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# Design and Installation of a Cost Effective Completion System for Horizontal Chalk Wells Where Multiple Zones Require Acid Stimulation

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This paper was prepared for presentation at the 1997 SPE Production Operations Symposium, held in Oklahoma City, Oklahoma, 9–11 March 1997.



## Abstract

An innovative completion design that allows multiple acid fracs to be performed in horizontal subsea chalk-formation wells with a single trip into the wellbore has recently been codeveloped by a major North Sea operator and an oilfield engineering/manufacturing/service company. The project was initiated to develop a system that would allow multiple acid stimulations to be efficiently performed in the shortest possible time in the North Sea Joanne Field. The system ultimately developed allows acid stimulation of up to 10 different zones in a single trip with no through-tubing intervention. The first well in which this new technique was used had 7 zones, and 3 additional wells with 10 zones each were later completed. The development of this system and case histories of the first four subsea wells requiring stimulation will be presented in the paper.

The key element of the system is a multi-stage acid frac tool (MSAF) that is similar to a sliding sleeve circulating device and is run in the closed position. Up to 9 MSAF tools can be run in the completion with isolation of each zone being achieved by hydraulic-set retrievable packers that are positioned on each side of an MSAF tool. Each sleeve contains a threaded ball seat with the smallest ball seat in the lowest sleeve and the largest ball seat in the highest sleeve. With this system, stimulation of 10 separate zones is accomplished in 12-18 hours by a unique procedure that lubricates varying sized low-specific gravity balls into the tubing and then pumps them to a mating seat in the appropriate MSAF, thus sealing off the stimulated zone and allowing stimulation of the next zone which is made accessible by opening the sleeve.

This technique provided a substantial reduction in the operational time normally required to stimulate multiple zones and allowed the stimulations to be precisely targeted within the reservoir. The case history data will provide comparisons in operational times between traditional stimulations and this new method as well as the significant enhancements to cost efficiency that resulted from its use. Additionally, this completion method allowed the stimulations to be designed and matched to the requirements of each reservoir zone, which provided the most cost efficient treatments possible.

## Introduction

The Judy/Joanne Fields are located in the central North Sea on block 30/7a (commonly known as the J Block of the UK North Sea), 280 kilometers South East of Aberdeen. The water depth is approximately 80 meters.

The complete field development consists of a 24-slot platform for Judy and a 12-slot subsea template for Joanne. Production from the Joanne subsea manifold is transported through two 12-inch pipelines, 5-kilometers in length, to the Judy platform.

To date, five Joanne subsea wells have been drilled and completed, four of which were in chalk formations, and thus, comprehensive acid stimulation programs were required for their completions. **Figure 1** is a map showing the location of the J-Block Judy/Joanne Fields.

## Well Design

Phillips' original plan had been to drill 60-degree wells in these fields; however, since drilling horizontal wells would allow a reduction in the number of well slots, which would subsequently reduce overall drilling costs, the decision was made to complete

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## Well Design
Phillips' original plan had been to drill 60-degree wells in these fields; however, since drilling horizontal wells would allow a reduction in the number of well slots, which would subsequently reduce overall drilling costs, the decision was made to complete horizontally. Additionally, it was felt that stimulation programs would be necessary to achieve the necessary production potentials. The new wells were designed to intersect the most productive reservoir layers twice to further maximize production. Ideally, each reservoir layer was to be stimulated using a design developed for its specific needs. Thus, it would be necessary to perform multiple stimulations targeted at the reservoir layers. **Figure 2** shows how the well path would intersect the individual reservoir layers.

A review of similar completions carried out by Phillips and other operators indicated that each zone would require between three to four days to stimulate. This would have meant a minimum of thirty days per well to complete the stimulation procedures. From the initial review, it was clear that the project could not support such greatly increased costs, and thus, an alternative method was needed. The resulting completion design was based on earlier completions performed by Phillips on the Hewett Field in the Southern UKCS. During these completions, the initial development phase of the Multi Stage Acid Frac Tool (MSAF) had taken place. This tool was instrumental in the success of the design, and will be described in more detail later.

The primary difference in the completion designs concerned the number of zones stimulated. The Hewett Field completions typically used only two MSAF tools that resulted in 3 stimulated zones, whereas the first Joanne completion (well M1) utilized six MSAF tools and the completions for wells M3, M4, and M5 used nine MSAF tools. **Figure 3** is a schematic of a typical Joanne completion.

