Journal of Applied Sciences 6 (15): 3116-3121, 2006
ISSN 1812-5654
© 2006 Asian Network for Scientific Information

Limit of Through-tubing Rotary Drilling (TTRD) Well Completion

Orodu Oyinkepreye David
Faculty of Resources, China University of Geosciences (Wuhan),
Wuhan 430074, Hubei, People's Republic of China

Abstract: Through Tubing Rotary Drilling (TTRD) technology a cost efficient infill drilling technique commonly applied in matured field. Offers means of prolong use of existing completion by exploitation of isolated marginal reserves from single (multiple) drainage point(s) either by concurrent commingled or sequential production as technically and economically feasible. The inherent negative aspects of TTRD drilling on existing main-bore completion and expected continuous use of it beyond its designed functional requirement suggest re-completion. When should this be executed? The critical aspects been relatively exhaustive, justifying the need for re-completion was utilized by applying decision analysis to model when to re-complete the well from a deterministic view. The first decision tree solution adopts optimizing segmented quarterly re-completion time and the other accounts for flexibility in time of re-completion by properly depicting subsequent alternate decisions to be taken from the planned exploitation of more by-passed marginal accumulation from a specific well within technical limits.

Key words: Through-tubing rotary drilling, well re-completion, decision analysis, infill drilling

INTRODUCTION

Through Tubing Rotary Drilling (TTRD) is an innovative drilling technology utilized to economically exploit by-passed marginal accumulation, also referred to as isolated reservoir pockets in matured oil fields. It is basically used for an infill-drilling programme to enhance oil recovery by continued use of existing completion string. The benefit of this scheme extends from financial, operational and environmental to risk. TTRD is one of the distinct Through-Tubing Drilling techniques of which Coiled-Tubing Drilling (CTD) is the other. TTRD is highly favoured to CTD not just on technical pros and cons but on the economics involved to achieve the desired aim. Both techniques had a significant impact on the infill-drilling programme in the North Slope of Alaska (Morrison, 2003).

TTRD is a slim hole side track technique with Kick-of Point (KOP) from within the existing original completion tubular or below the tubing tail pipe from the production liner. And, continuous production from the main bore is not considered due to depletion (Fig. 1). Such side tracks often referred to as drainage points or extended perforation zones are slim hole of about 11.43 cm (4½-in.) ID and has Measured Distance (MD) of about 1066.80 m (3,500 ft) (Reynolds and Watson, 2003), 1219.20 m (4000 ft) (Lawson and Van Nieuwenhuizen, 2002) from KOP. The slim hole is completed with 7.30 cm (2⅞-in.) or 8.89 cm (3½-in) flushed jointed liners (Lawson and Van Nieuwenhuizen, 2001; Reynolds and Watson, 2003), slotted liners, pre-perforated liners and expandable screens in open hole. These liners are often cemented in place or otherwise on the functional requirement of the completion depending on zonal isolation and formation characteristics. Recent development utilizes swelling elastomer packers for zonal isolation due to cementing complexities (Flatekvaal *et al*., 2006).

The need for optimal exploitation of oil fields, though hinge on increasing recoverable reserve within a field, this is further justified by the report accredited to Ross *et al.* (1992) that 40% of oil initially in place will be produced with available technology from existing reservoirs while 20% will be by-passed, 20% left in remaining oil columns and 20% as residual oil saturation. And 50% of oil in the by-passed and remaining columns can be economically produced with low cost drilling schemes and applying slim hole completion. This is where TTRD technology comes into play, been a low cost slim hole drilling technique. Of the essential benefits of applying TTRD, the financial benefit of extending the life of the well and operational benefit of possibly combining multilateral (ML) technology with TTRD prolongs the continuous use of the existing completion string and accessories.

