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Design & Implementation of CO2 Huff-n-Puff Operation in a Vietnam Offshore Field

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Abstract

The Carbon Dioxide Enhanced Oil Recovery (CO2 EOR) application to the offshore oil field in Vietnam has been investigated through an international joint study scheme between Japan and Vietnam since 2007 and a preliminary study for potential CO2 EOR application indicated feasibility to some extent. To reduce and mitigate technical uncertainties/risks in the field scale EOR implementation, in May 2011, a CO2 EOR pilot test was executed in a sandstone reservoir of Rang Dong oil field, offshore Vietnam.

The test was designed to be conducted as a single-well test, and generally called CO2 Huff-n-Puff. Major field operations included test string installation, pre-CO2 injection flow, CO2 injection (ca. 111 metric tonnes) and post-CO2 injection flow. Whole operation was performed satisfactorily with all objectives achieved. During the test, clear increment of oil rate and reduction of water cut were observed after CO2 injection as well as oil composition change. The contrast of CO2 injectivity and oil saturation change in the reservoir was confirmed by saturation logs, etc.

Being the first CO2 EOR application in Southeast Asia and also offshore application worldwide is rarely reported, the operational gained is especially valuable. This paper is to describe the process of engineering design, planning, onshore preparation and field execution leading to the success of the project[1].

Introduction

Rang Dong oil field is located approximately 135km offshore from Vung Tau, Vietnam. The field has been producing oil since 1998 from two major reservoirs, fractured granite Basement (BM) reservoir and Lower Miocene (LM) sandstone reservoir.

From 2007 to 2010, a study of CO2 EOR application for sandstone reservoir in Rang Dong field had been implemented. The study result indicated that more than 32 million barrels of additional oil would be recovered; however it will require huge investment for construction of CO2 supply infrastructure, CO2 separation/ recovery, and the modification of existing production facilities, etc. Therefore, CO2 Huff-n-Puff was selected as the first step preparing for field scale CO2 EOR application in the future. CO2 Huff-n-Puff is basically a well stimulation technique in one well, which composes mainly three stages i.e., 1) Inject CO2 into a single producing well [Huff], 2) Shut in the well to allow CO2 to dissipate and dissolve, and 3) Produce the well back [Puff].

Selection of test well was one of critical issues for a successful pilot test in terms of reservoir quality to secure good CO2 injectivity and high reservoir pressure to achieve minimum miscible pressure (MMP) as defined from the study[2] during CO2 injection. The selected test well was an oil producer of BM reservoir, which had well path penetrating LM reservoir at shallower section. The BM reservoir of the well was no longer producing oil and under schedule for sidetracking. Therefore, it was proposed to perforate 9-5/8" casing of the well to access LM reservoir for CO2 Huff-n-Puff test. **Fig.1** is the schematic of test well.

The entire project was carried out on the jack-up rig supported by CO2 workboat, working simultaneously on a wellhead platform (WHP) connected to a central production complex of Rang Dong field. During whole test, oil production from this field was maintained normally through production facility in this central production complex. The operation procedure is summarized as below.

1) Recover existing production tubing. Set cement plugs to P&A the BM reservoir.
2) Perforate 9-5/8" casing on wireline casing gun to access LM section.

3) Install test string and surface testing equipment.
4) Flow the well to clean-up and establish base production rate (pre - CO_2 injection flow).
5) Shut-in the well and run reservoir saturation tool, RST logging #1.
6) Inject approximate 100 metric tonnes (MT) of CO_2 [Huff] from CO_2 pumping vessel.
7) Shut-in the well for CO_2 soak and RST logging #2 to evaluate fluid saturation changes at the wellbore.
8) Open the well (post- CO_2 injection flow) [Puff].
9) Kill well and recover the test string.

Based on the reservoir simulation design, injection volume of CO_2 is optimized to 100MT as minimum volume to sweep the oil near wellbore; the soaking duration is theoretically a time required for mixture and reaction between injected CO_2 and reservoir oil and it is minimized to two (2) days including 1 day for RST logging after CO_2 injection; the duration for post-CO_2 injection flow [Puff] is minimized to four (4) days as a minimum duration to monitor production performance.