## Typical Joanne Completion Design

**1. 5-1/8-in. Tubing Hanger**. Horizontal (lateral) sub-sea trees were used to allow the completions to be run through them. The final operation prior to leaving the wells was the installation of wireline-set, metal-to-metal-sealing wellhead plugs in the tubing hangers.

**2. 5½-in. Tubing Retrievable Safety Valve (TRSV).** A non-equalizing TRSV with metal-to- metal seals was used to ensure reliability.

**3. 4½-in. x 1½-in. Side Pocket Mandrel (SPM).** These were run with blanked off annulus ports to enable electronic memory gauges with the same envelope dimensions as a standard 1½-in. gas lift valve to be installed in the completions during the stimulation without compromising full bore access. These gauges were run and retrieved using conventional gas-lift kick-over tools and gave valuable bottomhole information during the stimulations, clean-up procedures, and well tests.

**4. 4½-in. Sliding Sleeve Circulating Devices.** The SSD's were run to enable the upper completion/casing annulus to be circulated to inhibited brine.

**5. 30-ft.-Stroke Polished Bore Receptacle (PBR) / Seal Assembly with Annular Pressure Release.** Tubing calculations for operational conditions, particularly high volume acid stimulation and well testing, showed that a 30-ft. stroke expansion device was necessary. Ryton®/Teflon® /Ryton®(RTR).[1] premium seals were considered the most appropriate seals for the operating conditions that would be faced.

A molded seal was added to the RTR premium seals to ensure good sealing at the lower temperatures expected during stimulation.

A conventional shear-pinned PBR/seal assembly was used on M1 but concerns over induced torque led to the design of a special, annular pressure release that fitted on top of the PBR/seal assembly. In the closed (running) position, the PBR and seal assembly were clutched together to handle applied or induced torque. As a back up, it had a secondary shear-screw release mechanism that was isolated from any torque that could be applied or induced.

**6. and 9. 7-in. Permanent/7-in. Retrievable Packer (Multiple).** An important requirement in completions using multiple hydraulic-set packers is that no mandrel movement in relation to the slips of the packer should occur while setting. This enables any number of hydraulic-set packers to be set simultaneously without the requirement for expansion devices between the packers to account for mandrel movement. The packer selected for this project was a new hydraulic-set retrievable packer that had its first usage on the Joanne project **(Fig. 4)**.

The packer could be set up as either a permanent or a retrievable packer simply by installing a lock ring (permanent) or installing up to 16 shear screws (retrievable). When set up in the permanent mode, the packer could be retrieved by chemically cutting the mandrel.

This packer had large outside-diameter (OD) gauge rings at either end, which kept the other components of the packer from contacting the 7-in. liner. The packer elements and slips had a smaller OD in the running position than the adjacent parts. After completion of the first well (M1), the gauge rings were fluted to assist in fluid by-pass while the completion was installed in the liner.

**7. Selective Landing Nipple.** This nipple was run below the top packer as a contingency in case there were problems during installation of the completion and for use in future workover operations.

**8. 4½-in. Multi Stage Acid Frac Tool (MSAF) [Multiple].** This tool is the "heart" of the completion system. It is a sliding sleeve device that can allow communication between the tubing and annulus once the sleeve is moved to the open position. A ball seat is threaded on the bore of this sleeve, and when the correct size ball lands on the ball seat, applied pressure from above moves the sleeve to the down/open position. The ball and seat form a seal that prevents pumped fluid from entering lower zones, and thereby, diverts the fluid through the tool and into the tubing liner annulus. The MSAF tool is shown in both the closed and open positions in **Figure 5**.

For 4½-in. tubing, up to nine different ball/seat configurations can be used (see **Table 1**). The smallest ID seat is run at the bottom of the completion, and the largest ID seat is run at the top.

The sleeve in the MSAF was designed with an opening profile and a closing profile so that the tool could be selectively opened or closed as required during workovers. A hydraulically operated shifting tool run on coiled tubing was designed for this purpose. Note that in the tool version used on Joanne, the ball seats must be milled out before the shifting tool can be used.

**10. Pump Out/Cycle Plug**. On M1, a conventional shear-out shoe was run. This was replaced on the remaining completions with a cycle type plug, which allowed up to ten pressure cycles to be applied to the tubing before it was expelled. This was carried in a shear-out sub that could be sheared in the event that the cycle plug failed.

