Recent improvements in OPM Flow well handling

Stein Krogstad, SINTEF Digital

Why solve well-equations locally?

- Often more non-linear dynamics in wells than in reservoir
  - Keep number of globally coupled (costly) iterations to minimum
- Handle logic and constraints for groups and network
  - Keep number of globally coupled (costly) iterations to minimum
- Potentials
  - Solution of local well equation by definition

Local well-equations:
System of equations resulting from treating reservoir states as constants.

Local well-equations – default behavior in Flow

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- Solve well equations for a given fixed control value and mode

Possible drawbacks:

- Given mode/value might not be the most restrictive
  - Wasted iterations
- Given mode/value might not be feasible
  - Convergence failure
- In combination with group control / network, above bullet-points may cause additional problems (control oscillations)

Local well-equations with control mode/status switching

Aim: *Local well solve should always converge to the most restrictive mode and/or status*

Enabled by:

--local-well-solve-control-switching = true

- both standard- and multi-segment wells
- potential calculations
- operability checks

For each local iteration

1. *Update mode and status*
    - *if well is (temporarily) stopped, check if conditions allow re-opening, and update status*
    - *otherwise*
        - *if well can't operate, (temporarily) stop*
        - *otherwise, check well constraints and if violated, switch mode*
2. *Solve and update well state*
3. *Check convergence*

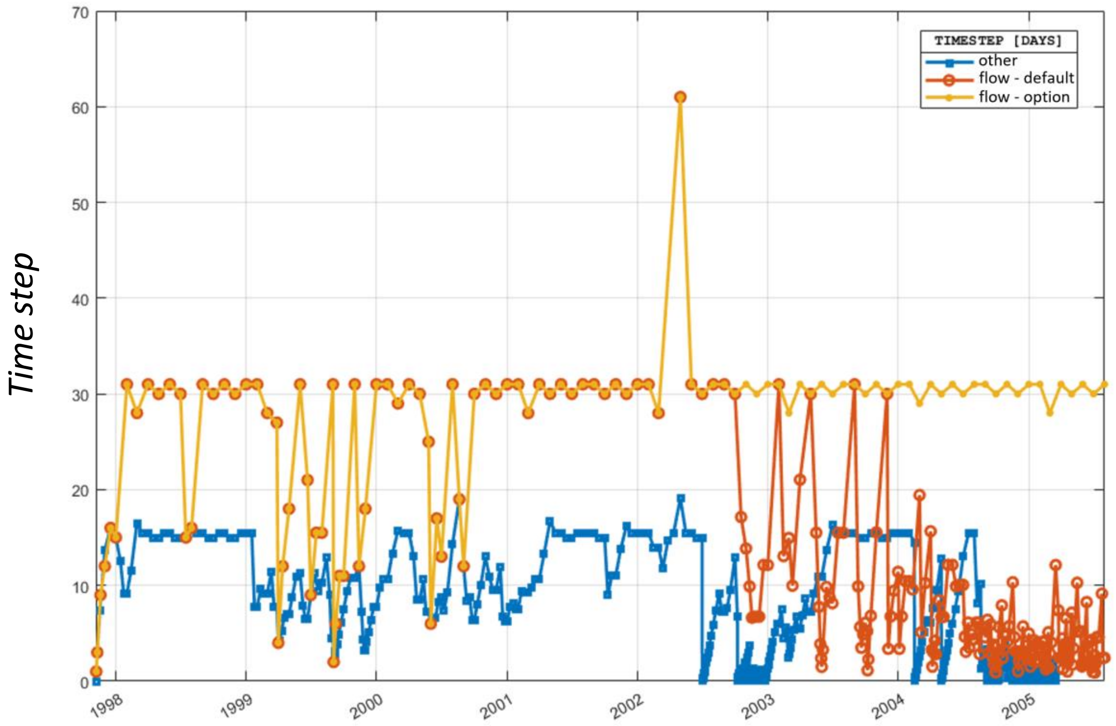
Local well-equations with control mode/status switching

Results:

- Increasing advantage with increasing model/well model complexity
- Typically, very valuable in prediction mode (wells stopping/re-opening)

BUT:

- Not sufficiently robust for THP-controlled wells



Norne depletion case

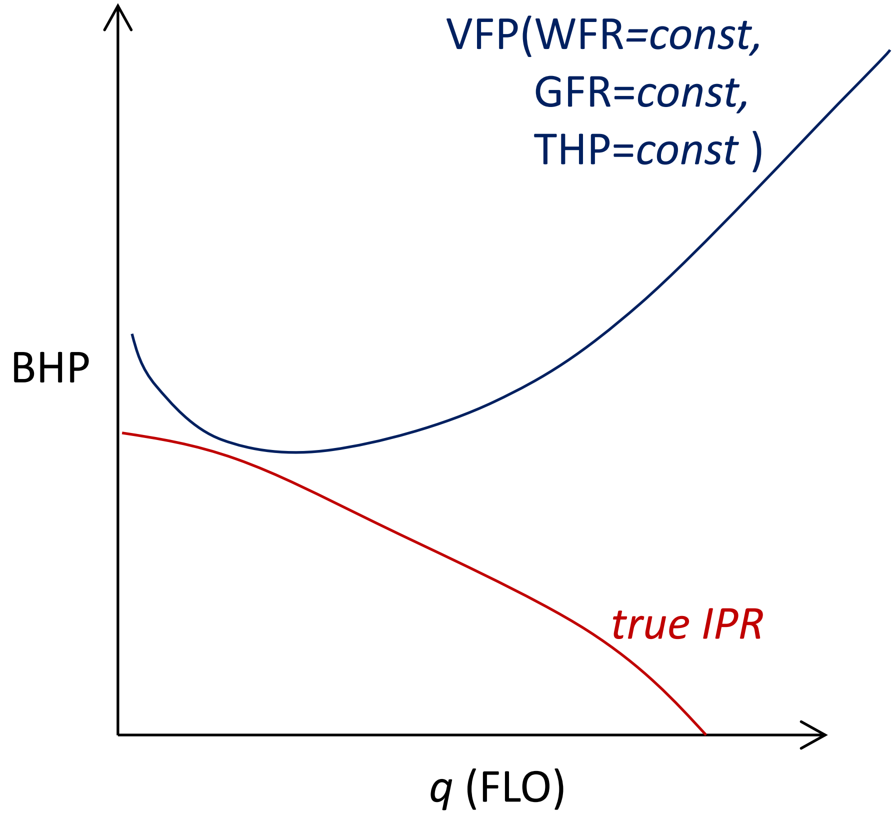
Implicit computation of IPR

For efficiency, local well-solves use simplified check for THP-operability

- may still run into problems for *slightly* inoperable cases

Default IPR computation in flow:

- based on connection rates at bhp=0,
- only *valid* approximation for nearly linear well-equations
- not really used

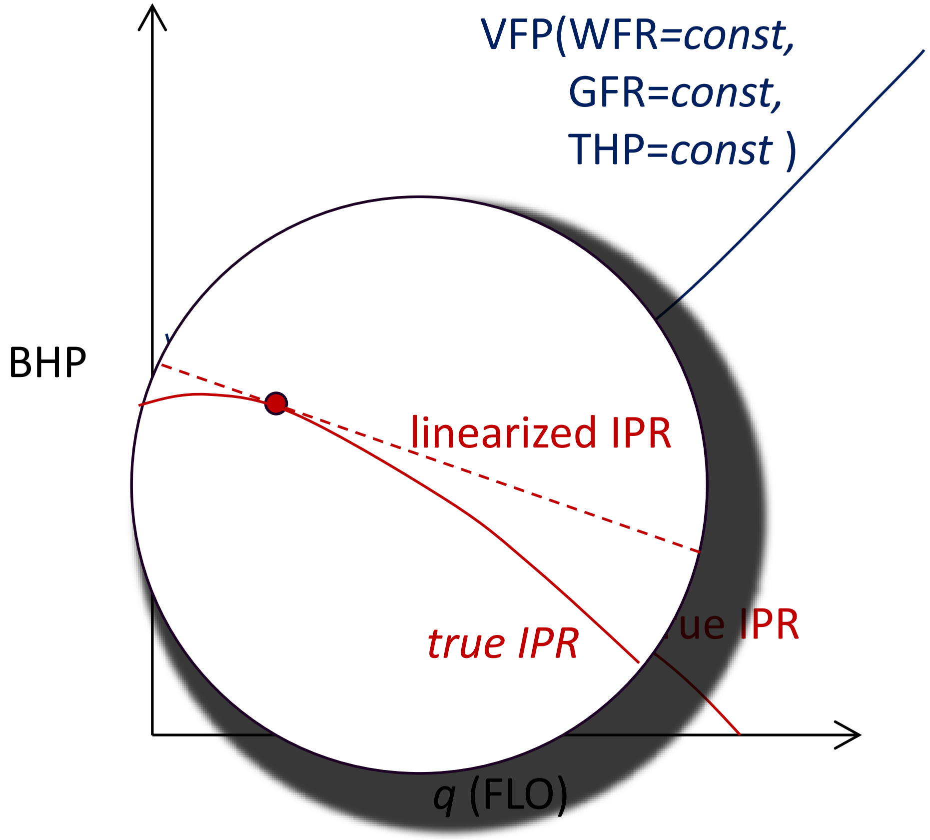


Implicit computation of IPR

Implicit approach:

Compute $\frac{dq}{d\text{BHP}}$ for current well-state using implicit differentiation