Statement of problem: The practice of TTRD application is accessing marginal accumulation with respect to its cost efficiency for as long as is economical. This research goes on to consider critical aspects of the prolong use of the existing completion for continuous production of hydrocarbons from side tracked drainage points but also

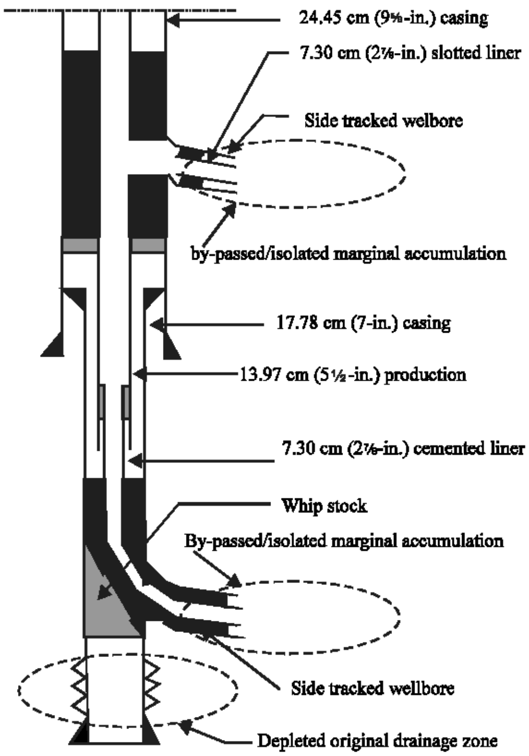

Fig. 1: Well completion schematic showing plugged main wellbore and two TTRD side tracks from production tubing and below the tubing

with the implementation of further TTRD side tracks leading to incorporating multilateral technology. It inevitably maximizes well slot for offshore matured field development and reduces the development cost per barrel by cheaply gaining access to more isolated pockets within the known measured distance limit of TTRD and ML technology. TTRD drilling lends itself to mechanical integrity issues of existing completion string and its components, such as on Christmas tree, valve profiles, down hole safety valve, well head and landing nipples (Morrison, 2003; Lawson and Van Nieuwenhuizen 2001, 2002; Scott and Black, 1998; Flatekvaal *et al*., 2006). According to Reynolds and Watson (2003), of particular emphasis is the metal loss of tubing near liner hanger. Though mitigated, but not completely ruled out. Another issue is the possibility of de-scaling Normal Occurring Radioactive Materials (NORM) with its consequence (Betts and Wright, 2004).

Optimizing TTRD leads to drilling more than one side track from a well even with the negative aspects enumerated. The existing completion was designed based on initial and forecasted functional requirement of the completion, reservoir characteristics and completion choice of which might not be similar to continuous production form isolated reservoir pockets. The above anticipated integrity issues and functionality expected of the existing completion prior to side tracking calls for re-completion for continued safe and economic exploitation of by-passed reserves. When should it be done? Answering this question falls within the domain of decision analysis. Of importance, worth mentioning is the deterministic and stochastic approach work on decision analysis as applies to re-completion and side tracking by Lerche and Mudford (2001) based on production decline limiting continuous production, success of operation and economic profitability all justifying the need for re-completion.

MATERIALS AND METHODS

Scheduling the appropriate time for re-completion leads to decision making requiring decision analysis problem solving technique by applying discounted cash flow model on parameters. A number of these parameters comes up as a direct result of the outcomes actually necessitate re-completion as its occurrence depending on its relative intensity and overall cumulative effect could abruptly cause or lead to production stoppage and invariably re-completion if economical. By utilizing a deterministic approach, these parameters are modeled into an equation to optimally choose when to re-complete the well.

Model build-up: Modeling in this respect is actually attempting to formulate an approach for optimally scheduling re-completion of the original exiting mother-bore completion for continued sustenance of production from a side track drainage point, or by accessing more marginal reservoir accumulation and in turn maximizing profitability. The approach is basically similar to the known decision analysis methodology and tends to highlight the various crucial factors that will necessitate changing the completion in the first place and will invariably incorporate this with cash investment and revenue accruable.

Key outcomes and parameters governing model Outcomes:

- Mechanical integrity of completion string; TTRD drilling jeopardizes the integrity of the completion string due to the possibility of internal wearing of the string and fluid corrosivity causing deterioration. The use of caliper and electric-line ultrasonic survey for inspection periodically shall confirm metal wear or thinning. This adds on the cost of replacement of damaged completion and completion string sections that are non reusable like Christmas tree etc, abrupt stoppage of production with the attendant implication of supply penalty cost. This penalty cost might be applicable to other outcomes but its inclusion seems minimal as production could still continue with the effects of other outcomes.

