# MODELLING TOOL FOR OPTIMIZATION OF GEOTHERMAL HEAT PRODUCTION SYSTEMS

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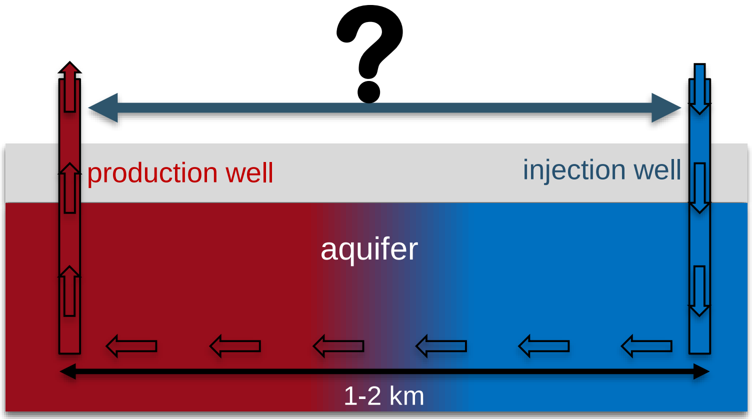
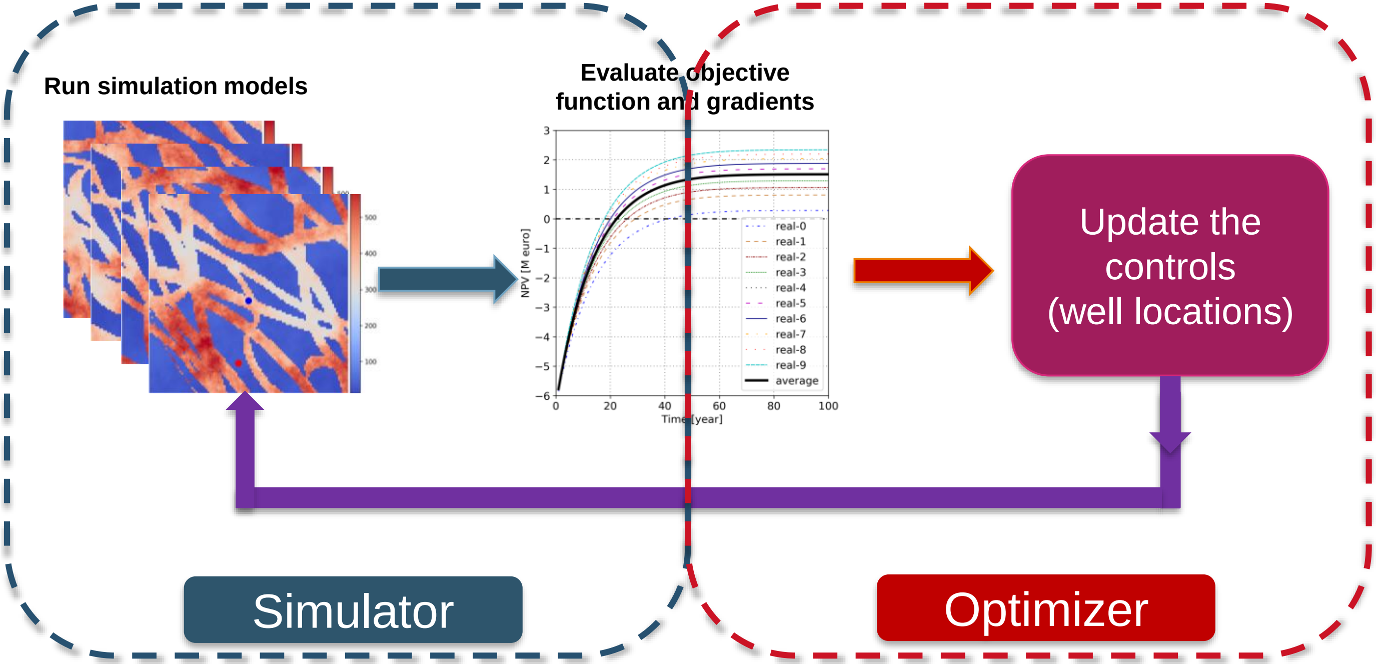
TNO innovation for life

# OPTIMIZATION OF GEOTHERMAL HEAT PRODUCTION SYSTEMS

- Geothermal fields traditionally developed using a system of two wells: ***doublets.***
- Spacing between the wells is chosen through engineering judgment.
- Potential scope to optimize well placement strategies to enhance performance and sustainability.



# OPTIMIZATION WORKFLOW




Find a robust simulation tool for optimization workflow for geothermal energy production systems

# MODELLING TOOL FOR GEOTHERMAL ENERGY SYSTEMS

- Reliable simulations are crucial in an optimization workflow.
- Modelling the heat transfer in an aquifer in geothermal processes is a highly nonlinear problem.
- The problem can be even more complex if vapor state or another gaseous component, such as $CO_2$ or $CH_4$, are present in the reservoir.
- Modelling fluid flow and heat transfer in geothermal systems needs robust simulators, which are capable to model various underlying complex physics.

