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**ECONOMIC ANALYSIS OF THE IMPACT OF INTELLIGENT WELL
COMPLETIONS IN RESERVOIR MANAGEMENT**

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ABSTRACT

Oil and gas production operations involve risks due to uncertainties in reservoir properties, equipment failure, and unforeseen future events; thus, evaluating and justifying field development projects is critical, as development projects incur large sums of money and once a field is developed, the entire architecture cannot be changed completely. Each E&P firm wants to optimize its overall profit in the long run; thus, it tries to enhance the field's ultimate recovery as cheaply as possible. Good reservoir management strategies are required to enhance recovery from the large volumes of residual hydrocarbons on the globe and in addition to the application of modern technology, integrated reservoir management comes handy. Intelligent completion is one of the methods that improve reservoir management and hence hydrocarbon recovery. This study gives an overview of intelligent completion technology, suggestions for deciding whether or not to adopt intelligent completion, and an assessment of field instances of intelligent completion installation. The case studies are drawn from two different fields where intelligent completions have been used. The simplicity of data gathering for reservoir management, additional oil production, and profitability parameters were used to compare intelligent completion to non-intelligent completion. The net present value, discounted payment period, profitability index, and growth rate of return are yardsticks used in economic research. Results revealed that dependable intelligent completion enhances reservoir management by allowing for data gathering and well monitoring. When compared to non-intelligent completions, using intelligent well completions in reservoir management can result in enormous cost benefit and additional oil recovery.

Keywords: Intelligent Well Completions, Reservoir Management, Production Rate, Decline Curve, Profitability Index

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1.0 Introduction

The exploration and production (E&P) industry's principal asset is reserves. Each E&P Company seeks to maximize its overall profit in the longer term; thus, it aims to increase cost-efficiently the ultimate recovery of the field. However, the majority of the hydrocarbons in place are not recovered; around 35% of the hydrocarbons in situ are recovered, leaving the remaining 65% unrecovered. The requirement to increase recovery from the vast amounts of residual hydrocarbons on the planet necessitates good reservoir management methods (Fowler, et al., 1996)

Integrated management of reservoirs is ongoing procedures that will make the reservoir operate well throughout its lifetime. It calls for multidisciplinary and technical resources to be used to maximize profit. A complete management plan for reservoirs includes plans for depletion and development, data gathering and analysis, research on geology and numerical models, production and reserve predictions, the requirements for facility and business optimization. These can make improved management of reservoirs more effective and boost hydrocarbon economic recovery (Satter, et al., 1994). Intelligent well completion is a component of the overall reservoir management optimization vision.

An intelligent well completion (IWC) is a completion system capable of measuring, transmitting and analyzing wellbore production, reservoir and completion integrity data, and enabling remote action; change valve chokes and optimize these parameters to better control the reservoir, well and production processes. The concept of intelligent completion does not generally refer to any capability for automated self-control but rather manual interface to initiate instructions to the well (Sharma, et al., 2002 & Silva, et al., 2012).

For each zone with permanent pressure and temperature gauges, the reservoir parameters are continually monitored on the foundation on which the valve chokes are reconfigured so that additional zones are produced simultaneously with one string or one well. Remote monitoring of completion is a system's capacity to deliver data, collected in or around the well, without needing a typical well operation access and entry. Therefore, IWC technology offers significant flexibility in the operation of conventional wells and multilateral wells as the independent control of each branch of the well (Yeten, et al., 2004 & Griffith, et al., 2012).

The basic element of IWC are acquisition and transmission system, flow control valves (FCV) and actuation system. The acquisition and transmission system are a set of equipment used to transmit and acquire reservoir data, while the FCVs control flow rate from a zone or in a level. The actuation system is a set of equipment that supplies power to the valves. When compared to traditional completions, IWC has significant advantages. IWC's main goals typically include maximizing or optimizing oil recovery and anticipating oil recovery, gas and water breakthrough, cutting costs and improving security. The installation of intelligent completion procedures is justified by zero intervention, particularly subsea or distant location wells and optimization of the production for multizone reservoirs (simultaneous production), horizontal wells, complicated reservoir structure, auto gas lifting, etcetera. The full benefits of IWCs are reservoir-specific; they are determined by reservoir quality, production rates, fluid contacts, gas and water coning, and so on (Robinson, 2003).

A review of the intelligent completion technology is critical to evaluate the decision whether or not to implement intelligent completion. An engineer is faced with challenges such as knowing the extent to which IWC improves data acquisition, reservoir performance, in terms of oil production, recovery, water and gas production control, in reservoir management and the economic viability of using the IWC (Greibenkin, et al., 2010, Davis, et al., 2007 & Jalali, et al., 1998)

This study would compare conventional completions to intelligent well completions by evaluating case studies of reservoirs that have intelligent completions implemented. The degree to which intelligent well completions impact the management of reservoirs and the economic benefits will also be investigated by determining IWC’s economic feasibility versus non-intelligent completion.

