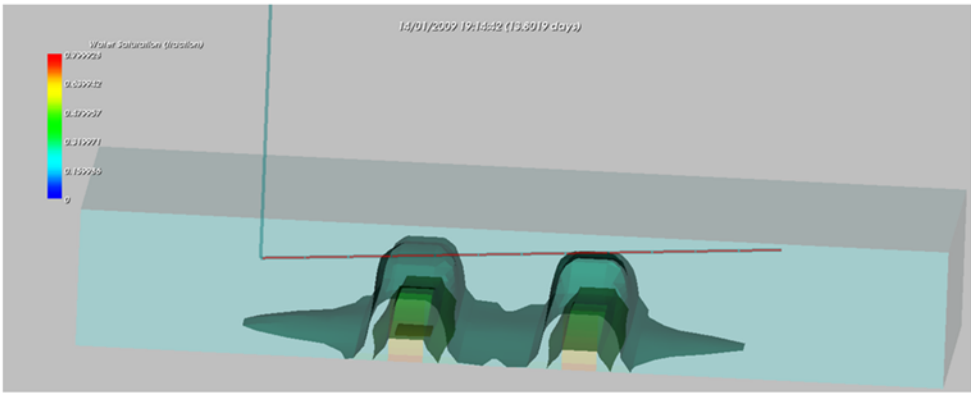
SMART WELL MODELLING

Design, Scenarios and Optimisation

Introduction

"Smart" or complex wells are in increasing use by operators as reservoir environments become more challenging. The wells include a number of smart devices installed to achieve a variety of objectives.

For example, Inflow Control Devices (ICDs) are used to mitigate water or gas coning effects in long horizontal wells. These devices are passive devices that have the ability to preferentially allow flow of the desired phase. The devices cause a higher pressure drop automatically to avoid excessive water or gas production in certain sections of the well without surface control. These are particularly important when considering reservoir heterogeneity; in their absence higher permeability regions in certain cases will allow large water-cuts/GOR, thereby severely affecting the well production performance as well as reservoir management due to poor reservoir sweep as shown in the picture below. Essentially, ICDs are an "insurance policy" against unexpected heterogeneity. The use of the devices can delay the start of artificial lift required for the well, which can improve cash flow by delaying capital costs.



Inflow Control Valves (ICVs) are also often used, allowing dynamic down-hole control. These are controllable down-hole valves, and the valve setting can be changed to achieve different objectives. They can also be used for mitigating coning effects, for multi-layered wells to control commingled production from different layers and even for multi-layered injectors for equalizing injection rates and sweep through all the layers.

Further complexities in design include smart wells with these devices placed on multiple wellbore laterals, dual tubings, multiple zones, mixed configurations of sections with screens and sections with these devices, sliding sleeves etc.

Objectives

Smart well design depends on the user objectives which can be quite varied. From a reservoir management point of view, the objectives are improving sweep and overall recovery from the reservoir. Optimising well performance implies reducing water-cut and GOR. From an economics standpoint the objective is maximizing NPV or profit.

The primary objective here therefore is to maximise an objective function (NPV or production) by investigating optimum device types and configurations for a single well. This will allow the other objectives mentioned above to be captured. Furthermore, the impact of reservoir uncertainty needs to be considered in the design as this can have an impact on the locations of the devices and their final configuration.

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Context

A number of case studies can be found in the industry investigating well design, however rarely is the effect of the design considered over the producing life of the well. Indeed, most designs are done at a single point in time, the impact of change in wellbore configuration on production calculated and the final design determined.

It is very important however to perform the design and run sensitivities over the entire producing life of the well. The reason for this is that as conditions change in the reservoir different well configurations will respond differently. For example, for wellbore design to avoid coning, a particular configuration might be optimal in early times but another in late times as the water/gas moves towards the well. The design should therefore consider the “best case” which is optimal for all times.

Additionally, investment is made for these devices in the present, however the return on the investment is only seen later in time. It will not be valid to make a final decision on the well design based on well results using a “snapshot”, as a particular configuration which may be the best today may not be the best in the long run.

Performing sensitivities and changing the wellbore layout can be a laborious task, as a very large number of possible configurations can exist for a given well. Coupled with uncertainty in the reservoir properties, it becomes extremely challenging with existing methods to analyse the possible scenarios to a satisfactory level.

Tools

A reservoir simulation model is required to understand the performance of these smart wells, as analytical IPRs do not have the ability to capture the detail of reservoir heterogeneity, fluid movement through time and wellbore performance. **REVEAL**, being an integrated reservoir simulator, is best suited for well design as it captures the full physics of the modelling with time and has the ability to define complex well descriptions easily. The different scenarios historically needed to be done manually or automated through a visual workflow in **RESOLVE** (which is a platform for advanced field management, logic and optimization).