- Production chemistry variation; the impact of possible fluid composition variation within the design life span and during the extended use of the existing completion, for instance fluid composition may become sour unexpectedly. This adds on the cost of specific material design to combat variation.
- Well deliverability; concerns fluid flow within the production system. Maximizing well productivity invariably leads to optimizing productivity index (PI, is a continually declining parameter that measures well deliverability) which relates to optimizing well's vertical lift performance and well's inflow performance. Improving productivity can possibly add on costs of matrix simulation to reduce skin effect, optimizing tubing size of main drainage bore, implementing artificial lift etc. It is all about optimizing the individual pressure drops of the production system from near well bore to the well head through the well bore completion and separation facility.
- LSA scales; referred to as hard mineral scales also called Naturally Occurring Radioactive Material (NORM); the accumulation and build up of scale of naturally occurring radioactive substance on completion tubular could be hazardous as such can also get to surface production and drilling equipment due to de-scaling from TTRD operation. This adds on the cost of clean up and future mitigation.

Parameters

- Capital expenditure (CAPEX) and Operating expenditure (OPEX); accounts for cash investment.
- Estimated recoverable reserve
- Oil price; both price and recoverable reserve accounts for accruable revenue.
- Cost Implication; cost implications of outcomes necessitating re-completion.

Case I: The outcomes highlighted above can dictate when re-completion should occur, but a question arises as to when will the effect of this five outcomes warrant re-completion. Therefore these outcomes occurrence in time influencing re-completion is allocated a deterministic probability estimate. The parameters of these outcomes are the cost implications coined parameters containing an element of probability and assigned the representative acronym PPET (parameters with probability element). The term probability attached to these parameters means the probability of occurrence as it influences re-completion decision making and not the probability over a range of values. PPET parameters arise due to utilizing the already existing completion beyond its estimated design life span and the effect of subsequent through-tubing rotary drilling operation on the integrity of the existing completion and also a rather drastic change in the time dependent inflow performance and vertical lift performance due to exploiting marginal accumulations with probably different reservoir characteristics from that of the reservoir the completion was designed for initially. It should be noted that TTRD technique is commonly applied in matured fields as such; the design life span of the completion is close to its end. In essence, completion design is based on the functional requirement of the completion, completion choice and reservoir characteristics. Where as, the completion life span also depends on optimizing tubular performance to that of the time dependent inflow performance for a specified period.

Of uttermost concern is examining the influence of the outcomes elaborated on the need for re-completion economically and aiding decision making before the first TTRD sidetracked well is carried out on the proposed infill drilling programme planned for. This will be able to appropriately estimate the required scheduled time for re-completion and the likely number of multilateral that will be feasible. Taking into cognizance the PPET parameters above apart from CAPEX and OPEX, some of these parameters are more critical than others, therefore shall inevitably be the deciding factor and criterion used to determine when re-completion should take place. This reasoning is based on intuition. The influence of these PPET parameters on the need for re-completion is accounted for by the probability of its occurrence. By cost implication, the author considers the cost implications on Health, Safety and Environment (HSE) in terms of company's in-house standard and government's regulatory standard and overall structural integrity which can cause an abrupt stoppage in production or reduce production drastically justifying change of completion, secondly, contractual agreement on supply of hydrocarbon. Estimates of PPET in this case are subjective based on intuition and experience in assigning the most probable estimate.

Exploiting marginal accumulations with TTRD technique is due to its economic feasibility compared to other technique. Hence, the economic drive seems to be the main focus other than the cost implication of the PPET parameters necessitating changes to recommend re-completion. The parameters CAPEX, OPEX and estimated recoverable reserve are also noted. This surely accounts for the cost and revenue accruable from the point of analysis or of re-completion to well abandonment. CAPEX is the cost required for re-completion including installation and well abandonment and OPEX stands for cost of future well intervention, work over, production cost, overhead cost. These parameters are combined and the time cost of money is taking into account by using an appropriate discount factor to bring all future cost and revenue to present value.

NPV of the above parameters accounts for the cost-benefit of re-completing the mother-bore well at a particular time (period). In addition, if at this time (period) an additional multilateral (sidetracked well) is drilled this will subsequently add on to CAPEX, OPEX and estimated recoverable reserve. However at what time (period) would it be most convenient to re-complete the mother-bore?