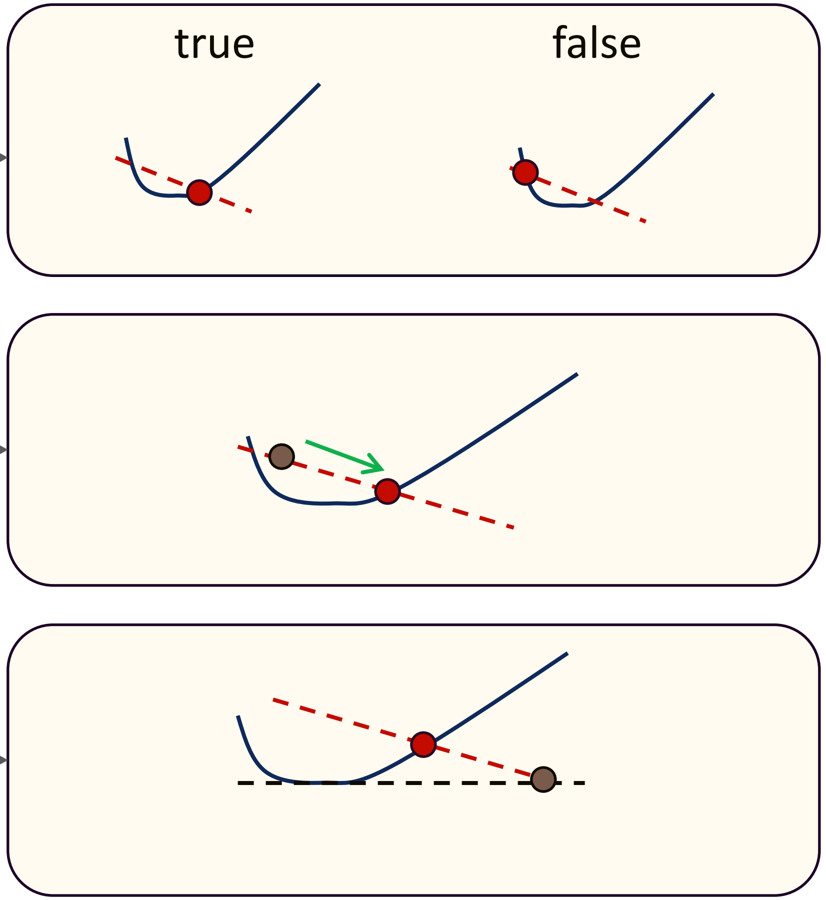
- requires one linear solve of well system
- assumes converged well-equations
- accuracy dependent on well convergence tolerance



Implicit computation of IPR

Ingredients for robust THP-solve

- isStableSolution
- estimateStableBhp
- estimateOperableBhp
  1. solve well for minimum bhp on current VFP-curve
  2. update linearized IPR
  3. estimate stable bhp



`--use-implicit-ipr = true`

Implicit computation of IPR

Results:

- Typically makes little difference for simple cases
- Robust handling of THP-controlled wells needed for some *difficult* cases
  - prevents excessive time-step cuts and/or failures
- Extra machinery (except stability checks) only kicks in for special situations, so virtually no added cost

Concluding remarks

- Several enhancements for more robust well handling triggered by real field cases
- Largest additions related to local well-solves and robust THP-treatment
- With larger and more complex models, all that can go wrong eventually will go wrong

Possible further uses of implicit IPR:

- *Semi-implicit* group control
    - avoid oscillations
- *Semi-implicit* networks
    - improve convergence/runtime

Implicit computation of IPR

Well equations with bhp-control:

$$E(x, p_w) = 0,$$

where x are well-unknowns and p_w is bhp control-value. We have

$$D_{p_w} E = \frac{\partial E}{\partial p_w} + \frac{\partial E}{\partial x} D_{p_w} x = 0,$$

so

$$D_{p_w} x = -\frac{\partial E}{\partial x}^{-1} \frac{\partial E}{\partial p_w}$$

Want to find $\frac{dq}{dp_w}$ for rates q:

$$\frac{dq}{dp_w} = \frac{\partial q}{\partial p_w} + \frac{\partial q}{\partial x} D_{p_w} x$$

$$= \frac{\partial q}{\partial p_w} - \frac{\partial q}{\partial x} \frac{\partial E}{\partial x}^{-1} \frac{\partial E}{\partial p_w}$$

Implicit computation of IPR

$$\frac{dq}{dp_w} = \frac{\partial q}{\partial p_w} - \frac{\partial q}{\partial x}\frac{\partial E}{\partial x}^{-1}\frac{\partial E}{\partial p_w}$$

- Control value not present in formulation of q, so $\frac{\partial q}{\partial p_w} = 0$.
- $\frac{\partial E}{\partial p_w}$ is zero except for a -1 at position of control equation
- $\frac{\partial q}{\partial x}$ obtained from AD-version of rates

1. Solve linear system $\frac{\partial E}{\partial x} v = \frac{\partial E}{\partial p_w}$
2. Assemble $\frac{dq}{dp_w} = -\frac{\partial q}{\partial x} v$