In recent years a lot of development has been done in **RESOLVE** to create a variety of data objects: the idea is that a data object can store data and perform a range of calculations e.g. PVT, tight reservoirs, well and flow assurance etc. These data objects also have support for visual workflows which means that a number of calculations can be automated and accessed through a real-time system.

The **RESOLVE** ICD Analysis Data Object is available in IPM 9 and is designed to build **REVEAL** simulation models for ICD and ICV optimisation studies and achieve the above mentioned objectives. The ICD Analysis Data Object uses full reservoir simulation, thereby allowing full life of well analysis rather than analysis only for a particular point in time. The use of **REVEAL** as an integrated well-reservoir simulation tool implies tight coupling between the response of the well and the reservoir, thereby creating a consistent numerical model.

The **RESOLVE** interface is very easy to use and does not require the engineer to have experience in numerical reservoir modelling: this makes it easy for engineers from various disciplines to build models. **RESOLVE** takes care of creating the full **REVEAL** model, ensures that the correct gridding is done based on the device locations and petrophysical data as well as automates the creation of various well configuration scenarios.

Case Studies

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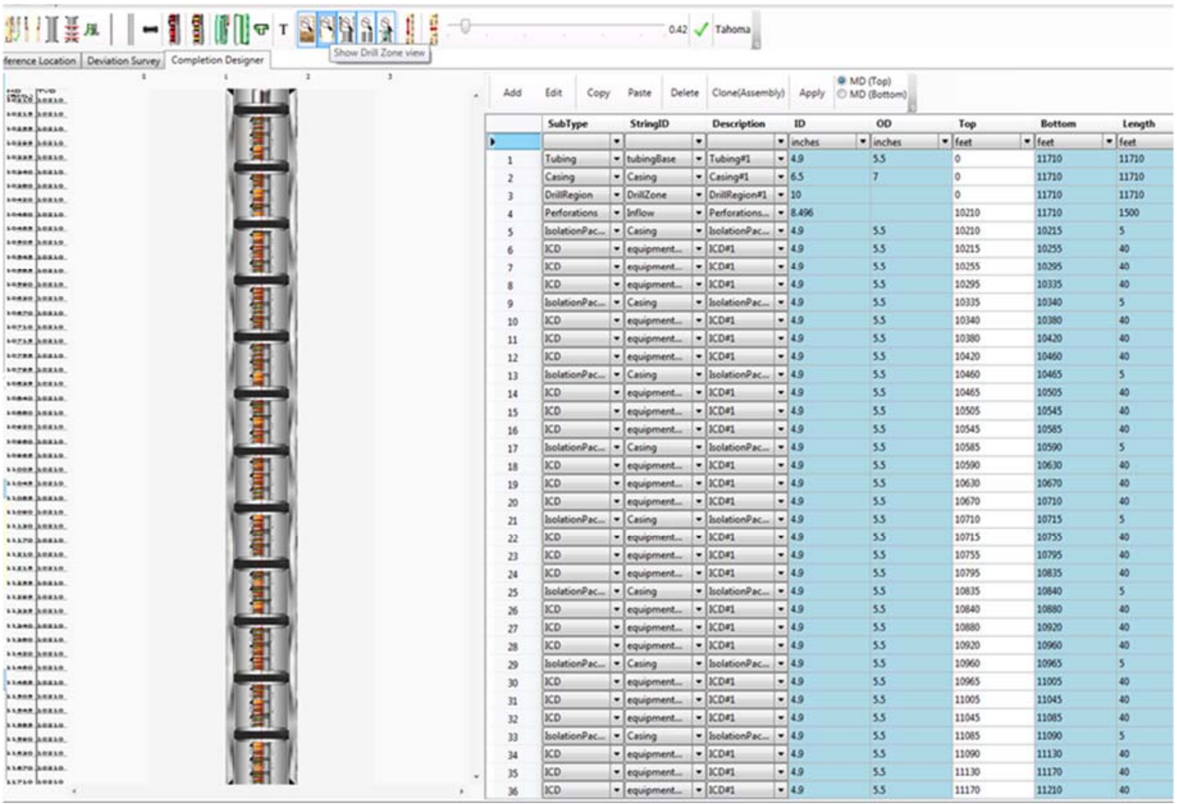
The basic idea here is that we define our PVT, reservoir conditions and a well description with a number of controllable devices. The locations, types and control of the devices then become part of possible scenarios for the ICD analysis data object.