Equipment Considerations

Being the first CO_2 EOR application in the region, a number of challenges were encountered in design stage, which were caused by:

1. Unconventional workscope.
2. Limited offshore experience worldwide.
3. Simultaneous operation with production activity.
4. Short time of preparation.

The following sections describe the key considerations and mitigations that led to the success of the project.

Test string

The locally available downhole DST tool e.g., packer, gauge carrier, reversing valve, slip joint, etc provide only 2.25" inside diameter (ID) whereas min ID of test string must allow 3.375" outside diameter (OD) logging tool to run through. Therefore, the new concept of test string was established to use 4-1/2" tubing and downhole completion equipment with min 3.813" ID to make the logging operation become feasible. Additionally, a 5-1/8" big-bore flowhead – an uppermost item of the test string was also mobilized from oversea to satisfy the min ID requirement.

Tubing stress analysis: The liquid CO_2 was stored in insulated tanks at temperature of -24degC and saturation pressure of 250psig. Depending on wellhead injection pressure, the temperature of injected CO_2 will change, and may be as low as approximately -20degC at the wellhead if the heater was not used or it did not work during CO_2 injection accidentally. A combination of the thermal contraction and high bottom-hole injection pressure (max. 5,000psig) was considered the worst case for stress analysis. Sensitivity analysis with various wellhead injection pressures and CO_2 discharge temperature was performed. The analysis result indicated a polished bore receptacle (PBR) was not necessary, however, for the purpose of retrieving the test string at the end of the test the PBR was finally integrated.

Downhole wireless pressure gauges: According to CO_2 injection simulation, bottom-hole pressure during CO_2 injection had to be maintained above MMP of 2,950psig and below anticipated fracturing pressure of 5,000psig. To serve for this requirement, the real-time acoustic pressure gauges were prepared. In principle, it allows acquiring real-time pressure and temperature data from downhole gauges without a conventional wireline deployment, therefore, the on-site well test engineer would be able to monitor downhole pressure and adjust the pumping rate accordingly. The real-time monitoring system also allowed controlling drawdown to minimize the risk of sand production during well flowing, as well as optimize the shut-in time for pressure build-up.

As result of above considerations, the string included 4-1/2" 15.5# PH6 tubing as major part; and disappearing plug (for setting packer), hydraulic-set packer, PBR, wireless gauge mandrel, Surface-Controlled Subsurface Safety Valve (SCSSV), and flowhead as downhole completion equipment. The well schematic during CO_2 Huff-n-Puff is shown in the **Fig.2**.

Material selection

The corrosive agent in LM reservoir fluid of Rang Dong field is negligible; however once injected, CO_2 is present in the wellbore and may cause two issues concerning the integrity of downhole and surface equipment

- First, with inherent nature, CO_2 acts as corrosive agent to metallic components in the presence of water.
- Second, CO_2 is a major contributor to explosive decompression damage to elastomeric parts of equipment. The seals can be damaged in forms of blisters, splitting, and cracks.

The downhole completion equipment: Metallurgy study was carried out to evaluate the corrosion level, then to select the most suitable metallurgy for completion equipment. The study was based on the anticipated well condition that CO_2 concentration from 90% to 50% during 4 days of post-injection flow and bottom hole flowing pressure at around 2,000psig. As result of metallurgy study, corrosion level was not expected to be severe in such a short time of service, L80 13Cr was then selected.

To mitigate the risk of damaging elastomeric parts of completion equipment in case of unexpected rapid depressurization of CO_2 - rich gas, all elastomeric part was selected to be resistant to explosive decompression. In addition, the guideline for bleeding off operation after CO_2 injection was also given to avoid any sudden depressurizations.

The tubing: Although it also exposes to CO_2-rich fluid, the corrosion effect is not critical like completion equipment because the tubing can tolerate the metal loss better than completion equipment while still maintaining its integrity. Another consideration is a short time service i.e., within 10 days after CO_2 injection; the 4-1/2" 15.5# T-95 PH-6 tubing was then selected. In order to control the quality of rental tubing (e.g. wall thickness, structural defects), the EMI (Electro-Magnetic Inspection) was carried out on full length of every tubing joints. The result of wall thickness was also used to determine the metal loss on the tubing by comparing wall thickness before and after the job, that would be a good reference for future use.