### Ball Material

Two different ball materials were used — phenolic plastic with a specific gravity of 1.3 and coated aluminum with a specific gravity of 2.5. The 1.3 SG phenolic plastic ball was the preferred choice other than for the cases in which the expected stimulation pressure necessitated the use of aluminum balls.

### Testing

*Flow testing* was carried out to determine 1) the minimum flow rates required to return the balls (aluminum and phenolic) to surface, 2) flow rates for pumping a ball through a seat with the minimum ball/seat clearance, and 3) flow rates for operating the MSAF tools.

*Pressure testing* was carried out to determine the pressure rating for phenolic ball/seat combinations for which there was no existing rating. In each case, three sets of phenolic ball / seat combination were pressure tested to destruction to establish the pressure ratings. Pressure ratings were calculated for the aluminum ball/seat combinations. **Table 2** shows the results of the destructive pressure testing of phenolic balls.

**Table 3** shows the shear strength test results of the aluminum balls. 100% values are based on 6061 aluminum with an ultimate shear strength of 9,000 psi, no safety factor, and assumption that the ball will be the point of failure. All values are taken at nominal dimensions with no accounting for tolerance or erosion.

### Completion Installation - General

Before running the completion, each well was perforated with tubing-conveyed perforating (TCP) guns. The multiple packers in each completion were spaced out in order to isolate the zones to be stimulated.

The installation plan for all the wells was the same. The completion was run in one trip to the safety valve, and the packers were set simultaneously since the packers had the same setting pressure. Then, the upper completion was unstung from the PBR, spaced out, and run back in with the TRSV.

As soon as each completion had been run and the packers had been set, spaced out and hanger landed, special high pressure, large bore (4-in. ID) equipment was rigged up on top of the 5-in ID flowhead for launching and catching of the balls. After all the surface equipment had been rigged up and tested, the stimulation operation was started by expelling the pump out/cycle plug and stimulating the lower zone (below the bottom packer). Once this zone had been stimulated, the smallest ball was lubricated into the completion and pumped on to its mating seat in the lowest MSAF. Once landed, over-pressure sheared the preset shear pins and allowed the sleeve to move to the open position, allowing stimulation of the zone through the MSAF tool and preventing pumped fluids from going to any lower zones already stimulated. The process was then repeated by pumping increasingly larger balls until all zones had been stimulated. All balls were then flowed to the surface and caught in the ball catcher.

For M1, which had seven zones, one stimulation vessel was able to carry enough acid to complete the stimulation program. However, two stimulation vessels were required for each of the wells with ten zones (M3, M4 and M5) because of the volume of acid which was needed for the increased number of zones.

### Completion Installation - M1

Seven packers and six multi-stage acid frac tools (all in closed position) were run. (see **Table 4** for the six different ball/seat configurations). For this well, the expansion device (PBR/seal assembly) was a conventional type, straight-pull (shear -screw) release. At the last minute, it was decided not to run the full completion in one trip because of concerns of prematurely shearing the shear screws in the PBR/seal assembly, which could be caused by back torque during installation into the horizontal section of the liner.

As a result, it was decided to run the lower half (PBR downwards) of the completion on a 95/8-in. liner hanger setting sleeve and hang off on the 7-in. liner top. Once the lower half of the completion was on depth, pressure was applied down the tubing against the pump-out plug (conventional shear screw release) to set all seven packers simultaneously. The upper half of the completion was then spaced out and stung into the PBR. The pump out plug failed during the packer setting procedure, (luckily just after the packers were set) which resulted in problems in pressure testing of the completion and tubing hanger.

Once all testing had been completed, stimulation of the lowest zone (below the bottom packer) was carried out. A well test was then run on this zone. The upper six zones were then stimulated individually by pumping down increasingly larger balls to land/seal on their mating seats in each MSAF tool. During this operation, pumping operations were continuous. The pump rate was reduced to 5 bbl/minute to lubricate each ball into the wellbore. The pump rate was then increased to 20 to 25 bbl/minute to transport each ball to within 500 feet of its mating seat, and again was reduced to 5 bbl/minute to pump each ball onto its mating seat.

Once each ball found its seat, the pressure was increased until the shear screws sheared, allowing the sleeve to move down to the open position. This allowed stimulation of the new zone through the sleeve. After stimulation, all six balls were flowed back to surface and caught in a ball catcher during the clean up flow.