2.0 Methodology

Two case studies of reservoirs that employed intelligent completions were examined. Material balance software (MBAL) was deployed for production forecasting utilizing decline curve analysis. For the economic analysis – OPEX, CAPEX, and profitability metrics such as Net Present Value (NPV), Payout Period (PO), Growth Rate of Return (GRR), and Profitability Index (PI) was utilized. The Monte Carlo simulation software (a spread sheet add-in, Oracle Crystal Ball) was employed for the uncertainty analysis of the economics of the two types of completions. Figure 1 shows the key phases in the workflow for this study, which is based on the model of Sakowski, et al., 2005.

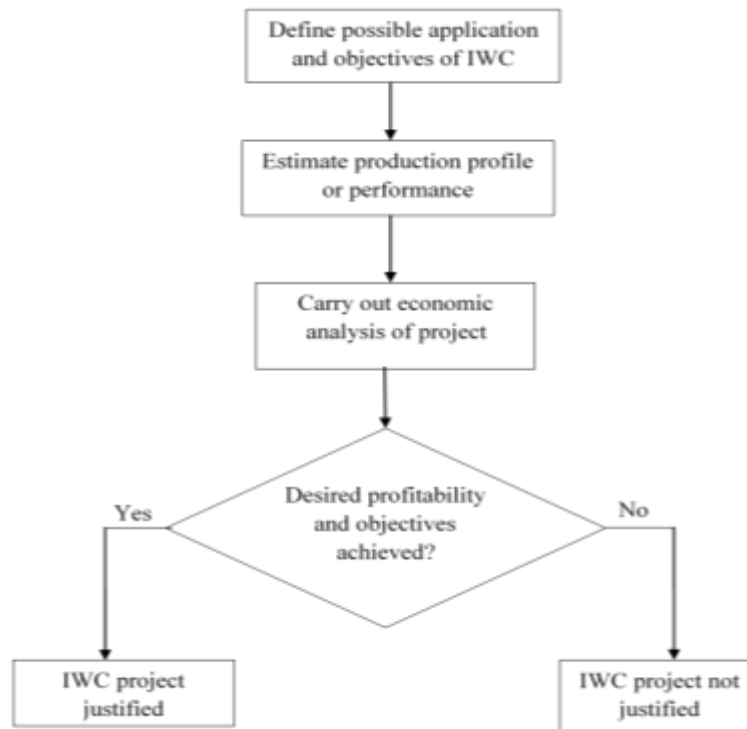


Figure 1: Workflow for reservoir and economic analysis of IWC

3. Result Analysis and Discussion

Actual field examples in which IWC was suggested and implemented as a solution to reservoir management issues in the field were assessed and compared to non-intelligent completions. The general assumptions for the case studies are shown

- Periodic year-end funds flow
- Royalty for Cumulative oil production less than 1MMSTB – 5%, Cumulative oil production greater than 1MMSTB – 12.5%
- Depreciation method - Double declining depreciation
- Oil price inflation - 2.5%
- Income Tax – 45%
- Discount rate – 12.5%
- 20% of CAPEX is expensed

Table 1: Input Variable Stochastic Distributions

Parameter	Distribution	Minimum	Most Likely	Maximum	Mean	Standard Deviation
Oil price inflation, %	Normal				2.5	1.6
Income Tax, %	Uniform	25		50		
Discount rate, %	Triangular	10	12.5	15		

3.1 Case Study 1: Commingled Production from a Two-Layered Offshore Field

The first case study (Behrouz, et al., 2010) is the use of IWC in an offshore field. The reservoir has an anticline structure, with two layers of sandstone separated by an impermeable shale layer. The reservoir does not have a gas cap, but it does have a powerful aquifer with an edge water drive mechanism. Three wells were planned for intelligent completion with commingled output out of a total of seven wells. Case specific assumptions are as follows:

- Drilling and completion cost for each well = \$7.0MM
- Equipment and installation cost of IWC without ICV = \$1.0MM
- ICV unit cost = \$0.5M
- Workover cost per year = \$1.0MM
- Operating cost = \$4/bbl. without workover
- Period considered is six (6) years
- No workover was carried out in the IWC over the six years

Additional input data used in the analysis for this case study are listed in Table 2

Table 2: Stochastic variable input parameter distribution

Parameter	Distribution	Minimum	Most Likely	Maximum
CAPEX IWC, MM\$	Triangular	8	9	11
CAPEX CW, MM\$	Triangular	6	7	9
Workover cost per year, MM\$	Uniform	0.5		2.5

3.1.1 Reservoir Management Strategy

The intelligent well completion (IWC) enabled reservoir pressure drawdown monitoring and individual layer productivity testing. Layer 2 was shut down due to an increasing water cut, as confirmed by reservoir monitoring. It was discovered that oil production from Layer 1 increased as a result of the reduction of back pressure caused by the increased water production rate from Layer 2. Figure 2 depicts the total oil output from conventional and intelligent wells during a six-year period.

