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Enhanced Multizone Single-Trip Sand-Control System Successfully Treats Six Zones in Offshore Indonesia Well

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Abstract

Although multiple-zone, downhole sand-control tool systems have been in use since the early 1990s, these systems had been designed for jobs that only required low-pump-rates with low-pressure differentials. Multiple-zone systems capable of high fracturing pump rates and the associated differentials only recently have been introduced to the oilfield. Although these jobs are becoming more common, most of the completions have been limited to four or five treated zones.

This paper presents a case history from Indonesia in which six discrete zones in an offshore deployment were treated successfully in a single trip. The challenges for this completion were numerous. Manufacturing lead time was very short, and the system would have to be adapted to the unique requirements of the completion design and the use of new components. Since the proppant and pump rating for these systems was based on five zones, rigorous analysis was necessary to ensure that a high pump rate, high differential pressure-rated single-trip, multiple-zone sand-control tool system was capable of treating six zones and that the crossover tool would survive the erosive effects of these extreme conditions.

To provide assurance of the elastomeric seal integrity of the service tool, a testing program was executed for treatments to provide tracking and verification of conditions. Procedures were prepared, and equipment was retained on hand to replace the service tools, if any leaks were evident. Since system installation experience was limited in this area, gathering sufficient knowledge and experience for system deployment had to be addressed quickly. This would require sharing of lessons learned, use of experienced personnel from previous installations, and conducting of detailed training discussions between subject matter experts and service personnel.

Deployment challenges and solutions, successes experienced at the well site, and the actual performance of the operations are discussed in this paper.

Field history

The Bawal field is in the South Natuna Sea, Block ‘B,’ 1,000 kilometers north of Jakarta, Indonesia. The average water depth across the field is 280 feet. The Bawal field was discovered in 1979 in the South Natuna Sea Basin; the field is the Miocene Middle/Upper Arang clastics on the structural crest of the NE striking 4-way dipping anticline, about 5 kilometers long and 2 kilometers wide. The Arang clastic reservoirs were deposited in a fluvial deltaic environment. The Bawal reservoirs consist of sub-angular to rounded, well sorted silt to extremely fine quartz sand. The initial development concept was to drill and complete 2 to 3 subsea wells and tied back to a nearby production facility, Hangtuah, which is 43km away. The first gas production target was 2012.

ConocoPhillips Indonesia, Inc. operates in this area and has completed multiple fields using two dominant completion methods:

1. Openhole stand-alone-screen (OHSAS)
2. Cased-hole frac-pack (CHFP).

The OHSAS completions typically are installed in horizontal wells or very-high-angle wells. The OHSAS requires special reservoir drill-in fluid (RDIF) with $CaCO_2$ to drill the reservoir section, run premium screen, wash pipe, and conduct mud-cake cleanout with acid or EDTA.

Typically, a CHFP is conducted with tubing-conveyed perforation (TCP) and alternate-flow-path sand screen being run in one trip; then, a frac-pack is pumped with visco-elastic fracturing fluid.

In the case discussed in this paper, the operator had planned to complete several wells in the Bawal and South Belut fields, which are located in the Block B Production Sharing Contract area of the South Natuna Sea in offshore Indonesia. These wells were needed to meet the gas production requirements anticipated for the area. These wells were to be completed as subsea wells in 250 to 300 feet of water depth. The reservoirs all require sand control and varying degrees of stimulation, high-rate water packing at rates of 8 to 20 barrels per minute, and fracture treatments at rates of 22 to 35 barrels per minute. The key to optimizing the development of these fields is to ensure that a single wellbore can be used to access multiple reservoirs, and thus, the number of wells can be minimized while maintaining optimum sand control through the use of fracpack and/or high-rate water-pack methods.

Historically, the operator has been completing subsea wells since 1999 to 2000 with downhole sand control using openhole standalone screen for single-zone completions and single-trip fracpack/high-rate water packs for multizone commingled production. For fracpack completions, the completion system used previously was only capable of treating up to 3 zones; hence, the treatment rate per zone became lower, and there was always an issue with slurry distribution. If more than 2 to 3 zones were required per well, a stacked fracpack completion was implemented.

