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Technology solutions and challenges for marginal development of heavy oil fields in CuuLong basin, offshore Vietnam



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ABSTRACT

The production of heavy oil at Dong Do field located in CuuLong basin is a success in the application of advanced technologies. Dong Do field is a marginal project in Vietnam, so its development requires to overcome several challenges, such as high water-cut from early stage, highly unconsolidated sandstone reservoir, flow assurance problems of sour and viscous crude oil, high power artificial lift system, and complex crude treatment at topsides, among others. Over the past decades, production technology application in heavy oil production has been widely deployed in the industry. Apart from the thermal method, the combination of gaslift and ESP technology makes the remarkable advances by enlarging the draw-down created over the conventional pumping lift in heavy oil projects. In fact, heavy oil production with a high flow rate has appeared water-coning in near wellbore region that made the water breakthrough early and water-cut increased rapidly. The pilot test of injecting diesel into heavy oil wells has been applied to producers with the positive results while significantly reduced water-cut comparing before wells shutin. This paper provides a thorough analysis of the new technologies that are applied to Dong Do field, highlighting its key difficulties and how they were resolved through a successful pilot and testing of the cutting-edge advanced solutions, improving the project reliability and thus motivating the consortium to move on to the new field. Also, the updated new heavy oil field schedule is described, highlighting the challenges to be faced during the next projects of marginal development.

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1. Introduction

Dong Do oil field was discovered in March 2010 by the appraisal well #3 drilled in the central part of BII.2.20 reservoir (Lam son JOC 2016). Based on the oil type classification (Speight, 2014), hydrocarbon in Dong Do field is near a heavy crude oil characterized by the 20^o API gravity and 17 cP viscosity. The question of how to develop this heavy oil at maximum recovery rate and the lowest cost was raised early.

The application of Electric Semisubmersible Pump (ESP) has been common in the petroleum industry (Manoj et al., 2021), but that is still less in Vietnam. Using the ESP lift system to produce heavy oil from only one formation is a preferable concept for this marginal field development with high challenges (Tran et al., 2016). Operators from the neighboring field employed ESP as an alternative method in the case of gas lift system unavailability, but the application in this project is to enhance artificial lift efficiency in heavy oil production (El-Moniem, 2020; Swadesi et al., 2021).

2. Heavy oil production technology for marginal fields offshore Vietnam

2.1. Dong Do heavy oil reservoirs

Dong Do field is located in the northwest of Blocks 02/97 in the northeast area of the CuuLong basin. Three pay zones were discovered in the Middle Miocene Upper - Lower Con Son formations (BII.2.20, BII.2.30, and BII.1.10) in the

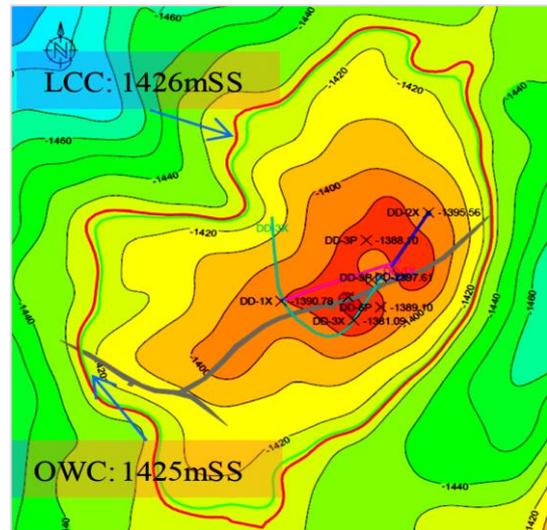


Figure 1. Area of BII.2.20 heavy oil reservoir with well locations (Lamson JOC, 2016).

wildcat wells (wells #1, #2, and #3) as stacked channel sandstones. Each gross sandstone package is about 30÷40 m thick, capped above by 10÷30 m of shale/clay stones.

These reservoirs are trapped within the simple four-way dip and faulted four-way dip closures (Figure 1) of a quite shallow depth (ca. 1200÷1700 mSS) with 60÷90 m relief. Oil-Water contacts (OWC) were encountered in four Upper-Middle Miocene reservoirs as verified with the log results and by Modular formation dynamics tester/Reservoir Characterization Instrument (MDT/RCI) pressures at 1425 mTVDss, indicating that these traps are not fill-to-spill, however, the hydrocarbon columns in these reservoirs are estimated to be up to 57 m (Figure 2).

