## Unlocking waterflood reserves in remote areas by cost optimization and risk reduction

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**Innovation feature:**

Waterflooding plays a very important role in the optimization of oil recovery factor in the Gulf of Thailand (GOT) and it has proved to be the most economic technique in improving oil recovery from the fluvial stacked sands which represent the most typical reservoirs. Several platforms in Chevron Thailand Operation have water injection pipelines to facilitate implementation of waterflood (WF) strategies. However, many platforms located in remote areas have no available water injection pipeline and thus for many years had not been considered candidates for waterflooding. In 2010, the Sea Water Injection Mobile System (SWIMS) was developed as an innovative solution to address this issue. This is based on a modular and mobile concept which permits the injection of sea water into sands at high rates while still maintaining stable displacements, unlocking WF reserves from the remote offshore oil reservoirs.

Due to the nature of business in the GOT, field development relies on having multiple platforms from which wells are drilled. Classically, primary production strategy consists of perforating individual sands, with gas lift as the main artificial lifting system. Some of the sands are extended reservoirs and can be correlated across large areas. While some areas show strong aquifer support after production, depletion is observed in other zones. Also commingle production and monobore completion constraints result in relatively low recovery factors. Improved oil recovery methods, can increase final recovery factors 2-4 times with waterflooding identified as a high impact strategy. While SWIMS allows implementation of waterflooding in platforms previously considered uneconomic, the incremental production was not always as expected. Initially, being limited to a single injection outlet with the unit's high operating costs and the necessary personnel to maintain 24-hr operation (which has to compete with other opportunities), finding the right WF candidate in the current low price environment became very challenging. Overcoming this challenge required ingenuity.

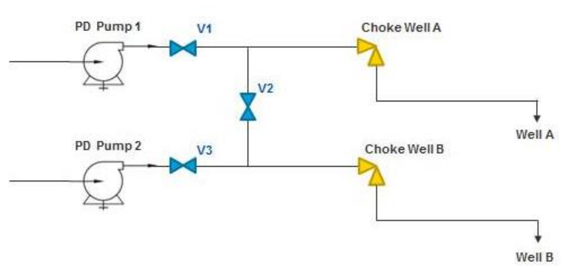


**Figure 1. Diagram of SWIMS with dual outlet modification**

An upgraded design allows for increased flexibility to inject water, using 1 or 2 injection pumps in parallel, and controlling water injection pressure using chokes or discharging directly from the pumps at different discharge pressure and different pump speeds (Figure 1). In case of spare pump capacity, one pump can remain in stand-by improving running time and maintenance frequency. These pumps and manifold configuration were tested and implemented successfully during 2015 where different processing rates and injection pressures were required in the multiple WF targets identified in the platform (Figure 2).

The team conducted a comprehensive lookback on past SWIMS projects and recognized lessons learned and best practices. Key data was collected and used for fit-for-purpose modeling and simulation to select the best reservoir candidates for short response time and incremental recovery of multiple reservoirs present at the same platform, for example at platform A. One primary and two secondary, smaller WF targets were identified and characterized, with the objective of processing them simultaneously. This allowed for lowering the unit operating cost per barrel of oil and at the same time, making it possible to water flood and optimize oil recovery from higher risk and marginal smaller reservoirs.

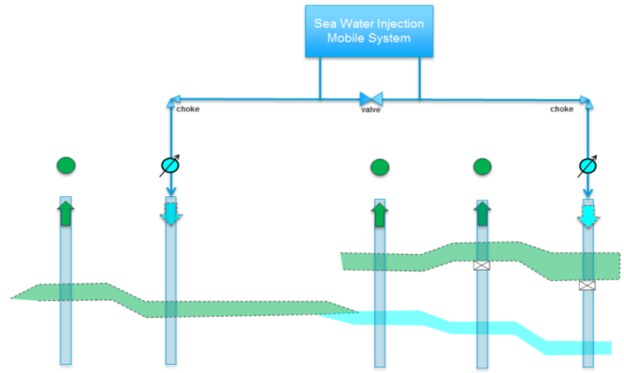


**Figure 2. WF targets located in one of the platform's fault block**

**Thailand E&P Industry impact and values**

As a result of the maturity of the GOT assets' development, the WF opportunities located in areas with water injection pipeline are reducing in size and number. Figures 3 & 4 show the WF stages toward execution reflected from 1 (Identification of opportunity) to 5 (Implemented opportunity), for both types of WF candidates (associated with line injection or SWIMS). These plots show that more than 50% of the remaining WF objectives require SWIMS operation and target smaller reservoirs, compared to the WF projects executed in the last 10 years, with estimated OOIP up to 40 MMSTB. By processing multiple WFs at the same time with SWIMS, we were able to reduce our projected operating cost & personnel requirements by 50%, pushing the limits of the SWIMS usage. The dual outlet setup let us combine medium and low-risk WF opportunities at the same operating expenses. Furthermore, combining marginal WFs with the primary target, allow us to access reserves that, while competing for resources with other operations (Figure 5), would be uneconomic on a standalone basis in a challenging oil price environment Thanks to the improvement in the reservoir management plans and operational considerations this strategy is currently our asset's 3rd most economic production driver. Significant challenges to implement Platform A

