MUFITS
Training Course

Day 3

T2EOS1; BLACKOIL; Wells; Faults

Program

- T2EOS1 and BLACKOIL modules
- Wells
- Export of PVT data from GASSTORE to BLACKOIL
- Faults

T2EOS1 module

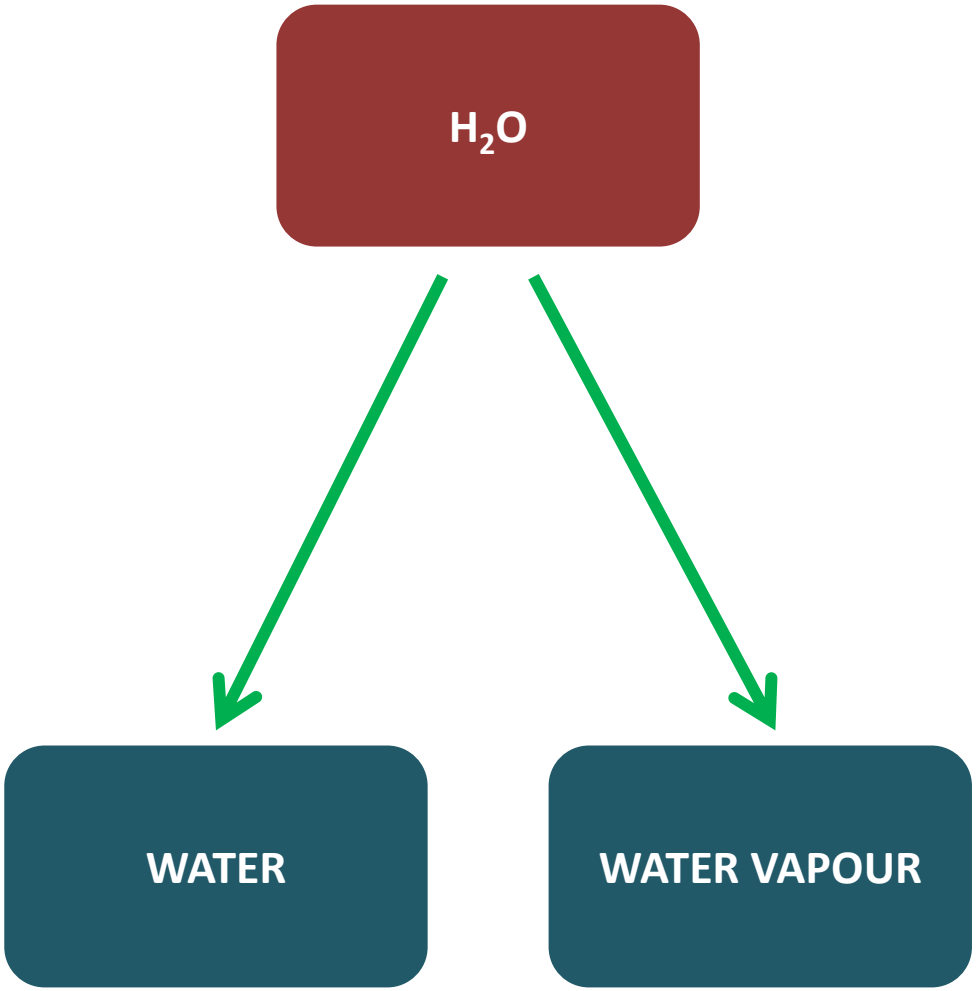
EOS module T2EOS1

T≠const

Components

Keywords

Phases



Options vs. EOS modules

	SIMPLMOD	T2EOS1	BINMIXT	BLACKOIL	GASSTORE
CAPPRES	Yes	No	No	Yes	Yes
HCROCK	Yes	Yes	Yes	No	Yes
HCFLUID	No	Yes	No	No	No
ISOTHERM	Yes	Yes	No	No	Yes
ADDPHASE	Yes	Not tested	Yes	Not tested	Not tested
EQL-ENDEQL (initial equilibration)	No	No	No	Yes	Yes
EOSNUM regions	Yes	No	No	Yes	No

EOS module T2EOS1

Single-component (H2O) single-phase and two-phase flows of after and vapor under subcritical conditions. This module is similar to TOUGH2/EOS1.

$$\frac{\partial}{\partial t}\ \phi(\rho_w s_w + \rho_v s_v\ + \mathrm{div}\ \ \rho_w w_w + \rho_v w_v\ = 0$$

$$\frac{\partial}{\partial t}\ \phi(\rho_w e_w s_w + \rho_v e_v s_v) + (1-\phi)\rho_r e_r\ + \mathrm{div}\ \ \rho_w h_w \mathbf{w}_w + \rho_v h_v \mathbf{w}_v - \bar{\lambda}\mathbf{grad}T\ = 0$$

$$\mathbf{w}_i = -K\frac{k_{r,i}}{\mu_i}\ \mathbf{grad}P - \rho_i \mathbf{g}\ ,\quad i = w,v$$

$$s_w + s_v = 1, \qquad \bar{\lambda} = \phi(s_w\lambda_w + s_v\lambda_v) + (1-\phi)\lambda_r\,, \qquad k_{r,i} = k_{r,i}(s_w)$$

$$\rho_i = \rho_i(P,T),\ \ e_i = e_i(P,T),\ \ h_i = h_i(P,T),\ \ \mu_i = \mu_i(P,T),\ \ \lambda_i = \lambda_i(P,T),\quad i = w,v$$

$$if\ (T < T_{eq}(P))\quad s_w = 1$$

$$if\ (T > T_{eq}(P))\quad s_v = 1$$

$$if\ (0 \le s_w \le 1)$$

EOS module T2EOS1

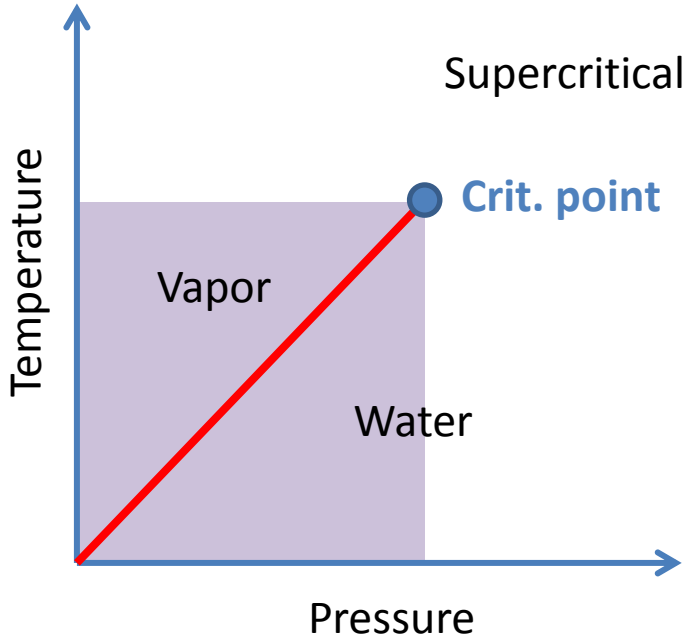
Single-component (H2O) single-phase and two-phase flows of after and vapor under subcritical conditions. This module is similar to TOUGH2/EOS1.