### Completion Installation - M3, M4 and M5

After the successful installation of the seven-packer completion in M1, it was decided to attempt maximization of the number of zones for the next three wells. After careful consideration of ball/seat bearing areas and ball/seat clearances, it was decided to optimize on ten individual zones (nine ball /seat configurations plus the zone below the lower packer).

It was also decided to fit annular pressure release assemblies to the PBR/seal assemblies so that the main completion could be run in one trip without fear of premature release of the PBR/seal assembly. Flutes were machined in the gauge rings of the packers to increase the flow rate past the OD of the packers while running in the hole.

The most significant change for the next three wells (apart from the additional 3 zones in each) was the replacement of the simple pump-out plug with a cycle plug carried in a shear-out sub. This change was made as a result of the problems experienced during the well M1 completion.

In these three wells, a mixture of phenolic plastic and coated aluminum balls were used. Phenolic plastic or aluminum balls were chosen dependent on the anticipated fracture gradient of the zone being treated. Once all ten zones had been individually stimulated, all nine balls were flowed back to surface where they were caught in a special ball catcher.

In the first two wells with ten packers/nine MSAF tools, M5 and M4, the completions were completed without incident. However, things did not progress as smoothly on M3, and a potentially disastrous situation developed.

After the M3 completion had been run, the packers set, hanger landed and the tubing tested, it was found that the cycle plug could not be expelled. To make matters even worse, the secondary pump-out shear ring also refused to shear. This was a serious problem as without a pumping path for the fluid to follow, it would have been impossible to get the balls down to their mating seats.

After numerous pressure cycles at the maximum allowable surface pressure, a leak developed in the completion below the upper packer. At the time, it was impossible to determine where the leak was, other than it was below the top packer. However, the fact that there was now a flow path meant the balls could now be pumped.

As it turned out, the smallest ball (1.5-in.) never found its seat, but the next ball (1.75-in) found its seat, operated its MSAF tool, and the upper eight zones were stimulated as planned. It was determined that the leak that had developed was between the two lowest MSAF tools as the smallest ball did not reach its seat, and the next ball did. Thus, eight zones out of the original ten were stimulated, and the well was salvaged. Total time taken to install the completions and carry out the stimulations and well tests is shown in **Table 5.**

## Summary of Completion Results

The key elements that contributed to these successful installations were:

1. **Multi Stage Acid Frac Tools (MSAF Tools)**
   The use of lightweight balls to operate downhole tools in a horizontal completion eliminated the need for coiled tubing intervention.
2. **Hydraulic Set Packers with no Mandrel Movement**
   The use of these packers enabled any number of packers to be run in a one trip completion without having to run travel joints between them to ensure that all packers would be set at the same time. The number of packers that could be run was limited only by the number of ball/seat configurations that could be fitted into a 4-½-in. completion.
3. **Annular Pressure Release with Clutch Joint**
   The use of this equipment enabled heavy tailpipe to be run without concern of reliability of shear screws, especially when subjected to applied or induced torque during installation into long horizontal liners. Clutch coupling in closed position allows rotation while running in the wellbore.
4. **Multiple-Pressure Cycle Plug**
   The use of this equipment as a plugging device in the tail pipe allowed various operations such as setting of packers and completion pressure tests to be performed without concern of reliability of shear screws that could be weakened with every pressure cycle.

## Important Points to Be Considered for Future Completions

1. Thorough preplanning of the overall completion program is essential so that contingency can be planned into the program to address difficulties that could occur.

2. Onshore testing needs to be carried out on any operation that has not been successfully performed offshore in the past (flow testing of balls, etc.).

3. The well in general and liner in particular needs to be properly cleaned and conditioned. This is essential for running ten packers in a horizontal liner.

4. Since the cycle/pump-out plug in the tail pipe is the one area in which problems did occur, further development is indicated. Although it appears to be the least important part of the completion system, it is actually one of the most crucial. If the plug expends early, the packers cannot be set, and the completion cannot be tested. If it does not expend, there is no flow path to enable the balls to be pumped to their mating seat.

5. Retrievable seats will make well workovers less costly and risky.

## Future Developments Planned

Work is currently being carried out to further improve the completion system with the following four main areas identified as candidates for improvement:

**Retrievable Seats.** Although this will necessitate through tubing

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