

The National IOR Centre of Norway

Polymer flooding. Simulation Upscaling Workflow

Project 2.7.1. Supplementary report to the recommended practices: Translation of IORCoreSim polymer model into Eclipse

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Executive Summary

The purpose of the activity was to demonstrate how an IORCoreSim model, reproducing core-scale experiments, can be used to set up full field OPM/Eclipse models and provide recommendations on the conversion workflow.

A 1D IORCoreSim model of polymer injection into an outcrop core (ca. 2D) was selected as a starting point. The 1D model was translated into E100 to reproduce the following effects:

- shear thinning/thickening
- adsorption and residual resistance factor (RRF)
- inaccessible PV and depletion layer effects

Additional modifications were made in the E100 model to ensure satisfactory match with the IORCoreSim results. Then, residual oil was added into the IORCoreSim model. After some minor adjustments of the E100 polymer model, a good match was obtained and 1D experimental models were used to set up 1D sector scale polymer models in IORCoreSim and E100.

A 1.5D model (i.e., a layered cross-section with no vertical communication) of an injector-producer pair was set up and used to further validate the obtained polymer model on permeability realizations with varying heterogeneity. For this purpose, an ensemble of 70 permeability realizations was generated with the same average permeability. The coefficient of permeability variation (The Dykstra-Parsons coefficient) varied in the range from 0.3 (almost homogenous) to 0.9 (highly-heterogeneous).

Realizations with low and medium heterogeneity (with the coefficient of permeability variation less than 0.6) showed very good match of key parameters (pressure drop, polymer adsorption and incremental oil recovery factor). However, many highly heterogeneous realizations showed mediocre match. A possible explanation is that in heterogeneous realizations the flow is dominated by high permeable layers with characteristics significantly deviating from those of the underlying experiment on the 2 Darcy core. The mismatch may be resolved for individual realizations by using polymer properties for higher permeabilities.

In general, the demonstrated workflow is functional and may be employed for conversion of IORCoreSim models. The current document is aiming to serve both as a self-contained executive summary and an accompanying note for the Jupyter notebooks and model files enclosed to the report.

Introduction

The current report elaborates on the part of “Polymer flooding. Simulation Upscaling Workflow” (Aursjø, Khrulenko, Nødland, & Hiorth, 2021) dedicated to conversion of IORCoreSim polymer models to Eclipse¹. The report is aiming to serve both as a self-contained description of the activity and an accompanying note for codes (Jupyter notebooks) and model files.

The activity purpose was to demonstrate how an IORCoreSim model reproducing core-scale experiments can be used to set up full field OPM/Eclipse models and provide recommendations on the conversion workflow.

The conversion was carried out with use of Python codes and documented in the Jupyter notebooks:

- I. **I_lab_model_to_E100.ipynb** – covers selection and conversion of core-scale model into E100
- II. **II_sector_models.ipynb** – describes sector-model set up and their validations runs

Similarly, the first and second sections of the report correspond to the notebooks. The notebooks sections are referenced through the text as X.Y, where X – Roman number of the notebook (I or II), and Y – section number in the notebook. Main conclusions are given in the third section. A brief transcript of the polymer keywords of the IORCoreSim model is placed in Appendix.

The following supplements are enclosed to the report and to be found in the respective folders:

- **codes** – Jupyter notebooks, their HTML versions, result files and figures
- **experimental_data** – experimental data (Lohne, Nødland, Stavland, & Hiorth, 2017)
- **models** – Eclipse and IORCoreSim models used in the study

¹ We did not test the proposed codes and workflow on OPM, though, as OPM shares many of E100 keywords, the results of this study should be valid for OPM with some modifications in model files.

List of Abbreviations

ICS – IORCoreSim

IPV – inaccessible pore volume

ORF – oil recovery factor

RRF – residual resistance factor

Software prerequisites

The following software/program libraries were used in the study:

- **Anaconda 1.10.0** distribution:
 - Python 3.8.5
 - JupyterLab (Version 2.2.6) notebooks (*toc* extension is highly recommended)
 - matplotlib (3.3.2)
 - numpy (1.19.2)
 - pandas (1.1.3)
 - scipy (1.1.3)
 - copy
 - os
 - pickle
- **IORCoreSimOutputReader** – library for reading IORCoreSim results (available in “.\codes\IORCoreSimOutputReader-master” or may be downloaded from <https://github.com/onoedland/IORCoreSimOutputReader>)
- **IORCoreSim**
- **Eclipse 2020.2**

1 Translation of core-scale model 1D model

1.1 Selection of 1D model.

A 1D model (*hp1530-t37131-v12.txt*) was used as a reference for polymer properties. The model reproduces a laboratory experiment with a single-phase polymer injection (HPAM 1500 ppm) in a Bentheim composite core (permeability: ca. 2 Darcy, porosity: 23.5%) at wide range of rates reproducing different flow regimes² (Lohne, Nødland, Stavland, & Hiorth, 2017). The experimental injection rates correspond to Darcy velocities of $4.44 \times 10^{-3} - 4.44$ cm/min ($2.67 \times 10^{-1} - 2.67 \times 10^{-3}$ cm/hr) and, when connate water is accounted for, flow velocities³ of $2.52 \times 10^{-2} - 25.2$ cm/min ($1.51 - 1.51 \times 10^3$ cm/hr). This experiment was selected because its core permeability was within 1 – 10 Darcy range of the Statfjord Group of Johan Sverdrup field which is considered for polymer flooding pilot (Eikje, et al., 2020).

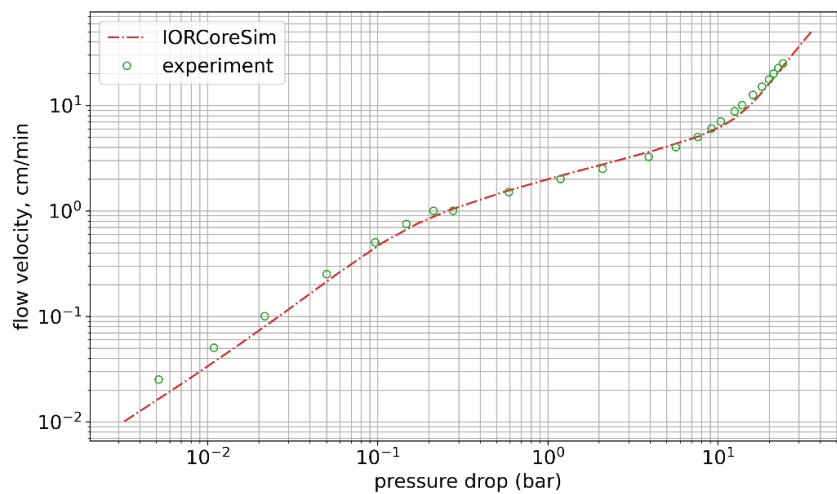


Figure 1. Flow velocity vs. pressure drop for the selected experiment and IORCoreSim model

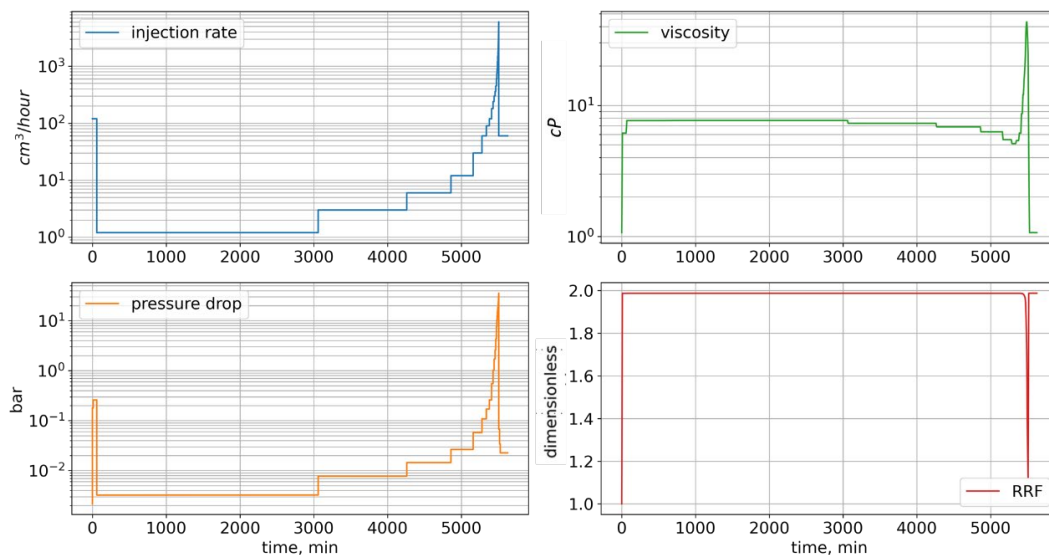


Figure 2. Essential input and output parameters of the model

² Important note: the same set of polymer model parameters is used to reproduce experiments on other cores with different permeabilities. Please consult the mentioned paper for more details.