Closing relations:

$$if\ (T < T_{eq}(P)) \quad s_w = 1 \quad - single-phase\ water$$

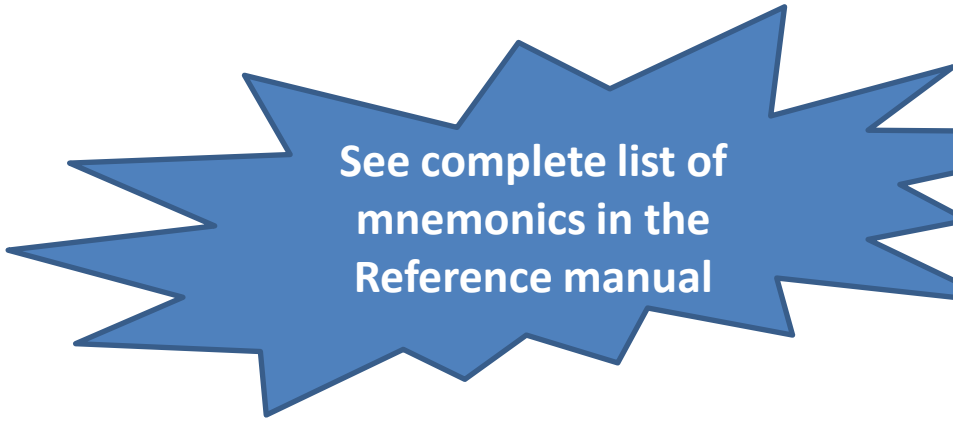
$$if\ (T > T_{eq}(P)) \quad s_v = 1 \quad - single-phase\ vapor$$

$$if\ (0 \le s_w \le 1) \quad T = T_{eq}(P) - two-phase$$



Mnemonics (T2EOS1)

Mnemonic	Description
SVAP	Saturation of vapour
SWAT	Saturation of water
TEQUIL	Equilibrium temperature (K)
TEQUILC	Equilibrium temperature (C)
DVAP	Density of vapour
DWAT	Density of water



Initial conditions

The initial conditions for every cell must be specified in the **INIT** section

There are 5 options to impose the initial conditions when using T2EOS1 module:

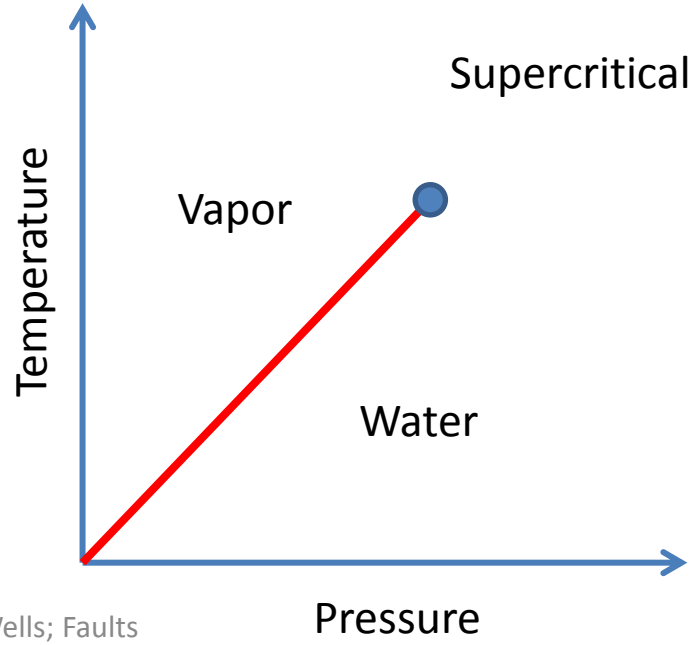
1) Specify pressure (PRES) and water saturation (SWAT) [priority 1]
2) Specify pressure (PRES) and vapor saturation (SVAP) [priority 2]
3) Specify temperature (TEMP) and water saturation (SWAT) [priority 3]
4) Specify temperature (TEMP) and vapor saturation (SVAP) [priority 4]
5) Specify pressure (PRES) and temperature (TEMP) [priority 5]

2-phase

1-phase

Note, that the TEMPC mnemonic can be used to specify the temperature in degrees of Celsius instead of the TEMP mnemonic which is for degrees Kelvin.

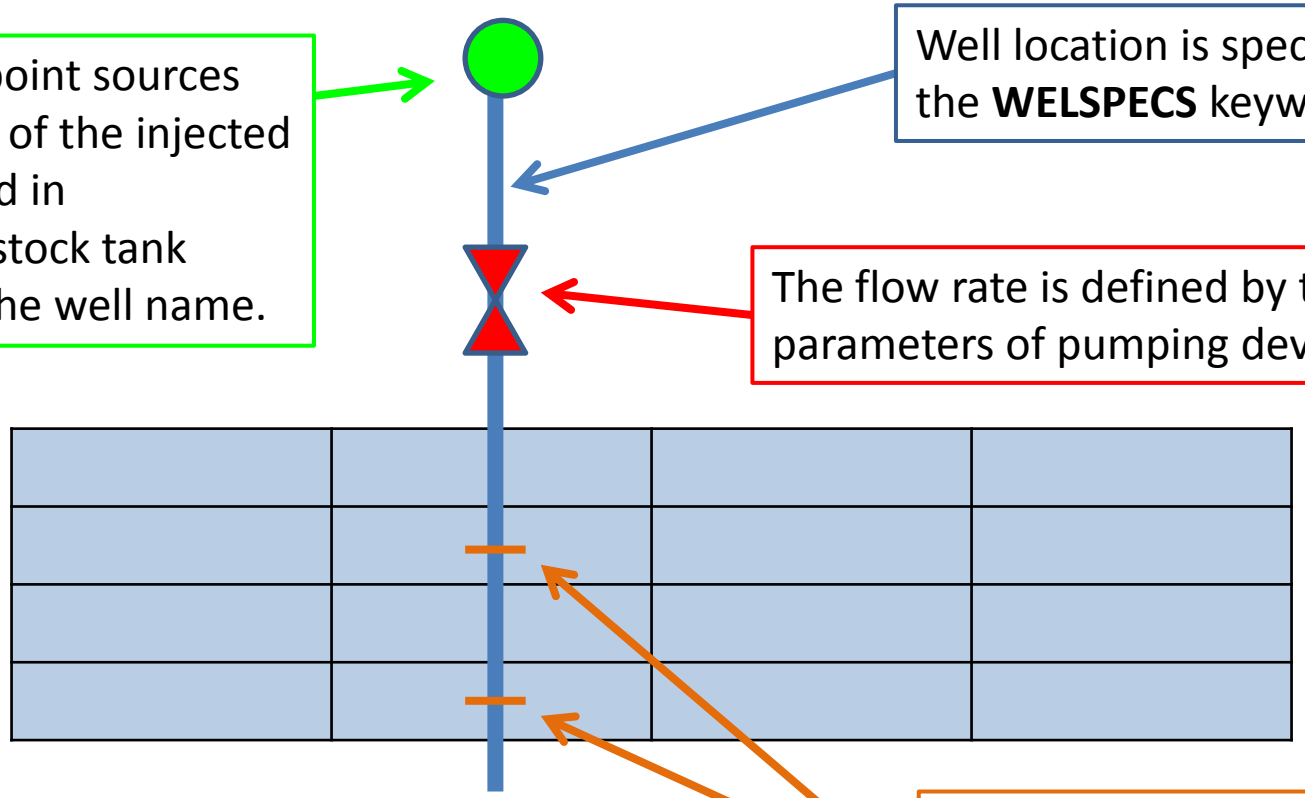
Note, that if parameters in a cell remain unspecified the simulation will be terminated after the INIT section.



Wells

Some notes on wells

Like in case of point sources the parameters of the injected fluid are defined in corresponding stock tank referred to by the well name.