Completing these wells with conventional stacked sand-control methods meant spending many rig days tripping pipe in and out of each well. The single-trip multizone methods previously used in the area typically would provide only a limited pump rate of up to 10 barrels per minute per zone and pressure ratings of 6,000 psi. For the new wells, the required fracture treatments would require a more robust system that would include a pressure rating of 10,000 psi due to sand-out conditions.

Another challenge concerned the fact that commingling these zones into one well has historically resulted in 50% less recovery compared to single-zone completions. Early water breakthrough coming in from one of the zones would cause the well to load up and die. Therefore, the operator also wanted to include installation of an intelligent completion system that would allow zonal isolation without intervention to optimize reserve recovery. The multizone fracpack completion not only would have to be capable of completing up to 6 zones in one run, but it also would have to be compatible with the planned intelligent-system equipment.

For the Bawal project, two other challenges existed. The first concerned the fact that the reservoir has more than ten sand layers in more than 2,000 feet of gross reservoir section; some zones also have bottom-drive water. The second challenge was that some of these zones can water out fairly quickly, and thus, they need zonal isolation and a water-control device.

Several development concepts had been proposed:

- Subsea wells vs. platform
- Well count of 1 to 4
- Sand control method; i.e., OHSAS vs. CHFP.

After performing an evaluation process, the development team determined that using two subsea wells to develop the field would deliver the best economic results. During the early planning stage, two subsea slant wells with OHSAS completions were planned. With further equipment trials, the well design was changed to one horizontal OHSAS completion the second subsea well would be completed with a single-trip multizone CHFP with 6 zonal isolations and 2-7/8-in. interval-control valves.

Well inflow calculations and associated risks can be evaluated with different well completion methods. Generally, openhole completions can deliver higher rates that are almost double when compared to CHFP rates. However, openhole isolation has been an issue for its long-term reliability in field trials and in the industry. The cased-hole fracpack delivers lower rates than those delivered with openhole completions, but case histories from operators in this and other areas have proven that cased-hole fracpacks have provided longer-term reliability. The intelligent-well system (IWS) control valve is another critical component for shutting off a water zone without rig or vessel mobilization, and the direct hydraulic IWS system also has become an industry-proven technology. Economics studies have shown that system reliability is a key factor for the well completion and that the remotely controllable intelligent-well system is an excellent candidate for water control, when the wells are completed subsea. Sand-screen applications with alternative flow paths cannot accommodate the 2-7/8-in. IWS valve installation. Since the Bawal-project challenges differed from the challenges addressed in most of the recent well-completion experiences in the area, a new completion design was needed, if the field was to be developed economically.

Based on the economic and risk evaluations, the enhanced single-trip multizone (ESTMZ™) cased-hole frac-pack tool plus the 6-zone IWS control valve was chosen as the method of choice to develop the Bawal field subsea wells.

Evolution of Multizone Completion history

Generation I

The Beta Field, located nine miles offshore Huntington Beach, California in federal acreage, provided the initial impetus for the development of the first single-trip multiple-zone gravel-pack system (Jeffers et al, 1983). The Beta field development included two producing platforms, “Ellen” and “Eureka,” and one facility platform, “Elly” (Visser, 1982). The first production commenced from the Ellen platform in January of 1981. The multiple-zone generation-1 system became known as the “Beta” system. The generation I system required that two concentric strings of pipe be run from the zone depth to surface to create the circulating flow path needed to perform a circulating gravel pack.

Generation II

The development of the Single-Trip Multizone System (STMZ™) and a Single-Trip Dual-Zone System (STDZ™) were driven by development requirements for the Xijiang project. The Xijiang Project included the development of two fields, Block 15/11 containing the 24-3 Field and Block 15/22 containing the 30-2 Field. Both fields lie 80 miles southeast of Hong Kong in the Pearl River Mouth Basin of the South China Sea (Bennett, J.S., 1996; Jeffers, R.G. et al., 1983; Rogers et al., 1997; Burger, R., et al.; 2010).