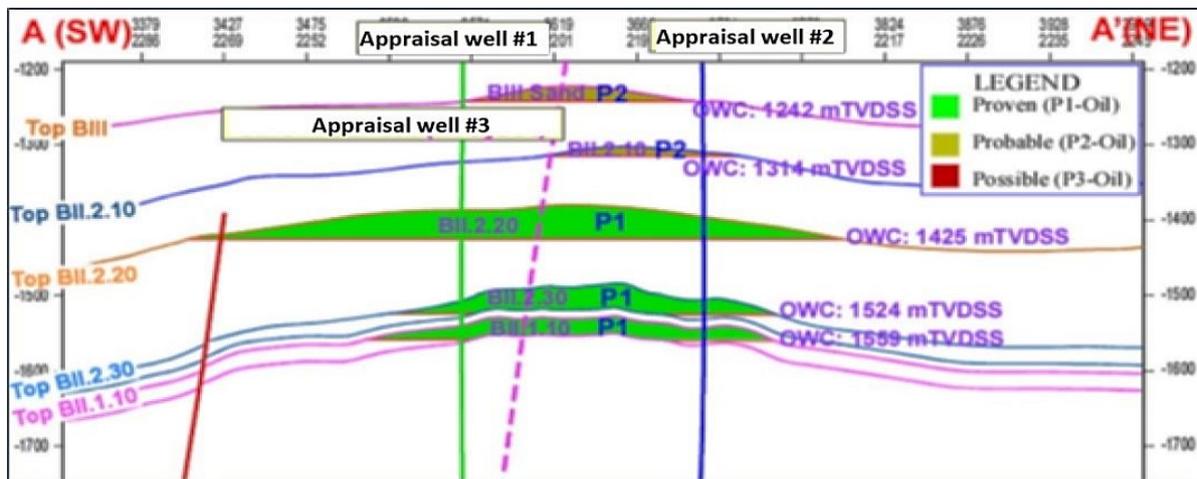


Figure 2. Dong Do heavy oil field cross-section with oil-water contacts (Lamson JOC, 2016).

The interpreted results of the conventional core samples in the BII.1.10 reservoir from well #3 fell into Fluvial and Floodplain sediments: Braided Fluvial, Overbank, Sheet Flood and Soil Facies.

The fluid of Dong Do field is a low shrinkage heavy viscous oil. It has the stock tank gravity of about 20° API and viscosity of 30 cP at the reservoir conditions. At surface conditions 50°C and atmospheric pressure, it has the viscosity of 85cP. With the bubble point pressure of 92 psig and Gas Oil Ratio (GOR) of 10 scf/stb, the reservoir fluid is undersaturated. Another feature of Dong Do crude oil is that it has high acid content with TAN (total acid number) that may vary from 0.5÷1.2 mg KOH/g and sulfur content of 0.3 wt%. This oil has a low n-alkane content, which suggests biodegradation, thus unlikely to cause wax deposition in the pipeline based on industry experience of similar heavy oil and operator's screening criteria. However, it is likely to form stable emulsions, which can expose very high viscosity characteristics and may lead to issues in the operation and production of the field. The compatibility of any crude or organic fluid with the oil should be investigated before being blended or added. Furthermore, it is strongly advised that the compatibility of any completion sequences designed for fluid like this should be investigated. The consistent measurements of reservoir pressure and temperature were achieved in the first four wells using downhole gauges and Repeat Formation Tester (RFT) tools at different depths in all Drill Stem Test (DST) operations. As a function of True Vertical Depth (TVD), the initial reservoir pressure increases from 1,700÷1,900 psia across the hydrocarbon zone while reservoir temperature ranges between 77÷82°C. With the appearance of H₂S in the Dong Do, it gives more challenges for not only drilling but also production well design process to ensure meeting the standards for high-risk operations.