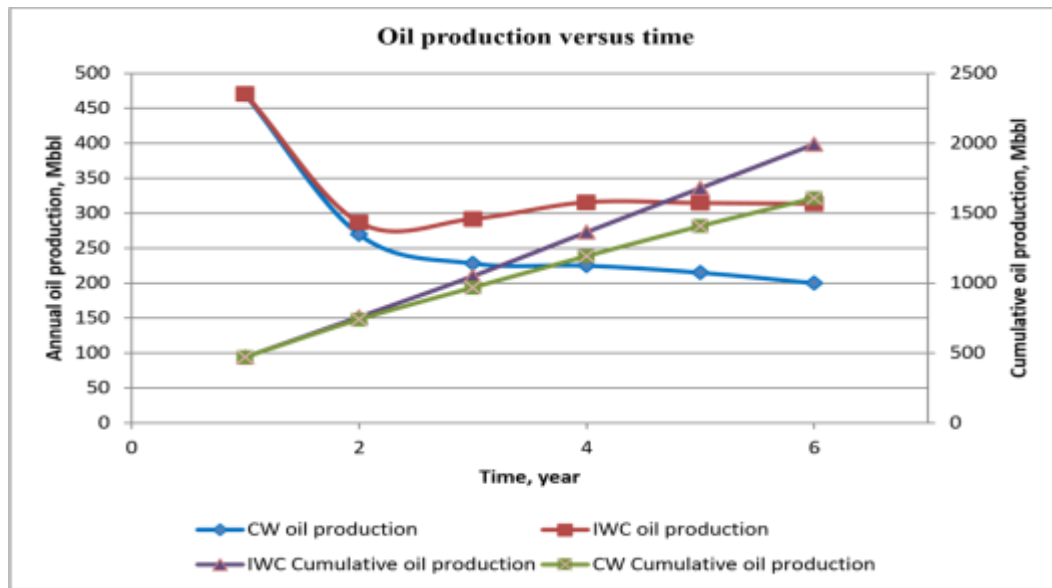


Figure 2: Production performances from IWC and conventional well

3.1.2 Economic Analysis

The NPV in both completions was positive, indicating that both projects are acceptable; however, the IWC provided a greater NPV than the conventional well. According to the uncertainty analysis, the NPV of the IWC at P90, P50, and P10 increased by 25.6 percent, 27.5 percent, and 30.1 percent, respectively, as compared to the conventional completion (Table 4). As a consequence, the IWC enhanced the well's economic performance, and these findings may be ascribed to the IWC's higher oil production rate and low well intervention costs and as a result, the IWC is superior to traditional completion.

Figure 3 depicts the sensitivity analysis of the NPV for both types of completions. It shows that the oil price and inflation have a positive influence on the NPV, but income tax, workover cost per year, and CAPEX have a negative impact on the NPV. This implies that a rise in oil price and

inflation will raise the NPV, but an increase in income tax, workover cost each year, and CAPEX will reduce the NPV. The Tornado chart in Figure 4 ranks the sensitive parameters from most sensitive to least sensitive. Accordingly, the oil price is the most sensitive to the NPV in both completions. The decision to whether or not implement IWC will be determined by the current oil price, because economic success is heavily reliant on money realized from oil sales.