# AVAILABLE TOOLS

- **OPMFlow**
  - Open source, fast development.
  - Flow and energy equations are solved simultaneously.
  - Include the effect of pressure changes on temperature.

- **ECLIPSE 100**
  - Industry-reference simulator.
  - Handles temperature like a tracer.

- **ECLIPSE 300**
  - Industry-reference simulator.
  - Flow and energy equations are solved simultaneously.
  - Water is allowed in the vapor phase.
  - Equilibrium state depends on temperature and pressure.

# MAJOR DIFFERENCES

- OPM does not handle the effect of temperature on phase **viscosity (**`VISCREF` keyword is not supported**)**.
  - Crucial for any non-isothermal flow simulation.
  - Important if **salinity** needs to be taken into account.
  - For this study, constant water viscosity for all cases is assumed.

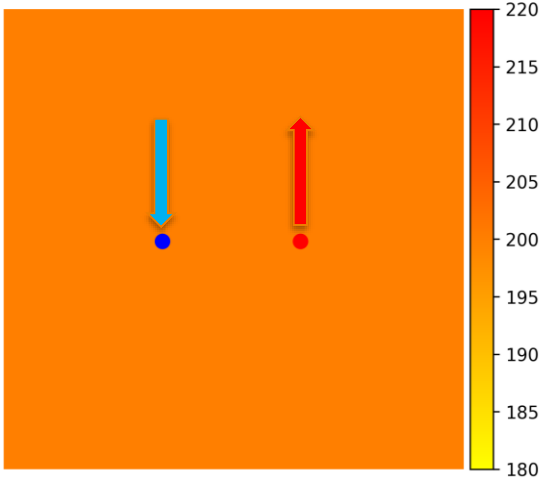
- OPM and E100 does not handle the effect of temperature on phase **densities**.

- In E100 the energy conservation equation is solved at the end of each converged time steps.

- OPM and E300 handle the effect of pressure changes on temperature.

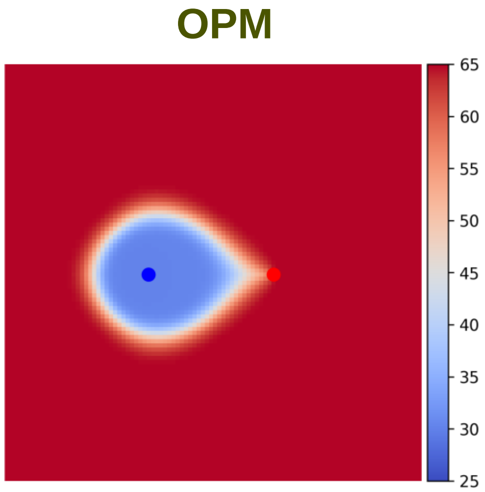
# MODEL DESCRIPTION

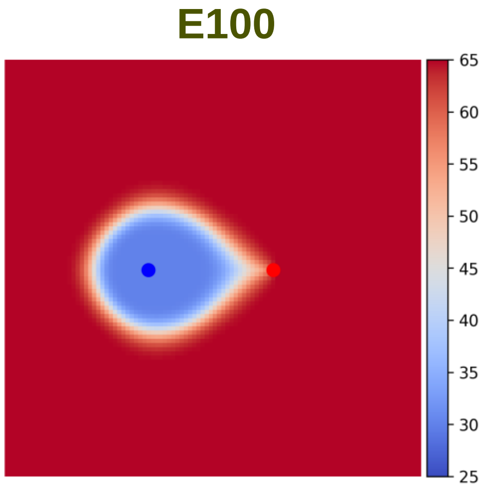
- **Geometry**:
  - 5000m x 5000m x 100m
- **Discretization**:
  - 100 x 100 x 1
- **Well inputs**:
  - Spacing: 1500 m
  - Radius: 0.1778 m
- **Well constraints**:
  - Rate constraint (160 m3/h)
  - Injection temperature: 30 C
- **Reservoir (aquifer) properties**:
  - Homogenous permeability: 200 mD
  - Thermal conductivity: 345.6 kJ/m/day/K
  - Heat capacity: 2700 kJ/m3/K
  - Initial pressure: 50bar
  - Initial temperature: 65 C
- **Fluid (water) properties**:
  - Viscosity: 1 cP
  - Density: 1000 kg/m3
  - Thermal conductivity: 51.84 kJ/m/day/K
- **Numerical settings**:
  - Time step: 1 year
  - Simulation time: 100 years