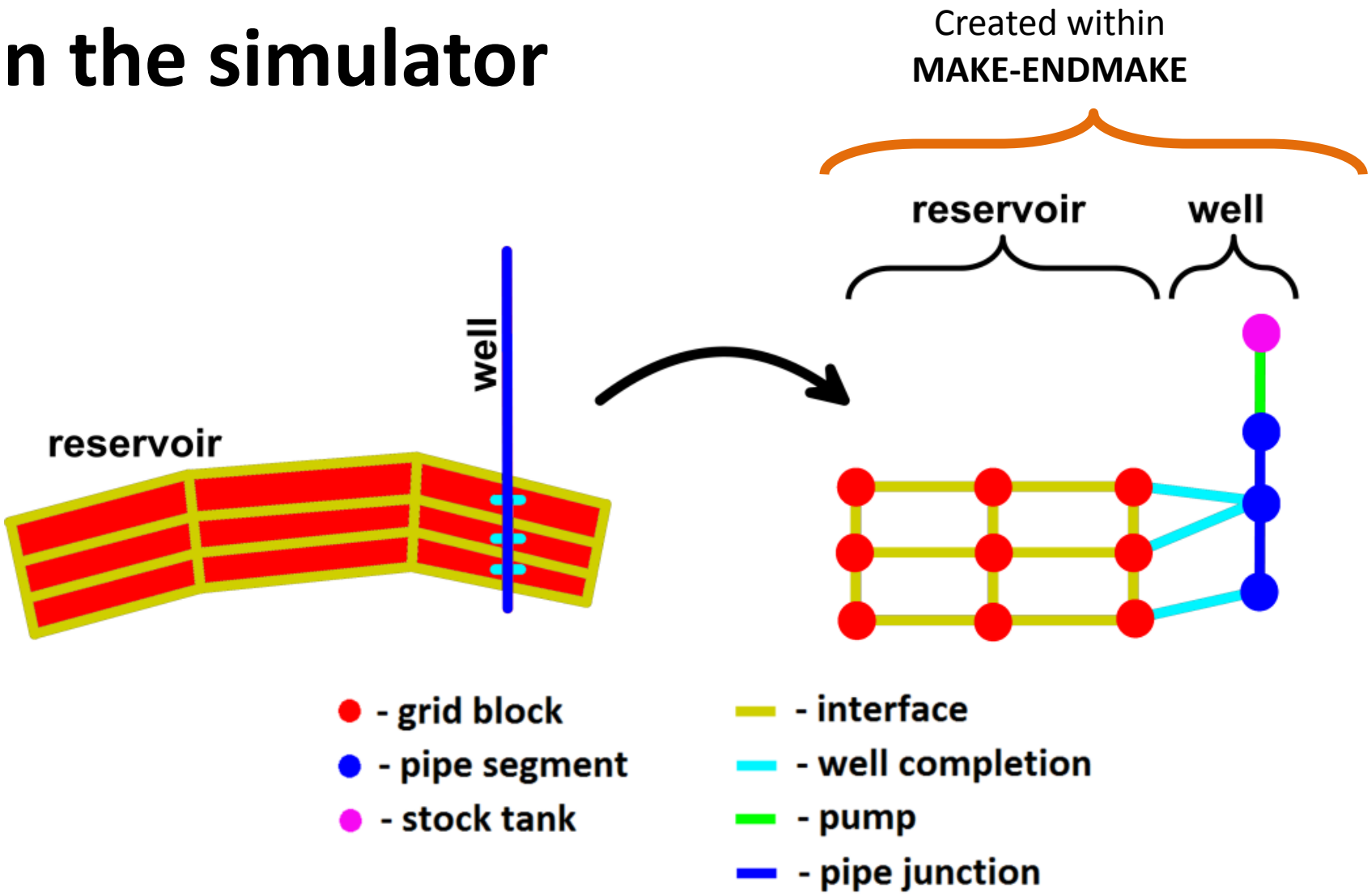
Well location is specified by the **WELSPECS** keyword

The flow rate is defined by the parameters of pumping device.

Well completions are specified by the **COMPDAT** keyword

The **WELSPECS** and **COMPDAT** keyword should be specified within **MAKE-ENDMAKE** brackets.

Reservoir models in the simulator



WELSPECS keyword

WELSPECS syntax

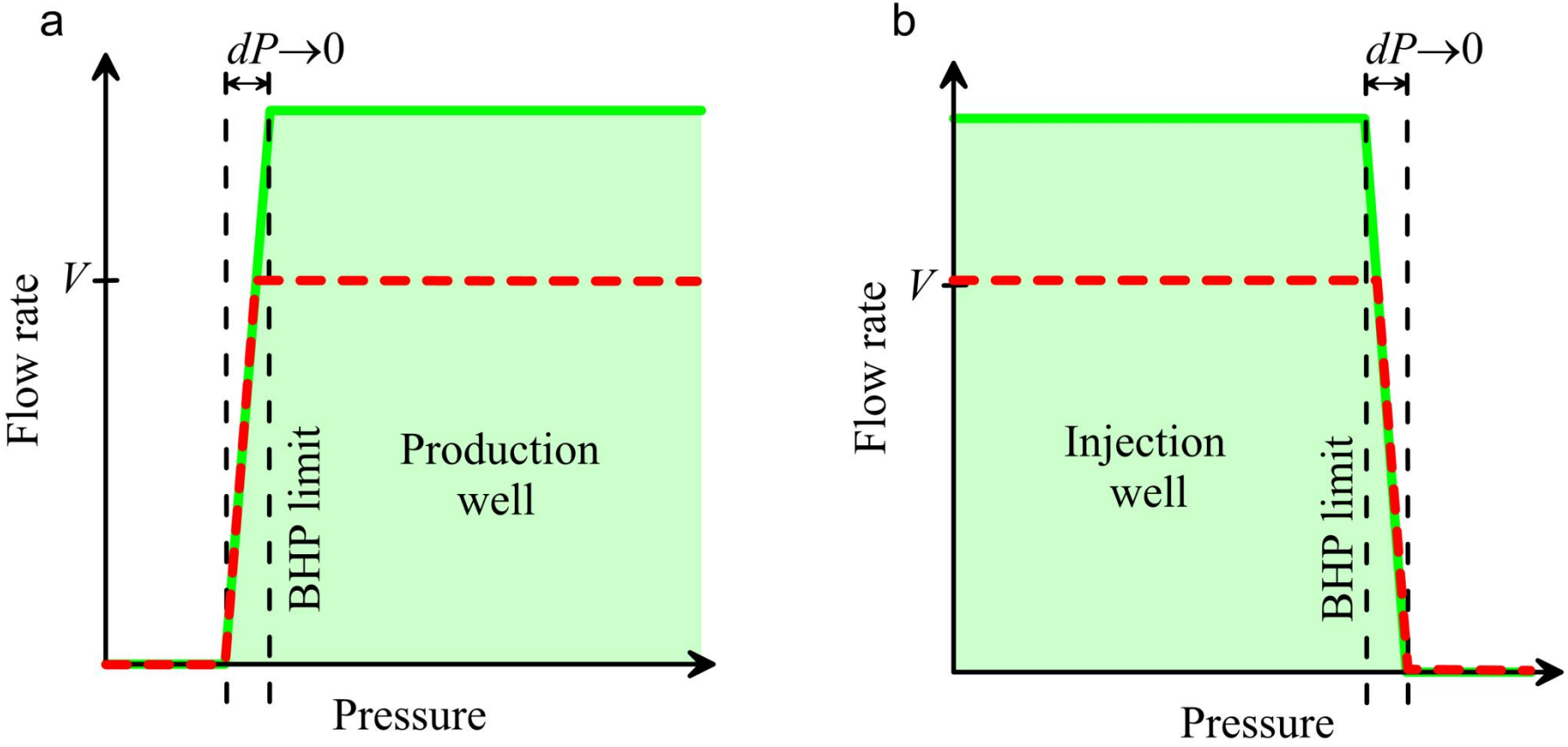
```
-- within MAKE-ENDMAKE brackets or in SCHEDULE section

WELSPECS
   name1 nu1 iloc1 jloc1 datum1 nu1 r0_1 3*nu1 eosnum1 5*nu1 fluxnum1 /
   name2 nu2 iloc2 jloc2 datum2 nu1 r0_2 3*nu2 eosnum2 5*nu2 fluxnum2 /
   name3 nu3 iloc3 jloc3 datum3 nu1 r0_3 3*nu3 eosnum3 5*nu3 fluxnum3 /
   ...
/

================================================================================

   name#    - well name;
   nu#      - a parameter not used at present;
   iloc#    - i-index of the grid block where the well head is located;
   jloc#    - j-index of the grid block where the well head is located;
   datum#   - reference depth for bottom hole pressure;
   r0_#     - drainage radius;
   eosnum#  - equation of state region number used for the fluid properties
              calculation in the well;
   fluxnum# - FLUXNUM region number assigned to all cells of which the well
              is constructed.
```