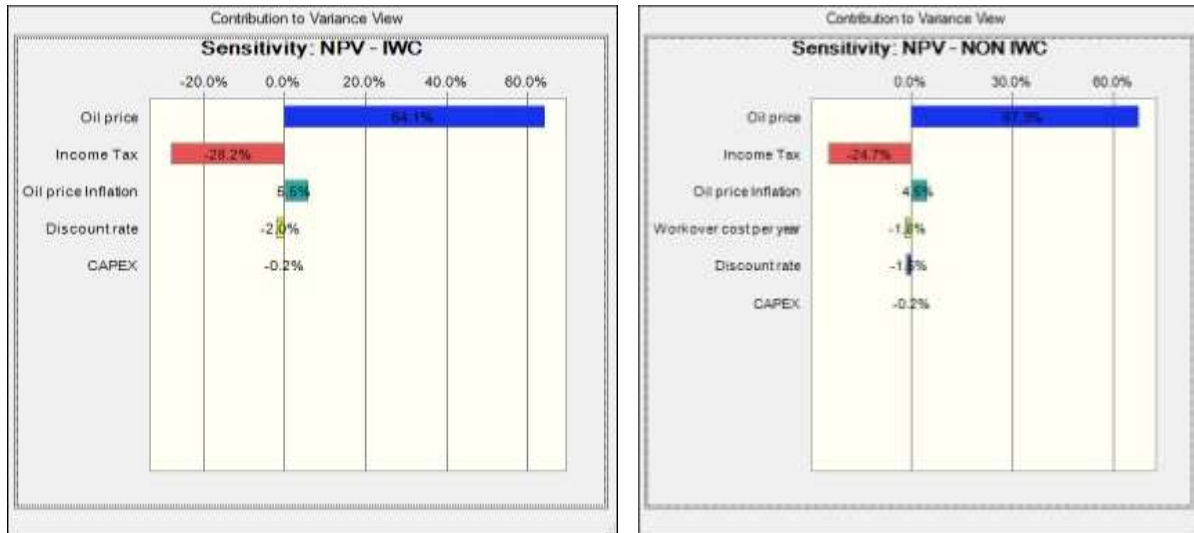


Figure 3: NPV sensitivity analyses for both IWC and conventional well

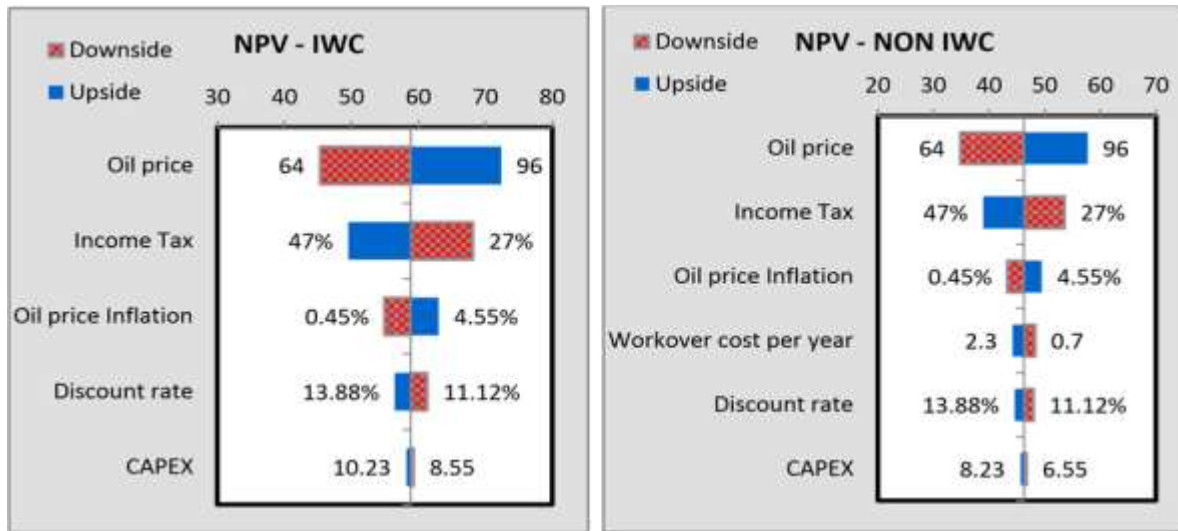


Figure 4: Tornado charts of the NPV for the IWC and the conventional well

Although the CAPEX for the IWC was greater, the operational cost is 29 percent lower than in conventional completion. For both completions, the payment term is fewer than seven (7) months, as shown in Figure 5 This demonstrates that, given a six-year economic life, investment for both completions are repaid early enough. The traditional completion payment term was somewhat

shorter than the IWC. This indicates that the IWC project is riskier than a traditional completion project, especially in a politically unstable country.

The PI and GRR were nearly identical for both completions, with a difference of less than 1%. For both completions, the PI was more than one and the GRR was greater than the 12.5 percent hurdle rate. This demonstrates that both initiatives are viable. Table 4 is a summary of the findings from this study.

The PI, GRR, and PO for both completions are also almost identical; IWC installation may be justified based on incremental oil recovery and NPV. The installation of an IWC is justifiable since it enhanced the well's recovery and economic outcome.

