DEVEX2018

Pushing the boundaries of open source simulators
A scalable alternative to commercial tools
for subsurface dynamic studies

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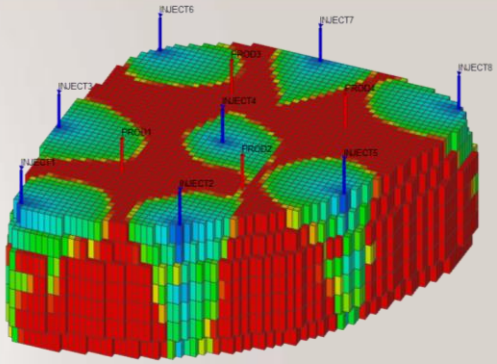
Value of open-source simulators and why to benchmark

Multi million dollar decisions are taken with commercial simulators. Licensing and cost however restrict thorough analysis.



Open Source Simulator brings the following advantages:

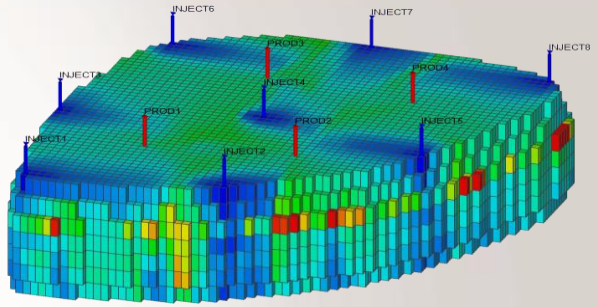
- Free of charge
- Ability to analyse results using ResInsight
- No licenses required to run reservoir models
- Run unlimited number of cases on a number of PC's using the cloud
- Write/ edit code to implement changes in the script
- 3D plots and results of good quality.

The study focus was in proposing a solution for validating the open-source simulators by using the experimental designs and other statistical methods to widen the testing ranges. The other aspect is to define the application areas for the open-source simulators and their areas for development.

The next step in the study would be to elaborate the workflow helping us understand where the difference in the results from the open source simulators are originating from. For example : well models, solvers, transmissbilities, black oil equations, discretization methods.

The Model used in the comparative study

- The Egg model is a synthetic reservoir model which consists of a collective of 101 relatively small 3D realization
- It has been used in numerous publications to demonstrate a variety of aspects related to computer-assisted flooding optimizations and History Matching or, in combination, closed-loop reservoir management.
- The model consists of an ensemble of 100 realizations of a channelized reservoir in the form of discrete permeability fields modelled with 25,200 grid cells of which 18,553 cells are active. The non-active cells are all at the outside of the model, leaving an egg-shaped model of active cells.
- Because the model has no aquifer and no gas cap, primary production is almost negligible, and the production mechanism is water flooding with the aid of eight injection wells and four production wells as shown opposite.



Variables	Range	Units
Porosity	20-30	%
Permeability- layer1	350-600	mD
Permeability- layer4	100-300	mD
Injection rate	2000-5000	m^3/day
Oil viscosity	3-4	cP
Water viscosity	1-1.2	cP
Bottom-hole pressure	385-390	psia
Oil compressibility	$4.0x10^{-5}$ - $4.6x10^{-5}$	1/psi
Water compressibility	$4.0x10^{-5}$ - $4.6x10^{-5}$	1/psi
Oil density	800-850	kg/m^3

Numerical simulators used in the study

- Eclipse 100 is the industry standard commercial reservoir simulator.
- Eclipse 100 has been tested and proven to be robust and reliable since its launch in 1982.
- Its able to transfer models from simulators such as BlackOil, Compositional and FrontSim.

SINTEF
OPEN POROUS MEDIA

- OPM Flow simulator
- ResInsight post-processor
- Open source tools (part of OPM project)
- Created by SINTEF
- Supported by a number of universities and companies including STATOIL and TOTAL
- Currently in open and active development

SINTEF

- The MATLAB Reservoir Simulation Toolbox (MRST) is mainly intended as a toolbox for rapid prototyping
- Created by SINTEF
- Supplies a wide range of solvers and workflow tools which can be combined to perform various tasks.