The STMZ differed from the "BETA" system in that the STMZ eliminated the need to run an inner concentric string from the surface (**Figure 1**). It also eliminated the handling at surface of the inner and outer string when moving the service string to the next interval to be packed. This was accomplished by adding a retrievable pack-off installed below the upper gravel-pack packer. The retrievable pack-off would seal around the outer flush-joint wash pipe. The pack-off isolated the openhole perforations from the casing annulus, allowing the casing annulus to be used during reverse-out operations. With this enhancement, only the inner concentric string was required to extend from the bottom of the hydraulic setting tool down to the gravel-pack service tool that contained the gravel-pack exit ports.

Generation III

The Generation I and II systems were both designed to handle gravel-pack treatments that used water or a viscosified gel as the gravel-carrying fluid. The gravel-pack treatments were placed at low pump rates and low sand-out pressures; i.e., 5,000 psi or below. The emergence of frac packing as a preferred treatment method in the 1990's led to the upgrading of the earlier single-trip systems to handle the higher sand-out pressures encountered with fracpacking. The pressure rating was raised incrementally to 10,000 psi. This required the use of higher-rated isolation packers andliner-top packers.

Generation IV

The requirements for the sand-face completions for field development located both offshore Indonesia as well in the ultra-deepwater of the Gulf of Mexico actually provided the stimulus for development of an improved single-trip multiple-zone gravel-pack system. The operators had specified a number of system requirements that the currently available systems could not provide. These criteria were:

- 10,000 psi system pressure rating ─ high differential needed for fracpac operations
- No atmospheric traps ─ due to high bottomhole pressures, atmospheric traps could cause component yielding and prevent the initial movement of the tool
- Positive isolation ─ with the possibility of charging formations and the need to prevent losses, the system had to be capable of holding pressure from both directions as well as isolate all other zones when each zone is being completed. This would be accomplished with the use of unperforated inner base pipe for the screen joints. Access to each zone for treatment would be provided by mechanical sliding sleeves that would be closed after each zone is treated. These sleeves are re-opened along with additional mid-zone sleeves for production access for all the zones.
- High-rate reverse outs ─ system would be required to minimize reverse-out rate/pressure limitations due to large pressure drop through the system down to the frac port
- Floating-rig capability
- Weight-down circulate and squeeze positions
- High Frac Rating ─ (45 barrels per minute, 2,000,000pounds of 16/30 bauxite proppant for 5 zones)
- Production setup must allow for frac-closing-sleeve isolation to assure sand control
- System must be testable before tripping into the hole (TIH).

Typically, a single-trip, multizone sand-control system will accommodate between 2 and 4 distinct zones. As many as eight zones have been completed with generation II and III systems. Previous to this six-zone completion, the selected generation IV system only had completed up to 4 zones.

Planning and Preparation

The generation IV single-trip multizone sand-faced completion system was selected for the Bawal, Tembang, and South Belut completions. All the well designs in this project would use a 9-5/8 inch 47 lbm/ft production casing string set and cemented across all zones. The completion design criteria would include 13cr flow-wetted equipment and common Nitrile or Hydrogenated Acrylonitrile-Butadiene Rubber (HNBR) elastomers. Zone perforation selection was limited by a minimum distance requirement of 45 feet between zones. All zones in a given wellbore would be perforated simultaneously via over-balanced tubing-conveyed perforating methods.

As mentioned earlier, the production sleeves in the generation IV multizone sand-face system are mechanically opened for production. For these completions, this was accomplished by running shifters on the lower end of the upper completion production tubing (**Figure 2**). As the intelligent upper completion system is run through the sand-face system, the sleeves are opened. The distance between the uppermost sleeve and the lowermost sleeve was just over 1,800 feet. The distance between the rig floor and the subsea tree was just over 300 feet. That meant that most of the production sleeves would be open when the rig installed the subsea tubing hanger. Since this is an intelligent upper completion, several hydraulic and electrical connections had to be made to the subsea tree. This takes several hours. With open production sleeves in the sand-face completion, fluid losses will occur while installing and connecting the subsea tree. To remedy this, a special sealbore extension was placed strategically in the sand-face system to allow a mating seal assembly to land while making up and connecting the subsea tree. This seal engagement stopped the annular fluid losses during this time. With the interval-control valves closed, fluid losses stopped entirely, until the subsea hanger was ready to land.