COMPDAT keyword

COMPDAT syntax

```
-- within MAKE-ENDMAKE brackets or in SCHEDULE section

COMPDAT
 name1 iloc1 jloc1 kmin1 kmax1 mode1 satnum1 tran1 d1 kh1 skin1 nu1 dir1 r0_1 /
 name2 iloc2 jloc2 kmin2 kmax2 mode2 satnum2 tran2 d2 kh2 skin2 nu2 dir2 r0_2 /
 name3 iloc3 jloc3 kmin3 kmax3 mode3 satnum3 tran3 d3 kh3 skin3 nu3 dir3 r0_3 /
 ...
/

================================================================================

   name#       - well name;
   nu#         - a parameter not used at present;
   iloc#/jloc# - i-index and j-index of the grid block where the well is
                 completed;
   kmin#/kmax# - k-index range of grid blocks where the well is completed;
   mode#       - if OPEN (default) the completion is opened for the fluid
                 transport; if SHUT the completion is closed off;
   satnum#     - saturation functions region (SATNUM) used for the calculation
                 of the fluxes through the completion;
   tran#       - this field is for explicit specification of the
                 transmissibility;
   d#          - wellbore diameter at the connection;
```

Pumping device properties

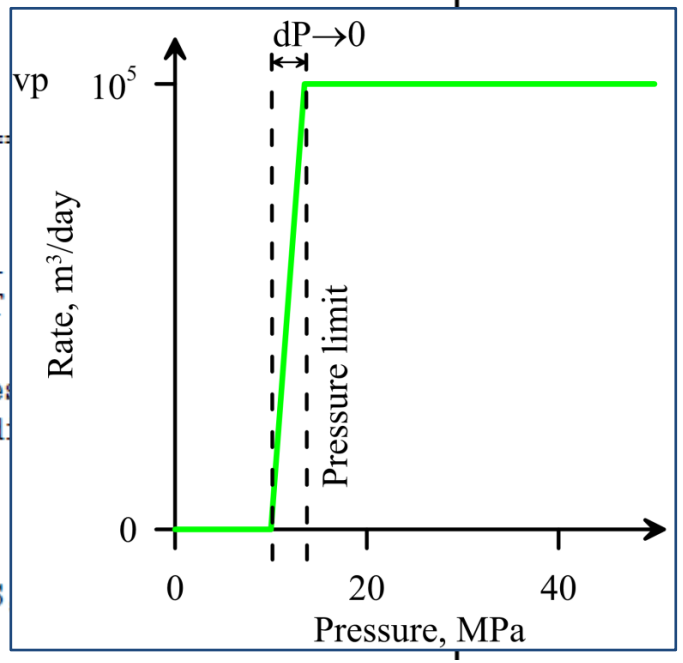


WELLPROD keyword

The parameters of production wells are specified using **WELLPROD** keyword

WELLPROD syntax

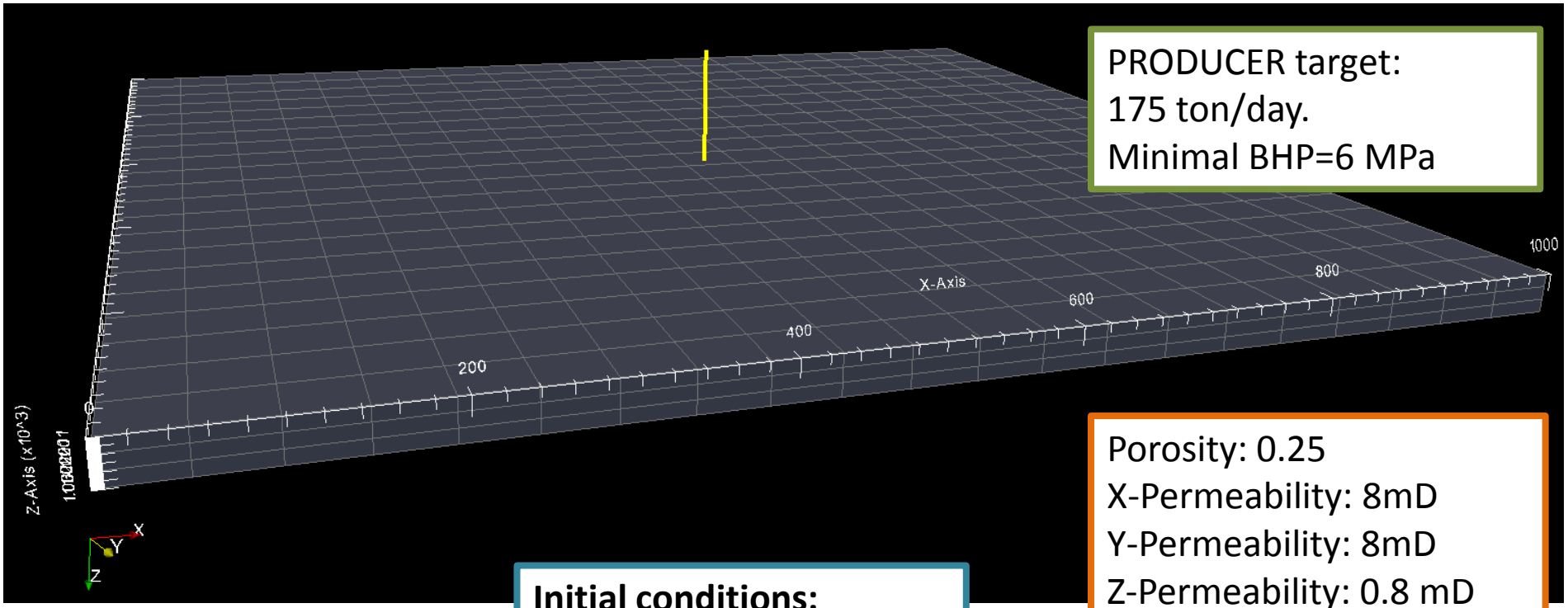
```
-- in SCHEDULE section

WELLPROD
   name1 mode1 targ1 volrate1 massrate1 bhp1 vp1 nu1 dimflag1 /
   name2 mode2 targ2 volrate2 massrate2 bhp2 vp2 nu2 dimflag2 /
   name3 mode3 targ3 volrate3 massrate3 bhp3 vp3 nu3 dimflag3 /
   ...
/

=============================================================

   name#     - well name or well name template;
   mode#     - well mode. Available values: OPEN - well
               STOP - well stoped above formation, SHUT
               isolated form the formation.
   targ#     - well operational target. Available value
               RESV - volumetric rate at reservoir cond
               bottom hole pressure;
   massrate# - mass rate;
   volrate#  - volumetric rate;
   bhp#      - bottom-hole pressure (either limit (MASS
               parameter (BHP));
```



Scenario 7

Grid: 21*21*3
Domain:[0,1000]*[0,1000]*[1000,1030] m
PRODUCER: i=11, j=11 completed in k=1,2

Simulate production for 9540 days reporting distributions every 180 days. Create plots for well flow rate, bottom-hole pressure and bottom-hole temperature.