Sensitivity analysis workflow used to test OPM and MRST against ECLIPSE 100

Design of experiment

- Full factorial
- Fractional factorial
- Plackett Burman

Exp #	A	B	C	D	E	F	G	H	I	J	K	Resp 1
1	1	-1	1	-1	-1	-1	1	1	1	-1	1	
2	1	-1	1	1	-1	1	-1	-1	-1	1	1	
3	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
4	1	1	-1	1	1	-1	1	-1	-1	-1	1	
5	1	1	-1	1	-1	-1	-1	1	1	1	-1	
6	-1	1	-1	-1	-1	1	1	1	-1	1	1	
7	1	1	1	-1	1	1	-1	1	-1	-1	-1	
8	-1	1	1	1	-1	1	1	-1	1	-1	-1	
9	-1	-1	1	1	1	-1	1	1	-1	1	-1	
10	-1	1	1	-1	1	-1	-1	-1	1	1	1	
11	1	-1	-1	-1	1	1	1	-1	1	1	-1	
12	-1	-1	-1	1	1	1	-1	1	1	-1	1	

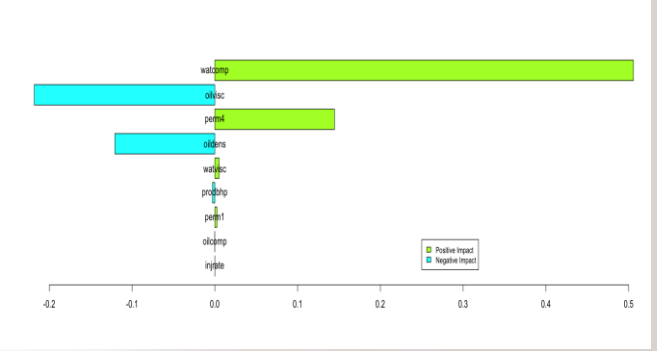
Sensitivity analysis

- Uncertainties on any input of the reservoir simulator.

```
Call:
lm.default(formula = Qo ~ poro + perm1 + perm4 + injrate + oilvisc +
    watvisc + prodbhp + oilcomp + watcomp + oildens, data = Design1.ECLIPSEwithresponses)
```

Linear model

- Linear model has the advantage that it can analyse the influence/prediction of the output.
- Shows the main and least influential variables in the linear model
- Rank influence of each uncertain input on KPI output

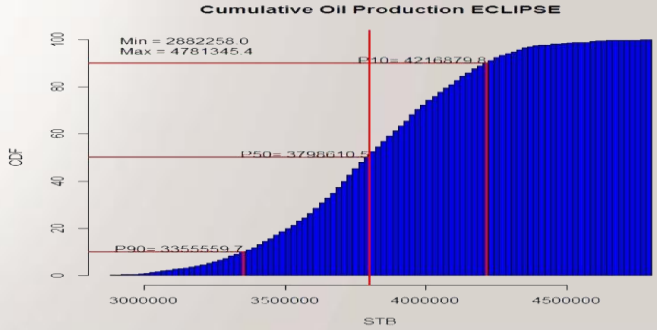


Monte Carlo simulation

- Linear model to be used as a proxy in order to run a Monte Carlo simulation which will predict the P90, P50 and P10.

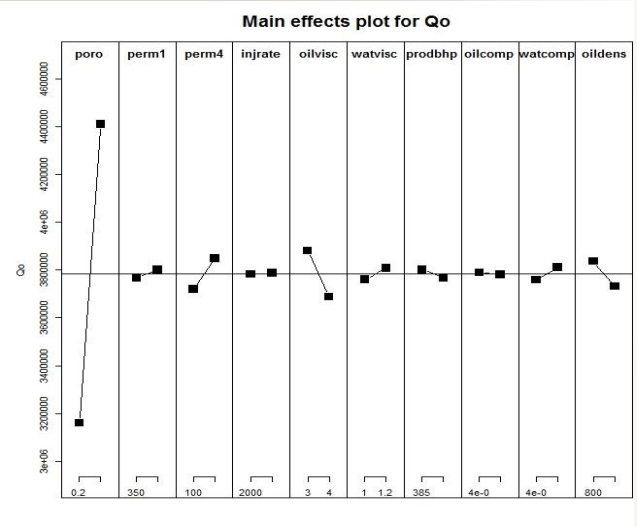
KPI

- Select representative realizations for multiple KPI's such as BHP, FPR, FCWT, THP, OPR using Pareto plot and CDF using R studio.



