Integrated constraints optimization for surface and sub-surface towards CAPEX free maximizing production

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Abstract. Integrated process operations and optimization are highly demanded in petroleum industries due to increasing costs. One of the advances is monitoring the integrated process by using single modeling and optimizing platform. This paper presents iCON, PETRONAS owned process simulation software, to predict the optimum pressure set point for separator train and choke valves’ opening, to maximize production in an existing facility. The source code developed was used to generate pressure and flow equation for each well to obtain material compositions for iCON model. Starting from current topside operating separator pressure, multiple case studies were run in iCON to produce production profiles at different operating pressures. The optimum pressure will be iteratively analyzed against the process constraint to locate the global optimum topside separator pressure set point. A single surface and sub-surface modeling platform ensures seamless data transfer, thermodynamic stability and efficient optimization iteration. The findings from this research are considered reaping the additional gas and oil production just by changing surface facilities separators set points and individual choke valve opening without violating process constraints.

1. Introduction

Fossil fuel continue to be widely used worldwide as primary energy resources, this is due to new resources of sustainable energy have yet to be developed. These conditions have motivated researches in the area of oil and gas production to explore new approaches to the application of optimization techniques to maximize oil and gas production rates and to minimize production cost.

Conventionally a standalone topside process model can only achieve production increment of up to 1%. In order to achieve higher production increment, an integrated topside process and subsurface model is required [1]. This modeling technique requires the integration of different modeling platforms for reservoir, wells, headers, topside facility, interconnecting pipelines between platforms and re-injection wells back to the reservoir. The main challenge is to develop a seamless interface communication between the different modeling platforms.

An integrated surface and sub-surface model and optimization contribute an important role during production because an integrated model can produce comprehensive and realistic operational recommendations. An integrated field model combined with optimization presents many link-ability challenges in terms efficient algorithms to eliminate thermodynamic instability when couple the models with optimization and sufficient hardware capacity to run the complex models.
Standalone topside optimization approach focuses on equipment performance which includes separators and compressors efficiencies as well as stable operation which can be achieved by proper process control strategy. By executing this approach, current performance of the processing facilities typically be benchmarked against the design capacity. The outcome of the work includes new operating separator pressure to ensure efficient gas and oil separation, new compressor speed or control configuration to meet gas export as well as gas lift/injection requirements, and new and/or improved control scheme with better tuning parameters for stable operation with the optimum production set points. By having all the recommendations implemented, the processing platform is able to achieve process stability with minimal tripped and unplanned shutdown.

Figure 1. Typical methodology for standalone topside optimization study.

Standalone topside optimization focuses on process stability which reduces the potential of production loss due to tripped or plant shutdown but it does not indicates the impact from topside operations to subsurface and vice versa. Unstable production in multiphase production systems and pipelines can cause serious operational problems for downstream receiving production facilities. Hence, integrated surface-subsurface optimization is the solutions to achieve global production optimization.

Several researchers have conducted research on various integration works Bailey et al [2] and Cullick et al [3] discussed complex petroleum field projects applying uncertainty analysis but the surface process facility was not considered. Integrated ECLIPSE and HYSYS simulators to model integrated field operation in a deepwater oil field was also conducted. These simulators were coupled by using Automation and Parallel Virtual Machine and apply a genetic algorithm for the optimization [4]. The use of integrated optimization in a daily operations setting of the LNG value chain was studied by [5]. To reduce computational time they chose simple models for all system components. A sizable gain could be identified by integrating all models into one model platform as opposed to many modeling platforms. Integrated operation and optimization to represent the value chain from reservoir to export terminal was also studied by Rahmawati et al [6] using realistic assumptions and parameter values. An integrated case study from reservoir to the surface processes and a simplified economic model to maximize field economics was also studied by Rahmawati et al [7].

In this paper an integrated first principle compositional thermodynamic model from well to surface processes is developed in one single platform iCON. The optimization objective function is to locate a CAPEX free operation settings by manipulating top site operating pressure and individual choke valve opening by satisfying surface facilities constraints. The model will create the operating profile to satisfy the maximum production envelope. Top site equipment capacities check are considered as global optimization constraints.
2. Modeling Strategy
An integrated field and optimization models play an important role during production optimization due to its ability to recommend comprehensive operational set points. Zainal and Hussein [1] confirmed that in order to achieve higher production increment, an integrated top site processes and sub-surface model is required. This modeling technique integrates the models using different modeling and thermodynamic platforms for reservoir, wells, headers, top site processes, interconnecting pipelines and reinjection well back to reservoir and/or wells.