³ The following flow velocity formulation was used in this study: $v_f = v_d / \text{poro} / (1 - S_{wcr})$

The group of charts below (Figure 2 and Figure 3) provides a brief overview of experiments (injection rates, pressure drop, viscosity, RRF) and behavior of polymer solution under different flowing regimes (polymer shear thinning, shear thickening and degradation).

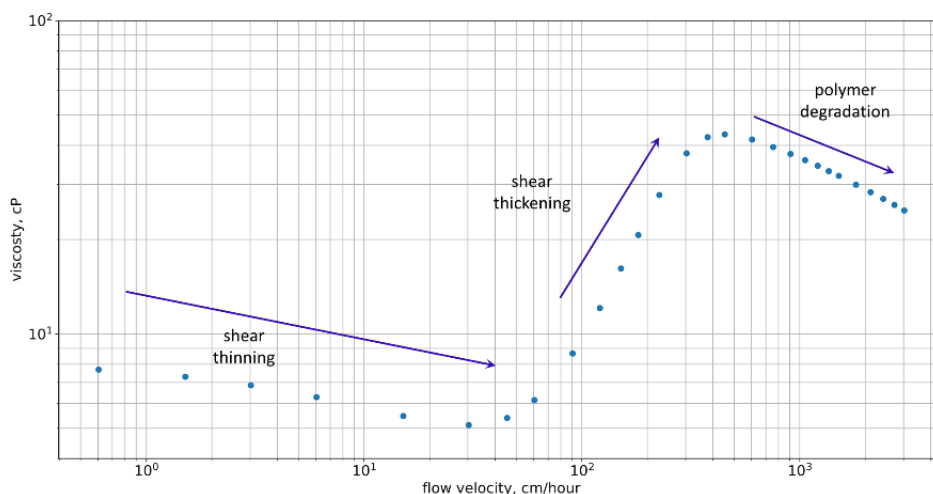


Figure 3. Illustration for different flow regimes in ICS simulation: viscosity vs. flow velocity

1.2 Basics of translation from IORCoreSim into E100

IORCoreSim provides a rich and flexible functionality for modelling polymer adsorption, RRF, shear thinning/thickening and mechanical degradation. Table 1 gives a brief overview of IORCoreSim polymer modelling options and their analogues in E100 Polymer model (Schlumberger, 2020a). It must be noted that not all IORCoreSim features can be reproduced equally well and directly. A brief transcript of polymer keywords for the IORCoreSim model in question is given in Appendix A.

Table 1. Overview of IORCoreSim polymer modelling facilities and their E100 analogues

Effect / option in IORCoreSim (Lohne, 2020)	E100 analogue keywords (Schlumberger, 2020a)
Adsorption	ADSORP (as parameters the Langmuir model) PLYADS (as a table)
adsorption scaling to permeability and porosity	Scaling to permeability can be done in ADSORP keyword. Additional scaling on a cell-by-cell basis can be done via rock mass density PLYRMDEN (i.e. the same rock adsorbed concentration from PLYADS/ADSORP results in different mass of adsorbed polymer due to different rock density)
RRF	2 nd record of PLYROCK within the region PLYKRRF or/and PLYCAMAX on a cell-by-cell basis
RRF scaling to permeability and porosity	PLYKRRF or/and PLYCAMAX on a cell-by-cell basis PLYKRRF or/and PLYCAMAX + using adsorption scaling to permeability in ADSORP keyword
Viscosity of polymer solution	PLYVISC
Depletion layer, inaccessible PV	1 st record of PLYROCK to model IPV changes of apparent viscosity were approximated by PLYVISC table
Shear thinning/thickening	PLYVISC/PLYSHLOG + SHRATE
Polymer degradation	No direct analogues. May be mimicked via reduced polymer injected concentration

1.3 Adsorption (1.3.2)

IORCoreSim provides many options to define the adsorption model. The IORCoreSim model in question employs irreversible Langmuir adsorption with scaling by the porosity-to-permeability ratio. This adsorption model can be almost directly approximated in E100 by ADSORP (as Langmuir adsorption

model) keyword. This keyword also allows for adsorption scaling with permeability. Alternatively, the PLYADS (i.e., a table of polymer rock adsorbed concentration vs. polymer concentration in solution) keyword may be used to specify the adsorption isotherm as a table.

Conversion of adsorption units must be made as E100 uses the rock adsorbed concentration per unit mass of rock, whereas IORCoreSim uses pore volume fraction. So, in order to convert the PV fraction into the rock adsorbed concentration the former must be multiplied by $\frac{m}{1-m} \frac{\rho_p}{\rho_r}$, where m – porosity, ρ_p and ρ_r – polymer and rock density, respectively.

1.4 Polymer solution viscosity (I.3.4)

In IORCoreSim polymer solution viscosity is defined by **cmpprop POLYMER**. Additionally, viscosity is affected by depletion layer effects specified by the **polyIPV** keyword. Degradation effects are specified via the **POLYDEGR** keyword.

A PLYVISC table was generated based on several runs with different injection concentration (I.3.4.3)⁴ at low velocities.

The PLYSHLOG keyword was used to reproduce shear thinning and thickening. The IORCoreSim model uses the Carreau model with variable parameters to describe shear thinning/thickening. Figure 4 demonstrates stepwise approximations of flow characteristics (including shear thinning/thickening) of the selected IORCoreSim model in E100 (I.3.4.6).

Severe convergence problems of E100 models were encountered during history matching. It was concluded that the poor convergence was caused by high contrast between the first and second injection steps (i.e., a very high injection rate was followed by a very low one). The convergence problems were resolved by setting injection rate at the first step to the lowest value and adding initial polymer concentration (equaling the injected one) to the E100 model.

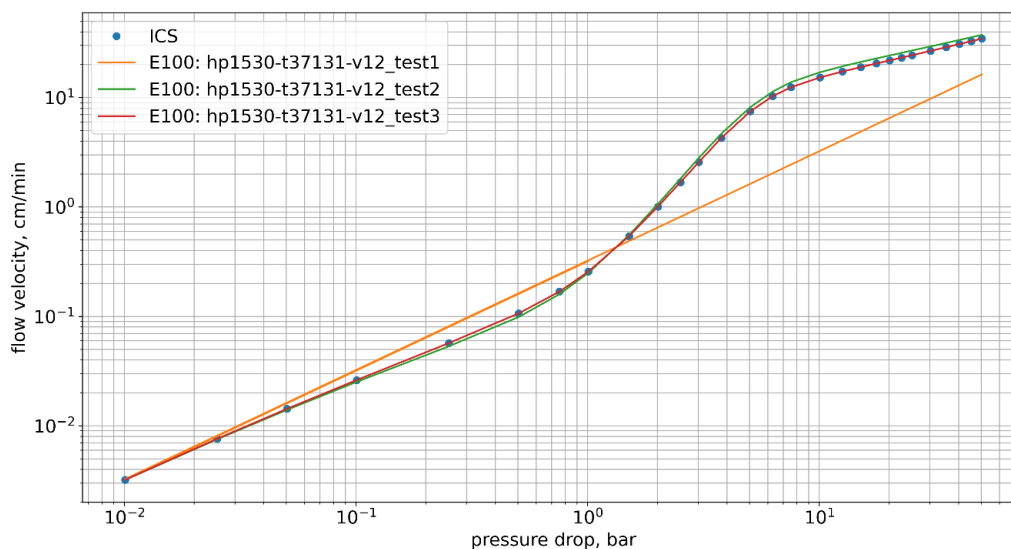


Figure 4. Flow velocity vs. pressure drop for successive approximations of PLYSHLOG table to match the IORCoreSim model

⁴ The concentration dependent polymer viscosity at low shear rate can be directly calculated from IORCoreSim equation 3.6 (I.4.4.1). However, as it was difficult to reproduce depletion layer effects, a PLYVISC table was sampled from model runs.

1.5 Inaccessible pore volume (I.4)

An additional set of models (S2, I.4) was built to verify adsorption and inaccessible PV effects. The recurrent section of both E100 and ICS models was modified to model injection of polymer at moderate injection rate. Inaccessible PV was matched directly via IPV specified by the 1st record of PLYROCK (see Figure 5).