PRODUCER target:
175 ton/day.
Minimal BHP=6 MPa

Initial conditions:
Temperature=307.8 C;
Equilibrium conditions;
Water saturation = 1.0

Porosity: 0.25
X-Permeability: 8mD
Y-Permeability: 8mD
Z-Permeability: 0.8 mD
HeatCondCoef: 2W/m/K
RockDens: 2650 kg/m3
RockHeatCapac: 1 kJ/kg/K

$$k_{r,l} = s_l^3$$

$$k_{r,g} = (1 - s_l)^2$$

RUN-file (scenario 7)

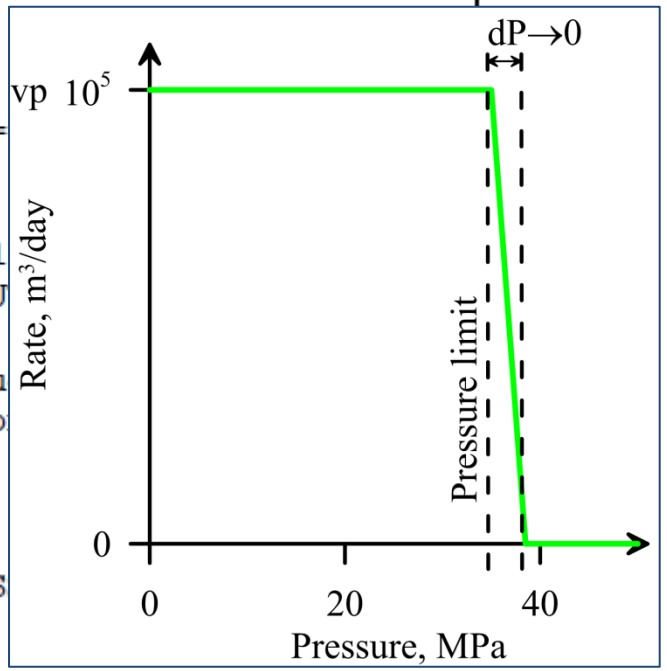
1. Open RUN-file in text editor
2. Run the simulation
3. Open LOG-file to see results

WELLINJE keyword

The parameters of injection wells are specified using **WELLINJE** keyword

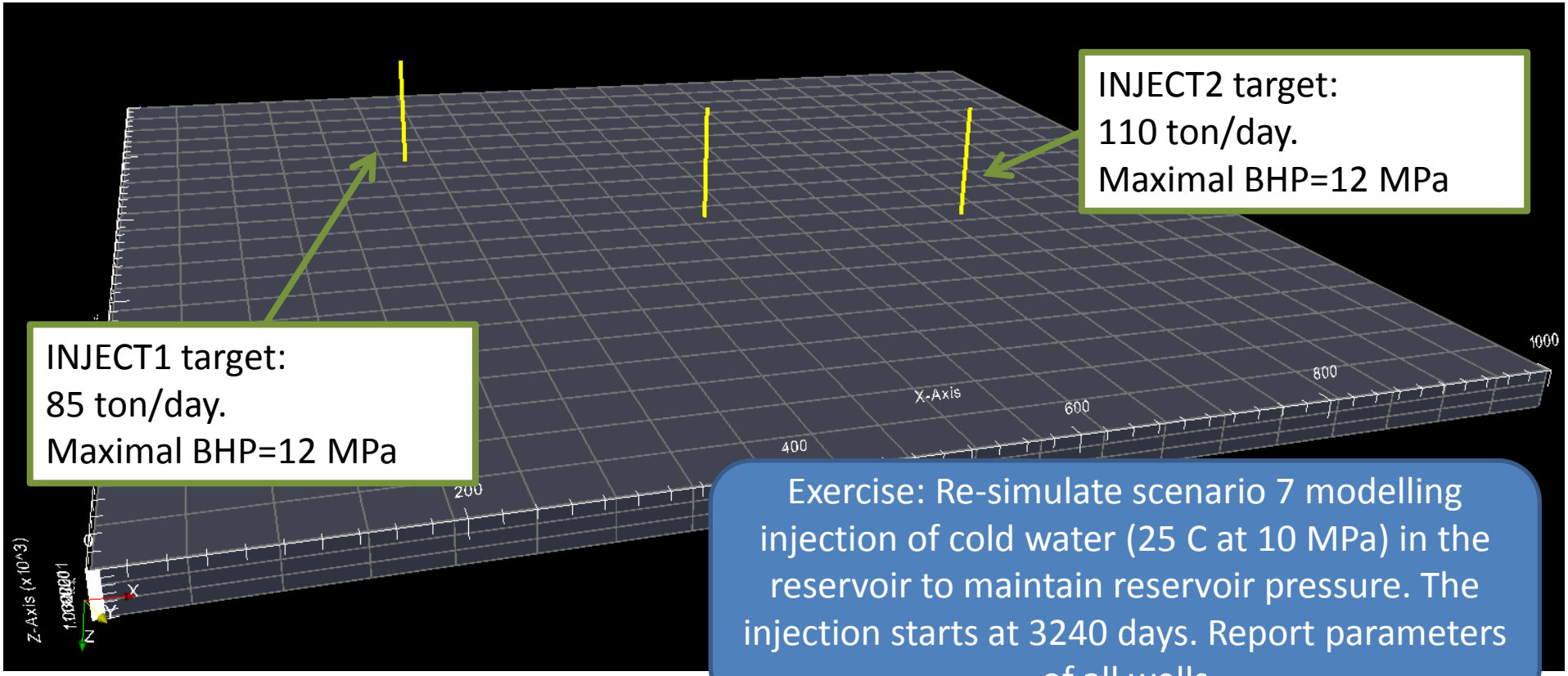
WELLINJE syntax

```
-- in SCHEDULE section

WELLINJE
   name1 mode1 targ1 volrate1 massrate1 bhp1 vp1 injtype1 dimflag1 /
   name2 mode2 targ2 volrate2 massrate2 bhp2 vp2 injtype2 dimflag2 /
   name3 mode3 targ3 volrate3 massrate3 bhp3 vp3 injtype3 dimflag3 /
   ...
/

=========================================================

   name#      - well name or well name template;
   mode#      - well mode. Available values: OPEN - wel
                STOP - well stoped above formation, SHU
                isolated form the formation.
   targ#      - well operational target. Available valu
                RATE - volumetric rate at stock tank co
                bottom hole pressure;
   massrate#  - mass rate;
   volrate#   - volumetric rate;
   bhp#       - bottom-hole pressure (either limit (MAS
                parameter (BHP));
```



Scenario 7 (exercise 1)

PRODUCER: i=11, j=11 completed in k=1,2
INJECT1: i=6, j=6 completed in k=1,2,3
INJECT2: i=16, j=12 completed in k=1,2,3



Exercise: Re-simulate scenario 7 modelling injection of cold water (25 C at 10 MPa) in the reservoir to maintain reservoir pressure. The injection starts at 3240 days. Report parameters of all wells

RUN-file (scenario 7; exercise 1)

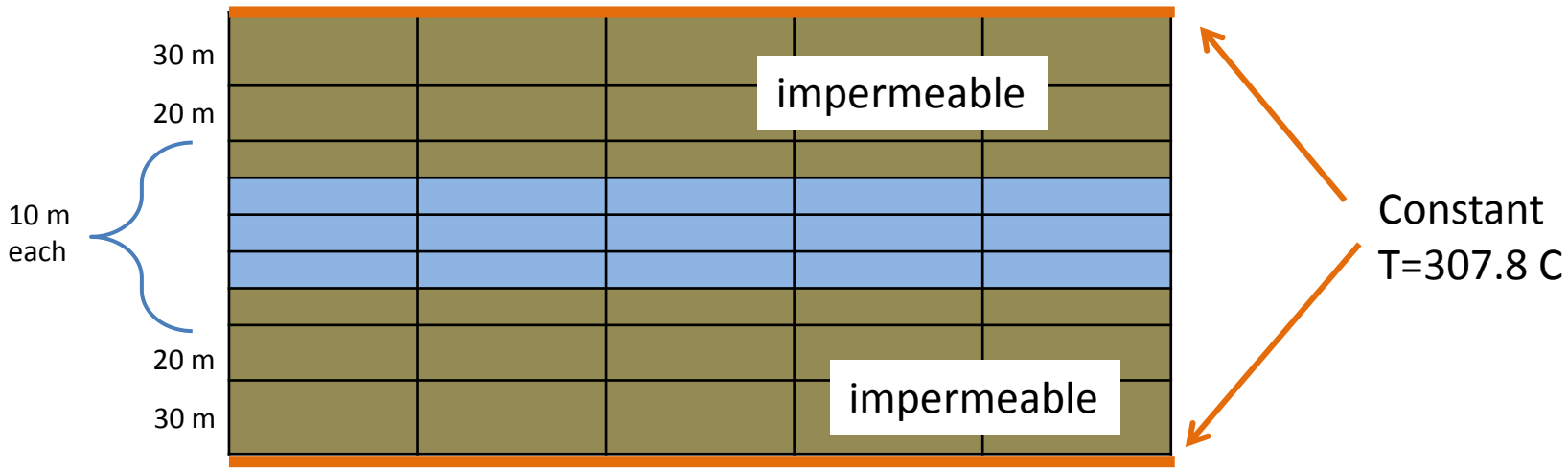
1. Open RUN-file in text editor
2. Run the simulation
3. Open LOG-file to see results