The generation IV multizone sand-face completion system has been tested extensively for erosion at maximum pump rates of 45 barrels/min. This testing simulated five discrete proppant-concentration ramp-up schedules to properly test the erosive effects of treating five zones. The system is rated to 3,750,000 pounds of high-strength proppant at up to 45 bbl/min. for all zones combined, with a maximum of 750,000 pounds per zone. For the Bawal well, six zones were treated; initially (**Figure 3**), the plan was to treat as many as eight zones. However, the total amount of proppant expected to be pumped through the system would be less than 200,000 pounds. The totality of the pump schedules was examined and analyzed by subject matter experts based on past experience and testing. The estimated effect on the tool system was deemed acceptable.

Other aspects of performing six to eight sand-control treatments with the same service tool assembly are seal wear and the potential for leaks. System leaks occurring during a sand-control treatment can cause proppant to be placed in the annulus above the packers, which can cause tool sticking. The generation IV multizone sand-face completion system was designed to include a test procedure that had to be followed at the end of each treatment. This testing protocol was documented in the procedure and executed successfully every time. As a contingency, a full back-up set of service tools was kept on location. Thus, in the event of an unsuccessful pressure test, the service tools could be removed from the well, all sleeves closed, and the service seals would be replaced with a new set. The replacement service tools would be run back into the system, the appropriate sleeves opened, and the treatments continued.

Due to the short manufacturing lead-times involved, the sand-face completion design was kept as simple as possible while meeting all of the system and installation requirements. The isolation packers that were run between zones were permanent type, hydraulic-set production packers. Due to the usage of the permanent isolation packers, shear subs between zones were not necessary. Spacer pipe required for proper placement of the isolation packers for each zone was sourced from the operator's supply. The generation IV multizone sand-face completion system's 10,000 psi rating was not required for these completions. A lower pressure rating was acceptable, so the materials selected were of a lower-yield 13% chrome for flow wet components and lighter-weight pipe. This change reduced the manufacturing lead time and material costs for the planned completions. The spacer pipe selected was 6-5/8 in., 24 lbm/ft 13% chrome 80,000 psi material. This caused a reduction in the burst-and-collapse rating of the designed system. This rating is based on the API ratings of the pipe: Burst is 7,440 psi and collapse is 5,760 psi. The expected treatment designs were analyzed, and this pressure rating limitation was deemed as acceptable to the project.

Equipment manufacturing began in mid-April, 2012. The screen used for the system was manufactured in Houston, Texas, USA due to access to the base-pipe required. All other sand face system components were manufactured in Singapore, relatively close to Indonesia. The intelligent upper-completion equipment was manufactured in Spring, Texas, USA. The manufacturing of all of the downhole completion equipment for this project was expedited, since customary lead times would have meant delays in the completion schedule. This created a logistical issue where air freight shipments had to be coordinated between the USA and Indonesia.

Tests performed in preparation for the first installation included burst-and-collapse testing of samples of the actual screen jackets to be used in the system. These tests were ordered to confirm the previously tested burst-and-collapse ratings stated for the screen joints. The repeated tests were performed in Houston, Texas, USA in May and July of 2012. The upper-completion design consisted of an intelligent completion system with interval control valves for each zone run inside the sand-control system. These interval control valves are separated by feed-through seal assemblies that allow the hydraulic control lines to reach all the valves. The design of the seal assemblies and flat-pack clamps provided for some eccentric assemblies in the upper completion. These eccentric assemblies were required to pass through the sand-control system. A successful drift test was performed in Carrollton, Texas, USA using sample components representing the multizone sand-control system and the intelligent upper completion. The test was performed to validate the compatibility of the intelligent completion tools and the ESTMZ equipment. To mitigate the risk of incompatibilities, the drift testing determined the required stabbing forces and validated the compatibility prior to the Bawal, Tembang, and South Belut completions.