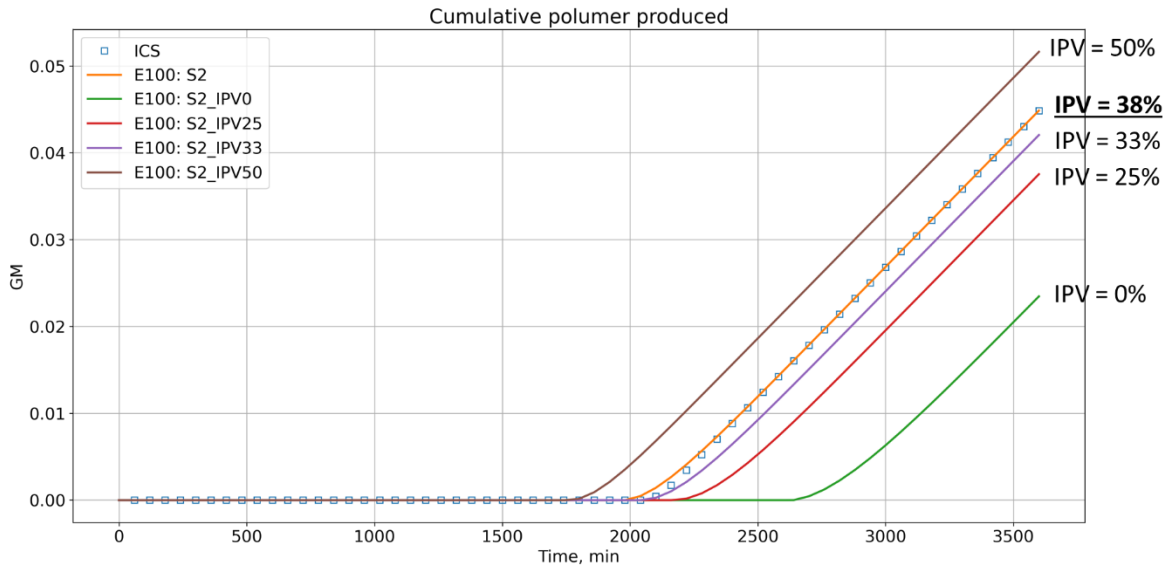


Figure 5. Successive approximations of IPV

1.6 Notes on RRF

In IORCoreSim, Residual Resistance Factor (RRF) is set by the POLYKRF keyword. RRF is dependent on water saturation, adsorption, water relative permeability, and additionally can be scaled by the porosity-to-permeability ratio⁵. RRF can also be set to decrease at high shear rates (Figure 7).

Figure 6 illustrates the calculation of RRF in E100 and links with the relevant keywords: the RRF parameters can be specified via the PLYROCK keyword and further adjusted on cell-by-cell basis with the PLYKRRF and PLYCAMAX keywords, for instance, if a permeability scaling is required.

$$R_k = 1.0 + (\text{PLYKRRF} - 1.0) \frac{C_p^a}{C_p^{a_{\text{max}}}}$$

PLYKRRF
PLYCAMAX

Figure 6. Scheme for calculation of RRF in E100 and links to the relevant keywords. C_p^a – polymer adsorbed concentration

In this study, the value of RRF from IORCoreSim was directly specified in the 2nd record of PLYROCK. The maximal adsorption value was set in the 5th record. We believe that the rate dependent effect can be generally neglected for the fluid flow outside the well grid block. In case it needs to be accounted for, it can be locally adjusted by PLYKRRF.

⁵ function **ads_rrf_ics** in I.4.3 reproduces the IORCoreSim behavior, for more details, please refer to the description of POLYKRF keyword in IORCoreSim User's Guide (Lohne, 2020)

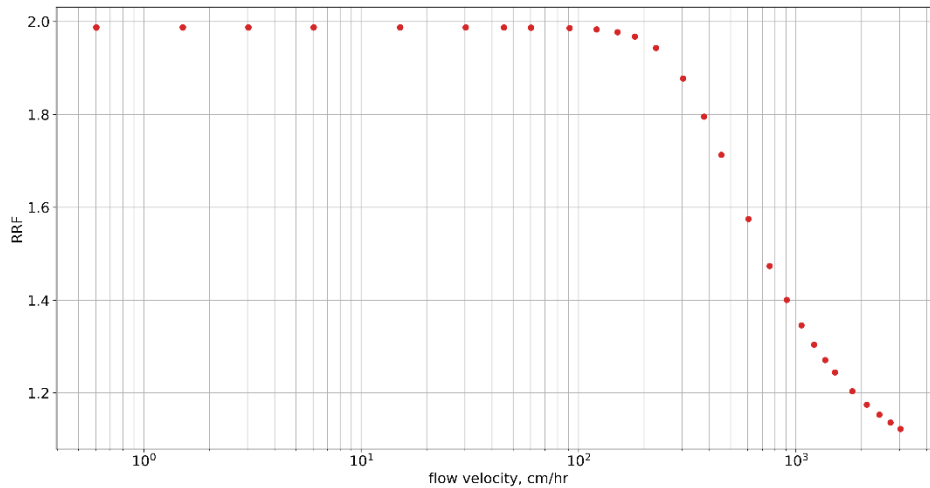


Figure 7. RRF vs. flow velocity

1.7 A closer look at depletion layer effects (1.3.4.8)

The original IORCoreSim model features the depletion layer option with “apparent polymer viscosity correction + IPV_d correction” (see Appendix A 2.3 and description of the POLYIPV keyword in (Lohne, 2020)). In practice, it means that the apparent polymer viscosity is dependent of the parameters in the underlying capillary tube model, such as relative and absolute permeability (Figure 8), porosity, water saturation etc. The viscosity table derived above reproduces the depletion layer effects for the particular combination of the mentioned parameters, and might not be valid for other ones.

Eclipse does not have the ability to reproduce the depletion layer effects directly. The use of multiple tables of polymer properties does not seem practical, as it would require setting up multiple PVT regions. However, the single Eclipse polymer property model (derived for the average porosity and permeability) may sufficiently well reproduce the depletion layer effects. This assumption will in the following be tested on the sector models.

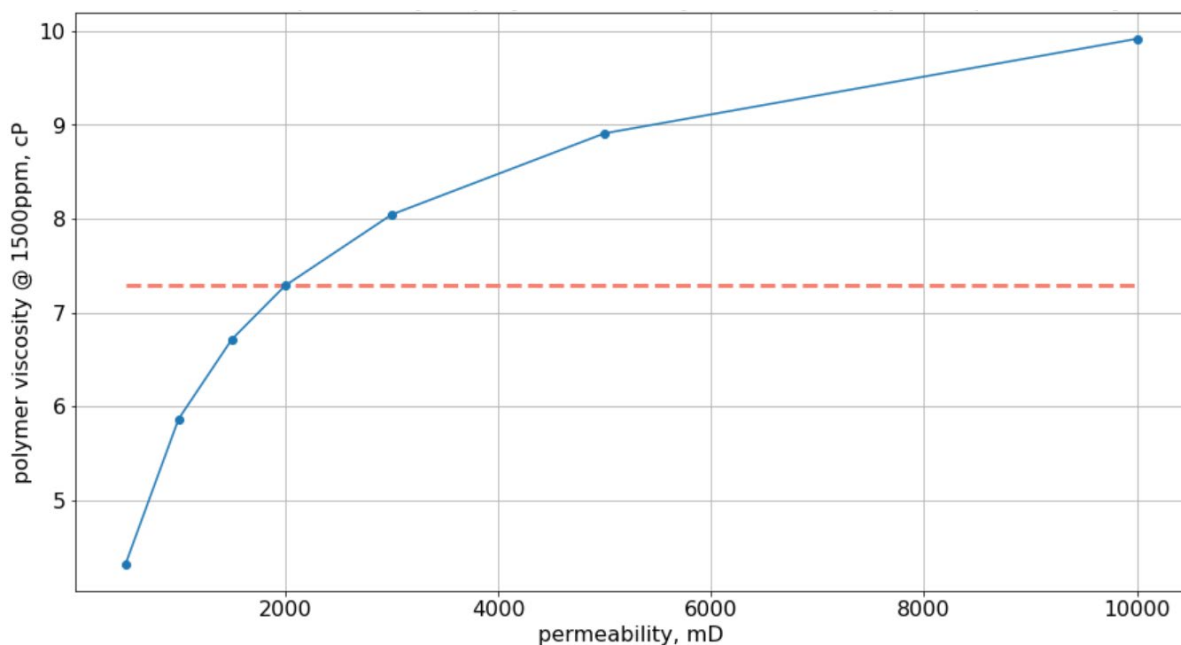


Figure 8. Effects of depletion layer option of IORCoreSim: polymer solution viscosity (@1500 ppm) vs. permeability

1.8 A closer look at numerical dispersion (1.5)

In order to investigate polymer effluent profiles and additionally verify translation of the adsorption model, an additional water injection step was included to the matched model from section 1.5. The E100 model showed much higher numerical dispersion of the polymer concentration compared to IORCoreSim (Figure 9).