2.2. Heavy oil recovery strategy

The selected development strategy for Dong Do field includes 6 oil producers with neither water nor gas injector. Due to the highly unconsolidated nature characteristics of these

sandstone reservoirs, the production wells have been completed with a slotted liner and screen system for the sand control purpose. The ultimate recovery estimates for heavy oil reservoirs have been made through dynamic simulation for an oil recovery of 16.7 million barrels (2P reserves) or 10% of recovery factor. The field is anticipated to remain profitable at that time and appraisal can be conducted to prove the additional volumes. Because of faster water breakthrough and poorer oil sweep in the wells which is 200 m longer, higher production was not achieved. Moreover, the directional wells are required to prevent operational issues with geo-steering due to highly unconsolidated sandstones of the reservoir. This type of formation is also not desirable especially when considering flow assurance aspects associated with slug flow and ESP operation.

Due to the characteristics of oil (high density, high viscosity, low GOR), the artificial lift is a must in order to achieve production targets. Electrical submersible pump (ESP) is the most appropriate artificial lift system which is beneficial to maximize production rate. For example, to get the average production of 1,500 BOPD, the pressure shall be increased from 1,560÷2,150 psia and thus need a high power ESP system (75 HP each ESP).

Initially, a gas lift was considered as a backup system as the effectiveness of this boosting method would be better evaluated once production had resumed, and would be utilised in the later production life of the field, after the emulsion inversion phenomenon has been seen. Results from the four production wells that have already been used, however, showed that this technology could be used as a backup since the production process began. Unlike the ESP installed downhole, the ESP size for this application is shorter and larger but has the same differential pressure and flow rate specifications. To manage greater free gas fractions, a gas handler is required. This system has significant difficulties from the higher viscosity brought on by the lower flowing temperatures and the less dissolved gas in the seabed position. This method would become the primary artificial lift system once the emulsion inversion phenomenon had reached, thus saving the cost of well intervention operation.

2.3. Submersible electric pump and gas-lift in Dong Do field

The similar data to simulate the submersible electric pump mining (ESP) model are calculated based on well parameters, fluid properties, and referring to the same test results with gaslift support. The results show that ESP's performance is better than that of gaslift (GL) with the stable flow reaching 1,500 barrels per day. ESP can work well with the increase of the water cut to 80÷90% and lower critical pressure and creates a larger drawdown. This will help the recovery factor to be higher than the GL method. ESP adds energy to increase the well-productivity. The equipment has a huge advantage over the GL method in extracting heavy oil with a low oil-gas ratio. This method helps improve the extraction rate to compensate for the decrease in oil flow and

increase the flow of water exploitation.

To optimise the production capacity of the well, the submersible electric pump will be applied to the Middle Miocene reservoir of Dong Do field (BII.2.20 and BII.2.30). The production wells will then be completed with a submersible electric pump combined with a backup gas system from the beginning. The submersible electric pump will be placed at the appropriate depth in the well completion equipment to optimise the extraction flow and be able to work in the harsh environments (sand, H₂S). The schematic diagram of the well equipment using the basic submersible electric pump is illustrated in Figure 3.

Figure 4 shows the equipment string where GL system is placed above ESP packer to provide a backup system as well as the optimisation capability in case of simultaneous production by both ESP and GL (Dennis, 2009; Tran et al., 2016).