This is accounted for by assuming a feasible production life estimate for recovery of marginal pockets within the range of the well under consideration as technically feasible with TTRD, integrity of existing completion and existing proven technology capability. With this, economic evaluation for re-completion shall be carried out on a quarterly basis of the estimated production life. Estimated production life refers to the continued production life from the time the first TTRD side track is drilled to the time the particular well is abandoned. The analysis for each quarter is done before drilling the first TTRD sidetrack well and taking into consideration future side tracks from same mother wellbore adding more recoverable reserves.

Model formulation with figure:

$$EMV_{Quarterly} = \sum_{t=P_f}^{n} \frac{CF_t}{(1+r)} - \sum_{t=C_f}^{m} \frac{CI_t}{(1+r)^t} - \sum_{i=1}^{4} P_i \left(\frac{(V_i)_k}{(1+r)^k} \right)$$

Where:

- P_f = First production attributed to first sidetracked well
- C_f = First capital investment attributed to first sidetracked well
- EMV = Expected Monetary Value (expected value of net present value)
- Pi = Probability of outcomes necessitating re-completion
- t = Time in years
- k = Time from first side track drilling
- r = Discount rate
- n = Total number of years of cash flow
- m = Total number of years of cash investment
- Cf_t = Cash flow for a given time, t
- Ci_t = Capital investment for a given time, t
- V_I = Cost implication of (outcome) necessitating re-completion having a probability (P_i)
- Σp_i = 1.0
- P_i = Probability of occurrence of parameters (PPET) having element of probability

The Fig. 2 depicts quarterly evaluation based on estimated production life expected for prolong use of the well for continued exploitation and production. Though each quarterly analysis is based on the parameters of the model equation above, it should be taken note of that the basis of computing Net Present Value (NPV) is the commencement of the infill drilling operation for the first TTRD sidetrack. The choice of when to re-complete is based on optimizing Expected Monetary Value (EMV).

Case II, flexibility in time of re-completion: This applies with the assumption that no re-completion was

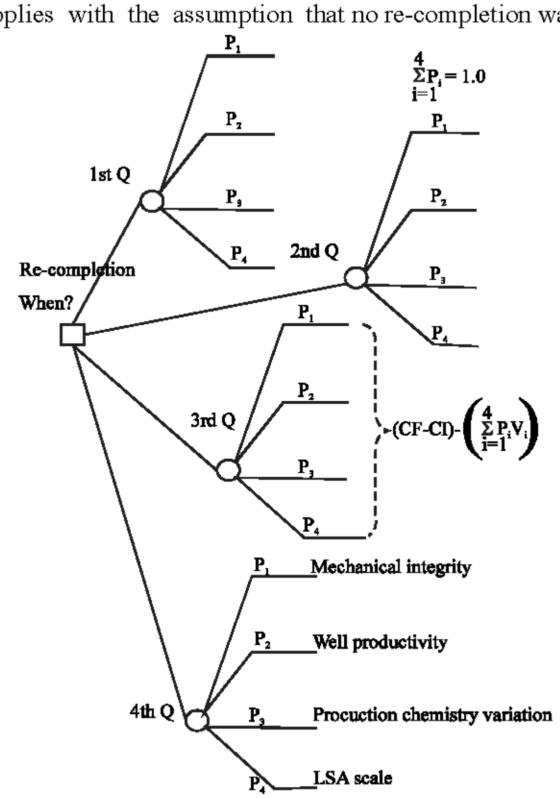

Fig. 2: Case I, decision tree model illustrating the various options (1st Q-4th Q) monetary value and their outcomes showing corresponding probabilities

undertaken prior to the first side track exercise. Also, on the note that at least an additional side track shall be incorporated there by adding further accruable reserves. That is, re-completion is also tied to the actual possibility of exploiting further marginal reserves within the limit of TTRD operation. The possibility of success for both the side tack and continued production from the existing drainage sidetrack are assumed feasible beyond any doubt of failure, subsequently leading to commingling or sequential production from all drainage zones.

