ICD's* OH Completions Success in Pan Orient Energy (Thailand) Production Transformation: "Reviving Horizontal Wells' Oil Recovery in Shallow Volcanic Fractures Reservoir"

Edward Bush (SPE Member #0512020), Pan Orient Energy (Thailand);
Gordon Goh (SPE Member #3221475), Bomb Pluksataweekul (SPE Member #3092275), Troy Fields (SPE Member #3058336), Schlumberger Overseas, S A. (Thailand)
***Note: ICD's = Inflow Control Devices**

Located in central Thailand in Wichian Buri province, concession L44 (See Figure 1) has been operated by Pan Orient Energy (POE) since 2005. Since the takeover of operatorship of the L44 concession by Pan Orient there have been 8 oil discoveries in unconventional fractured volcanic reservoirs and 3 oil discoveries in conventional sandstone reservoirs (See Figure 2). During this period, POE has substantially increased oil production to a peak of 7,000 BOPD net (i.e. 11,600 BOPD gross) through an intense exploration and appraisal drilling program. As indicated in Figure 3, production rapidly dropped off from the peaks as the volcanic reservoir macro fractures were drained at high initial flow rates (i.e. 1,200 to 5,000 bopd per well) leaving a substantial volume STOIIP behind (i.e. 92-88% as estimated from independent third party volumetric and material balance estimates) in the much lower permeability (i.e. 0.1-30 milli-darcies micro fractured matrix.

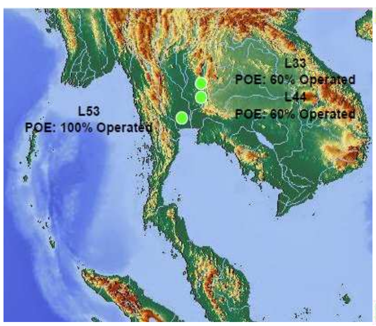


Figure 1: L44 oil field location in Thailand mainland

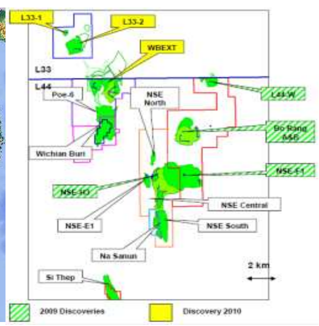


Figure 2: Bo Rang asset where first ICD's is deployed successfully

Further complicating long term production profile estimates and contributing to the low primary recovery factor is very strong aquifer present observed in all the volcanic reservoir fields. Super-permeability, steeply dipping macro fractures fractures (i.e. greater than 7 Darcies) containing less than 14% of the STOIIP quickly deplete of oil and thereafter act as major conduits for water from the large underlying water aquifer. This results in limited drainage/contribution from the lower permeability micro fractures.

The challenges of developing these types of unconventional reservoirs are many:

1. Being "shallow" at TVD's of 400-1,100m results in low initial reservoir pressures of between 800-1,200psi, resulting in low later well life deliverability.

2. Uncertainties regarding fracture extent, network and connectivity making initial reservoir modeling highly uncertain or almost impossible.

3. Massive drilling fluid losses (i.e. greater than 5,000 barrels) while drilling the reservoir section often resulting in "drilling blind" for extended periods of time.

4. Huge permeability contrasts between fracture systems results in highly variable inflow parameters for horizontal wells resulting in premature water breakthrough as outlined earlier.

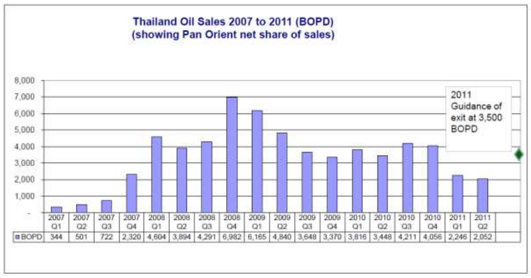
Point 1 is easily-addressed with the ESP and SRP pump assisted lift for production. Point 2 can be addressed through: a) sufficient well date with fracture detection and conventional log data supplemented by core data when practical (this is complicated by Point 3 - massive drilling fluid losses); b) pressure data analysis using flowing bottom hole pressure data from gauges run on most well completions. On point 3, i.e. drilling under total losses, can be managed with the effective use of lost circulation material (LCM) in the drilling mud.