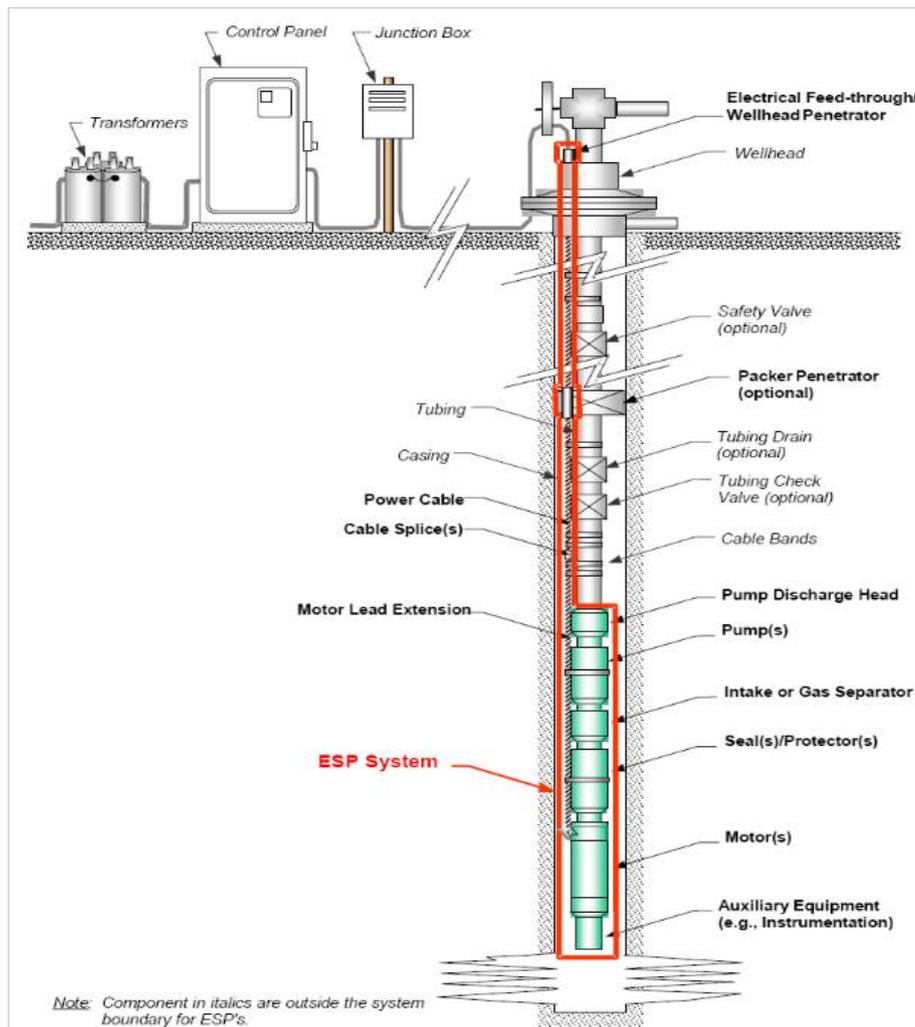


Figure 3. Single ESP system (Dennis, 2009).

Up to now, there have been four production wells drilled into BII.2.20 reservoir (Prod #2, Prod #3, Prod #4, and Prod #6), and one well into BII.2.30 reservoir (Prod #7). All of the wells are completed with ESPs that operate at the designed flow rate of about 1,500 bbl/day (Tran et al.,

2016). The flow rate range operates at a higher efficiency than the initial design. The ESPs have been operating for more than 5 years beyond the manufacturer's recommended replacement time limit (2.5÷3.0 years) as shown in Figure 5.