Scenario 7 (exercise 2)

Grid: 21*21*9

Exercise: Re-simulate scenario with 3 wells modelling heat exchange with impermeable overburden and underburden layers.

Cross-section view



Flags defined in cells

Flag mnemonic	Description
ACTNUM	0 – cell inactive; 1 – cell active; 2 – fixed parameters;
TYPENUM	1 – an ordinary cell, 2 – impermeable cell
ROCKNUM	Rock properties region number
SATNUM	Saturation functions region number
EOSNUM	Fluid properties region number
PVTNUM	ADDPHASE fluid properties number
FLUXNUM	Is used for boundary conditions specification
MPINUM	Grid partition
EQLNUM	Initial equilibration region number
FIPNUM	Fluid-in-place regions
INCONUM	No predefined meaning at present

TYPENUM flag

TYPENUM flag must be specified within the MAKE-ENDMAKE brackets

If TYPENUM=1 then the grid blocks is permeable;

If TYPENUM=2 then the grid block is impermeable. Only heat transfer equation is solved in such a grid blocks.

All input data that affect the number of balance equations, solved by the program, must be specified either in the RUNSPEC section or within the MAKE-ENDMAKE brackets.

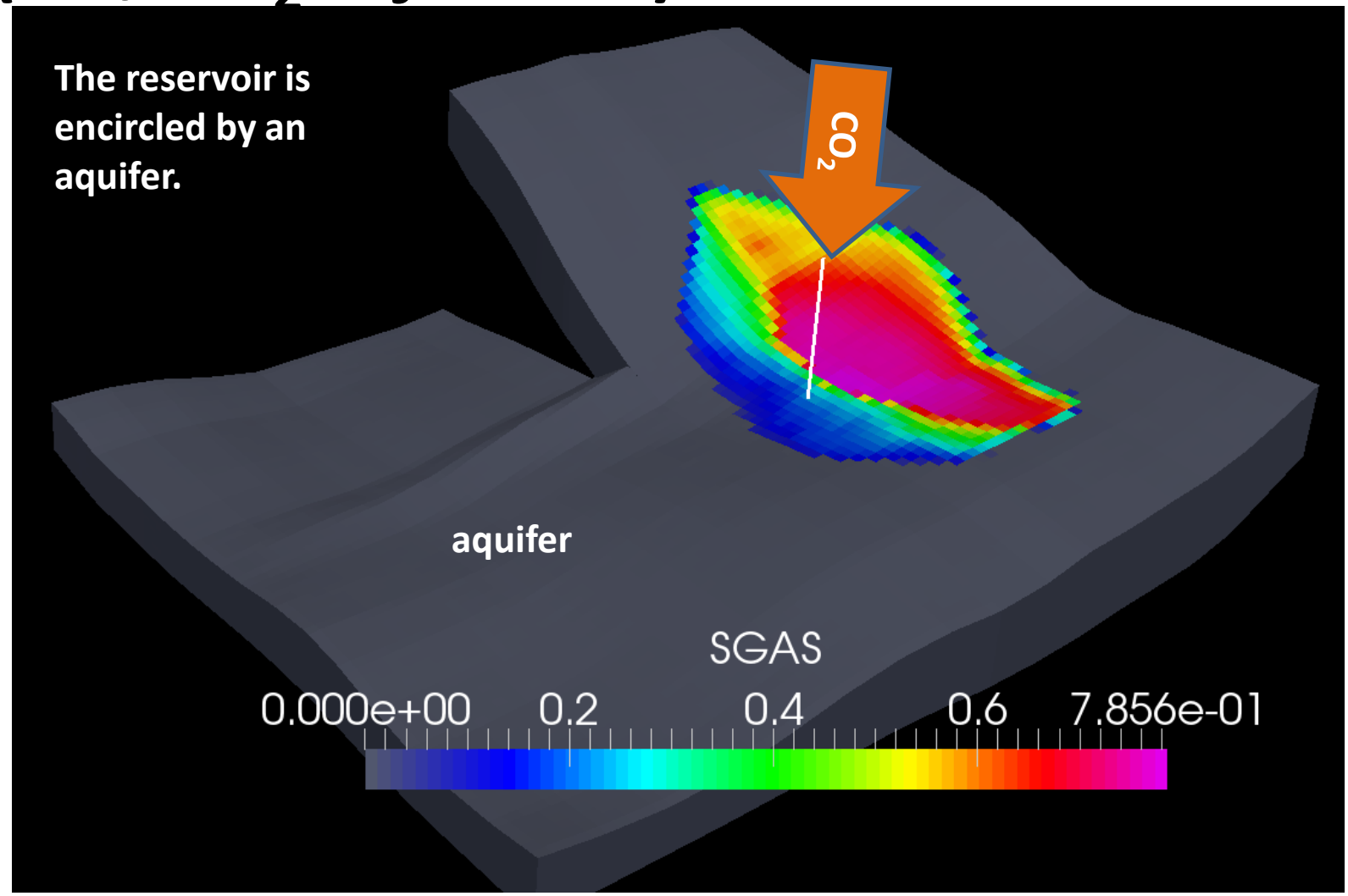
RUN-file (scenario 7; exercise 2)