The well itself is defined in the **RESOLVE** Well Builder data object, which is part of a larger initiative to build well models for a number of studies e.g. SAGD, ICD analysis etc. The following picture shows a typical detailed well built in the **RESOLVE** Well Builder object which is used for ICD/ICV design studies. The well has a horizontal section in the reservoir which includes alternating sections of packers and ICD equipment for zonal isolation.



The ICD analysis object allows the following to be captured:

⇒ Layers with porosity/permeability, anisotropy vs MD profile

⇒ Reservoir zones with Oil/Water contacts, different pressures to investigate e.g. multilayer completions

⇒ Tubing v/s annulus setting for the devices

⇒ Vertical, horizontal and multilateral wells

⇒ Results extracted from the **REVEAL** simulation model and NPV calculations for ready comparison of the scenarios

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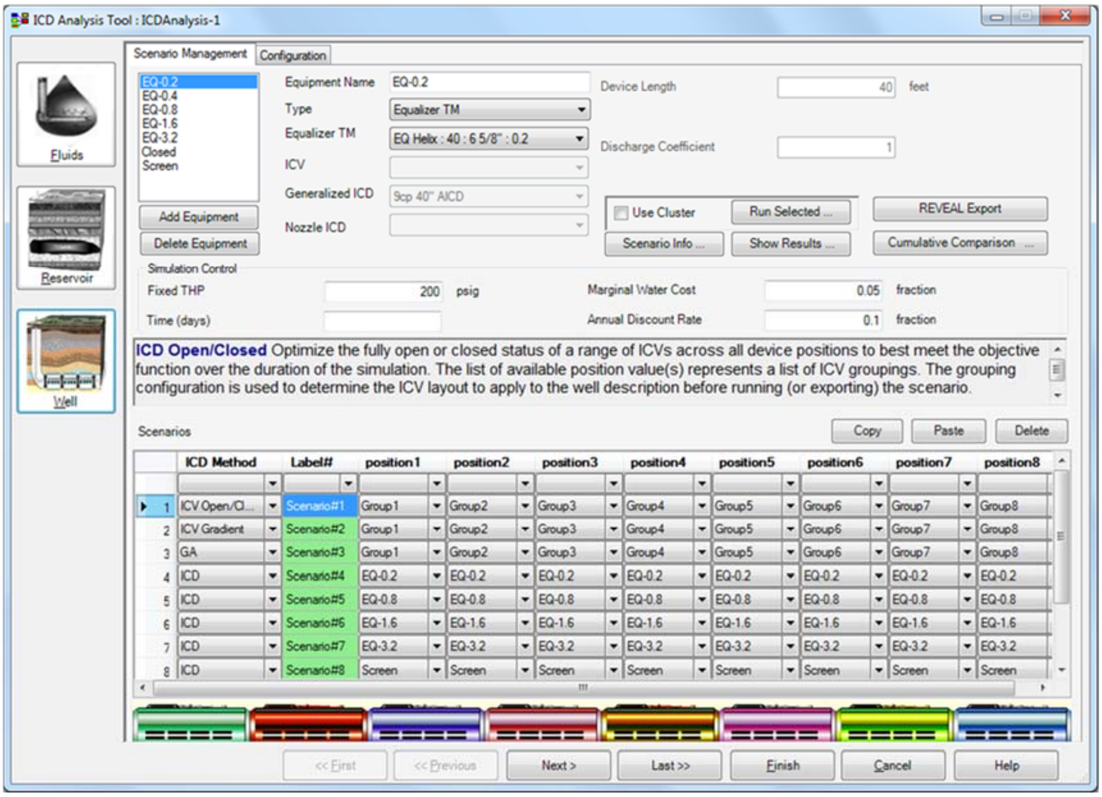
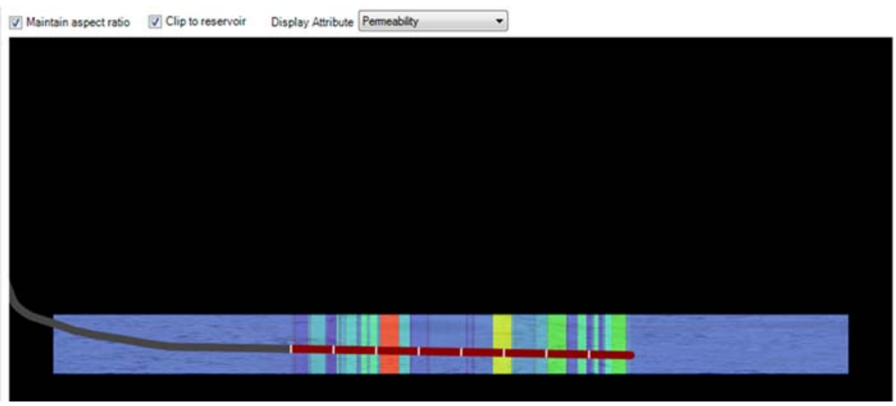
A variety of different scenarios can be run using the ICD Analysis Data Object. Furthermore, the scenarios can be run in parallel using the **Petroleum Experts** cluster program (**PxCluster**) which improves the total run time of all the scenarios considerably.