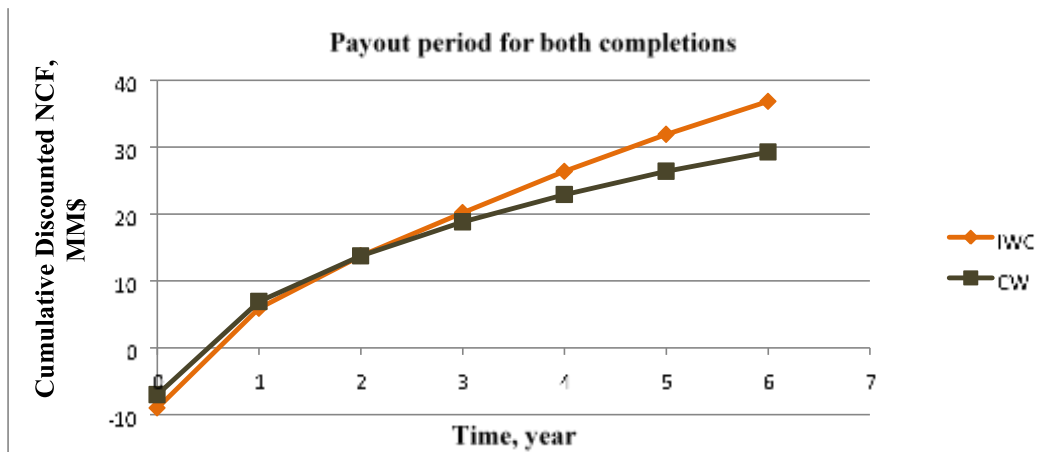


Figure 5: Cumulative discounted net cash flow versus time

3.2 Case Study 2: Multi-Lateral Producer-Injector Pattern Offshore Field

The second case study (Ajayi and Konopczynski, 2016) is a mature field in a poor permeability limestone setting. Multi-lateral wells and a producer injector design were used to increase oil output and preserve reservoir pressure; however, this resulted in excessive water production. Some multi-lateral producers reported as much as 99 percent water-cut, with a field average water-cut of 75 percent, resulting in a dramatic reduction in oil production rate.

For an analysis of Intelligent Well technology to restore field oil production, reduce water production, improve flood efficiency and enhance reservoir knowledge, a multi-lateral oil producer with four sectors was selected. After three and a half (3.5) years of production, the well was shut-in to install the IWC. Four inflow control valves (ICV) were added to each lateral in the intelligent completion design. Isolation packers were used to separate each lateral in order to monitor the different layers. For this example, two options were explored in this study. Evaluation of the well's performance over a ten-year period if; No well control system was installed; and Well control (intelligent system) was installed after three years of production.

Production history from the non-intelligent completion and the IWC were matched using exponential decline non-linear regression with medium data point weighting, and production was predicted for ten years. Figure 6 depicts the IWC production history and non-intelligent completion.

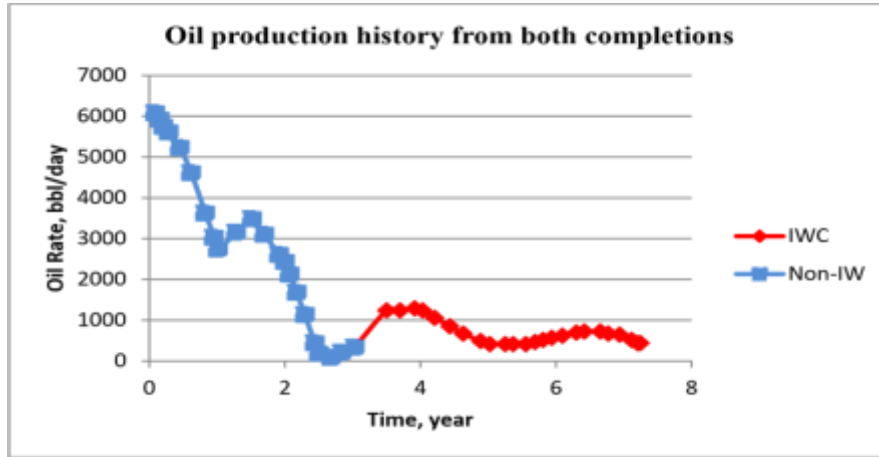


Figure 6: Oil production history from both completions

The specific assumptions for this case study are shown below and the stochastic variable input parameter distribution in Table 3

- Drilling and completion cost = \$3.5MM
- Well equipment cost = \$4.0MM
- ICV unit cost = \$0.5MM
- Intelligent system installation cost = \$1MM
- Operating cost without workover = \$3/bbl.
- Workover cost per year = \$1.0MM

Table 3: Stochastic variable input parameter distribution

Parameter	Distribution	Minimum	Most Likely	Maximum
CAPEX IWC, MM\$	Triangular	9	10.5	12
CAPEX NON-IWC, MM\$	Triangular	6	7.5	9
Workover cost per year, MM\$	Uniform	0.5		2.5

3.2.1 Reservoir Management Strategy

The IWC's downhole sensors enabled real-time monitoring of pressure drawdown and production from each lateral; the observed data was utilized to optimize intake from each lateral. The productivity index for each lateral was created at no additional expense. Because zones 1 and 4 generated a greater proportion of total water produced, the ICV for zones 1 and 4 was adjusted to totally closed, and the well was produced exclusively from zones 2 and 3.

In the IWC, oil production rose by 21% (Table 4) as compared to the non-intelligent completion. This is due to the employment of downhole control valves to optimize oil output in the IWC. Figure 7 depicts the oil production performance in both completions over a 10-year period.