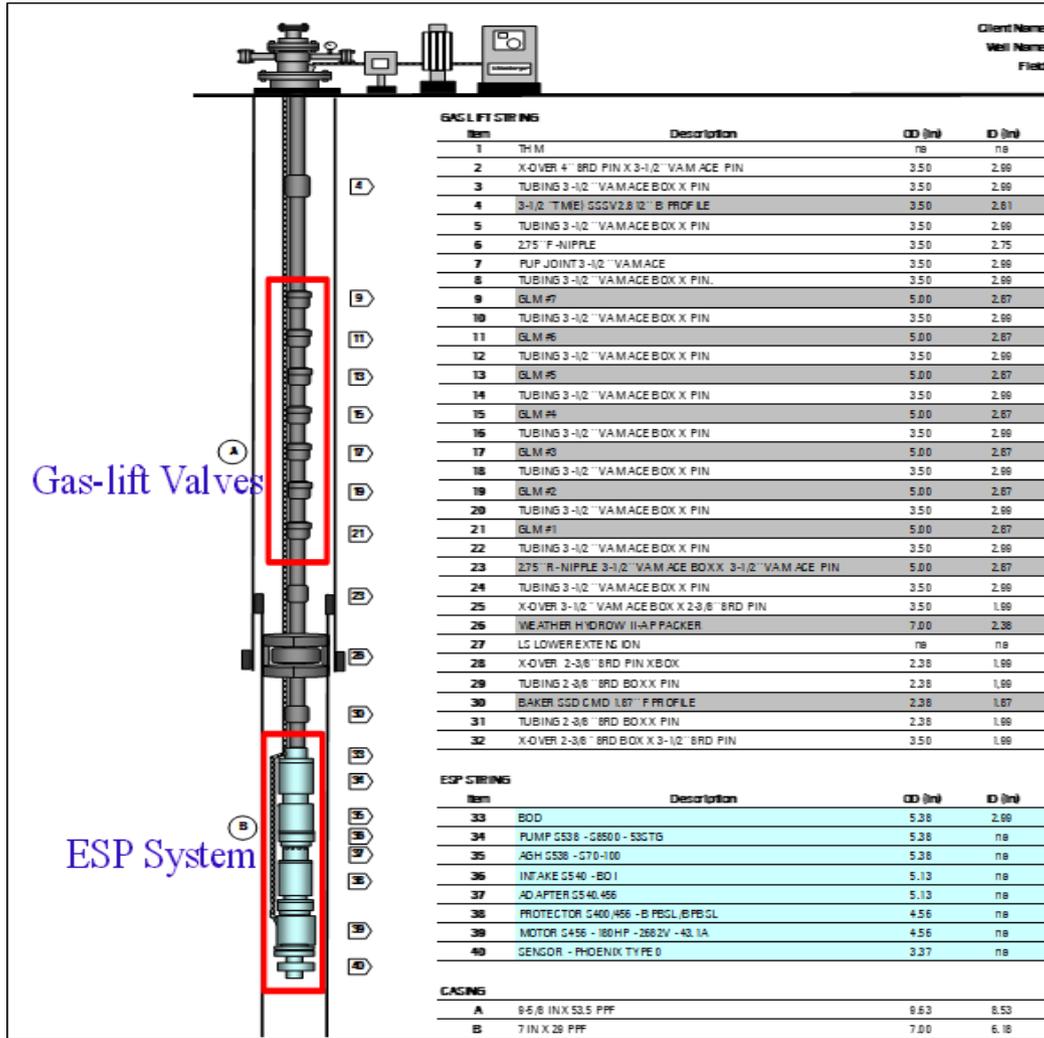


Figure 4. ESP and GL combination system schematic.

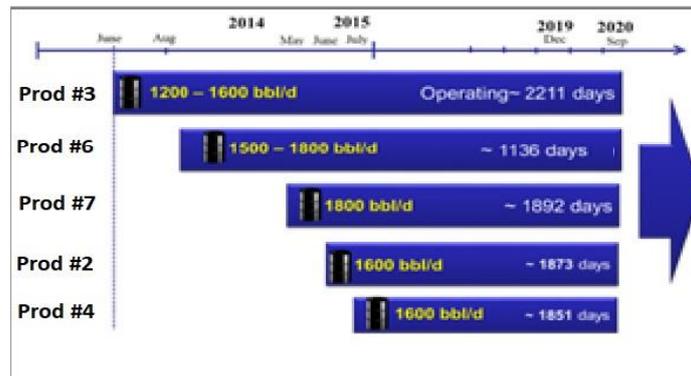


Figure 5. Current ESP's life in Dong Do field.

The actual pump life longer than recommended by the manufacturer revealed the optimal production technology from the design to operation processes. In summary, the success of ESP application in the heavy oil Dong Do field could come from the following:

- Exact evaluation of the rock - fluid, and reservoir performance (low temperature and pressure, low dissolved gas).
- Good design for lower and upper completion (with sand-screen to avoid sand production).
- Suitable selection of production technology with ESP and gas lift back up.
- Continuously monitoring and optimising ESP.

- Studying new solutions to improve ESP performance and enhance heavy oil recovery.

One of the important solutions applied is ESP and GL combination. Figure 6 shows the production performance with primary ESP and dual artificial lift system in the pilot test period (Dec-2015).

The varied injection gas lift rate is tested to analyse the behavior of ESP when supported by GL technique. Table 1 summarised the production performance and ESP action with and without GL (given the same choke size and frequency).

Table 1. Summary well test points for ESP + GL system analysis.

Parameters	Test a	Test b	Test c
Liquid rates (standard barrel per day)	1,340	1,740	1,830
Water cut (%)	72	72	72
Whp (psi)	294	441	448
Gas lift rate (mmscfd)	0	0.2	0.28
Pump discharge pressure (psi)	2,140	2,060	2,052
Pump intake pressure (psi)	1,670	1,650	1,664
Frequency (hz)	49	49	49
Hp (kva)	31.8	31.2	31

Three flow test points were systematically examined with: (A) only ESP, (B) ESP and GL 0.2 MMscfd, and (C) ESP and GL 0.28 MMscf as illustrated in Table 1. The incremental liquid between Test A and Test B is quite considerable around 30% and continues rising with more gas injected. It is noted that the power consumption also slightly reduces by 2% as a result of a lighter fluid column above the pump created by gas lift injection. Reducing power consumption is one of the crucial factors with ESP application of a longer life.