Case Study

The objective of the case study presented here is to come up with a design that maximises NPV by comparing various well configurations. The petrophysical data shows considerable variation in permeability and porosity along the horizontal well length. The presence of a strong aquifer makes this well a good candidate for wellbore optimization studies to delay water breakthrough and improve production. The following figures show the placement of the ICDs with respect to the permeability distribution in the reservoir along with the well trajectory through these regions.



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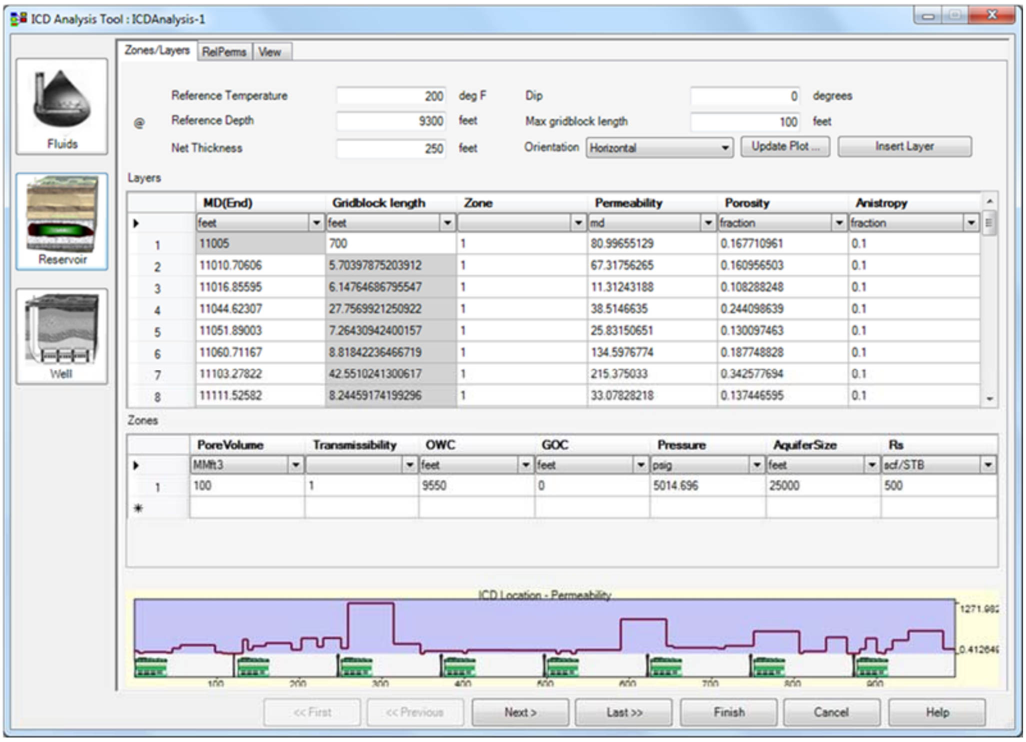

The following situations will be considered in order to come up with the optimal design:

⇒ Comparisons of different devices for a particular completion (ICDs v/s ICVs v/s screens)

⇒ Consider the design benefits of a range of ICD strengths. Determine the optimal configuration of different devices along the same completion

⇒ Investigate the use of ICVs and their dynamic control to maximise production

⇒ Look at the impact of running the simulation for a finite time versus running to an abandonment constraint

⇒ Consider if the optimum design changes due to reservoir uncertainty

The scenarios will be run for a fixed WHP as this is important to obtain a fair comparison. Fixed rate or fixed BHP will not give correct results as this will not be the response of the well in reality.

For example, a fixed BHP control will be advantageous for a well with screens as a smaller pressure drop occurs across the screen as compared to the ICD. The reality is that lower pressure drops across the screen will cause higher liquid and water production rates: this water needs to be carried to the surface which means that the BHP will be higher due to the response of the VLP. A similar argument exists for a well controlled by fixed rate.

Therefore for smart well optimisation, the well response to the surface must be captured to compare the designs.