Figure 10 summarizes results of several E100 runs with different maximal time step limit. The numerical dispersivity was estimated by a methodology developed to estimate physical dispersion (Brigham, 1974). The numerical dispersion was found to be proportional to the maximal time step. It can be readily seen that the E100 model required a significant time step reduction in order to reduce the numerical dispersivity to the theoretical value of half a block length. It is recommended to pay attention to this peculiarity of Eclipse while matching experimental polymer effluent profiles, and limit the dimensionless time step, if necessary, to 0.1 (i.e. to 10% of time required to fill a typical grid block pore volume at given injection rate).

Overall, the E100 and ICS cumulative polymer production profiles coincide (Figure 11), which verifies the translation of the adsorption model.

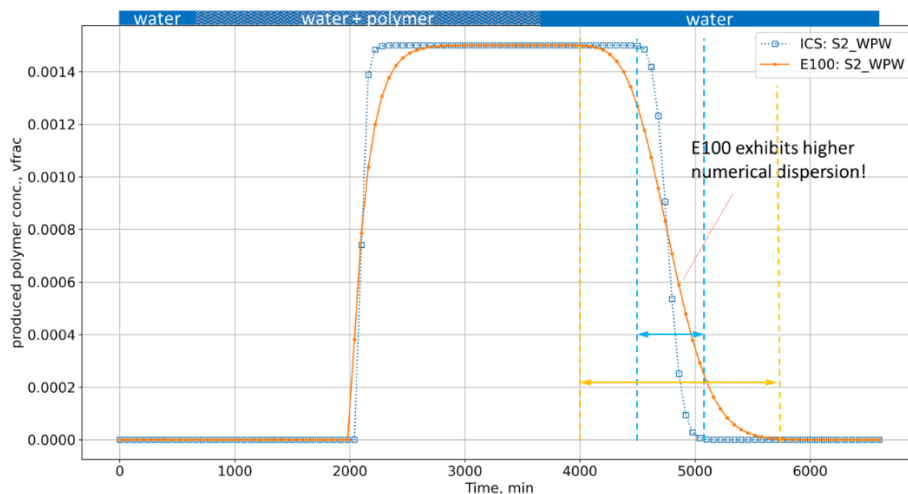


Figure 9. Comparison of polymer production profiles of IORCoreSim and E100

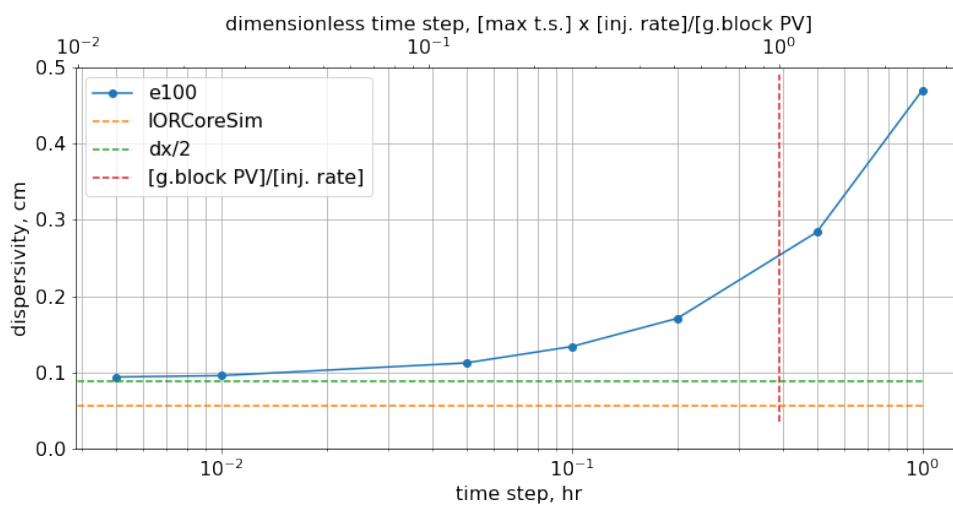


Figure 10. Numerical dispersion vs. maximal time step. Dimensionless time step is shown on the upper x-axis

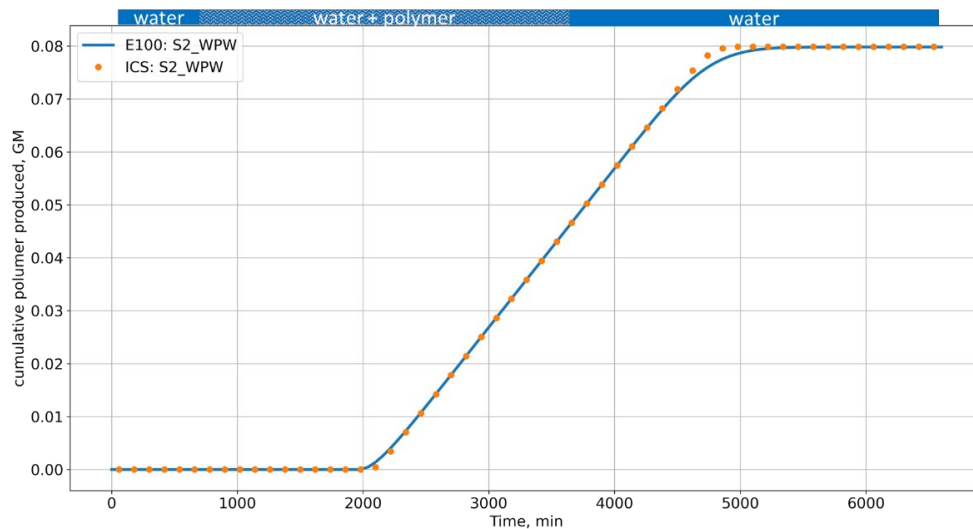


Figure 11. Cumulative mass of polymer produced

1.9 Notes on mechanical degradation

Currently, there are no facilities in E100 to directly model mechanical polymer degradation. However, it is easy to show that degradation occurs in a rather limited near wellbore zone and, therefore, can be neglected for the flow outside well grid blocks (assuming their typical size in full field models to be of about 50 meters).

Let us consider the radial flow velocity at different distances from the vertical wellbore (for the same porosity and permeability) for different drawdowns (Figure 12). It can be readily seen that the flow velocities at a distance of 25 meters are far less than the 300 cm/hr where degradation effects become pronounced (see Figure 3). As polymer degradation occurs at very high velocities in the near wellbore zone, it is reasonable to assume that mechanical degradation takes place mostly within well grid blocks.

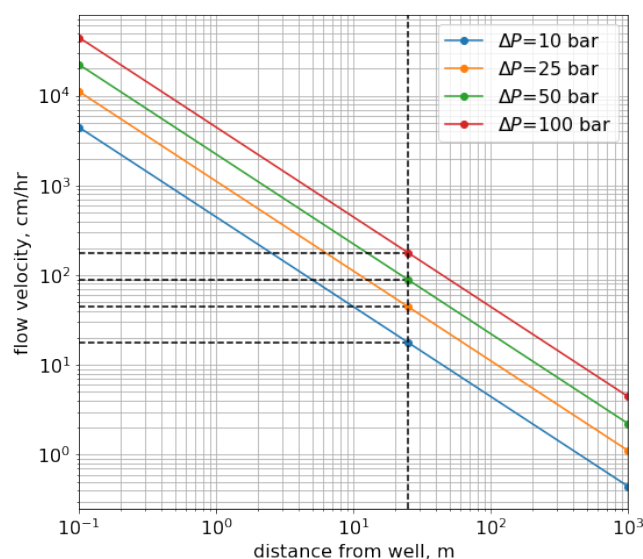


Figure 12. Radial flow velocity vs. distance from the well for different drawdowns.