The surface testing equipment: The plan was to use specialized piping and elbows instead of Coflexip for the upstream flowline (to connect flowhead to choke manifold) as countermeasure to mitigate the concerns during post-CO_2 injection flow as aforementioned. Like downhole equipment, seals/ packing of surface standard testing equipment were changed to the material which was resistant to explosive decompression damage.

Burning CO_2-rich gas

As result of reservoir simulation, the CO_2 concentration was expected very high (up to 90%) in early days of "Puff" operation, there was a serious concern on burning CO_2-rich gas and oil since the combustion experiments and worldwide experience showed that burning efficiency strongly decreases at CO_2 concentration over 40%. The low efficiency of burning process could lead to several risks for offshore operation:

- Unburned hydrocarbon gas accumulates around the jack-up rig and adjacent production facility that may cause fire or explosion.
- Sea pollution by oil spill.

In land well testing operation, the CO_2-rich gas is commonly cold-vented to the surrounding area; however, this practice is not applicable for offshore operation, especially where the complex of existing production platform is around. The solution was to modify the standard burner booms by introducing an additional gas line from which the hydrocarbon gas, received from adjacent wellhead platform, would dilute the CO_2-rich gas at the burner head and assist the burning process. The construction work included:

- Construct 3" pipelines from the wellhead platform production facility to 85ft-boom burners. The burners were installed on both Port and Starboard side for any change in wind direction during the test.
- Install additional gas line with burner head on the standard burner booms.

Those preparatory works were thoroughly planned and implemented in the manner of minimum impact to production operation. The construction of assisting gas line, installing burner booms and commissioning were completed and commissioned successfully prior project commencement when the rig was working on an adjacent well slot of the test well.

CO_2 Pumping Equipment

Once the project was conceived in February 2011, the operator contacted all major pumping service companies in Vietnam; however, only one service company was interested in providing this service. A huge amount of works were done within a short period of 3 months to complete pumping design and equipment preparations.

CO_2 source and supply: As environmental requirement, the liquid CO_2 had to be mobilized locally and no CO_2 was imported and many attempts was then made to source out liquid CO_2; However, there was no available CO_2 source in the South of Vietnam. The liquid CO_2 was finally purchased from a fertilizer and chemical company located in the North of Vietnam, approximate 1,800km away from Vung Tau. The liquid CO_2 was trucked to the supply base in Vung Tau and transferred to CO_2 storage tanks temporarily installed on a workboat. The route of CO_2 transportation from the source to Vung Tau then to the field is shown in **Fig.3**.

Although the plan was to inject about 100 MT of CO_2, the total amount liquid CO_2 of 163MT (99.97% purity) was trucked, including 25MT for equipment function test and 138MT was loaded out offshore. The extra amount was intended to cover, volume loss during transportation, pressure testing, cooling down equipment and dead volume of CO_2 storage tanks.

Handle cold liquid CO_2: During CO_2 pumping, the temperature of injected CO_2 could be as low as approximately -20degC at the wellhead as explained earlier. There would be several risks associated with this low temperature.

- First, cold CO_2 may cause brittle cracking to the test string.
- Second, such low temperature is beyond the temperature limit of seal/elastomer parts of some well completion components such as flowhead and SCSSV located at shallow depth where geothermal heat was not sufficient to heat up equipment against cold CO_2 being injected.
- Third, ice plug may be formed inside tubing if cold CO_2 is in contact with water present inside the tubing leading to restriction to pumping operation.

Increasing CO_2 temperature became crucial to the integrity of downhole equipment and pumping operation. However, heating liquid CO_2 is not common task in the region; therefore heating equipment was not readily available in the contractor's equipment package. Many attempts were made to source out the suitable heater; the steam-heat exchanger was finally selected with some modifications to make it workable at low temperature.

Equipment function test: Upon arrival of CO_2 pumping equipment to Vung Tau, the equipment was setup in an open yard for function testing, aimed to verify all pumping equipment was functioning properly and adequate to perform planned well treatment. Layout of CO_2 equipment during function test at open yard is shown in **Fig.4**.