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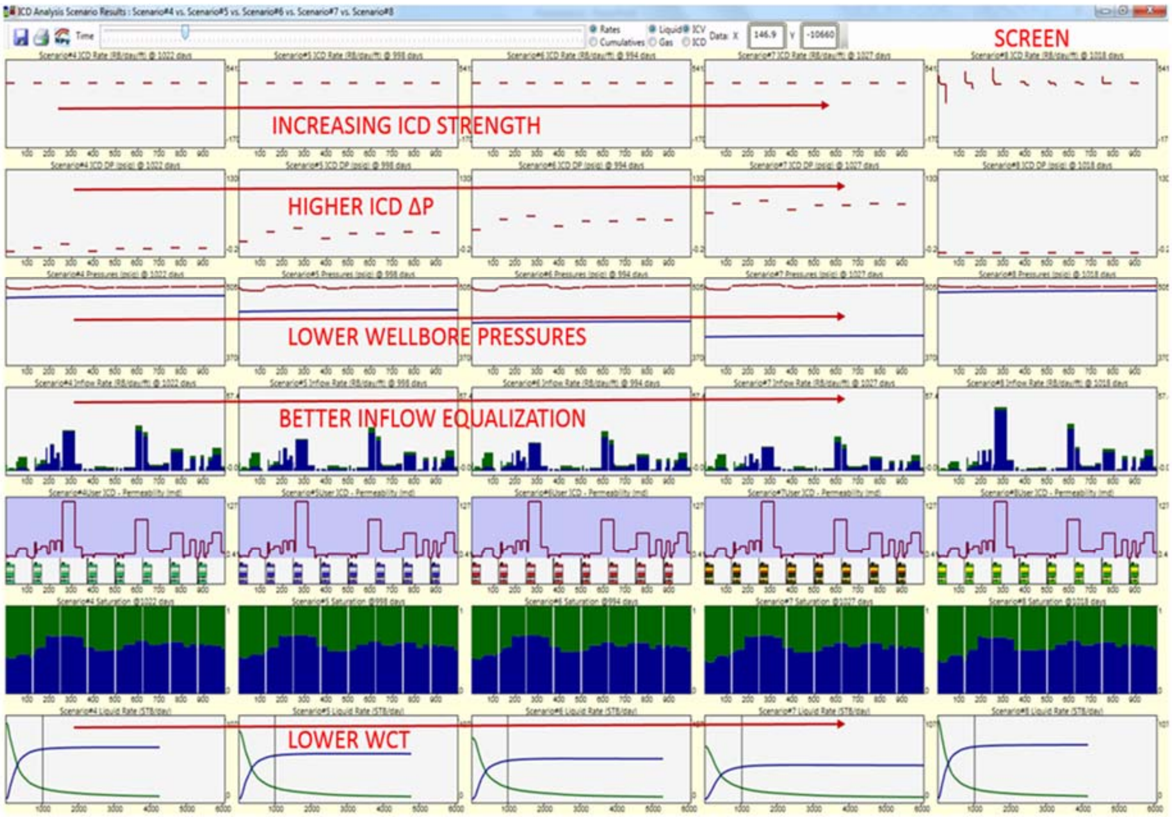
Results of ICD Comparisons

REVEAL models automatically created from the **RESOLVE** data object can be run to investigate the performance of different strength ICDs. The following figure compares the results for the same ICD placed in all the locations of the well with increasing ICD strength for four ICDs (Scenarios 4-7). A scenario with the well completed with screens (no inflow control) has also been run (Scenario 8). An additional scenario for ICD placement optimisation using a genetic algorithm has been run (Scenario 3) and is explained in the next section. The scenarios have been run for an abandonment WCT of 95%.

From the results we can see that as the ICD strength increases, the cumulative water-cut reduces. This is driven by the higher ICD pressure drops due to which the aquifer rises slower with time. The equalization of inflow in the well yields a better aquifer sweep in the reservoir and higher recovery.



The cumulative oil production and final NPV go through a maximum with increasing ICD strength and then reduce: this suggests that there is an optimum ICD size for maximising NPV. These results are reasonable, since with higher ICD strength higher WCT/ high permeability regions are choked, giving us more oil. If the ICD pressure drop is excessive, then eventually we lose production due to the high choking.