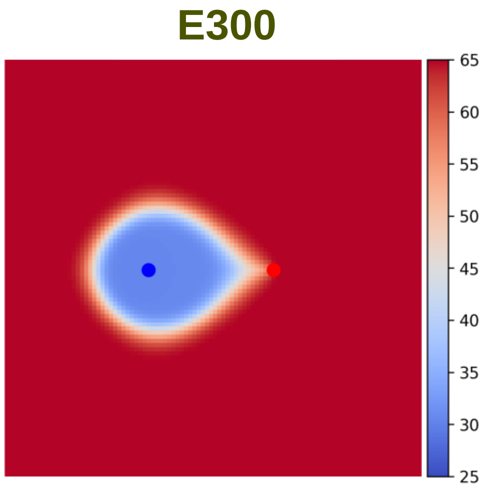


# RESULTS | TEMPERATURE MAP

## AFTER 100 YEARS OF PRODUCTION



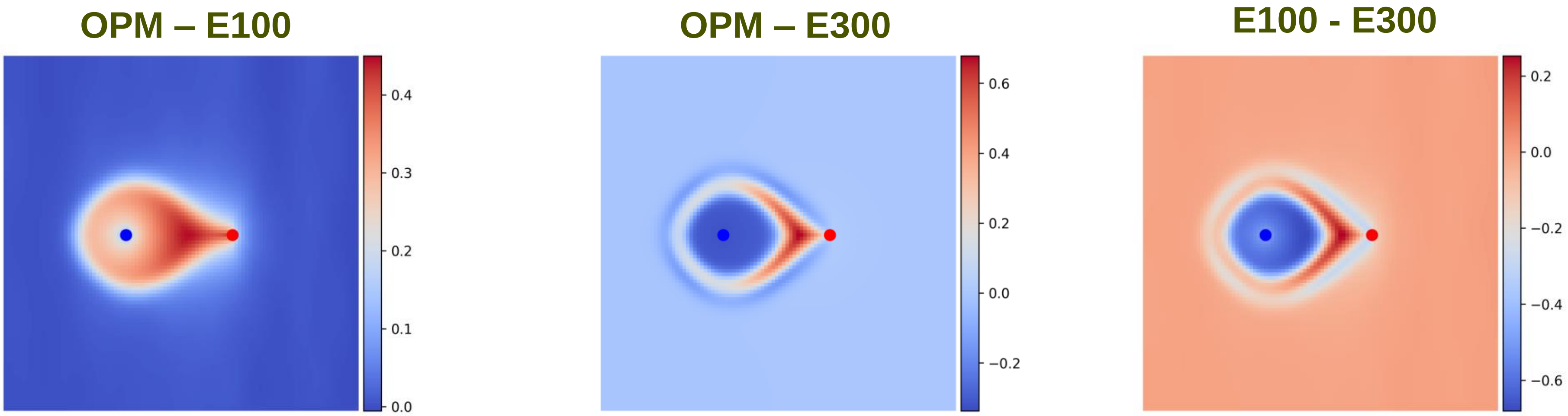




- All cases seems to have similar heat diffusion profile.
- The front shape looks the same.