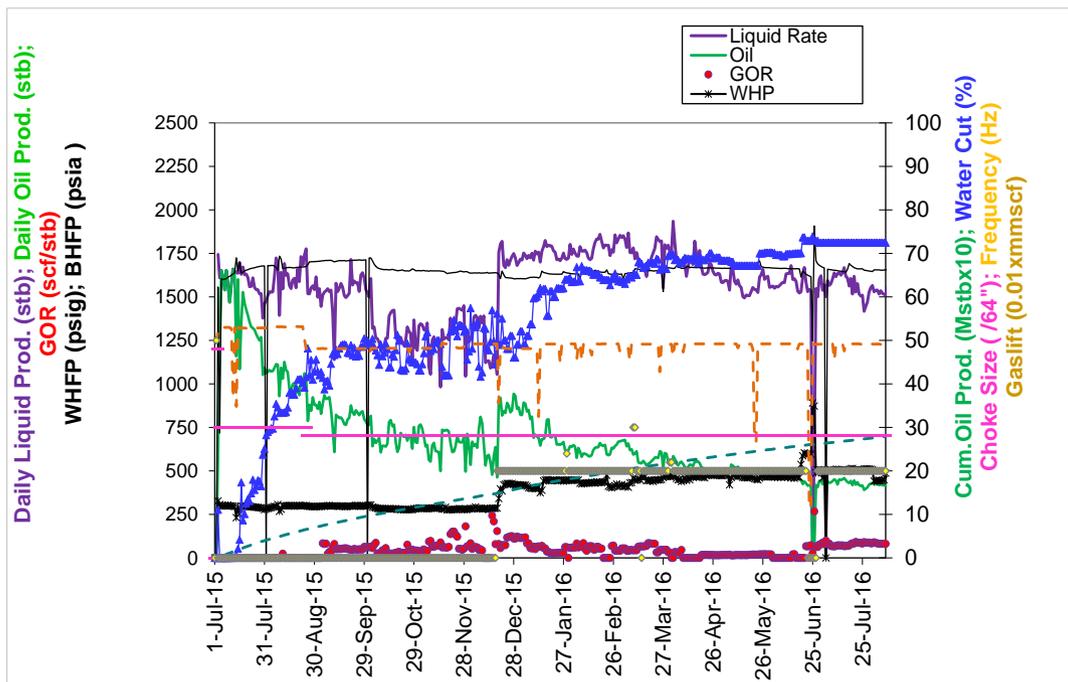


Figure 6. Well production performance with ESP & gaslift combination.

2.4. Diesel injection

In the case of shutting-in high water cut production wells, the water volume will settle down near the wellbore. After re-opening those wells, the oil rate will be reduced, and the water cut is higher than before shutting in. This phenomenon is caused by the effect of hysteresis that reduces oil relative permeability. The application of this hysteresis phenomenon can maintain the production for the high water cut wells after the shut-in stage by injecting non-wetting fluid (diesel). The re-starting of wells after the long shut-in period is easy and the oil production increases by about 20÷30%.

Figure 7 shows the actual oil rate jumps up and the water cut drops down with diesel injection (Nguyen et al., 2020).

One of the solutions improving heavy oil recovery is diesel injection which has been applied in reality. The Prod #3 in BII.2.20 has selected diesel injection to the wellbore. Before shutting-in, this well produced with high water cut, up to 89%, and oil rate at 185 standard barrels per day. After applying diesel injection, the results showed that the well restarted quickly and reached 350 standard barrels per day (excepting for the amount of diesel injection). The oil rate was higher, about 165 standard barrels per day (+ 85%); water cut decreased from 89÷76% (Nguyen et al., 2020). This better production

condition was maintained for 1 month, then the well returned to the previous conditions as before diesel injection (Figure 8).

Up to date, ESP in Dong Do heavy oil reservoir has been operated in good performance (excluding 1 ESP failure due to scale). To achieve success, selecting suitable production technology (hereby ESP and GL backup) is the priority. Moreover, the solutions to improve heavy oil production efficiency have been studied and commenced with the best results, respectively as diesel injection.