1. Open RUN-file in text editor
2. Run the simulation
3. Open LOG-file to see results

Scenario 8

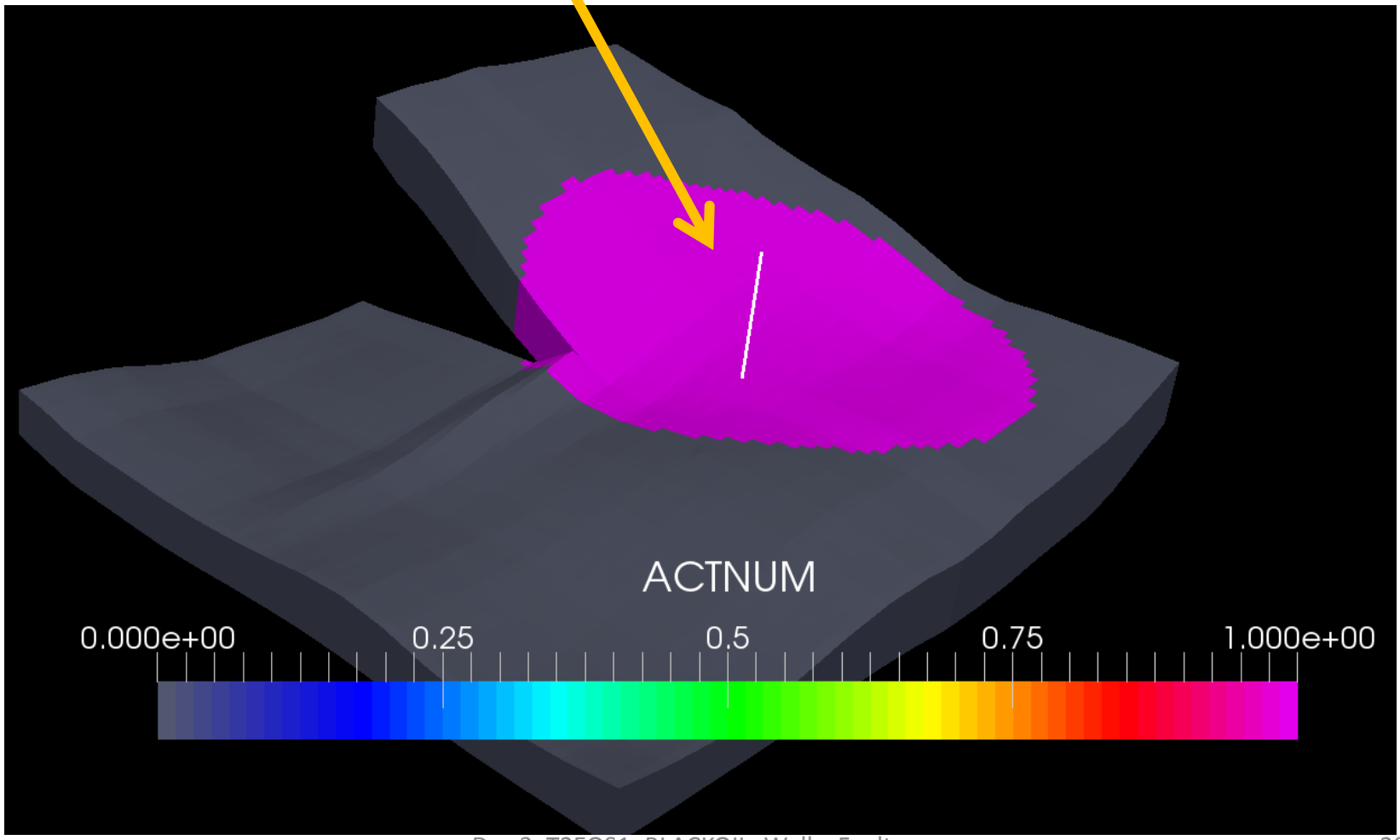
Scenario 8 (3D; CO_2 injection)

This is problem 3.1 from Class H. et al. 2009 A benchmark study on problems related to CO_2 storage in geological formations. Comput. Geosci. 13(4):409-434. DOI:10.1007/s10596-009-9146-x



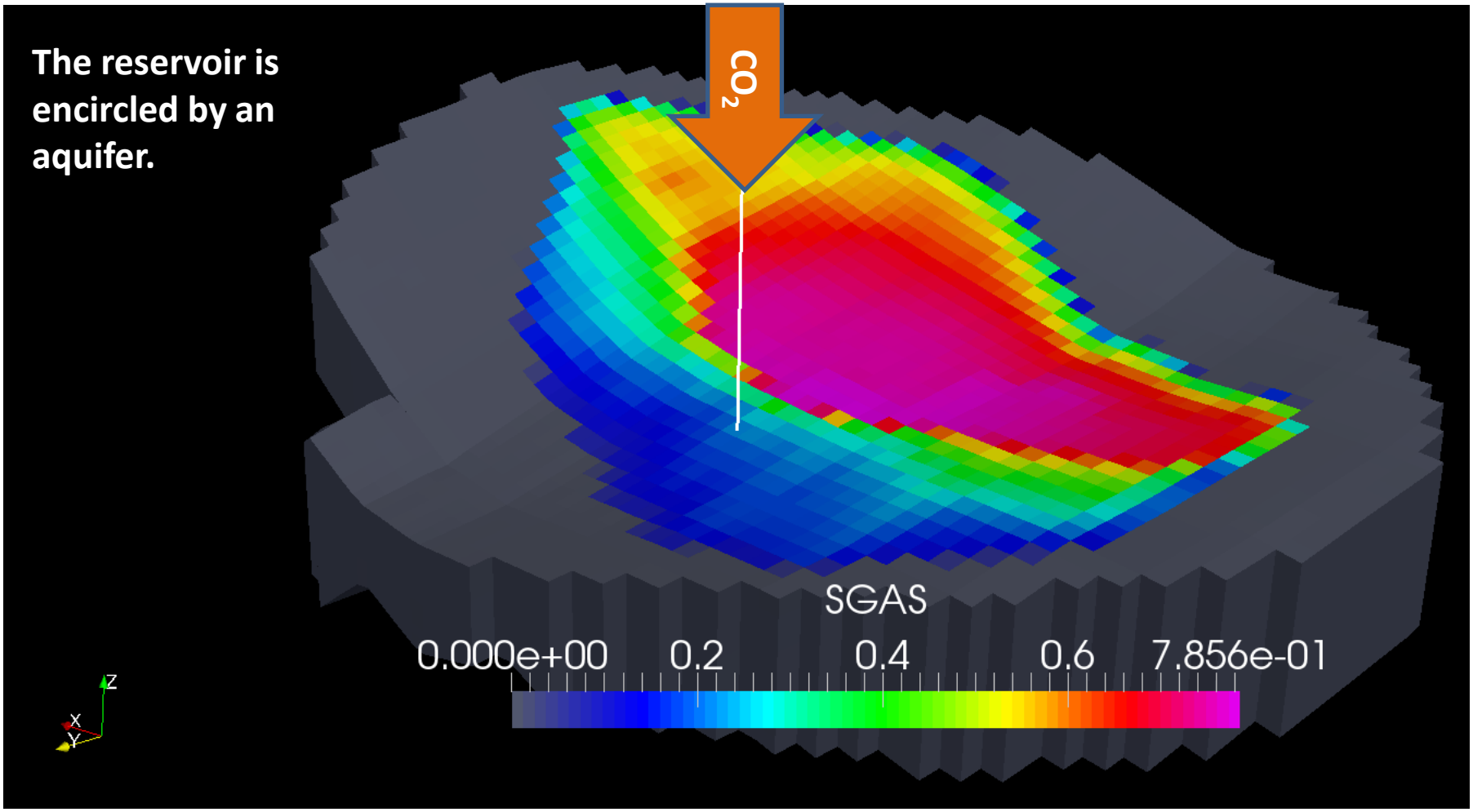
Simplification of Scenario 8

In order to reduce simulation time we will simulate flow dynamics only in this region ACTNUM=1.