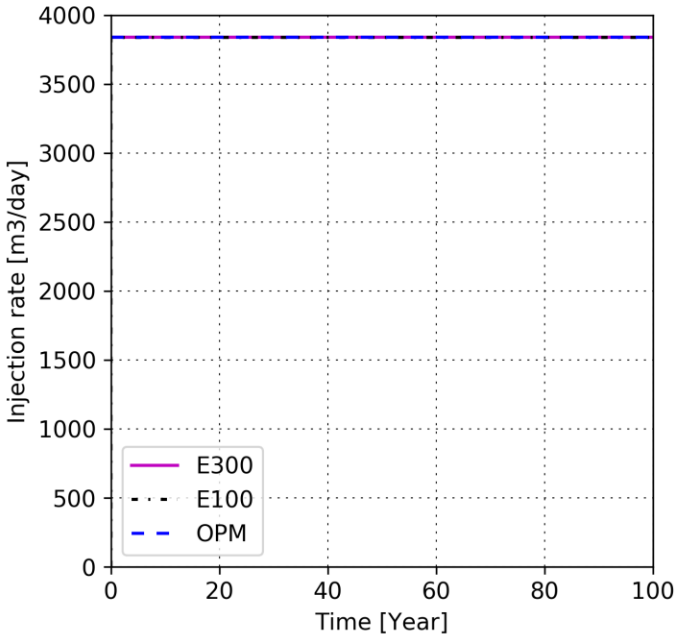
# RESULTS | RESIDUAL TEMPERATURE MAPS

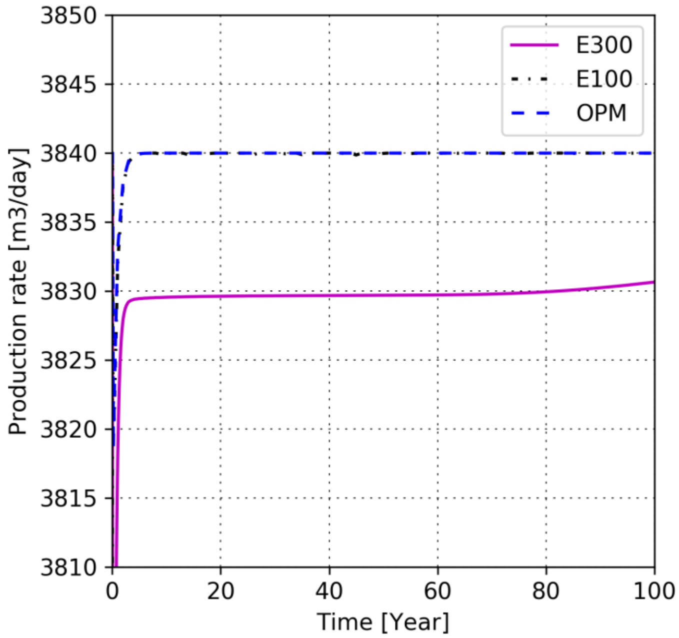
## AFTER 100 YEARS OF PRODUCTION




- OPM and E100 have the least differences.
- OPM has slightly higher temperature everywhere than E100 (max 0.4 C).
- Front position in E300 is slightly different ( results in -0.2 to 0.6 C difference):
  - Handling the equations differently.
  - Density variations during the flood, results in different volume rates in the reservoir condition.

# RESULTS | WELL RATES

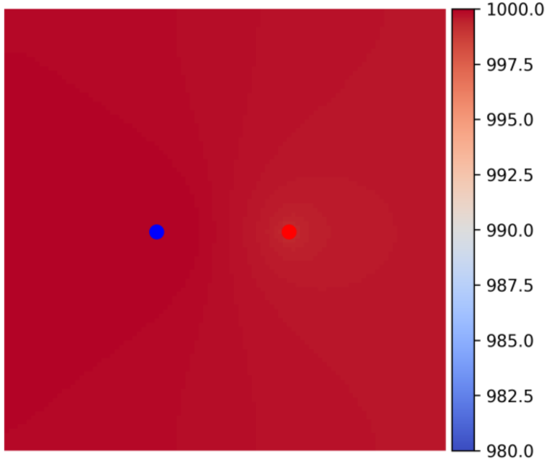


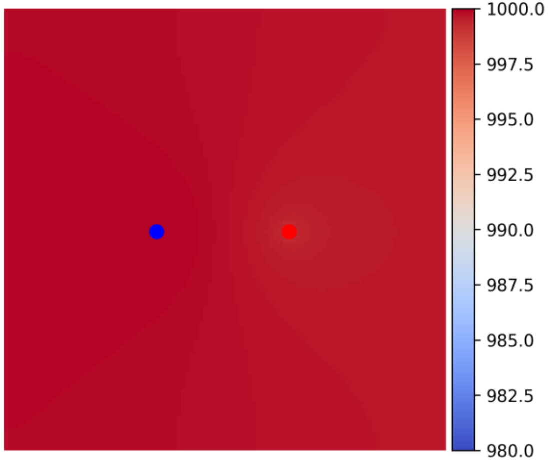

- **Lower production rate in E300:**
  - Density variations by temperature.
  - Production target cannot be met at the minimum bhp.

# TEMPERATURE DEPENDENCY OF DENSITY

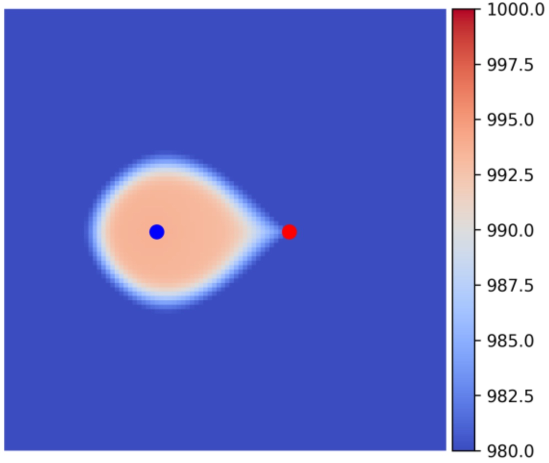
**OPM**




**E100**




**E300**

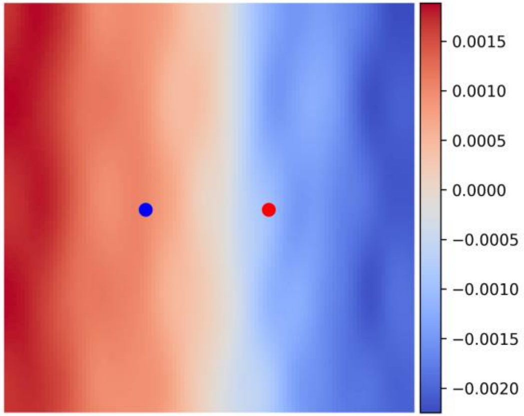



- Density does not change with temperature in OPM and E100.
- In E300 the density is changing by temperature variations.
- This results in different reservoir volume flow for different cases.