Litvak et al. [8] developed an integrated compositional model of the reservoir and surface facilities. This model using multiple modeling platforms and only valid to daily optimization for small fields due to unstable thermodynamic translation among the multiple platforms. A practical approach to use Vertical Lift Performance (VLP) curves generated by PROSPER software, to predict wells performance and production at different top site pressure set points, is used. High and medium headers complex network hydraulic and pressure balance analysis typically model in PIPESIM will be modeled within iCON steady state environment as a single modeling platform to avoid thermodynamic translation complications.

In this paper, the significant of using single integrated optimization modeling platform is elaborated and reviewed the effect of well lineup to the optimization interim result. Previous works on surface and subsurface are compared and discussed to prove the significant of this work. Iterative method to locate CAPEX free optimization point by manipulating well lineup, top site pressure, individual choke valve opening are discussed. Finally, CAPEX free optimization envelope is developed to cater for all possible manipulating variables changes.

Figure 2. Methodology for Integrated Optimization study.

Figure 2 explains the overall approach for surface sub-surface integrated optimization where the subsurface and topside facilities are modelled in iCON environment. Once the model has been validated with actual data e.g. well test data, pipeline data, topside operating conditions and gas, oil, and water production rate, then the model is ready to be optimized with process constraints.

This research aims to develop an integrated surface and subsurface model from individual well, pipelines and surface process facilities in single modeling platform namely iCON. The integrated model is used to generate CAPEX free optimization region towards maximizing oil or gas production at different well line up scenarios. Reservoir model is not considered in this study as the fact that they operate in different time scale.

The vertical lift well pressure-flow curves, intersecting points between Inflow Performance Curves and Out Flow Performance Curves, data use nodal analysis generated from PROSPER which consists of relationship of Tubing Header Pressure (THP), Water Cut, Gas Oil Ratio (GOR) and gas lift rate with well production rate (gas, oil and water) as illustrated in Figure 3. The subsurface optimization variables consist of gas lift rate, water cut and GOR while topside optimization variables are individual well choke valve opening and individual header pressure which translated to separators pressure. Multivariable regression tool will be coded within iCON software to obtain the correlations between THP, gas lift rate, water cut, GOR to the individual well production.
The source code developed will then be used to generate flow equation for each flowing well to get the final composition to iCON model. Starting from current topside operating separator pressure, multiple case studies will be run in iCON to produce production profiles at different operating pressures and individual choke valve opening to locate maximum oil/gas production. The optimum pressure will be iteratively analyzed against the process constraints to locate the global optimum point at topside maximum production.

![Figure 3. Individual Well Vertical Lift Performance (VLP) Curves.](image)

All the individual well models will be combined by production platform and the production rates for each platform is calculated and subsequently connected to respective production separator model in iCON. The topside optimization is conducted by manipulating the individual header pressure and choke valve opening to each well to determine the impact of those two parameters to gas and oil production from each platform. Figure 4 illustrates the process flow diagram of well models and processing facilities model in iCON. The data use in the well models are the sensitivity analysis from PROSPER and the data used for processing facilities are taken from the installed equipment datasheet and current operation and production data.

![Figure 4. Process Flow Diagram.](image)

Typically, the topside process is controlled using a distributed control system, while the wells are controlled manually by the operators through the choke valve stroke positions. Although this separate control system may not be optimal with respect to maximizing the full processing capacity of the surface facilities, its high operational reliability due to simple design complexity is an advantage. In addition to the natural variation in the flow rates and the multi-phase flow in each well, its dynamics are affected by the choke valve position and the gas lift rate. Also, there is the additional complexity introduced by using multiple production wells with individual process dynamics behavior and compositions. Add the dynamics of the topside process to this, and it is obvious that it may be difficult for a human operator to control the production chokes in an optimal manner.

Furthermore, the integrated model of topside and wells becomes more important when the process disturbances become larger (e.g. slugging wells). With unstable wells present, the platform operators tend to back off from the process capacity constraints to avoid process shut downs and flaring of gas in the event of excessive slugs entering the topside process. This in turn yield lower production rates which lead to a loss of revenue. With integrated well and topside model, it will also be able to operate closer to the process constraints with process disturbances such as slugging wells due to well pressure variations [9].

The production rates are set at the inlet of the topside process by use of the stroke position of the production choke valves for each well. There is no automatic feedback from the process to where the
production rates are set. The feedback is handled manually by the operators and the performance will naturally vary depending on the operator’s action. Especially, when one or more of the wells show natural variation in the feed rates, the feedback is slow and not optimal with respect to process requirements [10].

The process constraints (which limit the throughput) are typically located in the processing unit and the operational objective is to utilize the available capacity (constraint control) to the maximum. Since the production rate is set at the wells, introducing automatic feedback control from the constraints to the feed stream to the process is assumed to have great economic potentials in term of plant efficiency. However, the number of feed conditions (wells, water cuts, GOR, WGR) and different pressure setting options make automatic pressure flow relationship difficult to implement.