Point 4 has been the most challenging after considering a few water-cut delay/reduction efforts that have come to no avail. Analysis of the production from the 70+ volcanic reservoir wells recognized that after initial water production, the most typical response to reducing water cut (but met with minimal success) was to choke back total fluid production in an attempt to reduce coning and re-establish lower WC % production. In the more serious breakthrough situations, oil from a well went from thousands of barrels at kick-off to completely watering out and being abandoned within months (albeit, often after producing 200,000 or more barrels of oil during this period).

Deeper analysis of well production data highlighted that of the six horizontal/extended deviated wells that were ever drilled, only one had ever completely watered out and had to be shut-in. These 6 wells suggested the simple technique of drilling (perhaps not so simple while experiencing total drilling fluid losses and drilling ahead blind) and penetrating the maximum number of fractures for improved oil drainage with horizontal wells is in itself could be a modest "development break-through".

The only horizontal/extended deviated well that had experienced, at any time during its production life, 100% water production was BR-1RDST1. This well had initially produced at over 800 bopd with limited to no water, shortly thereafter going to a 100% water within a few months time. After a period of shut-in, the well was brought back on at approximately 50 bopd with a 90% water cut (i.e. after earlier cutting 100% water). These results suggested the possibility of oil recharge into the macro fractures from the more extensive and much lower permeability micro fractures and started the search for a technology that would take economic advantage of these observed production characteristics.

It was during this period that POE became aware of significant production success being achieved in the offshore Gulf of Thailand and elsewhere using an inflow control device ("ICD") whereby down hole inflow is balanced heel-to toe in a horizontal well bore. Hard data from these ICD's applied offshore wells' post-job production with months of deferred water breakthrough/continued water-free production and later reduced water-cut oil production appeared to be very encouraging and a possible breakthrough in addressing the production issues experienced in fractured volcanic reservoirs outlined earlier. However, these applications had all been in sandstone reservoirs.



2011 first half oil sales of 2,149 BOPD

Figure 3: POE share of Thailand Oil production from volcanic fractures reservoir development quarterly 2007-2011

The ICD's Innovation, Impact and Value:

Schlumberger, being the technology supplier of the successful ICD in offshore Thailand horizontal wells was contacted to determine technical ability, technology/operational limits and risk exposure. Further investigation cross-referenced successful ICD case studies from the middle-east fractured carbonate reservoirs, an analogy in some respects to fractured volcanic reservoirs.

It was decided that despite the uncertainty of the application the ICD technology to fractured volcanic reservoirs, it was worth a try. It was further decided that the ideal well to pilot the ICD technology on was the one horizontal/extended deviated well (i.e. BR-1RDST1) that had at one point in its life watered out completely. The logic behind this decision was that if it worked on this well it should be broadly applicable to any future newly drilled horizontal wells in any field redevelopment scenario that would result in the event of any success in the pilot.

ICD's application has been widely successful in sandstone reservoirs across the globe, starting with first application back in 1999 from the Troll field, North Sea operated by Statoil. In South East Asia sandstone reservoir, Malaysia is the pioneer user in this technology and Indonesia is closely following suit. However in the context of POE's fractured volcanic reservoirs, the most useful technical reference comes from the middle-east carbonate reservoir applications outlined in technical papers: SPE 134994, OTC 20129 and SPE 112471.

As detailed earlier, POE recognized that horizontal wells expose the wellbore to maximum fractures and thus improve the drainage area for oil recovery. However, production data indicated that horizontal wells on a standalone basis cannot guarantee the optimum performance required by distributing inflow throughout the entire horizontal length.