One of the most important parameter was the performance of steam-heat exchanger at various pumping rate and stimulated wellhead pressure. The function test was successfully performed with consumption of 25MT liquid CO_2. The conclusions of the function test were as followings.

- Entire CO_2 pumping package including the data acquisition system worked properly and accurately.
- Steam generator and heat exchanger capacity were adequate to heat up CO_2 to required temperature.

Installation of CO2 pumping equipment: Initially, a site survey was carried out on the jack-up rig to examine whether all CO_2 and testing equipment could be accommodated on the rig in term of deck space and deck loading for two objectives: 1) save cost for chartering a dedicated workboat and 2) mitigate the risk of wait-on-weather with CO_2 workboat.

As the result of the rig survey, it was not able to spot both testing gears and CO_2 pumping equipment on the rig due to limited deck space, therefore, a DP2 vessel with ca. 500m2 deck was sourced out to serve as a workboat. The CO_2 equipment package which mainly consisted of 8 insulated CO_2 storage tanks, CO_2 booster pump, 2 triplex fluid pumps, steam generator, heat exchanger, Coflexip, data cabin, and N_2 tank/ converter was installed on the work boat as shown in **Fig. 5**. Whole operation including equipment setup, sea fastening and CO_2 transfer took approximate 4 days. In total, 138MT of liquid CO_2 were equally loaded into 8 CO_2 storage tanks on the workboat.

Offshore Execution

Well preparations

The operation commenced with tubing recovery in the existing BM producer, then a hundred meter of cement plug was set to isolate BM reservoir. The wellbore was then circulated clean and displaced with completion fluid 1.07sg filtered KCl brine. Two 7" HSD 12spf 135/45deg phasing casing guns with PJO HMX charges were run on wireline to perforate 8m of 9-5/8" casing interval. Test string was run and packer was set successfully. Concurrently, surface testing equipment was spotted, rigged up, and prepared for well opening.

Huff-n-Puff Operation

Pre-CO2 injection flow: The well was flowed to clean-up and to get original production data with representative fluid samples for later comparison with post-CO_2 injection flow. The coiled tubing was run and kick-off the well by Nitrogen lift before the well could flow naturally with oil rate of 900-1,000bpd and water cut of 50-60% at 40/64" choke size.

Well fluid (oil/ gas/ water) samples were continuously taken for onsite compositional analysis in order to obtain a baseline of fluid properties before CO_2 injection. The oil and gas composition were analyzed to C36+ and C12+ respectively by gas chromatography every 3 hours. The water compositional analyses were done by titration method using chemical apparatus. In total, the actual quantity of onsite compostional analysis during pre-CO_2 injection flow were 8 for oil, 8 for gas 24 for water.

After 26 hours flowing, the well was shut-in at choke manifolds after confirming thestable flow was achieved. The RST logging #1 was run on wireline to evaluate original reservoir fluid saturation before CO_2 injection.

CO2 injection [Huff]: Upon completion of RST logging #1, the work boat approached the rig and Coflexip hose was picked up from work boat and landed on Coflexip hanger installed on the rig. After connecting Coflexip hose to 2" treating iron run from Coflexip hanger to the flowhead on rig floor, the entire surface treating line from the workboat to flowhead was tested to 5,000psia with Glycol. Pumping operation was then carried out smoothly at stable pump rate of 1.65bpm and calculated bottom-hole rate of 2.3bpm at desired bottom hole treating pressure. Maximum treating pressure was 2,131psia and 4,060psia at surface and bottom hole, respectively. The heat exchanger worked perfectly and delivered desired CO_2 discharge temperature, i.e. 12-15degC. The casing/ tubing annulus surface pressure was continuously monitored from workboat and drill floor during CO_2 injection and the integrity of the test string appeared good throughout the operation. Pumping data during CO_2 injection is shown in **Fig.6**.