In this study, we did not attempt to reproduce degradation effects in the near wellbore zone. However, the following workflow can be proposed to reproduce the process in a full field model with the assistance of IORCoreSim:

1. A radial IORCoreSim model is set up and run to track polymer properties of one of the grid blocks at representative distance from the wellbore.
2. Injected polymer concentration in the E100 model is then tuned to match polymer solution viscosity in the selected grid block of the IORCoreSim model, i.e., the alteration of polymer properties due to mechanical degradation is mimicked by an “effective” injected polymer concentration in E100.
3. The bottomhole pressure in E100 is matched to that of IORCoreSim by means of skin-factor or productivity multipliers.

It must be noted that the obtained “effective” injected concentration and well productivity multiplier are valid only for the given specific injection rate (i.e., injection rate divided by the effective perforated well length) and other well properties. So, the derived parameters must be validated for other wells and injection rates and, if necessary, updated according to the proposed workflow.

1.10 Two-phase experiments (1.6)

The 1D model was extended to two phases⁶. IPV and the shear rate constant were tuned to ensure a good match between E100 and IORCoreSim (1.4).

The fluid parameters were set as follows (Eikje, et al., 2020):

- oil and water viscosities: 0.4 and 2 cP, respectively
- oil and water densities: 900 and 1000 kg/sm³

The relative permeability table was adopted from the original model with slight modifications: capillary pressures were removed, Krw and Krow were approximated by power functions, while keeping the shapes (Figure 13).

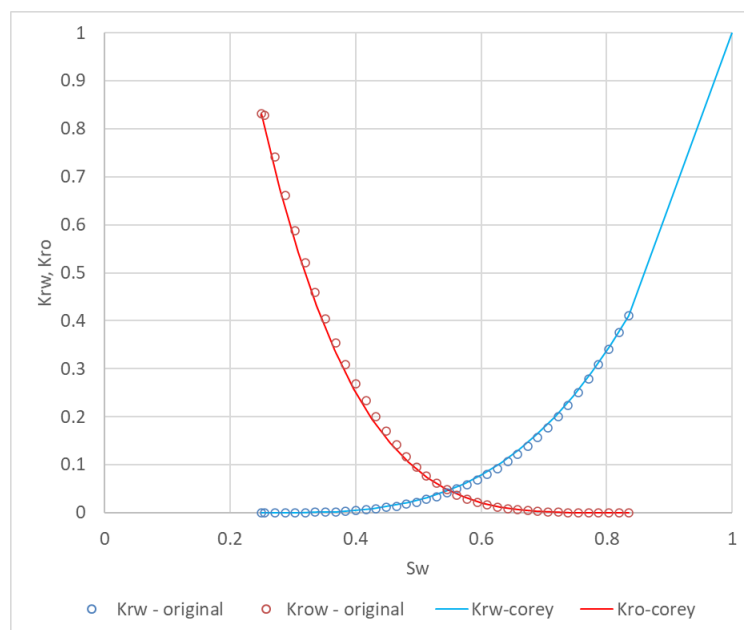


Figure 13. Relative permeabilities used in the model (shown with lines)

⁶ It must be noted that the IORCoreSim model was not specifically calibrated to describe polymer flow in the presence of oil due to lacking relevant experimental data. However, we believe that IORCoreSim, being based on physical models (for example, capillary tube model) and correlations, can produce consistent results even if it was calibrated only for one-phase experiment.

2 Validation on sector-scale models

2.1 Preparation of sector-scale model (II.2)

The derived polymer model was used to build a 1D model with the producer-injector pair at the ends (length of 500 m, representative for inter-well distance) in metric units. A very good match between E100 and the twin IORCoreSim model was achieved for 1PV polymer slug injection at Darcy velocity of 6.05 cm/hr.

2.2 Single 1.5D model run (II.3)

The 1D model was used to set up a 1.5D⁷ sector-scale test model (II.3). The general idea was to build a mechanical model of streamtubes between the producer-injector pair with 100% areal sweep efficiency to investigate influence of vertical heterogeneity (Figure 14).

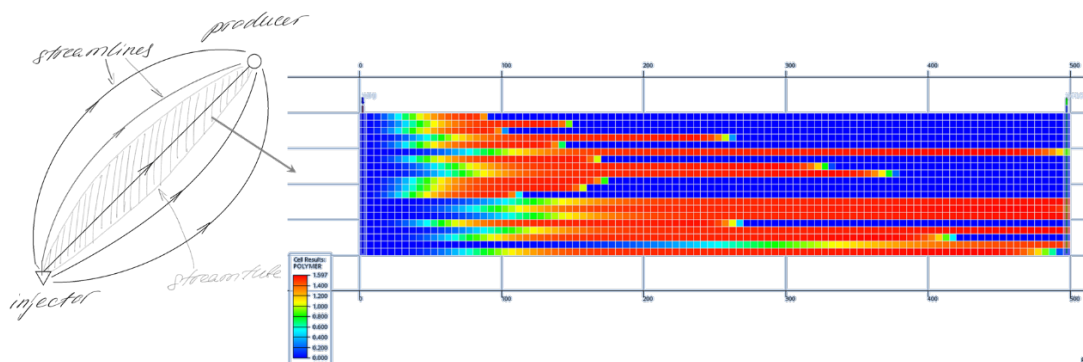


Figure 14. Schematic to illustrate rationale behind 1.5D model concept

One model realization with moderate heterogeneity (Dykstra-Parsons coefficient of $V_{dp}=0.5$) was selected for a test run and showed a good match between IORCoreSim and E100 (Figure 15).

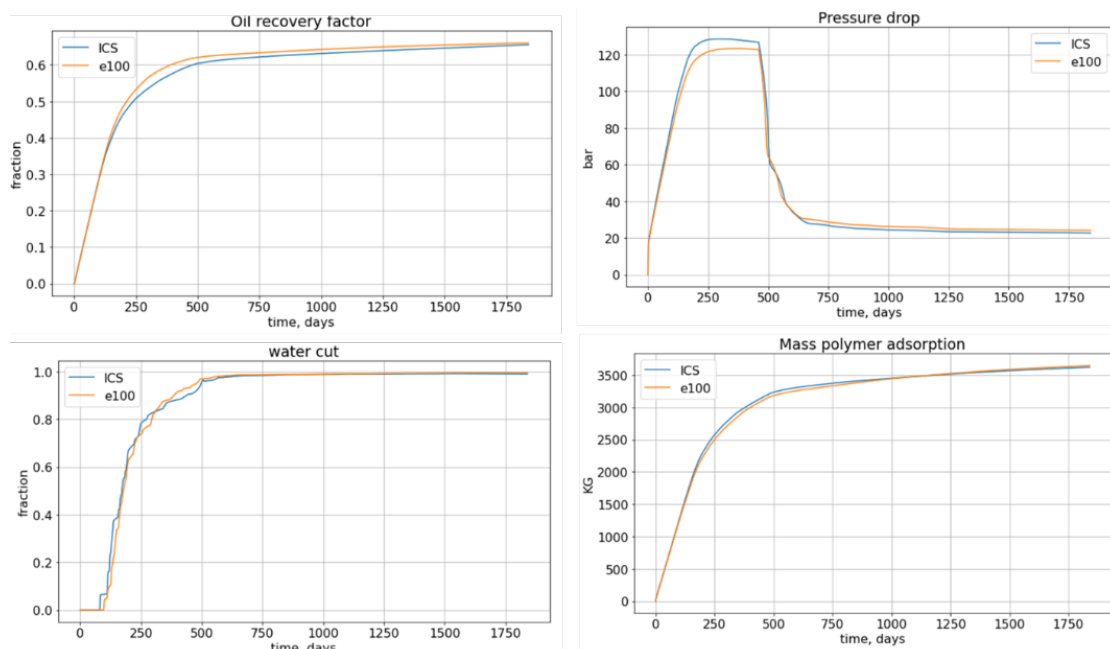


Figure 15. Comparison of results for 1.5D test model with moderate ($V_{dp} = 0.5$) heterogeneity

⁷ i.e. a cross-sectional layered-cake model with no vertical communication

2.3 Ensemble runs of 1.5D models (II.5)

10 realizations were sampled from a log-normal distribution corresponding to discrete values of permeability variation (Dykstra-Parsons) coefficient V_{dp} of ca. 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 (70 in total). The average permeabilities of all realizations were normalized to 2 Darcy⁸. Examples of realizations with varying heterogeneity are shown in Figure 16.