The detailed procedures used in completing the Bawal well were created as a result of the close collaboration between the operator and all the service providers. Detailed well reviews were conducted to refine the procedure. A critical well review was conducted to confirm that the equipment for the job was fit for the intended purpose and that the equipment was compatible. Procedures were reviewed to ensure they were complete and correct and that relevant calculations had been completed accurately. The competency needs of the personnel for the job were examined to ensure the needed people were available and assigned, and finally, the potential risks and contingencies associated with the job were discussed and documented. Multiple critical well reviews were held in preparation for the execution of the Bawal, Tembang, and South Belut completions. Subject matter experts from the operator and service providers from the USA and Indonesia were included via global conference calls. In addition, "complete-the-well-on-paper (CWOP)" meetings were held in Jakarta, Indonesia to review the procedure and logistics with the operator and service-provider personnel in detail that would be involved in the job execution.

The perforation gun selected was a 7-in. tubing-conveyed perforating gun with a 14 SPF, 56.5g RDX charger, 45-degree phasing, and 1.29-in. perforation entrance. A bucket test was conducted and witnessed in the TCP manufacturing facility prior to finalizing the TCP gun design; a centralizer was designed to be put onto each loaded gun in order to maximize the inflow area in the perforated casing.

Job execution

The completion equipment was shipped to location, and the Bawal well's completion began in mid-July, 2012. After perforating the well and performing de-burring operations, the sand-face completion system was made-up, tested, and run into the well. During the installation of the ESTMZ system, a majority of the issues encountered were related to the actual make-up of the various components. Since many mating components were constructed of different-material yield strengths, there were different torque values for each. Determining which torque value to use caused some confusion and some thread damages. Once the problem had become evident, the job was stopped, and everyone involved discussed the thread torque values and descriptions, and a chart was created to assist the tong operator. All equipment descriptions and torque values were entered into the torque turn computer before continuing to run into the hole.

Another unique challenge faced during this job was the running of the single-trip multizone system on a semi-submersible drilling rig for the first time. The service specialists identified and tracked their tool positions in the presence of an ever-changing tide and motion compensator. To work around this, the tool men had to establish a procedure to mark positions consistently in the same manner. The floating rig made it very difficult to identify positions within close proximity of each other; the one foot of movement between the treating position and the initial clean-out position was especially difficult to note. To maintain functionality and prevent any delays in reversing out the work string, the tool was moved through the initial clean-out position and directly to the full reverse-out following sand control treatments, while pumping on the annulus and taking returns on the work string.

One helpful tool in the completion was a software package that allows for the real-time monitoring of the downhole tool positions during the job (Grigsby, T., et al. 2012). This monitoring software can confirm the opening and closing of sleeves, service-tool positions, and movement during the job. The use of the software in these jobs was two-fold. First, the software was used during initial system spacing to insure that there were no conflicts between any given tool positions and other operations within the sand-face system, and second, it was used to monitor downhole tool positions and the state of the equipment to confirm successful tool operations conducted by the service specialists on the rig floor. During this job, the software had to be monitored and adjusted for changes in the rig's motion compensator.

The final upper zone was treated in early August, 2012. The six-zone intelligent completion was successfully installed. Subsequent well productivity tests were performed on each zone, and these tests were concluded by September 3, 2012. The total completion time, starting when the sump packer was installed on 23 July, 2012, was 42 days (**Figure 4**).

Lessons learned

The following table defines the lessons learned during the initial installation on this completion project and the solutions and best practices that resulted from the investigations (**Table 1**).

Table 1 — Lessons Learned and Conclusions

Activity	Finding	Immediate solution	Best Practice Developed
RIH 5½-in. tubing below sump seals	Threads on last joint of tubing are exposed while running concentric string	Use box-end thread protector.	Use a work plate fitted to the threads to run the concentric string.
Make up screen, blank and packers and RIH	Difficulty aligning and stabbing bulk-head seals when making up screen connections.	Use lubrication on the seals, align seals by using a man in the 'cherry picker' to align the screen manually.	Use man in cherry picker to manually align the bulk head.
Make up screen, blank and packers and RIH	Damaged two joints; threads are 13Cr, which increases potential to damage threads during make up.	Laid down two joints of blank resulting in NPT. Reviewed procedure and made adjustments.	Power wash threads, use proper amount of lubricant, visually align threads, and make up by hand as far as possible using only one person on the chain tongs. Visual ID on assy.

