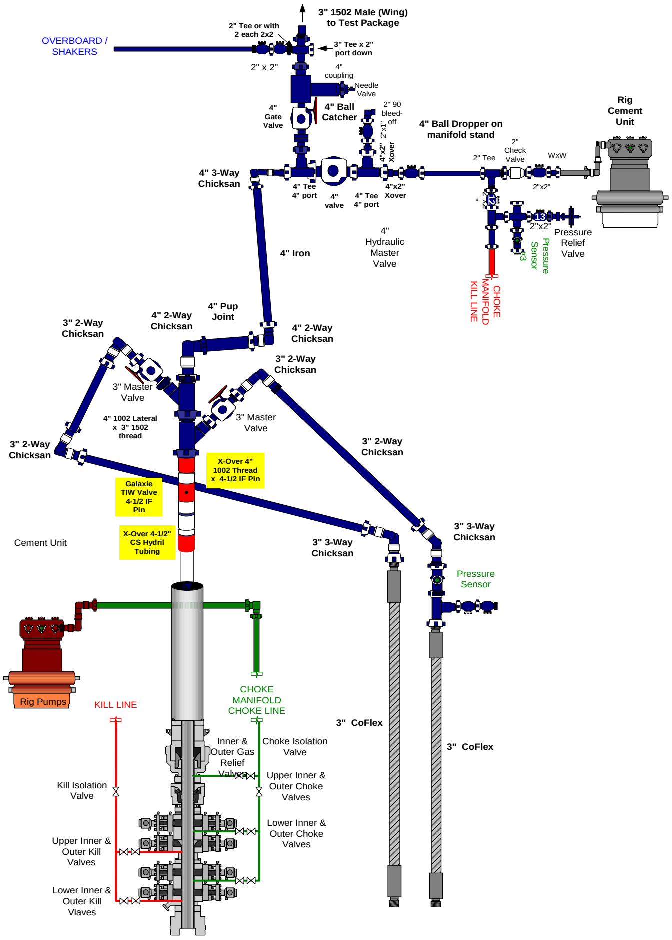
This well was perforated in three intervals from;

- 2,785m – 2,810m, (2,099m – 2,111m TVD), 4.5" Guns, Big hole charges, 12 jspf, deviation 62.1°
- 2,820m – 2,865m (2,115.3m – 2,135.3m TVD), 4.5" Guns, Big hole charges, 12 jspf, deviation 63.2°
- 2,870m – 2,910m (2,145.4m – 2,157.6m TVD), 4.5" Guns, Big hole charges, 12 jspf, deviation 64.5°

New perforations were added in 2 meter groups to each of the well perforation sets in the interested of reducing the risk of a screen-out caused by tortuosity, prior to running the packer assembly into the well.

The packer assembly (**Schematic 2**) is run to depth to allow the packers to straddle the three perforated intervals. This fracturing seal assembly is then run into the well and landed in the sealbore of the liner hanger packer. The tubing annulus was then isolated with the Blow Out Preventors (BOP) at the surface. During the fracturing treatment, annulus pressure was maintained by a rig pump and the pressure is monitored by both the rig crew and the fracturing control monitoring system. A 4" master valve was placed on the frac work string as tubing isolation as well as valves in the treating equipment lines of the frac spread (**Schematic 3**).

Schematic 3 – Wellhead Configuration



When the production liner assembly is run and set, all the sleeves and access to the perforations are closed. The initial fracture port is opened with pressure differential. All remaining intervals are manipulated using a ball which also acts as isolation for any fractured intervals located below the targeted interval. After the initial frac port is opened hydraulically, each sequential port is opened with a ball sized specifically to a seat made for that particular ball size.

Injection Test

The initial steps of this fracturing operation were to pump several pre-frac injections for diagnostic purposes. The annulus pressure was increased to 1,000 psi and then the tubing pressure was increased until the hydraulic fracturing port was opened, exposing the lower most perforated interval. This fracture port opened at 4,500 psi surface pressure as designed.

A Step Down injection test was then performed to evaluate the near wellbore perforation and tortuosity restrictions that may exist. Linear gel was pumped at rates from 25 bpm down to 12 bpm and then the shut-in pressure was monitored for 60 minutes.

The formation breakdown pressure was observed at approximately 2000 psi on the surface. The total measured friction observed at 20bpm was 500 psi. 100 psi was allocated to the perforations and 265 psi was attributed to tortuosity.

Calibration Test

The next test performed was a 325 bbl injection of a 35 pound gel loading delayed borate crosslinked gel. This was pumped at 20 and 25 bpm. The pressure decline post shut-in was observed for 60 minutes.

Frac Design

Based on the pre-job Step Down Test and the Calibration Test the fracturing parameters were adjusted in the Pseudo three dimensional fracture models. A summary of each of the wells is listed in **Table 1**.

Propped fracturing execution of frac ports 1 and 2 followed later by frac port 3

The KTM W6 ST was the first well to be fracture stimulated on the Kitina platform on April 13, 2007. The stimulation liner assembly was run into the hole on 4-1/2" tubing and set across three perforated intervals. During the treatment of the bottom and middle zones were fractured stimulated without shutting down the pumps.

100,756 lb of 20/40 Intermediate strength, light-weight, ceramic proppant (ISP) was placed in the lower-most interval and 106,154 lb of 20/40 ISP was placed into the middle perforated interval. A frac ball was launched immediately upon starting the flush of the first fracture. This allowed the lower fracture to be isolated and opened the fracture port of the second interval. **Figure 3** shows the responding data of these two fractures being placed.

You will notice that two proppant slugs were pumped in the pad fluid of fracture number 1. A proppant slug was late in being delivered on fracture number 2. The pumping rate is consistent at 20 bpm until the rate is reduced to have a controlled

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