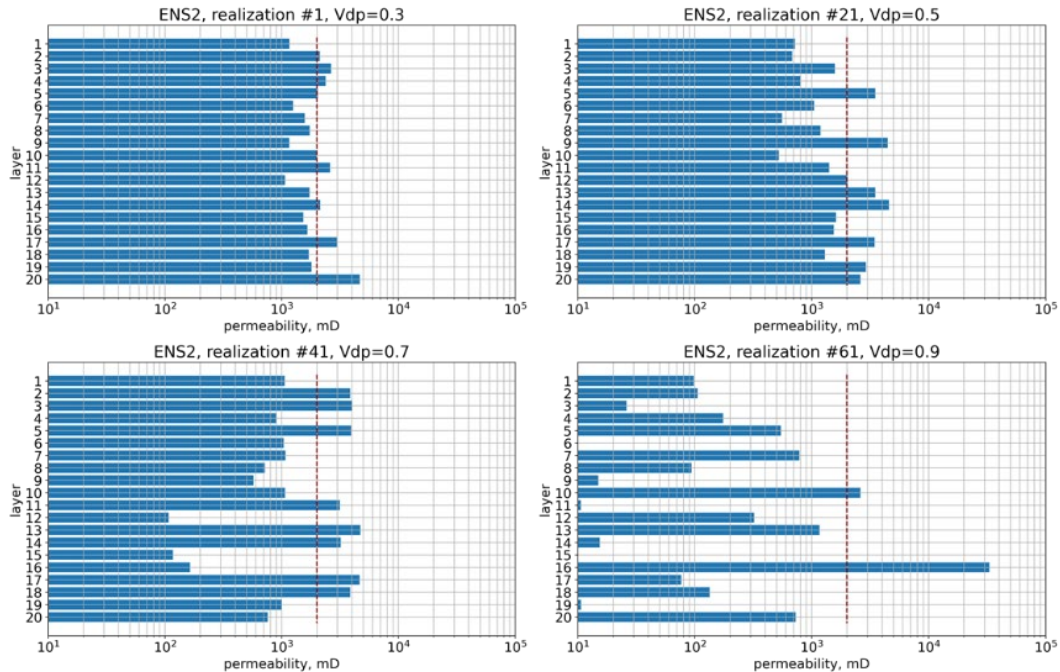


Figure 16. Examples of realizations with different heterogeneities

The ensembles of model realizations were run both in IORCoreSim and E100 for both water and polymer flooding. Incremental oil recovery profiles are shown in picture Figure 17. Mismatches of incremental oil recovery, adsorption and pressure drop are plotted in Figure 18, Figure 19 and Figure 20. It was observed that, while homogeneous and moderately heterogenous realizations were matched relatively well, the mismatch between IORCoreSim and E100 generally increases with heterogeneity. This phenomenon may be explained as follows: as heterogeneity increases the fluid flow is more and more dominated by high permeable layers whereas low permeable layers tend to be plugged by polymer. The flow characteristics of the high permeable layers significantly deviate from the 2 Darcy model which was used to derive the polymer parameters for E100.

We have not managed to find a way to resolve this problem on the ensemble level (i.e., to find a set of polymer parameters for E100 that would equally well work for all realizations). However, we believe that it would not be difficult to match individual realizations by using sets of polymer properties derived for higher permeabilities by the same approach.

⁸ Throughout the notebook and model files this ensemble is referred as ENS2, in contrast to ensemble ENS1 without the normalization. Further on we will focus on the results for ENS2, as the E100 polymer model was derived for 2 Darcy.

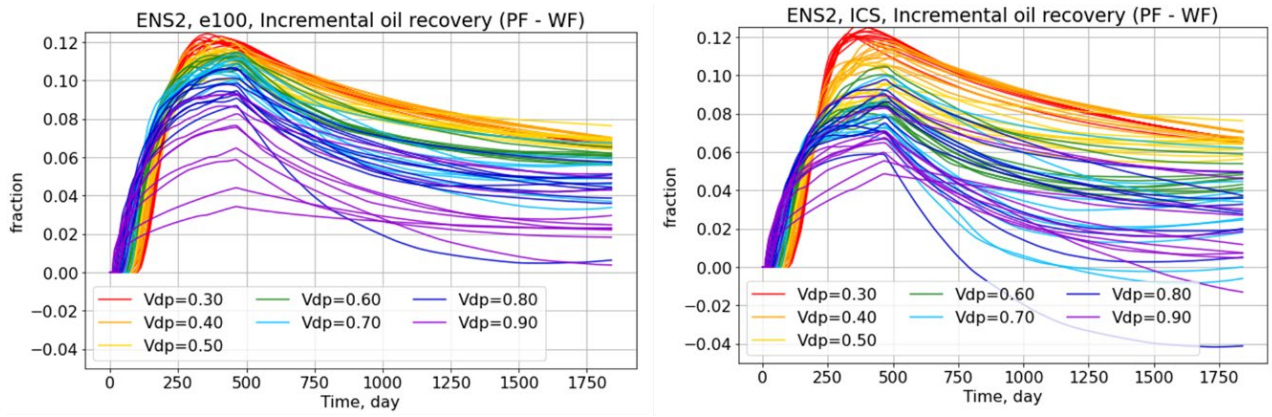


Figure 17. Incremental recovery profiles of E100 (left) and IORCoreSim (right figure)