During pumping operation, the CO_2 injection rate, pressure and temperature were continuously measured at upstream and downstream heat exchanger. The CO_2 mass was then independently calculated and the results agreed within 1% accuracy. Totally, 111.2 MT was delivered to the wellbore after 7 hours pumping, followed by pumping N_2 to displace CO_2 inside the tubing further down to the reservoir. The well was then shut-in for CO_2 soaking and the RST log to obtain the changes in fluid saturation after CO_2 injection.

Post-CO2 injection flow [Puff]: Considering enough CO_2 soaking time was achieved after 45 hours shut-in, the well was opened at small choke in order to eliminate the explosive decompression damage to elastomer of downhole equipment, and also to facilitate the burning process for CO_2-rich gas by adding hydrocarbon gas from wellhead platform. The choke size was increased stepwise to 40/64" finally and kept flowing for 48 hours as planned. The CO_2 concentration, as expected, was 97% at beginning and gradually reduced to 10% at the end of post-CO_2 injection flow. The assisting hydrocarbon gas was maintained at 2-7MMscfd that effectively burned CO_2-rich well fluid without any critical safety and environmental issues as illustrated in Fig.7.

In comparison with pre-CO_2 injection flow at the same choke size 40/64", oil rate was measured at 1,400-1600bpd i.e., 1.6-times increase with zero water cut in the first 24 hours, which was believed due to the effect of CO_2 EOR. The production performance in pre-CO_2 injection and post-CO_2 injection flow is shown in **Fig.8**.

Well fluid (oil/ gas/ water) samples were taken and analyzed at much higher frequency i.e., every 30 minutes compared to pre-CO_2 injection flow. In total, the actual quantities of onsite analysis during post-CO_2 injection flow were 184 for oil, 184 for gas and 46 for water. A huge amount of dead oil sample was also taken every 15 minutes for future validation.

At the end of post-CO2 injection flow, a memory production logging (MPLT) was conducted on slickline to determine flow contribution from two perforation intervals, followed by downhole sampling with two samples successfully taken. As the result of encouraging oil rate during the test, the decision was made to convert the well into oil producer. The test string was unstung from the PBR. A production tubing string was then run in hole, Xmas tree was nippled up and the well was tied in wellhead platform factility for long term oil production.

Conclusions

- The first offshore CO2 EOR Huff-n-Puff operation was successfully performed in safe and effective manner. The success of the operation was contributed by thorough design, preparation and implementation including equipments specially designed and constructed.
- The integrity of test string was maintained throughout the test. The full length EMI on all tubing joints after the service indicated negligible loss of wall thickness. Logging operation was carried out smoothly through the big-bore test string. The downhole real-time acoustic gauge worked effectively in providing continuous downhole pressure temperature data.
- Good and stable CO2 injectivity at desired bottom hole treating pressure was achieved. The design concept and execution procedure for an offshore liquid CO2 pumping was established including selection of suitable CO2 pumping equipment, dedicated work boat, pumping simulations and function testing.
- All flowing parameters were acquired during well flowback. The increased oil production and reduction of water cut was confirmed in CO2-post injection flow. The effect of CO2 injection was successfully confirmed by production profile and numerical well model calculations[3].
- The CO2-rich gas was effectively burned by application of assisting hydrocarbon gas via the gas line temporarily constructed.
- Following the success of this project, an inter-well CO2 EOR pilot test has been considered as the next step before the field scale application.

Acknowledgements

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Unit Coversion Factors

lb x 2.204622E+03 = mt
degC x 1.8 + 32 = degF
in. x 2.54E + 00 = cm
ft x 3.28084E + 00 = m
bbl x 1.58987E - 01 = m3
Pa x 6.894757E + 03 = psi

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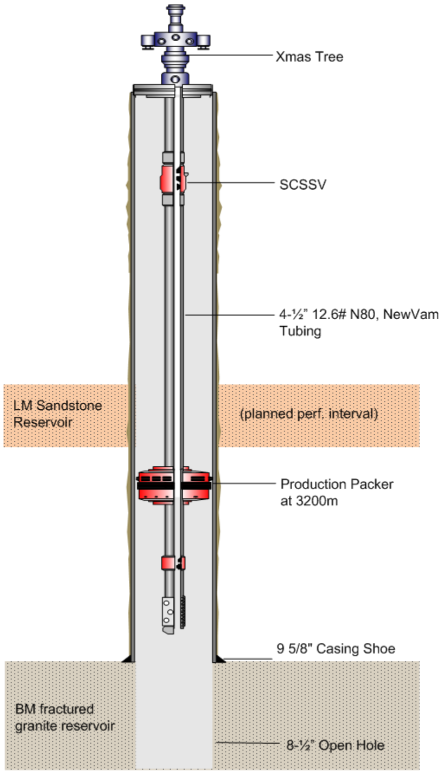