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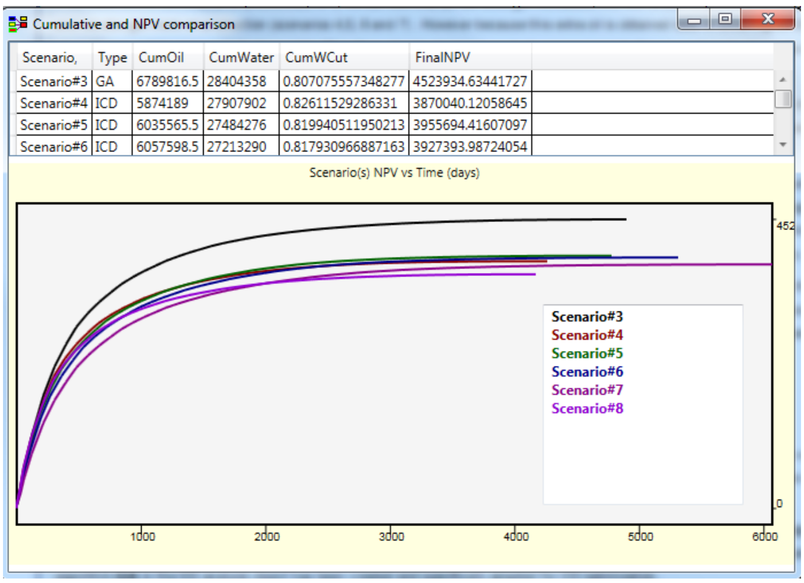
If we observe the cumulative oil production/NPV, we can see that as ICD strength increases, the well is able to produce for longer and we also get more oil production (Scenarios 4,5, 6 and 7) . However because this extra oil is obtained later in time, higher ICD strength may not be economically favourable. Therefore, design decisions made by comparing only the present production rate or cumulative oil production will not be the best economically.

The advantage of working with NPV is that we account for the fact that different simulations run for different times in our comparisons. The NPV is calculated by discounting the oil production to present value using a user-defined discount factor and has units of cumulative production (e.g. MMSTB).

Comparing scenarios 4-8 from the graph, we can see that the NPV curves cross each other in early times. This shows that with higher ICD strength, we reduce water-cut and increase oil production, but the benefit of this oil production is seen in longer term simulations. However if the ICD pressure drop is excessive (scenario 7), then this case is the worst amongst ICDs. Having screens (scenario 8) gives the least NPV which shows that for this case study, some inflow control or zonal isolation is necessary. The comparisons between the manually created ICD cases (Scenarios 4-8) show small differences in final NPV. However using the genetic optimiser (Scenario 3) gives a substantial increase in NPV compared to all the ICD cases (Scenarios 4-8) and is explained in the next section.



Scenario,	Type	CumOil	CumWater	CumWCut	FinalNPV
Scenario#3	GA	6789816.5	28404358	0.807075557348277	4523934.63441727
Scenario#4	ICD	5874189	27907902	0.82611529286331	3870040.12058645
Scenario#5	ICD	6035565.5	27484276	0.819940511950213	3955694.41607097
Scenario#6	ICD	6057598.5	27213290	0.817930966887163	3927393.98724054

Running models to abandonment also gives a good idea of how the well will perform throughout its life. It is possible to run the simulation for a fixed time, in which case the best case result can differ from running to abandonment especially in the scenarios here where the NPV curves cross each other. The decision on what is the best simulation time for these comparison studies needs to be made by considering the overall objectives and the time period over which the return of investment is desired.

Genetic Algorithm for ICD placement Optimisation

From the results of the various ICD cases above, it is clear that there can be a very large number of additional scenarios when we look into the possibility of placing more than one ICD type in the well. For example, we may wish to place high strength devices in areas with higher permeabilities, but place low strength ICDs or screens in low permeability regions.

The ICD data object includes an **integer genetic optimiser** for ICD placement optimisation. ***RESOLVE*** already has GIRO, an integer optimiser for well routing optimisation which is valuable for overall field management and optimisation. However the genetic algorithm (**GA**) in the ICD analysis object has been created and specifically adapted for ICD optimization.

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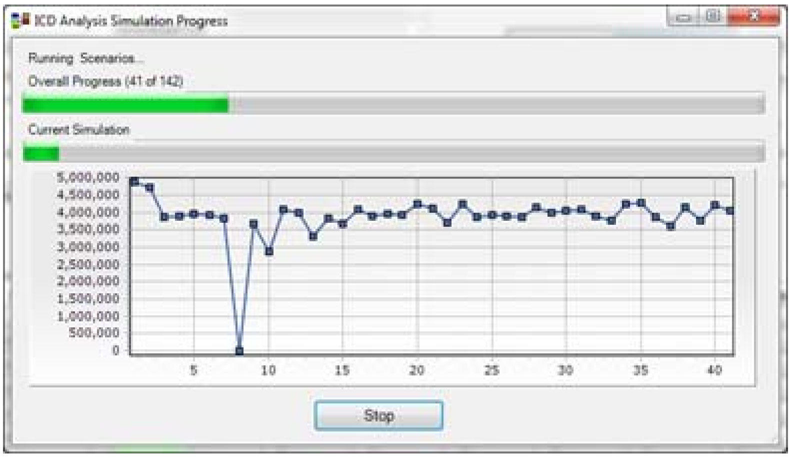
The GA method finds the best case scenario by determining new cases based on the best results of previous cases. The new cases are determined using genetic algorithms, where the "genes" i.e. ICD locations of high NPV cases are combined to create new "children" (i.e. new scenarios). Therefore, by evaluating a small number of cases from the total number of possible combinations and running the simulation models, the optimum configuration can be found.