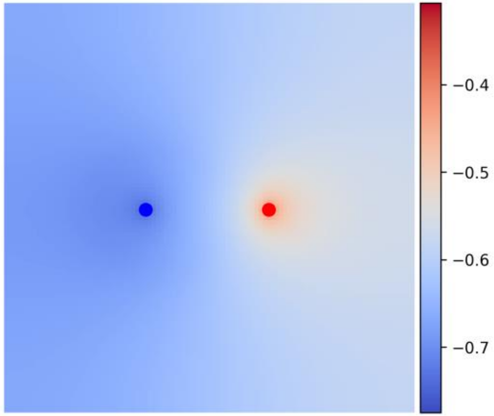
# RESULTS | RESIDUAL PRESSURE MAPS

## AFTER 100 YEARS OF PRODUCTION

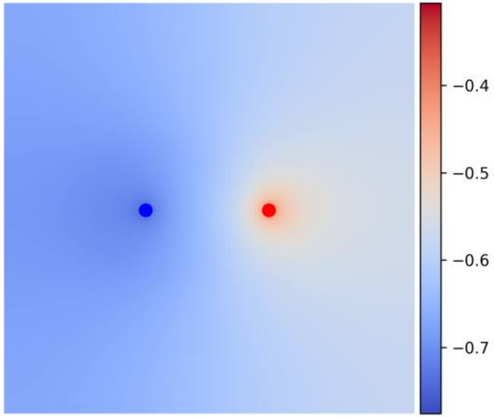
### OPM – E100




### OPM – E300



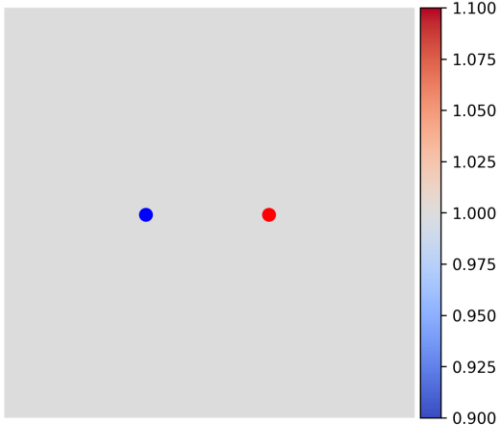

### E100 - E300



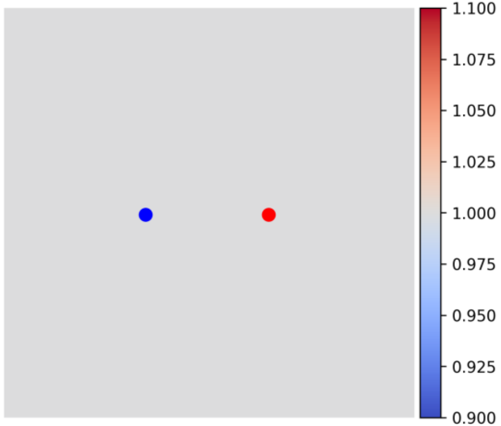

- Pressure profile in E300 is slightly different:
  - E300 temperature and pressure equations are handled differently.
  - Equilibrium state depends on the temperature as well.
  - Volume rate at the reservoir condition is slightly different.