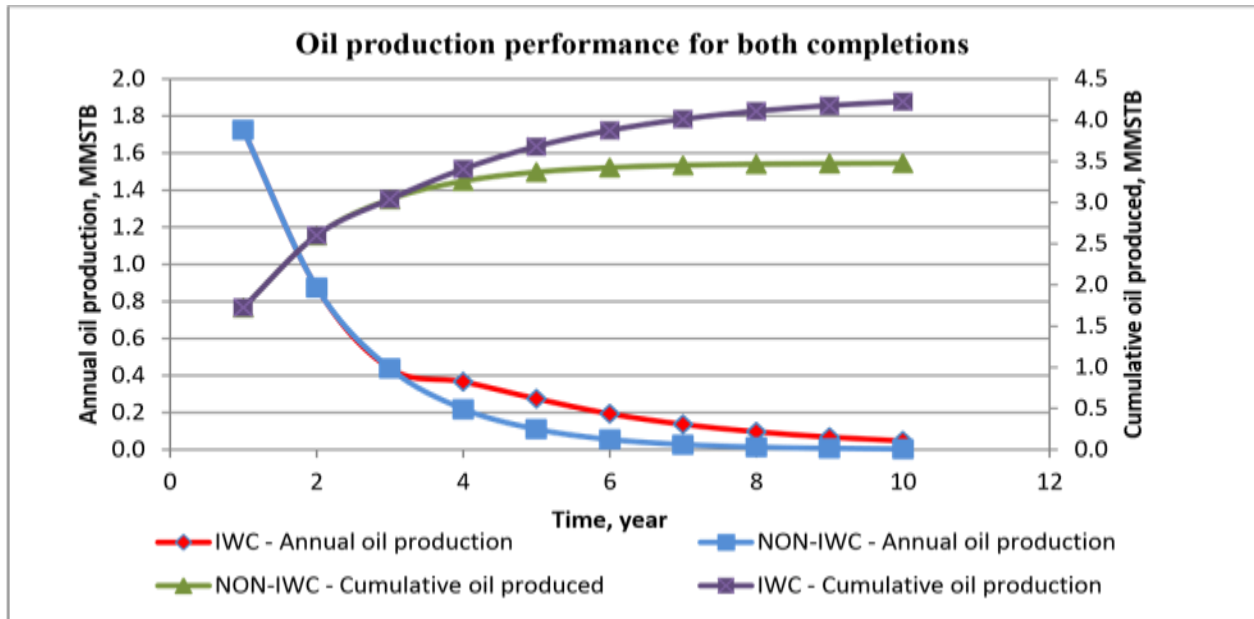


Figure 7: Oil production performance for the two scenarios

3.2.2 Economic Analysis

The NPV was positive for both completions, the PI was more than one, the GRR was greater than the hurdle rate, and the payment term was ideal. This demonstrates that both projects are acceptable, but the economic conclusion of the IWC was more appealing than that of the non-intelligent completion.

According to the stochastic analysis, the IWC had a greater NPV than the non-intelligent completion. The IWC provided a 17.5%, 18.5%, and 20% rise in NPV at P10, P50, and P90, respectively (Table 4). This demonstrates that the IWC investment provided greater value than the non-intelligent completion. The increased NPV at the IWC can be ascribed to improved oil recovery and lower operating costs (decreased by 23.3 percent). The high workover cost in non-intelligent completion results in a high operational cost.

Figure 8 depicts the impact of the oil price, income tax, oil price inflation, workover cost per year, discount rate, and CAPEX on the NPV in both completions. Oil prices and inflation have a positive influence on NPV, but income tax, workover cost per year, and discount rate have a negative impact on NPV. This demonstrates that a rise in oil price and inflation improves the NPV, but an increase in income tax, workover cost, and discount rate decreases the NPV. Figure 9 depicts the Tornado chart for both completions. The Tornado chart (Figure 9) ranks the variables from most sensitive to least sensitive. In both the IWC and the non-intelligent completion, the oil price is the most responsive, while CAPEX is the least sensitive. As a result, if the price of oil falls, both projects may become less appealing.