This negative impact of downhole inflow imbalance along the entire horizontal wellbore is much worse in fractured reservoir due to the high contrast in permeability between macro fractures, micro-fractures and whatever matrix may exist. In order to provide an inflow control defense system downhole, ICD's application proved to normalise non-uniform influx that causes sub-optimal horizontal well production. In POE's application of Schlumberger nozzle-ICD's, ICD's pressured drop control on the inflow is achieved purely from the kinematic energy losses (i.e. non-frictional-based pressure loss and viscosity-independent) when inflow across the nozzle aperture is self-regulating on influx control downhole. This is achieved with the Bernoulli's nozzles' principle stating nozzle's pressure-drop, ΔP_N is proportional to 'square of inflow velocity', V^2 whereby

$$\Delta p_N = \frac{\rho}{2*Cf} v^2$$

Also,

$$\Delta p_N = \frac{\rho}{2*Cf} \frac{Q^2}{Anoz^2}$$

Two stages of ICD response in POE fractured volcanic application can be described whereby:

Stage 1: A proactive delay in water breakthrough/ encroachment via high-perm fractures.
[High influx velocity (v) due to depletion of the high permeability streaks fractures are suppressed/slowed down by the responding nozzle's back-pressure, ΔP_N quadratically resulting in the benefit of re-distributing the macro production drawdown towards the less productive (i.e. less permeable micro-fractures/matrix) zones so that oil inflow can be promoted from these lower PI zones to create an overall balanced inflow contribution]

Stage 2: Reactive water-cut reduction impact.
[It is achieved again by the nozzle's back-pressure, ΔP_N responding quadratically to the in-surging of the higher mobility velocity phases (i.e. usually water/gas compared to oil) from the higher-perm fractures as compared to lower-velocity fluid dripping-in from the lower-perm micro-fractures/matrix where it usually contains the lower mobility oil or lower water-cut mixed oil influx]

The combined result of the two stage reaction is a more distributed well clean-up achieved from heel to toe in a fractured reservoir horizontal well. This is the precursor to facilitate the maximum impact of a horizontal to re-distribute inflow and sweep across the entire length drilled. Otherwise, in a conventional non-ICD horizontal, the norm is usually that only 1/3 of the horizontal section is contributing. In POE's fractured reservoir example, this 1/3 figure is likely substantially less where only one large macro fracture may be contributing oil production. As a result, within a period as little as one month, the oil charged fracture is over-drawn and the underlying aquifer influx breaks through this single, large fracture. ICD technology thus creates an overall more balanced influx from heel to toe enabling better sweep and more oil contribution from the micro-fractures resulting in longer term productivity.

In the POE/ Schlumberger collaboration applying this innovative ICD technology solution, a few non-conventional production innovations will be used based on the success of the BR-1RDST1 ICD pilot and will be standardized for use in future wells, these include:

1. On high water-cut wells, instead of choking back at surface and/or performing cyclic production, a sequential increase of ESP pump rate to induce more / effective downhole influx balanced by ICD's nozzles will be established. This has revived an existing close-to-abandonment well (i.e. BR-1RDST1) from a declining 50 BOPD (i.e. pre-ICD) to production > 200 BOPD post ICD. This is a significant result as depicted in Figures 4 and 5.

2. Instead of halting drilling when a single major fracture is penetrated, in order to achieve higher recovery factors and more sustainable oil production, longer horizontal wells utilizing ICD technology need to be drilled.

3. The issue of low reservoir pressure support in the shallow volcanic reservoirs compromising ICD's required downhole sacrificial pressure drop is resolved with the optimal utilization of ESP lift force. Hence, in future large fluid capacity ESP's are planned to induce more rate to insure effective downhole inflow balancing for future ICD horizontal wells

4. Rather than completing the open hole horizontal section with simple slotted-liner or left barefoot, ICD completions with multiple water-swell and oil-swell packers for annulus isolation are now deployed integrating wireline and mud log data to optimize design parameters and nozzle-sizings. The use of the above data and summary of mud losses versus depth, provides the background parameters for the placement of swell-packer placement and how many to be applied.