Fig.1 – Schematic of existing BM oil producer

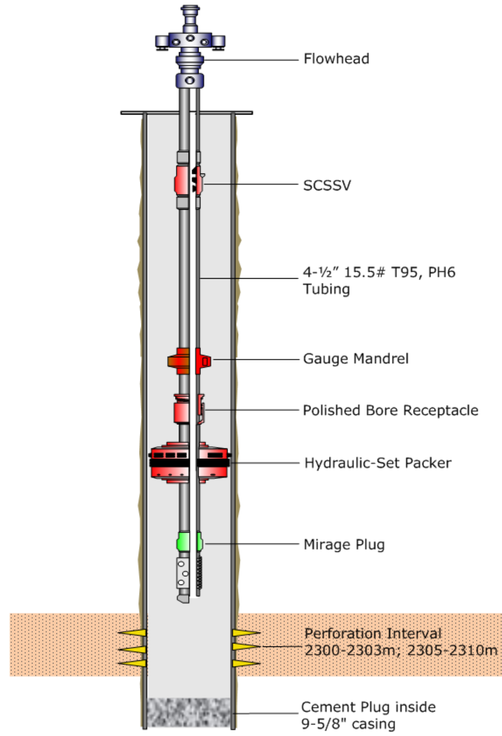

Fig.2 – Well schematic during CO2 Huff-n-Puff

Fig.3 – Route of CO2 from the source to the field

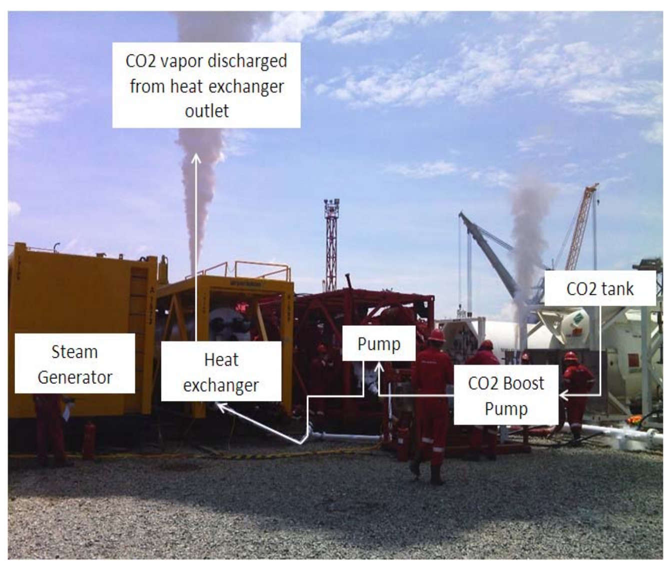