The outcomes necessitating re-completion as in the first case of segmented re-completion time considered is applicable but applied differently. All outcomes include the parameters of OPEX, CAPEX, recoverable reserve and price in the form of revenue and all cash flow accruable due to an additional side track drainage point. Each outcome adds on cost (cost implication) that is exclusive to that outcome in the form of PPET that contributes additional cost to OPEX and CAPEX. This reduces the parameters of each outcome to just OPEX, CAPEX and revenue. OPEX and OPEX for each outcome are specific to that outcome.

Accounting for flexibility in time is brought about by the influence of time as a variable in the function of estimated recoverable reserves from production decline estimation. By analytical maximization or otherwise of the resulting mathematical expression of the expected monetary value for the re-completion alternative, the optimal time for scheduling re-completion could be derived. This approach follows closely that of Lerche and Mudford (2001).

DISCUSSION

This study considered the cost implication of critical outcomes that necessitates re-completing a TTRD single (multiple) side track drainage zone (zones) from an original well slot (mother well bore) in a matured field infill drilling scenario. Decision analysis was applied based on critical exhaustible outcomes to model when to re-complete the well using a deterministic approach.

Re-completing of such wells calls for minimizing cost since the aim of the TTRD technique is to minimize the cost of side tracking in mature fields to exploit by-passed marginal accumulations. The standard approach is re-completing the well prior to the first side track (Lawson and Van Nieuwenhuizen, 2002) due to integrity issues. Integrity of existing completion tubular not being an issue prior to side tracking, then, whenever it arises the economics is determined if it shall be feasible. Lerche and Mudford (2001) focused on optimally scheduling re-completion or side track based on influence of production decline in producing drainage zone using exponential decline, probability of killing production in current drainage zone and success of proposed side track into another drainage zone and economic viability of the exercise. Their work though all encompassing generally applies to re-completion and side tracking but not specific to TTRD technique for side tracking through tubing, so did not consider the negative aspects of TTRD drilling on existing completion. However, the approach was based on the flexibility of occurrence of re-completion.

This study treats two approaches to re-completion, the detailed explanation on segmented quarterly time, Case I and flexibility of time of re-completion Case II. Though not all encompassing, Case I, focuses on critical outcomes apart from the success of operations not considered that also calls the shorts for re-completion pegging cost implication due to the negative aspects of these outcomes by applying expected value concept. Figure 2 decision-tree diagram depicts the decision alternatives at the nodes. The prolonged period of production being relatively small compared to the production life of the original well's production led to considering optimizing re-completion on a quarterly basis. However the delta property of expected value concept was utilized in which a constant added to each outcome is equivalent to adding the constant to the EMV of the outcomes (Newendrop and Schuyler, 2000). The constant in this case are cash flow from accruable recoverable reserve from drainage zone(s) and cash investment from capital and operating expenditures for completion, drilling and sustaining production from the drainage point(s).

The model for Case II is quite similar as both cases are obviously based on the same the probabilistic outcomes from P_1 to P_4. From Fig. 3 for Case II and Fig. 2 for Case I, the alternative decisions to be taken are different while the outcomes are similar but applied differently with different parameter set up. The outcomes for Case II are based on objective estimates unlike Case I which is subjective. The decision tree seems more realistic simulating continuous alternate decision to be taken during the planned exploitation of more marginal reserves from a specific or dedicated single well.

Optimally scheduling re-completion of the existing (mother bore) completion section of the well shall serve as a guide prior to the first TTRD side track to decide when re-completion should be done. And as well as highlight the salient aspects requiring the need to re-complete the well. The resulting EMV from Case I does not really serve any financial purpose other then suggesting the appropriate time to re-complete, while Case II can be reasonably sufficient as it considers using objective estimates of cost implications. NPV on cash investment