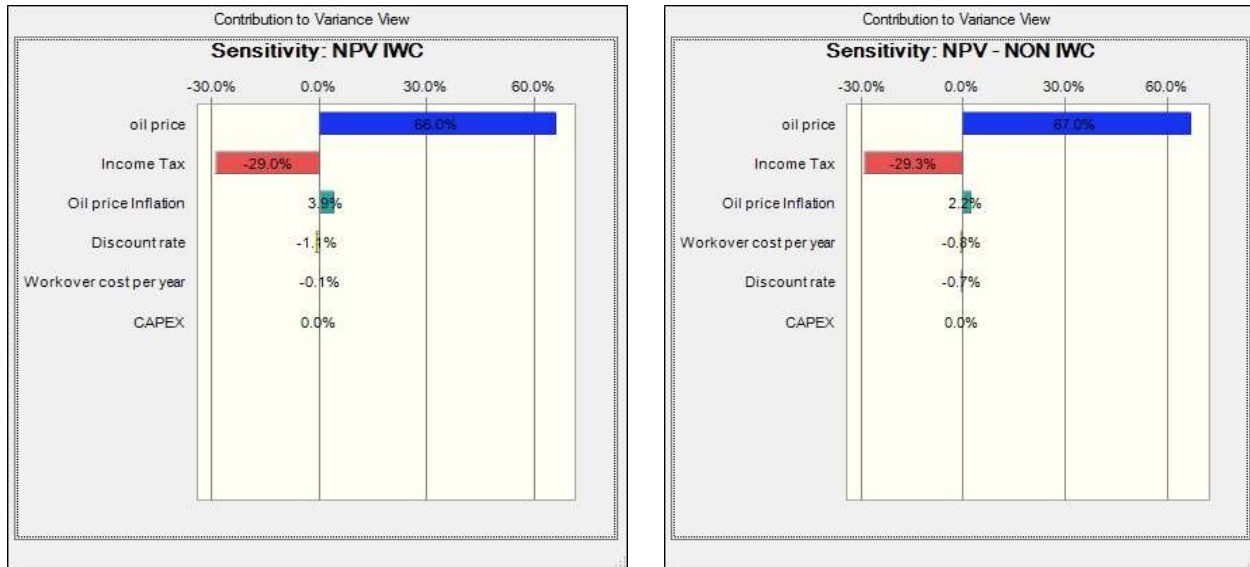


Figure 8: NPV sensitivity analysis for both types of completions

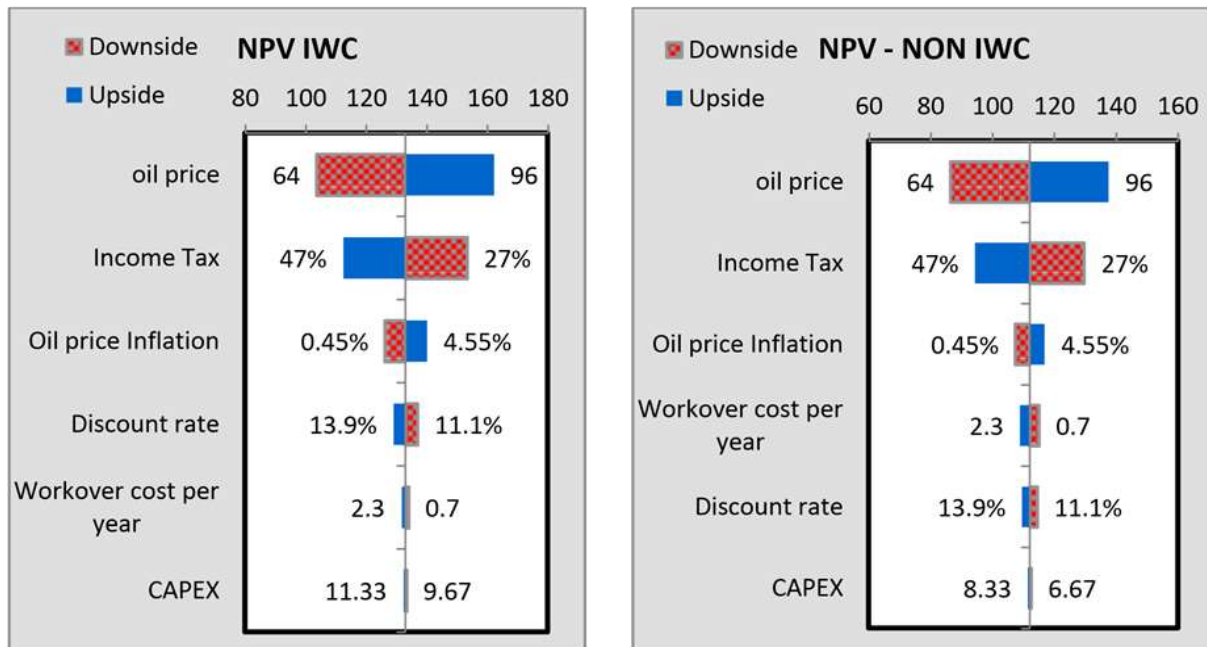


Figure 9: Tornado chart of the NPV for both wells

The payment time in both completions is depicted in Figure 10. In both cases, the payment term was shorter than three (3) months. This demonstrates that investments in both projects over a period of ten years of output are repaid quickly and have the same risk exposure.