# TEMPERATURE DEPENDENCY OF VISCOSITY

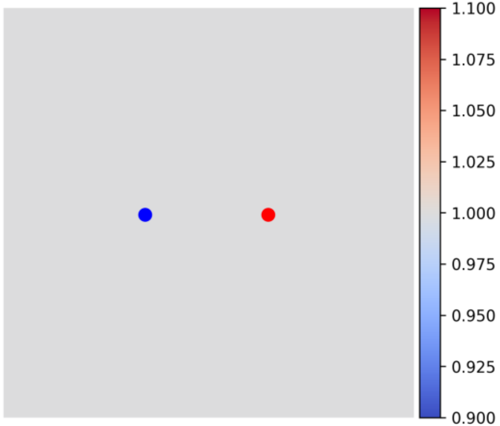
## OPM




## E100




## E300



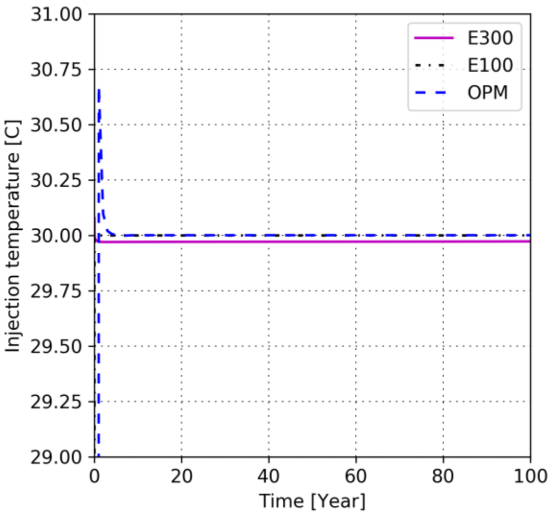

- OPM does not support the effect of temperature on fluid viscosity.
- In E100 and E300 it is possible to include the effect of temperature on the phase viscosity.
- To have a fair comparison the viscosity assumed to be constant in all cases.

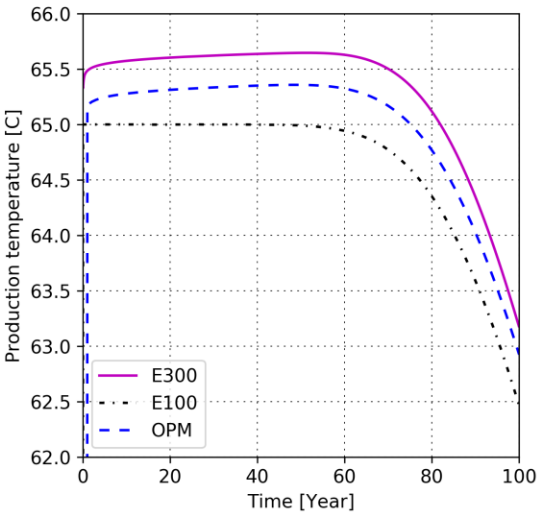
# RESULTS | WELL TEMPERATURE

- OPM does not report the fluid temperature in the wells: *using grid block temperature.*

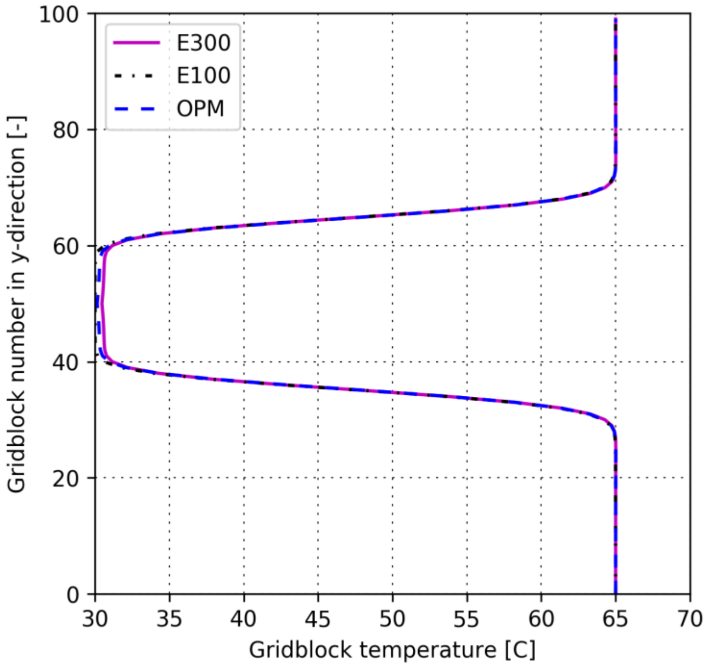
- Heat breakthrough in occurs almost at the same time (~60 years) in all cases.

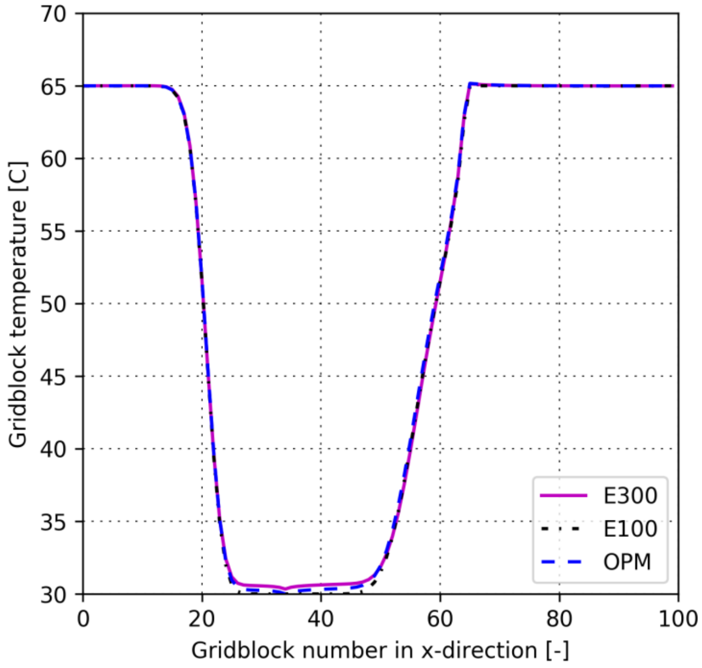
- Slight increase in production temperature in OPM and E300:
  - Equilibrium state depends on both temperature and pressure.
  - Pressure variations affect fluid temperature.