Fig.4 – Layout of CO2 equipment for function testing

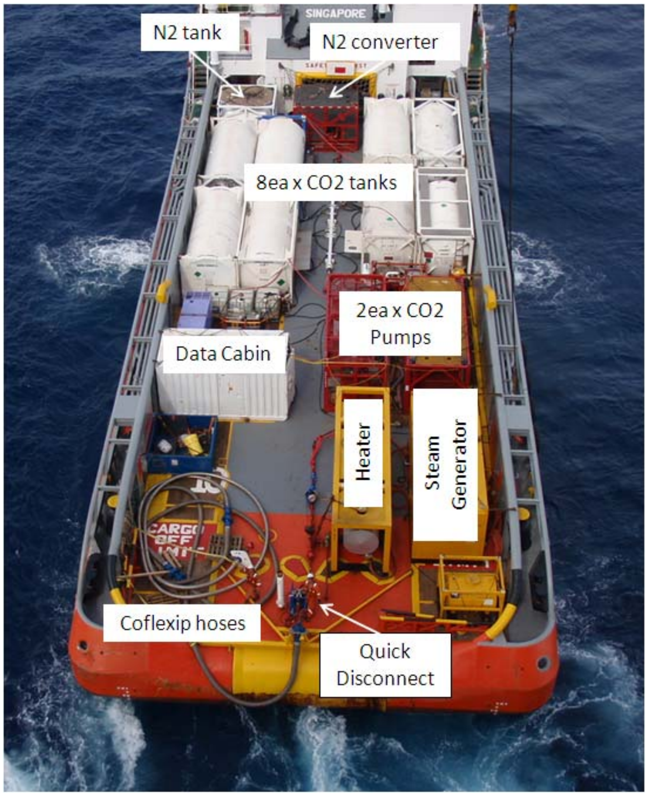

Fig.5 – Layout of the CO2 equipment on the work boat

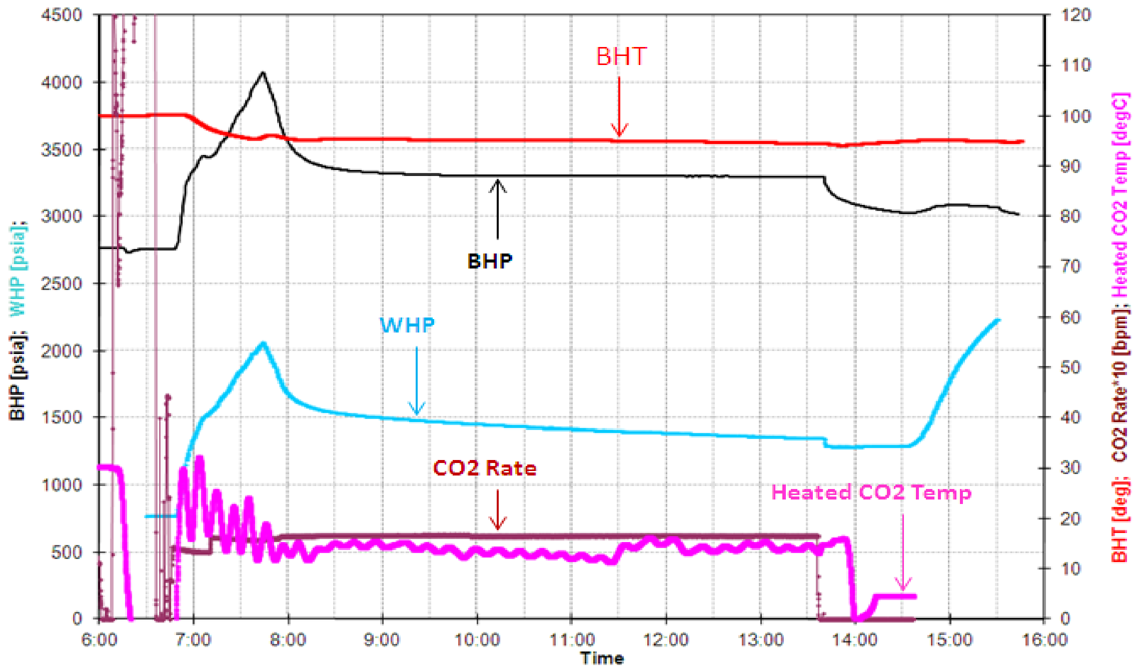

Fig.6 – Pumping data during CO2 injection