Torque connections with power tongs	Over torqued connections, due to wrong values entered into computer.	Cross check all torque values according to engineering design. Re-enter all values	Prior to RIH with assemblies, tool supervisor and tong supervisor will input all values into computer. This will be done offline prior to start of job.
Torque connections with power tongs	Wrong descriptions on threaded connections	Cross check all torque descriptions according to engineering design. Re-enter all descriptions	Prior to RIH with assemblies, service supervisors will input all values into the computer. This is to be done offline prior to start of job.
Torque connections with power tongs	Misunderstanding of assembly material: 80ksi Vs. 110ksi	Stop job, pull all engineering data sheets, and confirm torque of each component.	Ensure torque values of every piece of equipment is reviewed prior to job. Conduct thorough internal well review prior to first job of project.
Make up screen, blank and packers. RIH	Drifts for 6-5/8-in.32# and 24# pipe cannot be identified by the naked eye.	Use only the 6-5/8-in. 32# (smaller) drift. Place red tag on 24# drift stating not to use.	Use only the 6-5/8-in. 32# drift during RIH operations.
Make up screen, blank and packers. RIH	Three-way adapter handling sub is not long enough to accommodate the elevators	Cross over to 3 ½-in. EUE lift sub.	Change the design of the three-way adapter to fit the pipe elevators.
Make up screen, blank and packers. RIH	Well-control kill subs are large and difficult to handle	Prepare well-controlled subs by making up with TIWvalve before RIH.	Order new well-control subs for each connection. New well-control subs will be 18-in. and cross over to NC-50 drill pipe.
Service tool movement on a floater	Difficulty to adjust space out to tide change, too many marks on pipe noting positions.	Re-establish positions and clearly mark pipe.	Establish procedure of marking pipe and monitoring tide changes.
Service tool movement on a floater	Difficult to find initial reverse position	Use full reverse as primary reverse out position	Apply *Management of Change* (MOC) on current procedure to use 'full reverse' as primary reverse position during heavy heave situation.
Service tool movement on a floater	Incidental opening of mid-joint production sleeve (MJPS)	Run back in hole and close MJPS. Modify pup joints for that particular zone	When possible, space out MJPS far enough below indicator coupling to avoid this issue.
Real Time Visualization Service (RTVS)	Difficult to keep calibration due to rig compensation	Constant communication between RTVS operator and tool supervisor.	Will make standard to recalibrate RTVS at each indicator coupling.
Perforate well over-balanced	High skin	Under balanced perforation	Use industry under-balanced perforation practice.

Conclusions

Single-trip multizone systems have been in use since the early 1990's, but only recently have proven their value in high-rate fracpack multizone installations. Previous installations with this type of system had been limited to four zones and tested for five zones. By recognizing this limitation, the provision of procedural steps to insure the integrity of the system and service tools and installing contingencies were the keys to ensuring the success of this operation. This successful completion was executed by 1) overcoming time-limitation obstacles, and 2) the open collaboration between the operator and the service providers involved. Predicting potential problems and planning ways to avoid or remedy them proved to be a valuable exercise for assuring success in these operations.