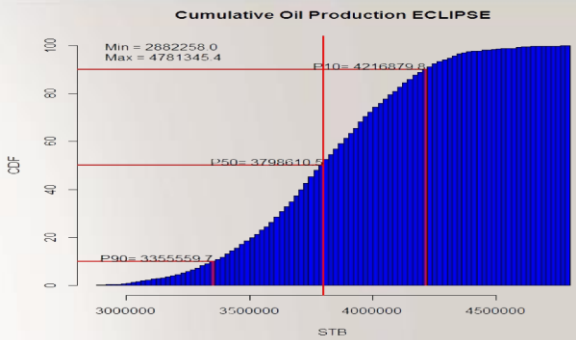
Open source simulators testing results

- Benchmarking framework used numerous KPIs such as cumulative oil production, water cut and field pressure.

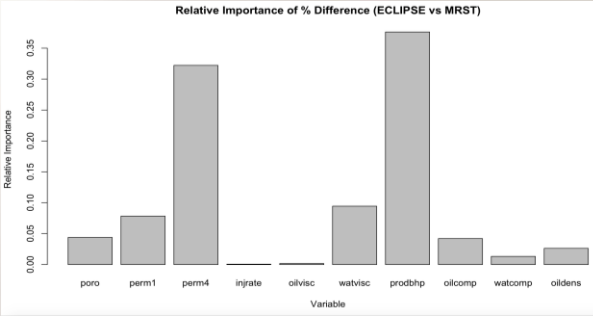


- Sensitivity analysis have shown that porosity, oil viscosity and permeability were the main influencing variables.

- Monte Carlo runs (1000) were made to calculate the cumulative distribution function (P10, P50 and P90).
- The percentage difference of output from open source and commercial simulators are shown opposite for cumulative oil production.
- Relative importance graph have shown that the permeability of the 4th layer of the model and BHP target/limit influence the difference in results the most.
- The open source simulators proved that the benchmarking method is reliable within the realms of the study.
- Next step is to test other reservoir simulators (including companies in-house) using this workflow.



ECL / SINTEF OPM		ECL / SINTEF MRST	
No. of Cases	ECLIPSE vs OPM - % Difference	No. of Cases	ECLIPSE VS MRST - % Difference
Case_1_Cum_Oil_Prod	0.0405%	Case_1_Cum_Oil_Prod	0.0583%
Case_2_Cum_Oil_Prod	0.0706%	Case_2_Cum_Oil_Prod	0.0525%
Case_3_Cum_Oil_Prod	0.0836%	Case_3_Cum_Oil_Prod	0.0908%
Case_4_Cum_Oil_Prod	0.0672%	Case_4_Cum_Oil_Prod	0.0563%
Case_5_Cum_Oil_Prod	0.0543%	Case_5_Cum_Oil_Prod	0.0607%
Case_6_Cum_Oil_Prod	0.1062%	Case_6_Cum_Oil_Prod	0.1359%
Case_7_Cum_Oil_Prod	0.0676%	Case_7_Cum_Oil_Prod	0.1052%
Case_8_Cum_Oil_Prod	0.0583%	Case_8_Cum_Oil_Prod	0.0987%
Case_9_Cum_Oil_Prod	0.0791%	Case_9_Cum_Oil_Prod	0.0939%
Case_10_Cum_Oil_Prod	0.0721%	Case_10_Cum_Oil_Prod	0.0953%
Case_11_Cum_Oil_Prod	0.0865%	Case_11_Cum_Oil_Prod	0.0706%
Case_12_Cum_Oil_Prod	0.0753%	Case_12_Cum_Oil_Prod	0.0942%



Challenges and opportunities of working with open source reservoir simulators

- We were able to apply the open-source simulators for infill drilling evaluation and to an extent EOR studies we were completing (e.g. polymer flooding).
- Upscaling, screening of geological models, suitable to do history matching (relies less on the features the simulator needs for prediction)
- No issue compatibility with Eclipse, input and output files.
- We see the strength in open-source simulators in terms of running quick screening studies or using it as a first approach/mechanistic models.
- Going forward, the open-source simulators need to evolve across a wider number of scenarios including unconventional resources, complex wells and handling facilities constraints.
- The codes are readily available for the implementation of in-house functionality for companies of any size.
- Truly probabilistic workflows will be enabled by removing the restriction of number of simulation scenarios to be run.