Large fields where oil production is in decline (due to high water cut wells) and the identification of an optimized production strategy will be importance to maximizing the return on investment. It is necessary for an integrated well and topside model to be developed to cater for more representative in maximizing oil and gas production [11]. Recent studies have presented multiple model platforms the required suitable and accurate time stamp for optimization to work. Look up tables were also used to determine multiphase flow from each reservoir without considering surface facilities installed capacity as constraint variables. Potential revenue predicted from recent studies on integrated model was based on single point optimization without giving optimization validity envelope which is difficult to implement.

3. Modeling Results

There are two models were developed in this work namely iCON steady state and iCON dynamic. iCON steady state is focused to optimizing the separator train pressure and individual choke valve opening to maximize production. Dynamic model is used to check the controllability show stoppers due to additional production arising from the new optimized set points coming from steady state model. The comprehensive Surface and Sub Surface models were developed in iCON to represent the interaction between multiple well behaviors and surface process facilities to generate optimized operating envelope at different active/inactive well configurations.

Figure 4 shows the surface and sub-surface simulation model in iCON. Due to the space constraint, only small parts (e.g. well connection in Fig. 4(a), and low-pressure system of a surface facility in Fig. 4(b)) of the overall simulation network is shown. Separator train pressures are optimized in surface model while individual choke valve opening is optimized in sub-surface model. In this work iCON optimizer is used to locate the optimization point and eventually the optimization envelope.

The integrated model is tested and compared against the operating envelope to ensure model robustness prior to production optimization. Optimization objective function (OF) is setup to maximize the oil and gas production. Manipulative variables (MV) include individual header pressure and individual choke valve opening at each well. Existing equipment design are used as the constraints such as capacities of the pipes and valves.
Figure 4. Typical flow diagram of (a) well model connected to a Medium Pressure (MP) header, and (b) some part of surface processing facilities.

Once the constrained optimization point is located, the optimization procedures are repeated at different well line up scenarios. Finally, the optimization validity envelope is constructed to represent CAPEX free optimization region. Table 1 shows the changes of manipulated variables during the optimization run.

Table 1. Optimized manipulated variables versus running period.

| Optimization Period | Var 1 | Var 2 | Var 3 | Var 4 | Var 5 | Var 6 | Var 7 | Production (bbl/d) | Delta |
|---------------------|-------|-------|-------|-------|-------|-------|-------|-----------------|-------|
| Initial Value       | 270   | 40    | 50%   | 50%   | 50%   | 50%   | 800   | 5669            | -     |
| After 3 days        | 214.5 | 61.29 | 51.1% | 53.6% | 51.1% | 51.1% | 700   | 5794            | 125   |
| After 5 days        | 212.6 | 64.26 | 50.3% | 54.1% | 49.7% | 53%   | 705.3 | 5809            | 15    |
| After 6 days        | 212.6 | 64.26 | 50.3% | 54.1% | 49.7% | 56.2% | 705.3 | 5822            | 4     |
| After 7 days        | 212.6 | 67.47 | 50.3% | 54.1% | 49.7% | 56.2% | 705.3 | 5826            | 4     |
| After 8 days        | 214   | 68.64 | 51.1% | 55.1% | 47.3% | 57.2% | 707.8 | 5830            | 4     |

Where:
Var 1: Medium Header Pressure (psig)
Var 2: Low Header Pressure (psig)
Var 3 - 6: Medium Pressure Well Valve Opening (%)
Var 7: High Header Pressure (psig)
Production increase:

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= \frac{(125+15+4+4+4)}{5669} = \frac{152}{5669} \times 100\%
\]

= 2.7 % (equivalent to 152 bbl/d of oil production increase)

Figure 5 and 6 are typical iCON Optimizer setup after 3 and 8 days of running respectively. Each day of running results were tabulated in table 1 and plotted as in figure 7. From figure 7, production increase has plateaued after 6 days of running period. Oil production increment is accumulated after it reaches plateau state and is considered as one point in CAPEX free optimization envelope. The same procedures are repeated at different well lineup scenarios to ensure all possible well configurations are covered. Well lineup configuration coverage is crucial to safeguard a realistic optimization set points are applied during the implementation period.
4. Conclusion
The constrained optimization technique applied above represent realistic optimization set points for implementation within the optimization envelope. Convergence time varies from 5 hours to 6 days to reach plateau increment of oil production depending on top site mode size, well lineup configurations and initial value of steady state point. CAPEX free optimization envelope generated is specific to predetermine well characteristic coming from PROSPER results and only valid as long as the well properties are maintained.

![Figure 7. Production increase versus running period.](image)

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