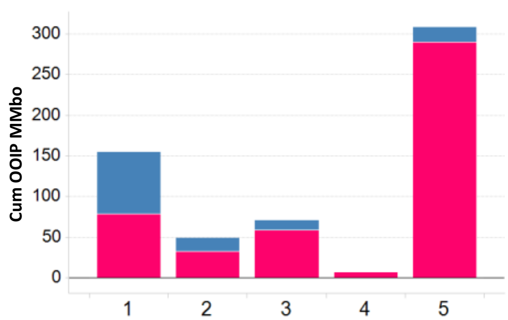


**Figure 3. Target of cum OOIP opportunities (blue: SWIMS; red: pipeline) and development phase.**

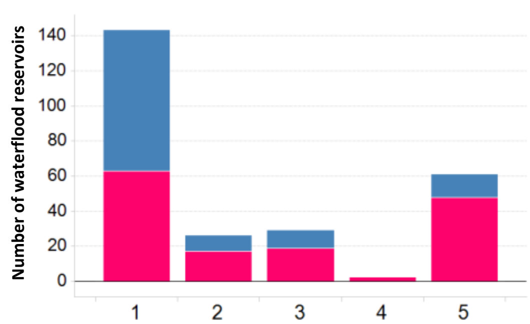


**Figure 4. Number of reservoirs (blue: SWIMS; red: pipeline) and development phase.**

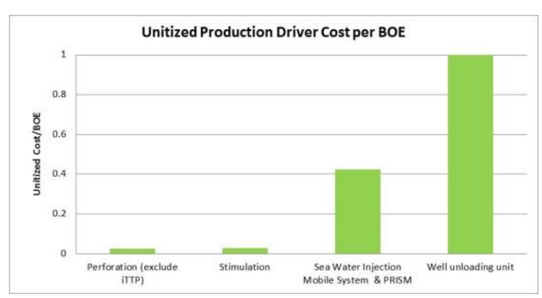


**Figure 5. Operating cost for SWIMS dual outlets compare to classic operation expenditures**

project included DMF approval packages for wells' conversion, building the production baseline, bottom-hole pressure data gathering, communication plans with offshore personal, and reservoir surveillance monitoring tools setup. Setting of the injection pumps and sea water lifting pumps capacity was also required. The use of a dual water injection outlet with flow metering system and realtime data provided full control on the water injection rates, increasing the chance of success. For the platform presented a 6 month period of dual outlet injection is generating 0.6 MM$ of savings, reducing operating time in 33%.

The comprehensive surveillance plan involves a monitoring program for Chloride content (Figure 6) which help us to identify water breakthrough, working as a cheap tracer with low laboratory cost and simple technical requirements when compared to more expensive conventional tracer job . This data supports a proper study of transit time and water distribution for future WF enhancement projects including realignment and Enhanced Oil Recovery (EOR).

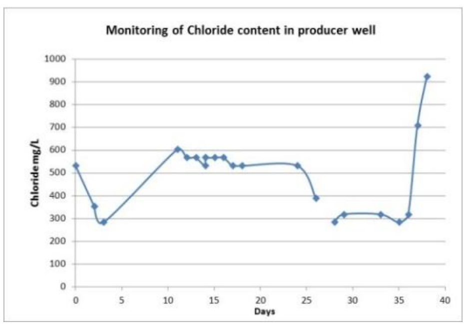


**Figure 6. Chloride content in producers**

The 2015 initial results for the primary target using SWIMS are very encouraging: oil rate increased 4 times with very low water-cut; this result accounts for 50% of the platform A oil production. The second target is currently being flooded concurrently, while the team is completing the implementation of procedures to begin injection in the third WF target. Evaluation of changes in the contract, in order to improve the capacity for sea water injection, operation constraints and to further increase the number of water injection outlets to three is our next step in the challenge of improving cost efficiency ratios and our success rate in remote areas. Over 100 MMbo of resources requires SWIMS due to remote locations with average oil in place of 1 MMbo per reservoir which can represent over 45 MM$ investment. Potentially targeting 19 platforms and reducing up to 60% the total time required to process all the WFs can generate 30 MM$ savings developing 6 to 9 MM barrels of oil from previous expensive and inaccessible areas; bringing a new value for the Gulf of Thailand.

**Why this project should win the award**

Dual outlet strategy using SWIMS represents more than 10% of the current WF production and has the benefit of: 1. Economically waterflooding marginal and riskier reservoirs located in remote areas which represent 50% of the remaining WFs in our asset, to gain incremental oil in the current challenging price environment. 2. Reducing the SWIMS operating cost per barrel of oil by 50% for the primary and the overall multiple reservoirs WF program of the platform. 3. Lowering the abandonment oil rate threshold for individual reservoirs when SWIMS unit is taken out and water injection is discontinued, thus maximizing the ultimate recovery of the waterflooded reservoirs. 4. The possibility to increase to triple outlets for simultaneously injecting in multiple reservoirs can eventually optimize the operating cost and recovery in remote areas.