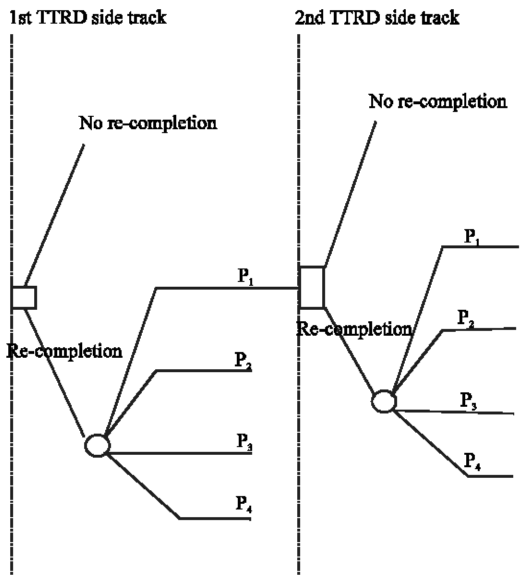

Fig. 3: Case II, Decision Tree model showing alternatives having similar outcomes to Case I, with possibility of incorporating flexibility in re-completion time

and cash flow shall still determine the economic profitability of executing the infill drilling programme as is the standard practice.

Furthermore, according to the characteristics of expected value concept, the outcomes have to be mutually and collectively exhaustive, that for this study has to be placed in proper perspective and better understood. Equally optimization of re-completion has to be properly modeled against the segmented time of optimization quarterly as suggested in Case I. Case II, applying flexibility seems to be a much better approach, but, both approaches should consider the success of operations as re-completion could result in failure of the new drainage point during drilling and also total isolation or partial lose of the existing drainage point(s). Case I could be further modeled for continuous side tracking exercises as well as determine time of re-completion in time instead of quarterly range estimation. Lastly, parameters utilized are not in nature precise, therefore the uncertainty of parameters has to be accounted for. This paragraph already suggests the need for proper use of optimization techniques in conjunction with decision analysis as more matured field shall and has to be economically exploited.

NOMENCLATURE

CAPEX	= Capital Expenditure
EMV	= Expected Monetary Value
HSE	= Health, Safety and Environment
ID	= Internal Diameter
KOP	= Kick of Point
LSA Scale	= Low Activity Radioactive Scale
ML	= Multilateral Technology
NORM	= Normal Occurring Radioactive Materials
OPEX	= Operating Expenditure
PPET	= Parameters with Probability Element
TTRD	= Through Tubing Rotary Drilling

REFERENCES

Betts, S.H. and N.H. Wright, 2004. NORM management and disposal options, risks, issue and decision making. SPE Paper 86661, SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Calgary, 29th-31st March, 2004.

Flatekvaal, T., E. Saeverhagen, O.E. Eng, N. Jepson, J. Oyovwevotu, J.F. Namtvedt and M.M. Price, 2006. World's First TTRD Well Drilled from a Floating Platform on the Njord Field, North Sea-From Concept to Reality. IADC/SPE Paper 98880, IADC/SPE Drilling Conference, Miami, 21st-23rd February, 2006.

Lawson, F. and F. Van Nieuwenhuizen, 2001. Through tubing drilling on north cormorant cuts costs. Drilling Contractor, July/August, 2001.

Lawson, F. and F. Van Nieuwenhuizen, 2002. Cemented completion and TTRD prove out in north sea: New methods still face technical challenges. Offshore International, 62: 52, 55-56.

Lerche, I. and B. Mudford, 2001. Risk evaluation for recompletion and sidetrack developments in oil fields. SPE Paper 71418, SPE Annual Technical Conference and Exhibition, New Orleans, 30 September-2 October, 2001.

Morrison, J.W., 2003. The Transfer of TTD Technology between Provinces. SPE/IADC Paper 79863, SPE/IADC Drilling Conference, Amsterdam, 19th-21st February, 2003.

Newendorp, P.D. and J.R. Schuyler, 2000. Decision Analysis for Petroleum Exploration, 2nd Edn., Planning Press, Colorado, pp: 86-89.

Reynolds, H. and G. Watson, 2003. String design and application in Through-Tubing Rotary Drilling (TTRD). SPE Paper 81096, SPE Latin American and Caribbean Petroleum Engineering Conference, Port-of-Spain, 27-30th April, 2003.

Ross, B.R., A.M. Faure, E.E. Kitsios, P. Oosterling and R.S. Zettle, 1992. Innovative slim-hole completions. SPE Paper 24981, European Petroleum Conference, Cannes, 16-18th November, 1992.

Scott, I.J. and F.J. Black, 1998. Slim-Hole Sidetracked Cuts Costs by 50%. SPE Paper 50578, SPE European Petroleum Conference, The Hague, 20th-22nd October, 1998.