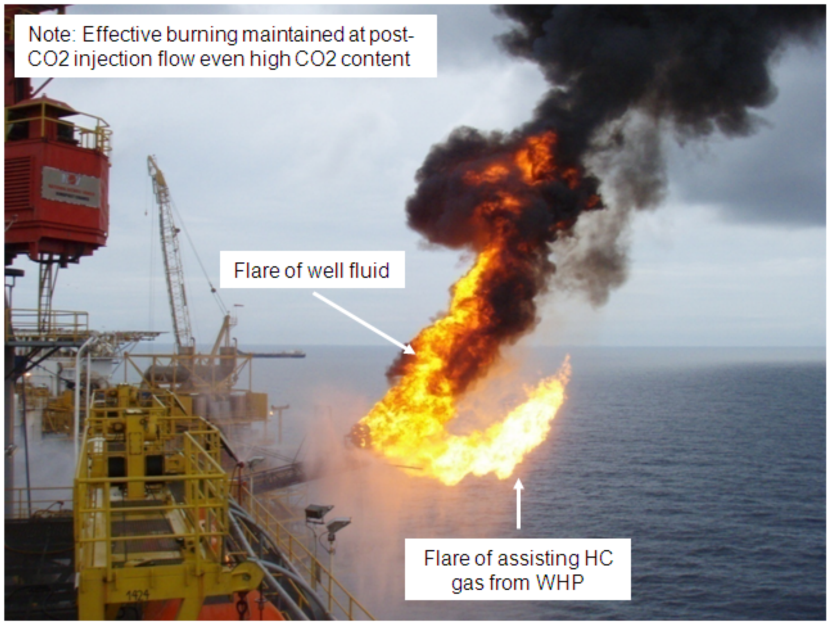

Fig.7 – Burning CO2-rich well fluid

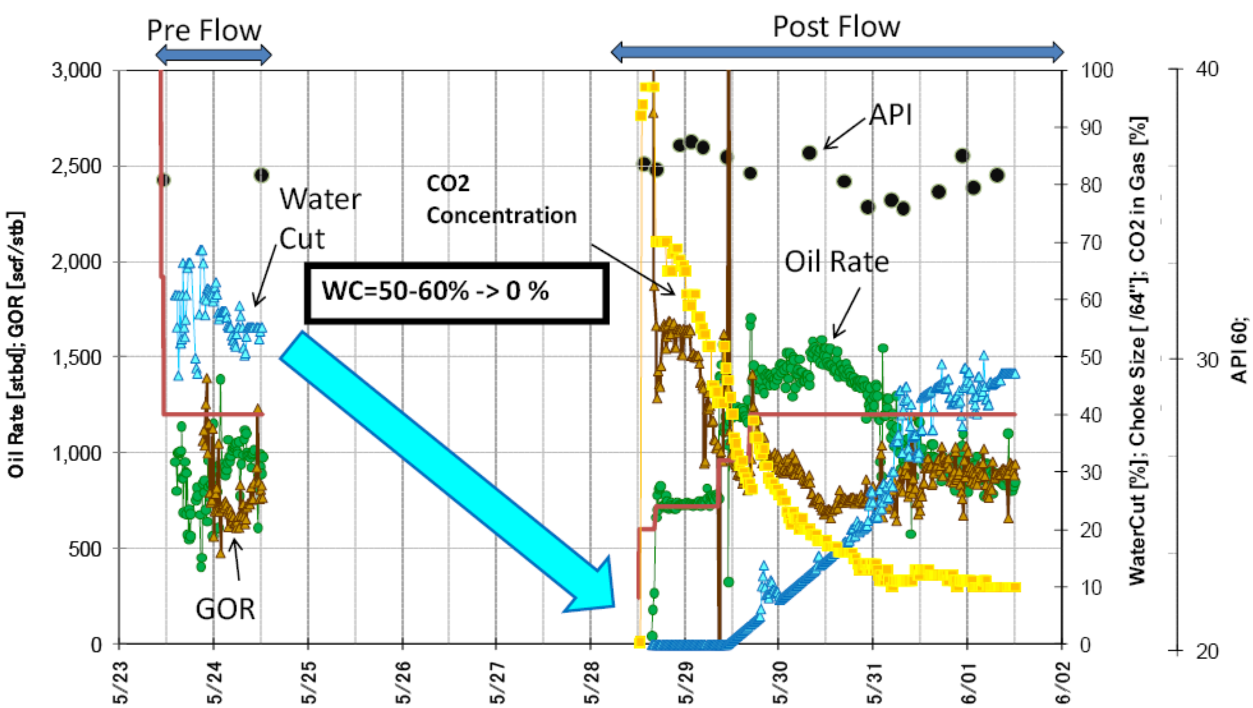

Fig.8 – Production performances in Pre-CO2 injection and Post-CO2 injection flow