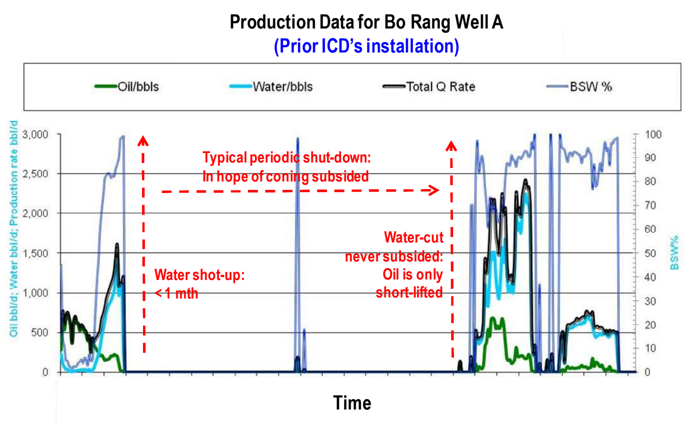


Figure 4: Horizontal well barefoot production prior to ICD's

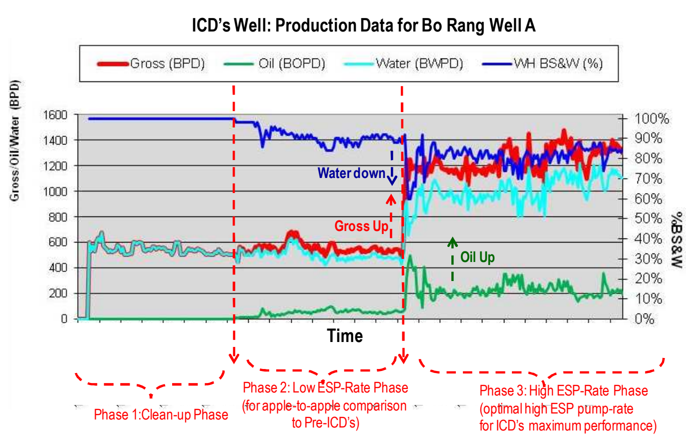


Figure 5: Production upon recompletions with ICD's

In summary, the ICD's technology application using the existing BR-1DRST1 well as a pilot was a highly successful result substantially increasing the oil production by a factor of 4 from a "worst case" well where oil had decreased from an initial rate of 800 bopd to the pre pilot rate of 50 bopd at a water cut of 90%. The implications of the future use of horizontal wells utilizing ICD completions in existing field redevelopment and new field development are potentially very positive from both a reserves and economic point of view. The collaboration between Pan Orient Energy and Schlumberger on the ICD pilot at BR-1RDST1 represents the model for a successful relationship between operator and contractor in addition to being a first for the successful application of ICD technology in fractured volcanic reservoirs.

Why this project should win the Thailand Annual E&P award:

The ICD technology innovation defined in this paper has broken away from the paradigm of new innovation that is costly and complicates an existing production/development plan due to onerous costs and operational requirements, not to mention a high failure risk after significant capital expense.

The relatively low cost application of ICD technology applied to a marginal oil field in onshore Thailand detailed in this paper was a materially positive success from both a reserves and economic point of view. With its single-string one run-in-hole (RIH) trip, ICD's execution is a low-risk and simple operation, i.e. comparable to running standalone screen procedures. Further, the pilot well selection was not a low risk "for sure" situation but one of using the "worst case" type well where any success could be reasonably assumed to translate to a large number of future and existing lower risk wells if successful results were achieved.

In the broader context of ICD technology application in Thailand, this is a "game changing" technology that can alter the way horizontal wells are completed in highly heterogeneous reservoirs.

Already, 3 operators in Thailand are adopting this application to its full potential of assisting horizontal wells to achieve their full production potential. In one application, more fluvial pockets of sands are now feasible to be connected with longer ICD's horizontal to control inflow distribution and to manage water encroachment. In another application in high Darcy channel sands, ICD's lower completions become a safeguard of an inflow control defense system that reduces the threat of sudden gas blown-down and/or premature water breakthrough/fingering upon depletion. Over the one-year span of ICD's technology use in Thailand, any doubts of its success has been answered with the successful results of post-job production profiles showing incremental oil, water breakthrough delay and water-cut reduction and most-importantly, it allows for an economic production transformation for marginal oil fields. In returns, this will open up more willingness for low-margin oil field development, attracting more small independents and creating healthy technology effectiveness and options for better ultimate oil recovery in Thailand Oil and Gas.

ICD technology's use in POE's onshore Thailand operations from its initial introduction in Thailand Gulf offshore sandstones application was timely, with the potential to revive oil production from existing fields in a high oil price (i.e. >$100/bbl) environment.