The result is a combination of screens and ICDs along with "Closed" sections (i.e. solid tubing).

The final NPV of the optimised ICD case (Scenario 3) has been shown previously and has a significant benefit to the manually calculated ICD scenarios (Scenarios 4-8).

Results of ICV Optimisation Cases

Using the ICD object in **RESOLVE**, it is also possible to place ICVs instead of ICDs along the well and investigate the advantage of dynamic ICV control to optimise production. **REVEAL** has two in-built ICV optimisation methods for the purposes of finding the optimum ICV setting at each time-step in the simulation which maximises oil production.

The first method is derivative (Gradient) based, and calculates continuous ICV settings between 0 (fully closed) and 1 (fully open). It tests one ICV at a time to find the ICV setting (flow area) that maximises oil production for the well keeping the others constant. This procedure is repeated for each ICV in the well. The final result is a list of ICVs with their flow areas (or opening fractions) that maximises oil production for that time-step. This calculation is done at each time-step in the simulation.

The second method is integer based (Open/Closed) and calculates ICVs that are either fully open or fully closed. It works similarly in that it tests one ICV at a time and checks whether we get an increase in production by either fully closing or fully opening the ICV. This is repeated for each ICV in the well such that we get the Open/Close status for each ICV that maximises oil production. This calculation is done at each time-step in the simulation.

It is possible to prove using a choke response curve that the Open/Closed method will give more production than the gradient method. This is because the oil production for the well either continuously increases or continuously decreases as the ICV size increases, giving the maximum when the ICV is either fully open or fully closed.

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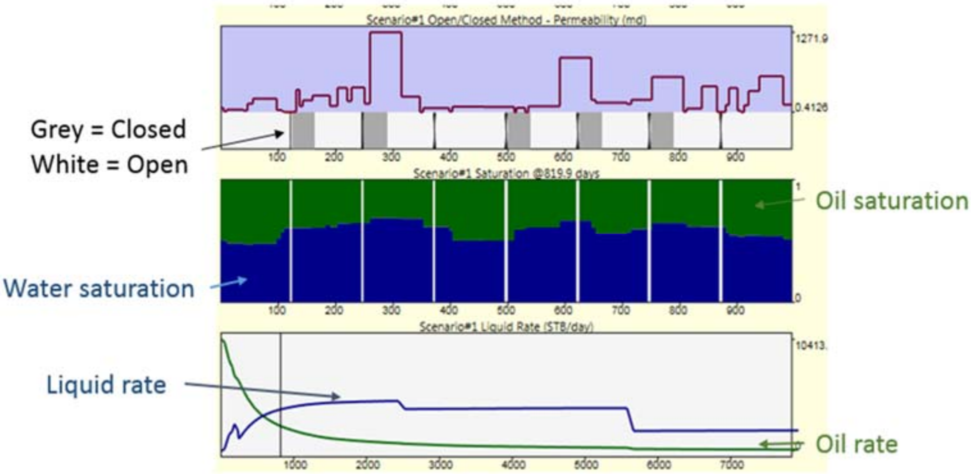
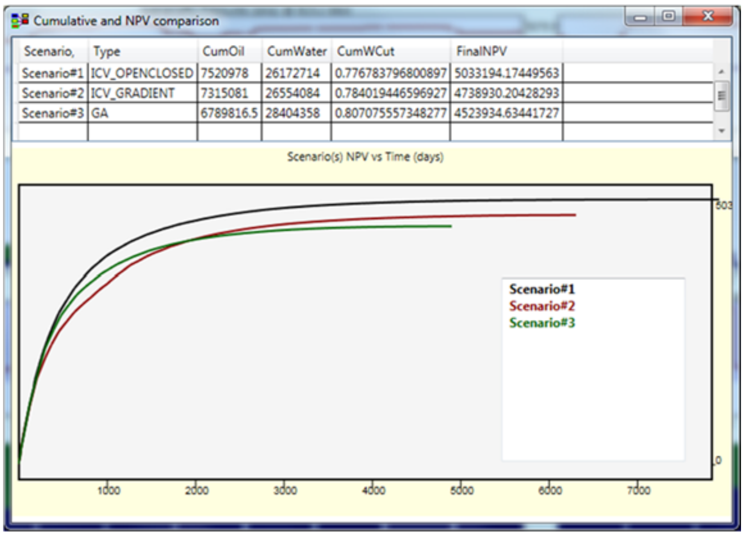
The Open/Closed status for the ICVs at a particular point in time along with the fluid saturations and production rates for the well are shown in the figure below.