3.Future challenges

The success of ESP application in 6 wells has proven the operational feasibility of the development plan conceived for Dong Do Field. For the subsurface development, many solutions to improve heavy oil production efficiency have been conducted by applying the simulation modellings, such as infill wells, water/gas injection, polymer, and diesel injection. The results of the production simulations indicate the challenges of improving heavy oil recovery. Most of them showed quite low recovery factors, excepting for infill wells with the densely well pattern and diesel injection. Thus, diesel injection has been conducted in reality with the positive results, and infill wells are proposed (El-Moniem 2020) in the next phase as a major solution to enhance heavy oil recovery in BII.2.20 Dong Do field.

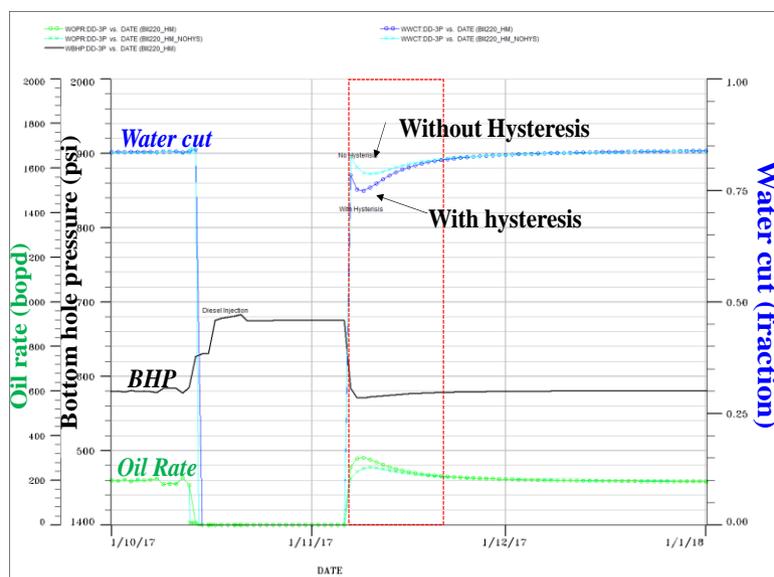


Figure 7. Simulation results of diesel injection application for ESP well.

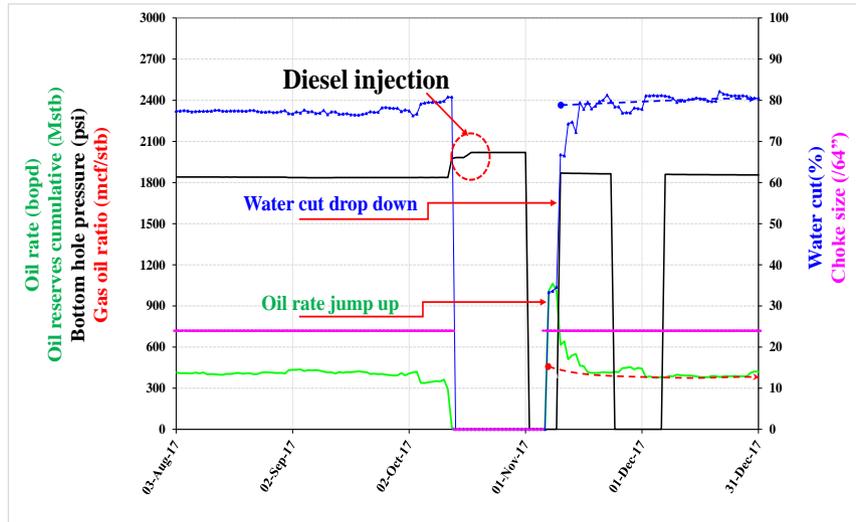


Figure 8. Diesel injection solution applied for ESP wells in Dong Do heavy oil field.

With the first production of Kinh-Ngu-Vang (KNV) oil field scheduled to start soon and the results obtained so far, the flow assurance and processing of this heavy and viscous oil become the main challenges (Wang et al., 2015). Crude oil analysis of KNV displays a gravity value of around 14.6° API, low pour point of 9°C and high sulfur contents of 0.273 wt% and asphaltene content of 7.3 wt% which should be taken into account in terms of HSE issues, completion, and facility design.