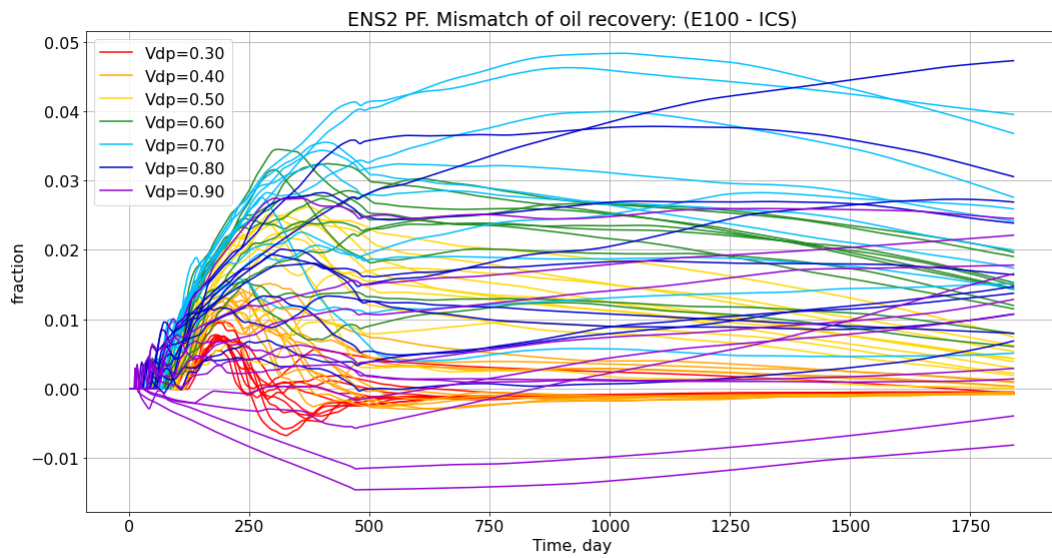


Figure 18. mismatch of incremental oil recovery (E100 - ICS) polymer flooding

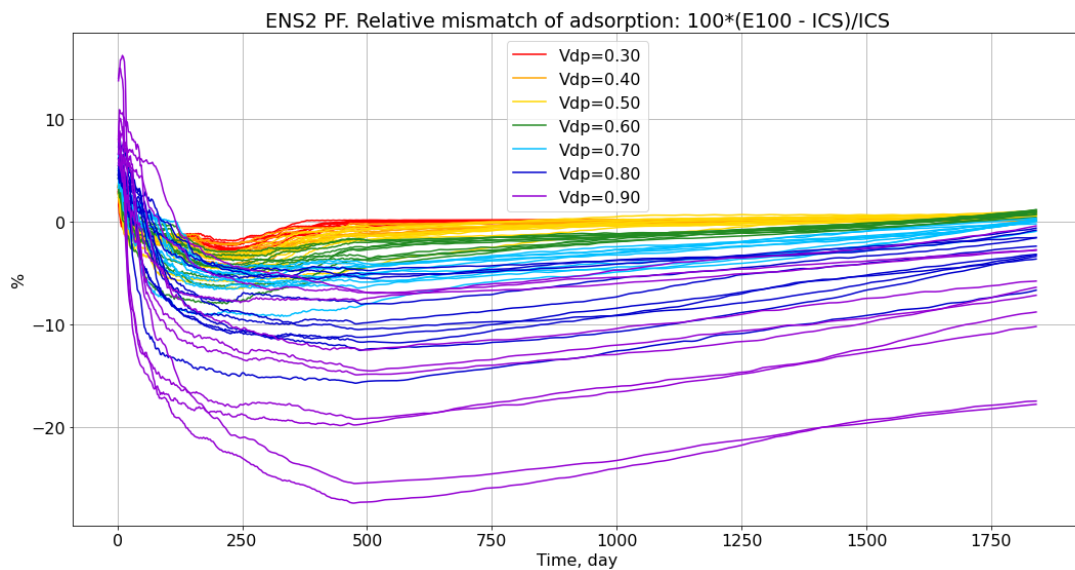


Figure 19. Relative adsorption mismatch

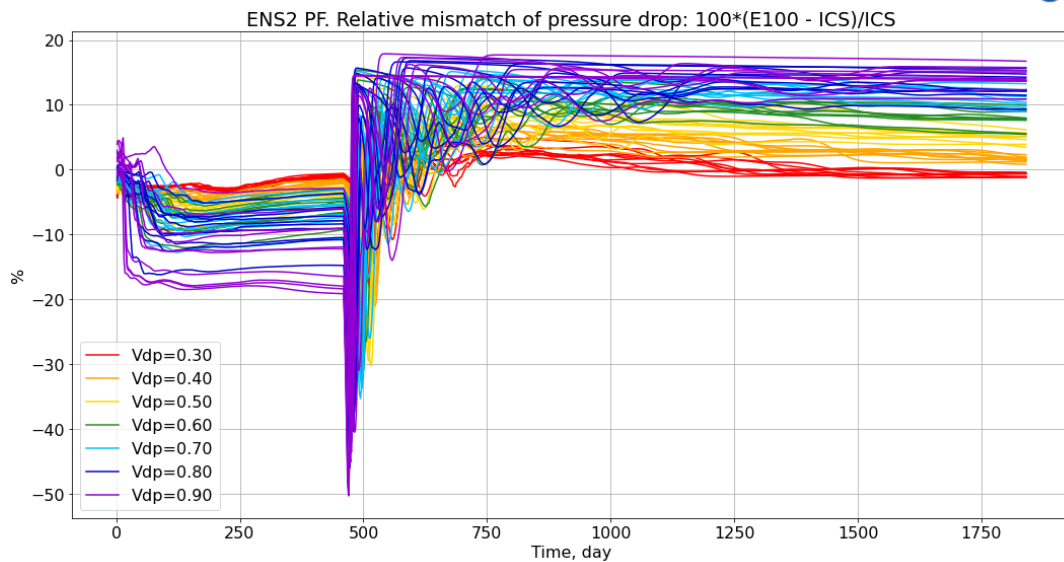


Figure 20. Relative pressure drop mismatch

A few words must be said about the scaling of RRF to permeability. It can be readily seen in Figure 20 that heterogeneous E100 models tend to tangibly overestimate pressure drop after 500 days, when pure water is injected. I.e., heterogenous flow systems have higher RRF than necessary, because RRF in E100 is incorrectly scaled to adsorption.

As it was mentioned above, in sections 1.2 and 1.6, E100 has sufficient functionality to reproduce RRF from IORCoreSim (with exception of dynamic effects at very high flow rates). However, it was observed in many ensemble runs, that the literal RRF translation worsened match of ORF, adsorption and pressure drop. So, the selected RRF scaling partly compensates for the depletion layer effects (Figure 8).

Thus, the final set of Eclipse polymer properties was a result of a tradeoff between simultaneous matching of ORF, pressure drop and adsorption, during and after polymer slug injection. Again, realizations with low and moderate heterogeneity tend to reproduce IORCoreSim results at least sufficiently well.

3 Lessons learned/Conclusions

1. The study demonstrated how polymer flood model in IORCoreSim can be translated into Eclipse. A set of keywords for the Polymer option of E100 was derived from a IORCoreSim core-scale polymer model. The developed Eclipse model was able to reproduce behavior of IORCoreSim.
2. Core-scale Eclipse models showed relatively large numerical dispersion of polymer compared to IORCoreSim. The numerical dispersion was found proportional to maximum time step. It is recommended to pay attention to this peculiarity of Eclipse while matching experimental polymer effluent profiles and limit dimensionless time step, if necessary, to 0.1 (i.e. to 10% of time required to fill a typical grid block pore volume at given injection rate).
3. The core-scale model was used to set up cross-sectional sector-scale models. The models were validated on ensembles of permeability realizations. The validation results showed that while homogeneous and moderately heterogenous realizations were matched relatively well, the mismatch between IORCoreSim and E100 generally increases with heterogeneity. This phenomenon may be explained by disproportional contribution of high permeable layers into the flow. As their flow characteristics significantly deviate from the 2 Darcy core model used to derive polymer parameters.
4. We have not managed to find a way to resolve this problem on the ensemble level (i.e., to find a set of E100 polymer model parameters that would equally well work for all realizations). However, we believe individual realizations can be matched by using sets of polymer properties derived for higher permeabilities by the presented approach.

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Appendix A. Brief transcript of IORCoreSim keywords defining polymer properties

The current section provides a quick reference and example for the polymer model keywords (Lohne, 2020)

1 cmpprop

This keyword specifies fluid properties, polymer properties:

- 1st record: density, viscosity, and adsorption models
- 2nd record: parameters of viscosity model at low shear rate
- 3rd record: parameters for shear thinning
- 4th record: parameters for adsorption model
- 5th record: parameters to scale adsorption to porosity and permeability

cmpprop

```
* Name Prefc Bw density Cw PrefV TrefV°C visc BTw TC(°C) BPw
SSW 1 1.0 1.0 4e-5 1. 20. 1.07 570.6. 133.15 0 /
OIL 100 1.0 0.75 1e-4 1. 20. 0.90 1500. 273.15 0.0016 /
(similar input as wat)
* Polymer
-- 1st record
* name Pref Bf density compr iads vismodel
hpan 100 1 1 0 almir 3 /
```

Item	Name	Description	Default
1	<i>cname</i>	Component name for identification. An empty record terminates the keyword.	-
2	<i>Pref</i>	Reference pressure for compressibility, Units : user defined, e.g. [bar]	1 bar
3	<i>Bf</i>	Volume factor = $V(Pref)/V_{surface}$	1
4	<i>density</i>	Density at <i>Pref</i> . Units : user defined density units, e.g. [g/ml]	1 g/ml
5	<i>compr</i>	Compressibility at <i>Pref</i> . Units : user defined inverse pressure units, e.g. [bar ⁻¹]	0
6	<i>iads</i>	Flag indicating adsorption model. Options: ... almir : Langmuir type, irreversible adsorption. ..	n
7	<i>Pvismod</i>	Flag indicating which shear thinning model to use. Options: 1 Meter's equation. 2 Carreau model with constant parameters 3 Carreau with variable parameters	1

```
-- 2nd record
* eta hug1 hug2 Tref Tfact Mv alfaMv
2424 0.247 0.091 20 0.005 15000000 0.6 / viscosity at low shear
```

The second POLYMER record defines viscosity at low shear rate:

Item	Name	Description	Default
1	<i>eta</i>	Reference intrinsic polymer viscosity $[h]_0$ in units $[\text{cm}^3/\text{g}]$. Typical range of values for good viscosifiers: 3000-5000 cm^3/g .	4000
2	<i>hug1</i>	The Huggin's constant, reported to be 0.4 ± 0.1 for a range of polymers in good solvents. Units: [dimensionless]	0.4
3	<i>hug2</i>	Third viscosity parameter, k'' . Units: [dimensionless] Note: entering a negative value will trigger the Martin equation.	0.1
4	<i>Tref</i>	Reference temperature for viscosity. Units: $[\text{°C}]$	20°C
5	<i>Tfact</i>	Temperature dependency of the intrinsic viscosity $[h]$. Units: $[\text{°C}]$	0.005
6	<i>Mw0</i>	Polymer molecular weight $[10^6 \text{g/mol}]$	1
7	<i>alfaMw</i>	Exponent for dependency of $[h]$ on M_w . Typical range (0.5-1).	0.7

The third record defines shear thinning.

```
-- 3rd
* Carr_na Carr_nb Carr_la Carr_lb Carr_x
  0.0782   .560   .00031   1.0   1.0 /                shear thinning
```