# TEMPERATURE PROFILE ALONG THE INJECTOR
## AFTER 100 YEARS OF PRODUCTION



# OPM: PROS AND CONS (1)

- ***Availability:*** It is an open source (free) software. Makes it possible to be effectively used for optimization (no license bottlenecks).

- ***Accuracy and reliability:*** Benchmarked with ECLIPSE for geothermal (non-isothermal) simulations. Extensive comparative analysis showed a good agreement with ECLIPSE. However, two important mechanisms are currently missing in OPM:

  - OPM does not handle reference pressure for **viscosity** calculations. Subsequently, the water viscosity remains constant despite temperature variations. This can have an important effect for geothermal systems especially when the effect of salinity is considered.

  - OPM does not take the **density** correlations with temperature into account. This can result in non-realistic reservoir volume flow, which may affect producer bhp. However, its effect is trivial for field development and aquifer performance simulations.

# OPM: PROS AND CONS (2)

- ***Flexibility***: It is extensively used in oil and gas community and thus it has quick development support team. It is also compatible with ECLIPSE and PETREL input files, which makes it possible to model more complicated cases.

- ***Speed**:* It is rather slow for bigger models, e.g.,
  - OPM simulates 100 years of production from a 3D model with 200000 cells in 800 seconds whereas E100 does it in 60 seconds. This is actually because E100 solves the energy conservation equations at the end of each converged timestep.

# FEATURE SUMMARY COMPARISON

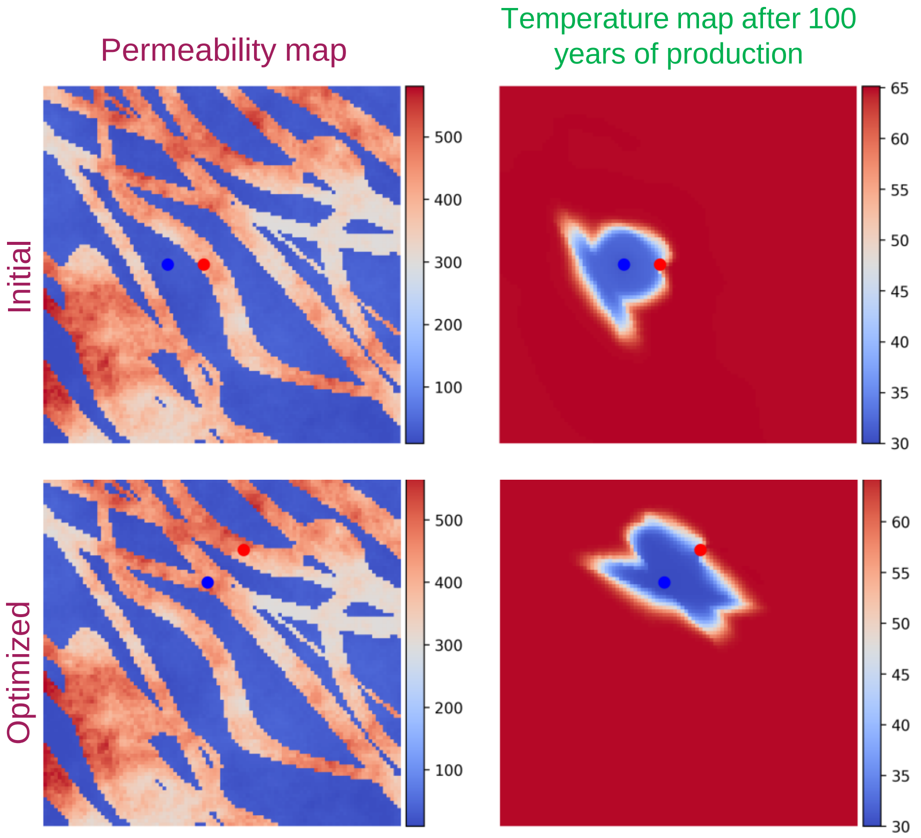
| flow simulators | LGR | CGS | VSC | DNS | MPH | MCO | TPR | TTH | WI | CK |
|---|---|---|---|---|---|---|---|---|---|---|
| OPM | ? | ✓ | ✗ | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ | ✗ |
| E100 | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ | ? |
| E300 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

| feature | CODE | feature | CODE |
|---|---|---|---|
| local grid refinement | LGR | transient pressure solution | TPR |
| complex grid support (faulted petrel) | CGS | calculation of well index | WI |
| dependency of viscosity on temperature | VSC | transient thermal solution | TTH |
| dependency of density on temperature | DNS | calculation of well index | WI |
| multiphase support | MPH | geochemical effect on flow properties | CK |
| multicomponent support | MCO | | |