As flow assurance efficiency is a key for the success of heavy oil production in CuuLong basin, heat loss of flowing fluid on the seabed shall be taken into account. Additionally, before the first oil, it's crucial to the experiment reliable chemicals to avoid some problems such as high viscosities, scaling, asphaltenes, naphthenates, hydrates, and foaming (Zhang et al., 2019). High viscosity fluid has great impact on the trajectory as it causes more resistance to flow and thus significant pressure drop (Santos et al., 2014). Viscosity of reservoir fluid is affected by temperature, pressure (due to gas dissolved in fluid), water-cut, and shear rate caused by ESP. Despite the low reservoir temperature, controlling viscosity of fluid in the well is easier (Sun et al., 2021). However, fluid viscosity may increase significantly on the sea bed and in the riser, as temperature reduces and the degassing process of the live oil occurs. An experiment of emulsion tendency and stability with increasing

water-cut using synthetic brine has proven that production fluid should be treated with emulsion breaker before reaching the ESP inlet (Swadesi et al., 2021). Viscosity control by injecting drag reducing agent into the oil stream had been also studied (Sun et al., 2021). However, the results of recent lab tests indicated that drag reducing agents were not effective with pure oil and may only be effective with the high water-cut fluid (over 20%). Diesel can greatly reduce the viscosity of heavy oil but it requires a large volume of diesel thus not an economic method. The self-scaling tendency of the Middle Miocene formation water had been proved by two different models. Both these models revealed a potential risk of the calcium carbonate scale deposition, particularly in the high temperature spots, from well downhole (ESP discharge) to topside. Therefore, the scale should be controlled by injection of inhibitors to downhole as soon as formation water flow into the well. Because the oil has a high total acid number (TAN) (10 mg KOH/g), existing emulsions may be stabilized by naphthenates or carboxylate soaps. To assess this risk, a lab test was conducted to determine whether the production system has tendency to form calcium or sodium naphthenates. According to the test procedure established, naphthenates and carboxylate soaps does not pose any issues to the topside processing plant. The other experiment with with different approaches are also being conducted. Asphaltene and flocculation

precipitation of CuuLong heavy oil was also analysed. It is very challenging to predict asphaltene stability based on the dead oil only, thus three different approaches were used: SARA analysis to compute colloidal instability index (CII); Oliensis spot test in which dead oil is titrated with hexadecane to determine the onset of asphaltene flocculation that can be seen on filter paper. The onset of asphaltene by natural depletion from reservoir pressure to bubble point at reservoir temperature is now being determined in experiment with live oil. Once confirmed, asphaltene deposition could be controlled by the chemicals injected at the pump intake. A defoamer additive is necessary to be used because foam is anticipated to develop in the separator at the facility based on Dong Do production performance. For the ease of the operation during well startup commissioning, well shut-in, well restart, ESP restart, and subsea system preservation, guidelines and procedures were written for these operations. In order to avoid difficulty when restarting, produced fluids should be displaced by diesel. The detailed procedures are required for the well startups and restarts to prevent hydrates formation and flow instabilities. During these operations, it may also require thermodynamic or kinetic inhibitors to be injected into Christmas tree to prevent hydrate formation.

4. Conclusions

The successful Dong Do field development was carried out in an exceptional situation with heavy and viscous oil, a highly unconsolidated sandstone reservoir, and marginal economics. To demonstrate that the development concept was feasible, numerous operational and technical obstacles had to be overcome. The execution of the Dong Do field's infill wells as well as production wells in other heavy oil fields was encouraged by good performance of electrical submersible pump (ESP). A major advancement in the artificial lift design was made as a result of the hybrid system of artificial lift technology (ESP supported by GL) helps reduce pump workload downtime and provides the flexible capacity to ramp up production when necessary. The combination system allows ESP to operate beyond its designed frequency/flow rates which

ultimately results in a cost-saving of replacing the new pump and improving oil recovery factor. Diesel injection is a good solution to improve oil production which has been proved by actual results. This solution should be recommended to other operators when the production wells with high water cut.

Since the difficulties regarding to ESP application as artificial lift have been overcome, the flow assurance of this high viscosity oil and its complex processing at the production plant become the main challenges. The intensive studies on these issues are being carried out to guarantee a secure production throughout lifespan of the project.

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Author Contributions

An Hai Nguyen - methodology, writing original draft and supervision; Vinh The Nguyen - writing - reviewing and editing ; Thang Manh Pham - writing - reviewing and editing. All authors are legally responsible for such information.

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