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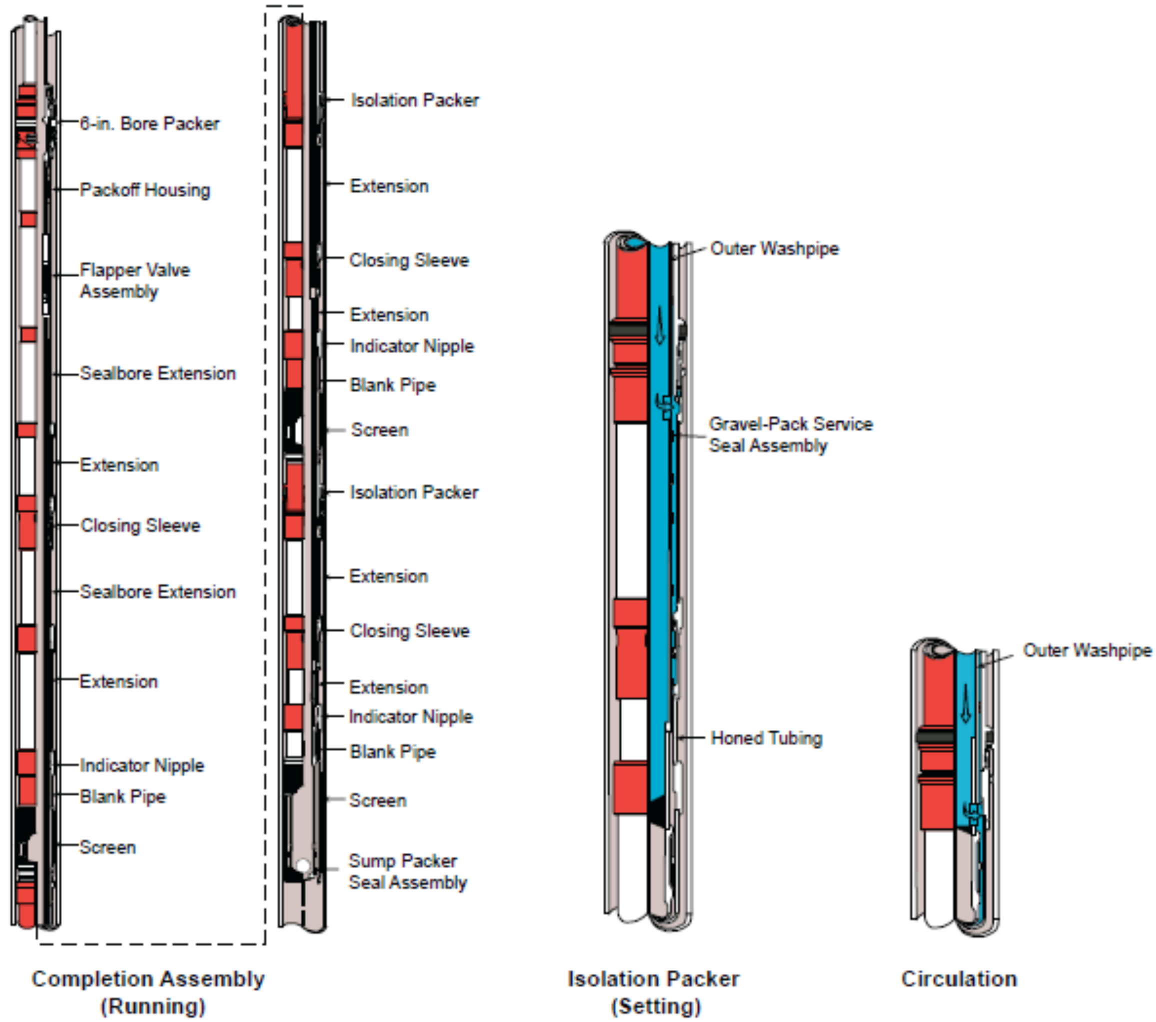

Figure 1— Early Single-Trip Multizone Gravel Pack System

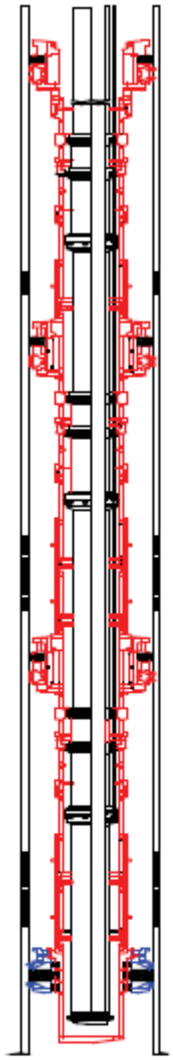

Figure 2 — Generation IV multizone system with intelligent completion.