Final comparisons of the best cases

The figure below compares the NPVs for the ICV Open/Closed case (Scenario 1) with the ICV gradient method (Scenario 2) and the ICD genetic algorithm method (Scenario 3).



Scenario,	Type	CumOil	CumWater	CumWCut	FinalNPV
Scenario#1	ICV_OPENCLOSED	7520978	26172714	0.776783796800897	5033194.17449563
Scenario#2	ICV_GRADIENT	7315081	26554084	0.784019446596927	4738930.20428293
Scenario#3	GA	6789816.5	28404358	0.807075557348277	4523934.63441727

The ICV Open/Closed method yields the best NPV compared to all cases (including ICD, GA, ICV gradient cases) in this example. This will be expected, as continuously monitoring and controlling the well can give higher production than using a fixed device (ICD). The practicalities and economics of having the ability of dynamic control in the well will dictate the final design based on ICDs (GA - Scenario 3) or ICVs (Open/Closed - Scenario 1) for this case study.

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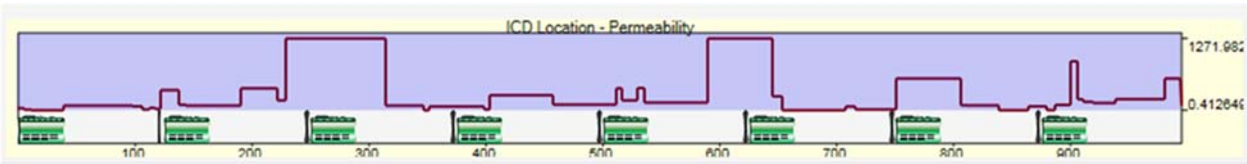
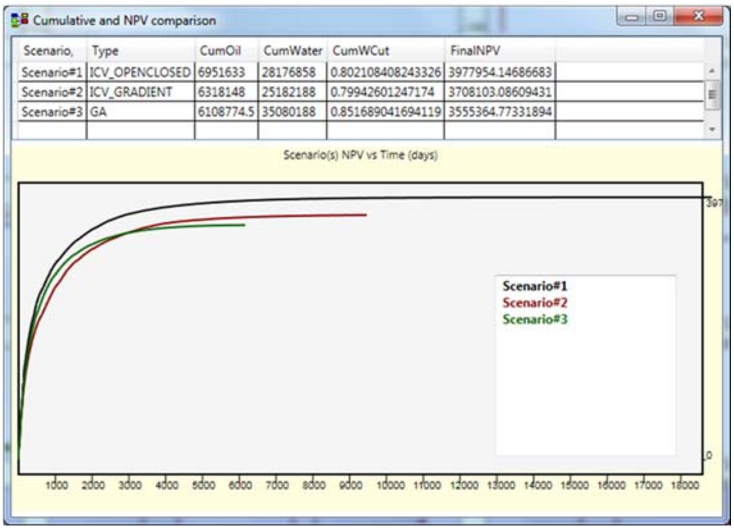
Reservoir Uncertainty

Having run the previous scenario cases, the objective of understanding the impact of reservoir uncertainty on our "best case" scenario can be achieved using the ICD object. The scenarios can be rerun for a different permeability profile and readily compared. The figure below shows the ICD placement relative to the modified permeability profile.



The results of the scenarios show that again the ICV Open/Closed method yields the highest NPV as compared to the ICV Gradient and the GA (see figure below). The GA optimization method, however, yields a different ICD configuration for the well due to the different permeabilities. These results can then be compared to the scenarios of the previous permeability profile to make a decision on the best configuration to be used for the well.



Summary

The **RESOLVE** ICD analysis data object uses the simulation capabilities of **REVEAL** to run and compare different layouts for meeting the overall objectives. These objectives are maximising NPV or profit along with reservoir management and inflow equalization along the well.

In conclusion it is very important to consider the impact of various wellbore configurations over time which can only be achieved using **REVEAL** simulations. Investigating ICD placement by looking at results only at one time-step will not be the best for the entire life of the well as demonstrated by the results of the case study.

The ICD data object uses the NPV to compare different scenarios which accounts for the effect of time in the simulations. A genetic algorithm calculates the optimum configuration of ICDs for a given well based on the results of the simulation models. ICV optimization methods for dynamic control are available in **REVEAL** to calculate the optimum settings at each time-step for all ICVs that maximise oil production. A decision on the final well design can be made by comparing the detailed and overall results of the different scenarios.