Item	Name	Description	Default
3 rd Record read only if <i>Pvismod</i> = 3 : Carreau model extended.			
1	<i>Carr_na</i>	1 st parameter a_n for shear thinning exponent n	0.3
2	<i>Carr_nb</i>	2 nd parameter b_n for shear thinning exponent n	0.8
3	<i>Carr_la</i>	1 st parameter l_a for the polymer relaxation time l_1 describing the transition from Newtonian to shear thinning fluid. Units: [sec]	1
4	<i>Carr_lb</i>	Exponent l_b for the polymer relaxation time l_1 describing transition from Newtonian to shear thinning fluid.	0.00029
5	<i>Carr_x</i>	Tuning parameter for the transition from Newtonian to shear thinning fluid. A higher value results in a sharper transition. Typical range: 1-2. Units: [dimensionless]	1

```
* b      Qm      (adsorption)
  1000000 0.00044 1 /
```

Item	Name	Description	Default
4 th Record read only if <i>iads</i> = alm, almt, almir : Langmuir type adsorption.			
1	<i>b</i>	Adsorption parameter. Units: inverse of concentration units. The value should be chosen to get an appropriate ratio $bc/(1+bc)$, which denotes the fraction of Q_m adsorbed at concentration c .	-
2	<i>Qm</i>	Maximum adsorption capacity. Units [pv fraction] for volumetric components.	-
3	<i>ScaleQmF</i>	Flag indicating if scaling of Q_m with porosity and permeability should be used. Options: 0: No scaling 1: Q_m scales with $(f/k)^a$.	0
4	<i>irflag</i>	Flag indicating different adsorption parameters should be used for each <i>rocktype</i> :	0

		0: A single set of adsorption parameters uses for all rocktypes 1: This record is read <i>nrock</i> times. Item 3 and 4 are only read the first time. Each record must end with a slash '/'.	
--	--	---	--

* kref pororef
721.7 0.223 /
/ - empty slash - terminates the keyword cmpprop

		5 th Record read if <i>ScaleQmF</i> = 1 . If <i>irflag</i> =1 (activated input for all rocktypes), the record should be repeated <i>nrock</i> times, each time terminated with a slash, '/'.	
Item	Name	Description	Default
1	<i>Q_kref</i>	Reference permeability for scaling. <u>Units</u> : user defined, e.g. [mD]	-
2	<i>Q_firef</i>	Reference porosity for scaling. <u>Units</u> : volume fraction.	0.2
3	<i>Q_alfa</i>	Scaling exponent <i>a</i> . <i>Qm</i> scales with $(f/k)^a$	0.5

2 polyIPV

This keyword defines options for modelling of inaccessible pore volume (IPV) and depletion layer

-- IPV0 dplFlag fdpl aM tau Rcpd alfadp cpd0
0.1 2 1. 1. 3 /

Item	Name	Description	Default
1	<i>ipv0</i>	Constant part of inaccessible pore volume, IPV_0 , for polymer (pores less than polymer molecule size) in units, [PV fraction]. Typical range: 0 – 0.2	0
2	<i>dplFlag</i>	Flag indicating polymer depletion model to be used. Options: 0: Not used 1: Volume of depletion layer (IPV_d) will be added to $IPV = IPV_0 + IPV_d$ 2: Apparent polymer viscosity correction + IPV_d correction	0
3	<i>fdpl</i>	Multiplication factor or thickness of depletion layer, f_{dpl} . The thickness $d = f_{dpl} \cdot R_h$, where R_h is an effective radius of polymer molecule in solution.	1
4	<i>aM</i>	Exponent for modifying the viscosity ratio effect on apparent viscosity, a_M . A value <1 will reduce the effect.	1.0
5	<i>tau</i>	Tortuosity parameter of the formation which is used in expression for the effective pore radius. Defined as $t = (L_t/L)^2$. Note: this constant tortuosity parameter will not be used if the more flexible tortuosity model is activated with keyword rtort (accounts for variation in permeability, porosity and saturation).	3
6	<i>fcpd</i>	Relative concentration in the depletion layer from which the depletion layer viscosity is computed.	0
7	<i>alfadp</i>	Exponent describing how the thickness of depletion layer depends on polymer concentration, suggested value $a_{dp} \leq 0$, where 0 corresponds to constant thickness and -0.75 is reported for HPAM.	0
8	<i>cpd0</i>	Reference polymer concentration below which depletion layer has constant thickness.	0.001

3 rockshear

Parameters for calculation of in-situ shear rate

rockshear

2 /

Item	Name	Description	Default
1	<i>alfac</i>	Rock shear rate modification factor for use with the polymer model, units [dimensionless]. Typical range: 2-5	2.5
2	<i>gam_dFact</i>	Dampening factor for in-situ shear rate: If polymer is shear thickening in the near-well bore area, the distribution of injected polymer solution may be unstable in multi layered models. This can be solved by computing shear rate as a weighted average of the values from present and previous time steps. Range: [0, 1), where the value is the weight of the old shear rate, i.e., 0 indicates no dampening.	0
3	<i>Well_PFlag</i>	Flag indicating treatment of polymer in well blocks: The shear thinning, thickening and degradation taking place close to the well bore is not captured if well is perforated in a large grid cell. This flag can be used to trigger numerical integration of the polymer behaviour for the block, which will improve simulated well pressure and degree of shear degradation. Options: 0: Option not used 1: Numerical integration of polymer equation is used.	0
4	<i>dRw0</i>	Used if <i>Well_PFlag</i> =1. The first radial interval used in numerical integration of rate dependent polymer rheology and molecular mechanical degradation for the well block. Recommended range: 0.001 - 0.01 m. Minimum value restricted to 0.0001 m. <i>Units</i> : user defined units, e.g. [m].	0.01 m
5	<i>dRVfact</i>	Volumetric incremental factor used for calculating radial intervals in the numerical integration of polymer properties in the well block. Restricted range: 1.1-2. Recommended range: 1.2-1.5	1.5

4 polydegr

Defines parameters for modelling of shear thickening and mechanical degradation

polydegr

```
--el_lamf el_m2 el_x2 degr_ratef degr_alfa degr_beta
```

```
4 1.5 3 0.0015 3 1.0 /
```

Item	Name	Description	Default
1	<i>el_lamf</i>	Modification factor C_{el} for estimation of relaxation time parameter l_2 that denotes onset of elongation (shear thickening). Units: dimensionless.	4
2	<i>el_m2</i>	Slope of $\log(m_{sp})$ versus $\log(\dot{\gamma})$. Units: dimensionless.	1.5
3	<i>el_x2</i>	Tuning parameter for the transition between shear thinning and shear thickening. A higher value will give a sharper transition. Typical range: 1-3	2
4	<i>degr_ratef</i>	Degradation rate factor, r_{deg} . Units: fraction molecular ruptures/sec.	0.0015

-	<i>degr_Fsc</i>	Polymer critical shear stress constant. Units: [Pa] – NOT USED in version 1.264 or later, included in <i>r_{deg}</i> .	55
5	<i>degr_alfa</i>	Exponent <i>a_d</i> describing degradation dependency on shear stress. Units: dimensionless	3
6	<i>degr_beta</i>	Exponent <i>b_d</i> describing degradation dependency on molecular weight. Units: dimensionless	1

5 polyrkf

Activates permeability reduction to the water phase due to adsorbed polymer.

polyrkf

```
--rp_fact rp_mod rp_lamf rp_n rp_x
1.0 3 0.5 1.0 4 /
```

Item	Name	Description	Default
1	<i>fmrp</i>	Modification factor for permeability reduction factor. The assumed model value is <i>fmrp</i> =1, which can be tuned based on experiments.	1
2	<i>rkf_mod</i>	Integer indication which model is used for computing the permeability reduction. Options: 0: no permeability reduction 1: use adsorbed polymer 2: adsorbed polymer extends out from the wall 3: extended volume occupied by adsorbed polymer decrease at higher shear rate	2
3	<i>rp_lamf</i>	Parameter (<i>C_{rp}</i>) for onset of reduced swelling of adsorbed polymer. If <i>rp_lam</i> > 0, then shear rate reduction in RRF (residual resistance factor) is activated. (used if <i>rkf_mod</i> =3). Units: [s ⁻¹]	0.4
4	<i>rp_n</i>	Shear reduction exponent used if <i>rkf_mod</i> =3	0.5
5	<i>rp_x</i>	Shear reduction parameter used if <i>rkf_mod</i> =3	3
6	<i>SOp</i>	Specific surface area of polymer used with a Carman-Kozeny approach for estimating an upper limit for RRF. Only used if <i>rkf_mod</i> ≥ 2. Units: [m ² /ml]	7000