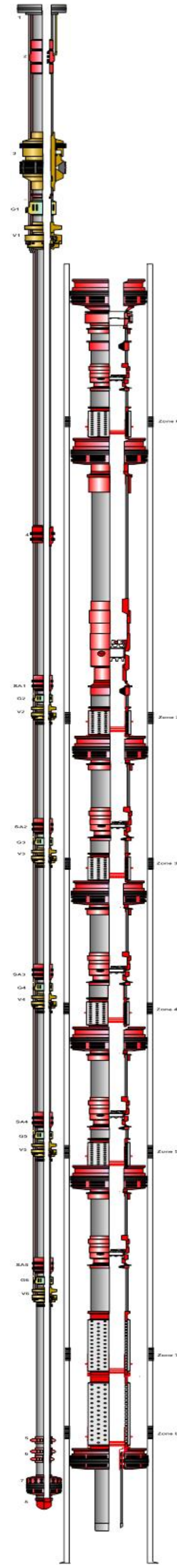

Figure 3 — Single-Trip Multizone Diagram for Bawal 1

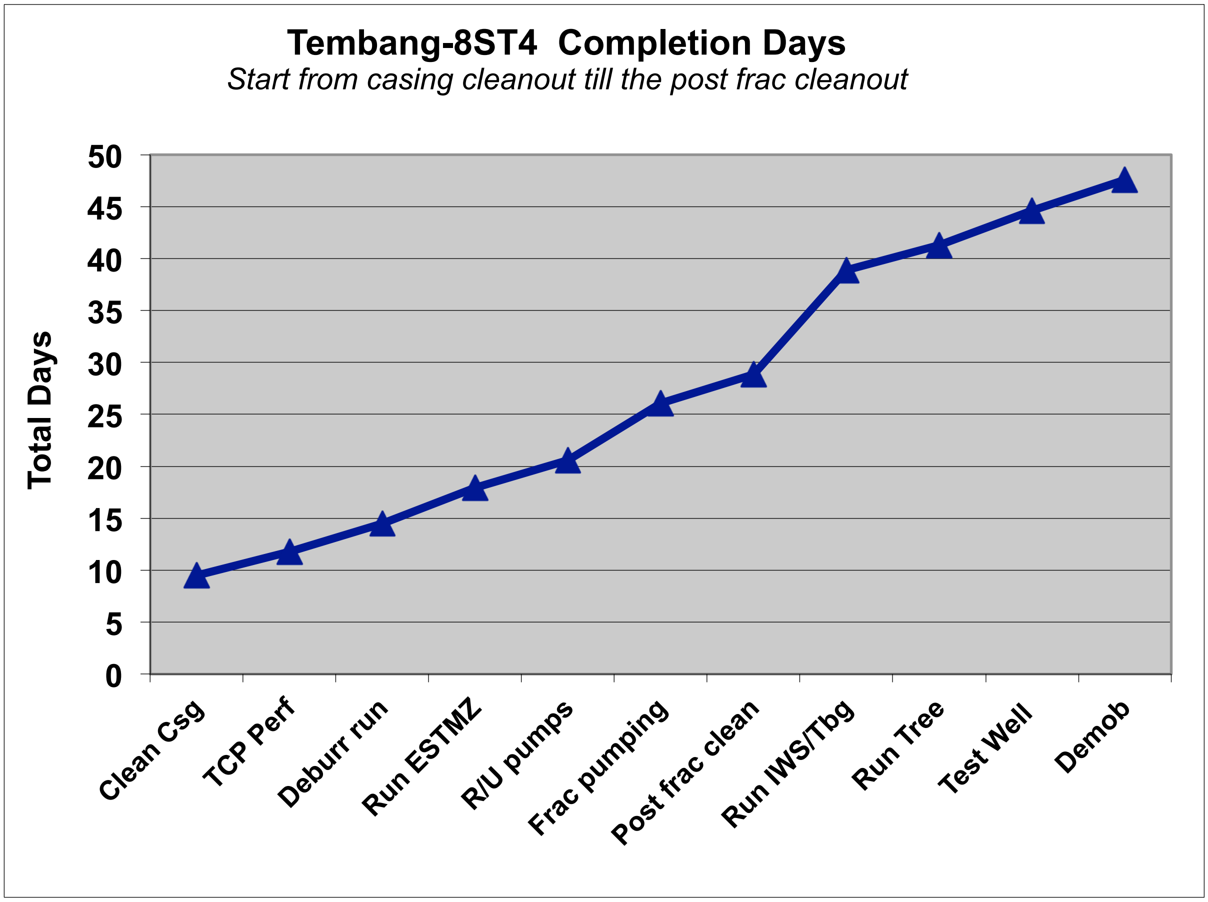

Figure 4 — Completion time detail.