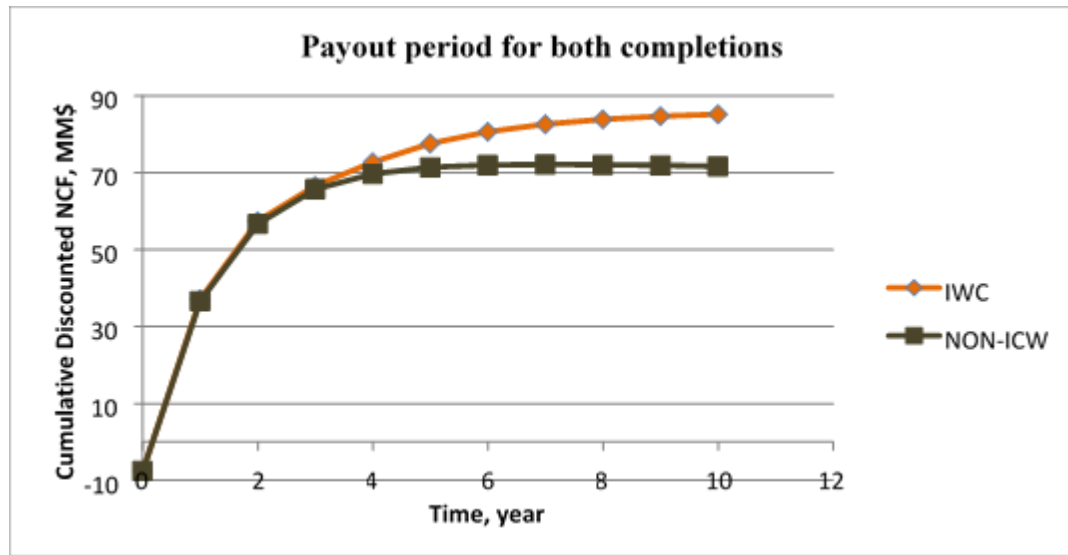


Figure 10: Cumulative discounted net cash flow versus time

The overall return on investment dollars for the IWC was \$3.05 per dollar, whereas the non-intelligent completion was \$2.73 per dollar. This results in an 11.7 percent increase in PI in the IWC as compared to the non-intelligent completion. This makes the IWC more appealing.

The IWC's project worth plus reinvestment prospects was 25.78 percent, while the non-intelligent completion was 24.36 percent, a 1.42 percent difference. This demonstrates that the investment in IWC was superior to that in non-intelligent completion. Because the objectives of the IWC installation which are reducing water production, increasing oil recovery, and making reservoir data gathering easier were fulfilled, as well as the better economic outcome and therefore IWC implementation is justified.

IWC deployment is recommended for this case study since it is highly cost effective and permits reservoir optimization.

Table 4: Summary of results obtained for Case Studies

Parameters		Cumm. Oil Prod. (MMbbl)	Deterministic Economic Results							Stochastic Results of NPV (MM\$)		
			NPV (MM\$)	Operating Cost (\$/bbl prod.)	OPEX (MM\$)	CAPEX (MM\$)	DPO (Months)	PI	GRR (%)	P90	P50	P10
Case 1	IWC	1.992	36.83	8	5.98	9	7.2	2.01	26.38	43.15	58.06	76.28
	Conv.	1.607	29.58	11	10.82	7	6	2.03	26.60	33.16	45.54	60.75
Difference %		23.9	25.90	-27.20	-44.80	28.60	1.20	-0.99	-0.22	30.10	27.50	25.60
Case 2	IWC	4.224	85.21	15.67	10.5	2.04	-	3.05	0.2578	99.18	131.07	169.84
	Conv.	3.475	71.63	20.42	7.5	2.04	-	2.73	0.2436	82.62	110.65	144.54
Difference %		21.6	19	-23.3	40	0	-	11.7	1.4	20	18.5	17.5

4. Conclusion and Recommendations

4.1 Conclusion

This study compares the use of intelligent well completions for reservoir management against non-intelligent or conventional well completions. The goals of this research are to offer a methodology for guiding the planning and decision-making process for adopting IWC, as well as to show the benefits and limitations of IWC. To investigate the uses of IWC, case studies of two fields where it has been applied were examined. Daily production history from both IWC and non-intelligent completion were matched, and prediction runs were performed. The simplicity of data gathering and well monitoring, incremental oil recovery, NPV, Discounted PO, PI, and GRR were among the factors used to assess the viability of adopting IWC.

Based on the results of the analysis of the case studies presented, the following conclusions are drawn:

- The incremental oil recovery from IWC over non-IWC ranges from 21.6 to 38 percent.
- IWC is more economically feasible than Non-IWC; NPV from IWC exceeds non-IWC by 17.5 percent to 40.6 percent for the case studies examined in this paper.
- The NPV is affected by the price of oil.
- When comparing IWC field operating expenses to non-IWC field operating costs, IWC OPEX may be decreased by 9 percent to 45 percent.
- The payout time for IWC is a week to a month shorter than for non-IWC, however it is preferable.

4.2 Recommendation

Based on the results obtained, the following recommendations are thereby brought forward:

- In this study, the oil production prediction was based on a decline curve analysis. In comparable analyses, it is advised that reservoir modeling be utilized for production forecasting.
- A production period of five to six years following the adoption of the IWC was examined in this study. In order to evaluate the advantages of IWC, the full life cycle of the field, from IWC deployment to abandonment, should be examined.
- Statistics on all intelligent completions deployed, including their level of success, failure risk, failure kinds, and suppliers, should be gathered to assist the planning process and real field deployment of intelligent completion.
- A pre-installation or pre-development test should be performed to ensure the intelligence system's dependability.
- More study on intelligent system hardware should be conducted in order to increase its dependability.

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