# WELL LOCATION: 2D HETEROGENOUS

## SINGLE DOUBLET SYSTEM

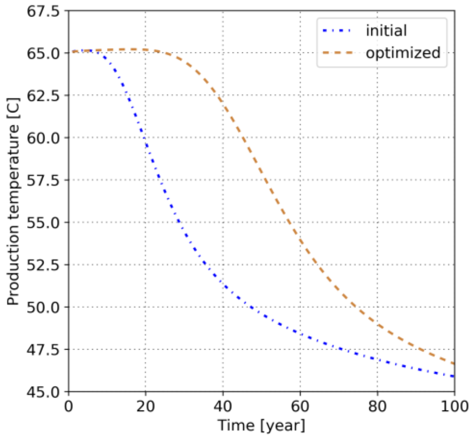
- Shale permeability ≈ 20-30 mD
- Channel permeability ≈ 350 – 450 mD
- The injector was initially placed in the shale.
- High injection pressure and early heat breakthrough result in lower income than the cost: fixed OPEX and electricity cost.
- **Injection and production wells located in separate channels after optimization.**

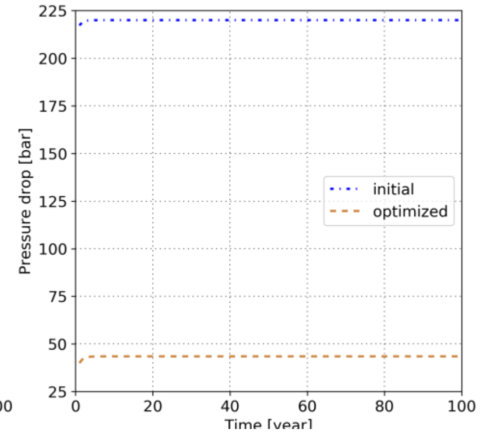


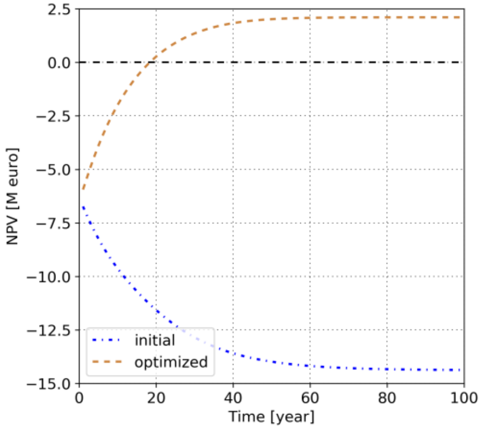
# OPTIMIZATION: 2D HETEROGENOUS (1)

## SINGLE DOUBLET SYSTEM

- Injection pressure increase to 260 bar in the initial case.
- Heat breakthrough occurred after 10 years in the initial case. .
- Injection pressure reduced to 45 bar after optimization.
- Heat breakthrough delayed to year 25 after optimization.
- Pressure difference reduction as well as late heat breakthrough inreased the NPV.



# BEDANKT VOOR UW AANDACHT

Voor meer inspiratie:
**TIME.TNO.NL**

# FLOW SIMULATION DOMAIN

| flow simulation domains | LGR | CGS | VSC | DNS | MCO | TPR | TTH | WI | CK |
|---|---|---|---|---|---|---|---|---|---|
| heat storage | ~ | ✘ | ✓ | ✓ | ~ | ✘ | ✓ | ~ | ~ |
| aquifer performance | ✘ | ✘ | ✓ | ✘ | ✘ | ✘ | ✓ | ✓ | ~ |
| induced seismicity | ✘ | ✓ | ✓ | ✘ | ✘ | ✘ | ✓ | ✘ | ✘ |
| field development | ✘ | ✓ | ✓ | ✘ | ✘ | ✘ | ✓ | ✓ | ✘ |
| geothermal+dissolved CO2 | ✘ | ~ | ✓ | ✓ | ✓ | ✘ | ✓ | ~ | ~ |
| well tests | ~ | ~ | ✓ | ✘ | ✘ | ✓ | ✘ | ✓ | ✘ |
| well trajectory & stimulation | ~ | ~ | ✓ | ✘ | ✘ | ~ | ~ | ✓ | ✘ |
| fractured reservoirs | ✘ | ✘ | ✓ | ✓ | ~ | ✘ | ✓ | ✓ | ~ |
| near well bore THMC coupling | ~ | ✘ | ~ | ~ | ~ | ✘ | ✓ | ✓ | ✓ |