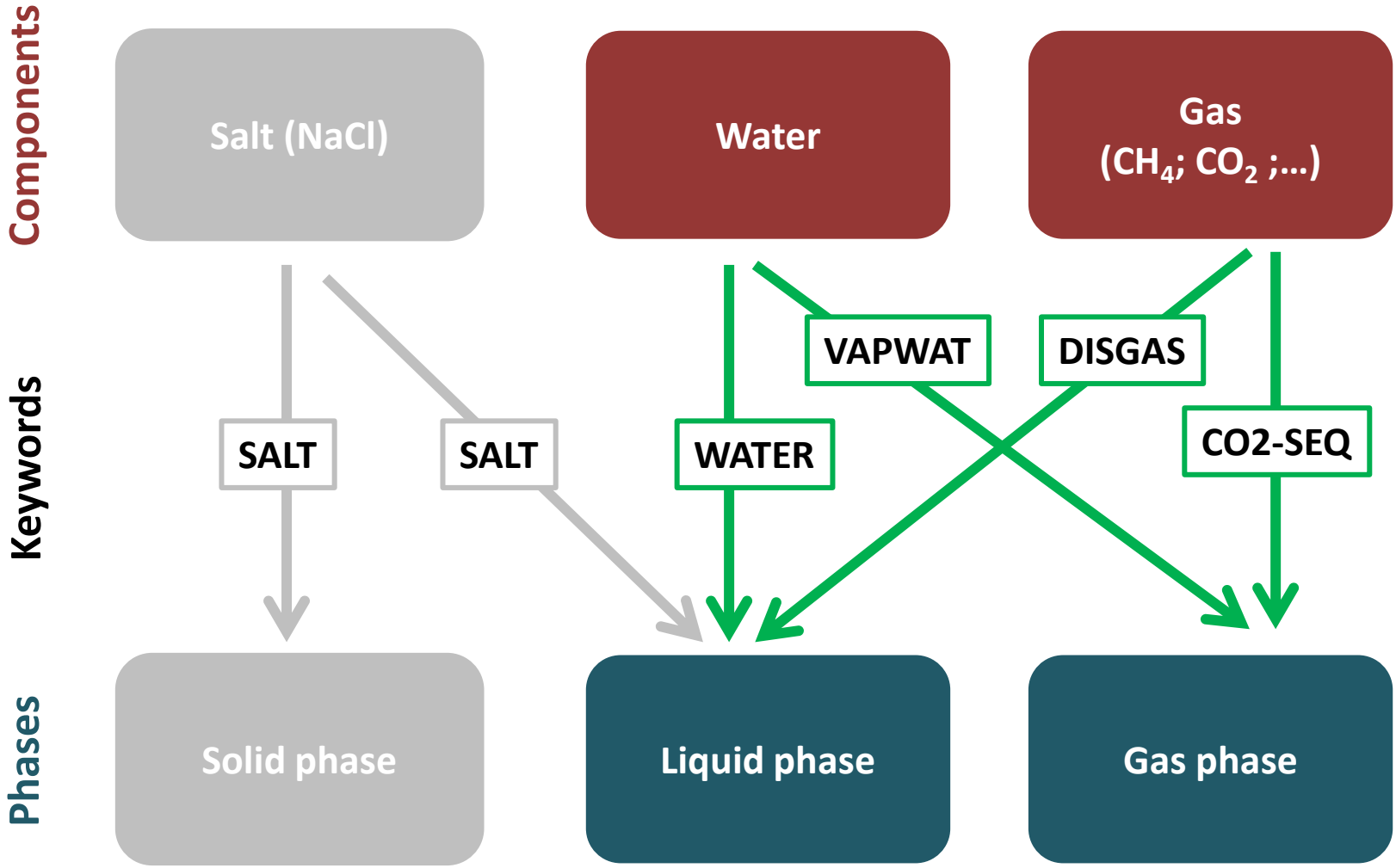
Simplification of Scenario 8

Thus, we will consider the following problem:



EOS module GASSTORE

T≠const



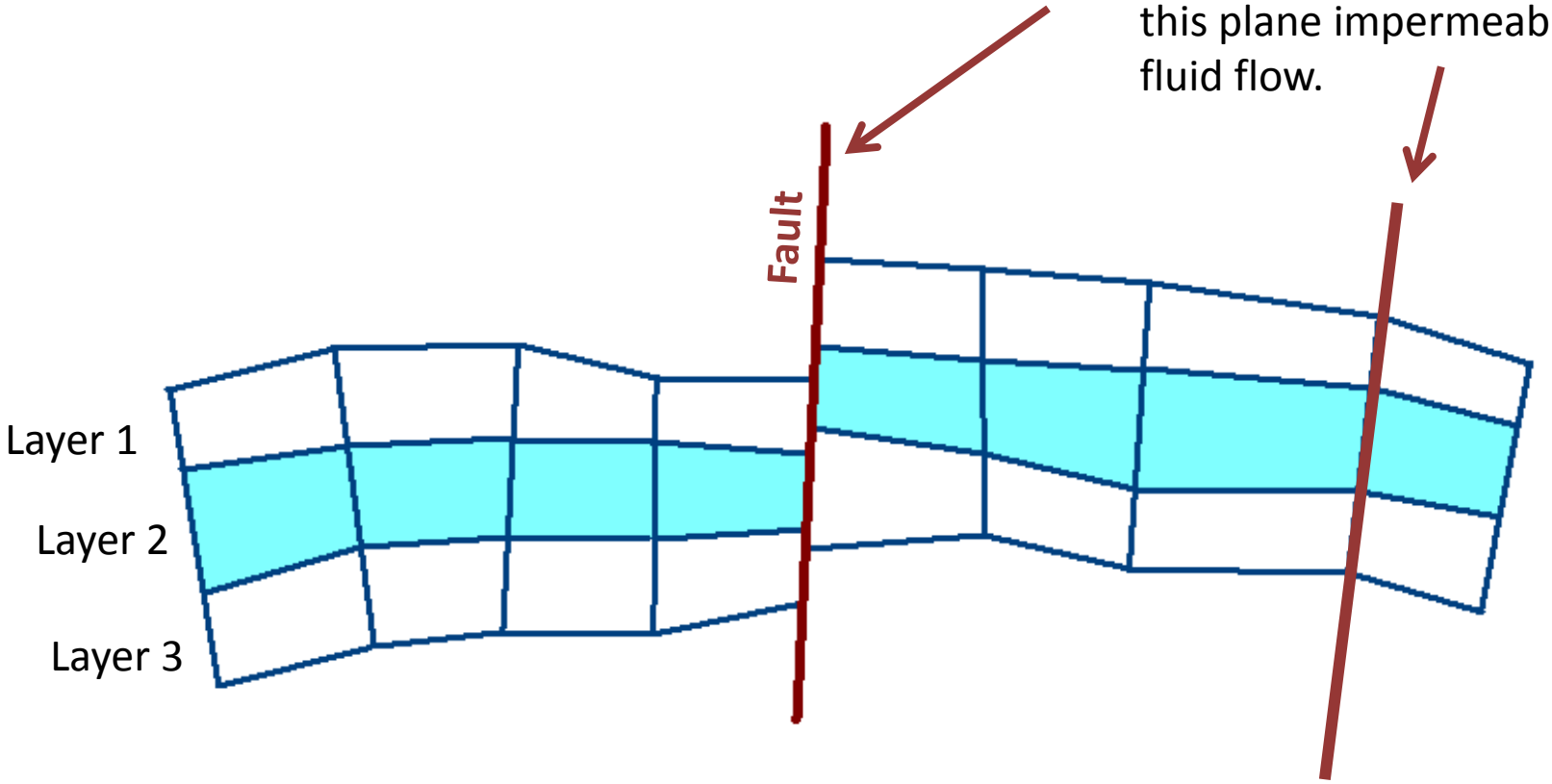
RUN-file (scenario 8; GASSTORE)

1. Open RUN-file in text editor
2. Run the simulation
3. Open LOG-file to see results

Faults

Faults

Using the Faults option you can reduce permeability (transmissibility) across the fault plane, or you can make this plane impermeable for fluid flow.



Cross-section view

FAULTS keyword

The fault faces are introduced using the FAULTS keyword.

FAULTS syntax

```
-- within MAKE-ENDMAKE brackets

FAULTS
   name1 imin1 imax1 jmin1 jmax1 kmin1 kmax1 face1 /
   name2 imin2 imax2 jmin2 jmax2 kmin2 kmax2 face2 /
   name3 imin3 imax3 jmin3 jmax3 kmin3 kmax3 face3 /
   ...
/

================================================================================

   name#       - a character ID of the fault;
   imin#-imax# - the boundaries of the input box along i-indexation axis.
                 By default these values are equal to '1' and the 2nd
                 argument of the keyword MAKE, respectively;
   jmin#-jmax# - the boundaries of the input box along j-indexation axis.
                 By default these values are equal to '1' and the 3rd
                 argument of the keyword MAKE, respectively;
   kmin#-kmax# - the boundaries of the input box along k-indexation axis.
                 By default these values are equal to '1' and the 4th
                 argument of the keyword MAKE, respectively;
   face#       - falut face tag. Must be one of
                 'I-','X-' - fault face coincides with the grid block fac
                             the negative direction of the i-index coordinate
                             line;
```

See full description in the Reference manual

MULTFLT keyword

The transmissibility multipliers across the fault are introduced using the MULTFLT keyword.

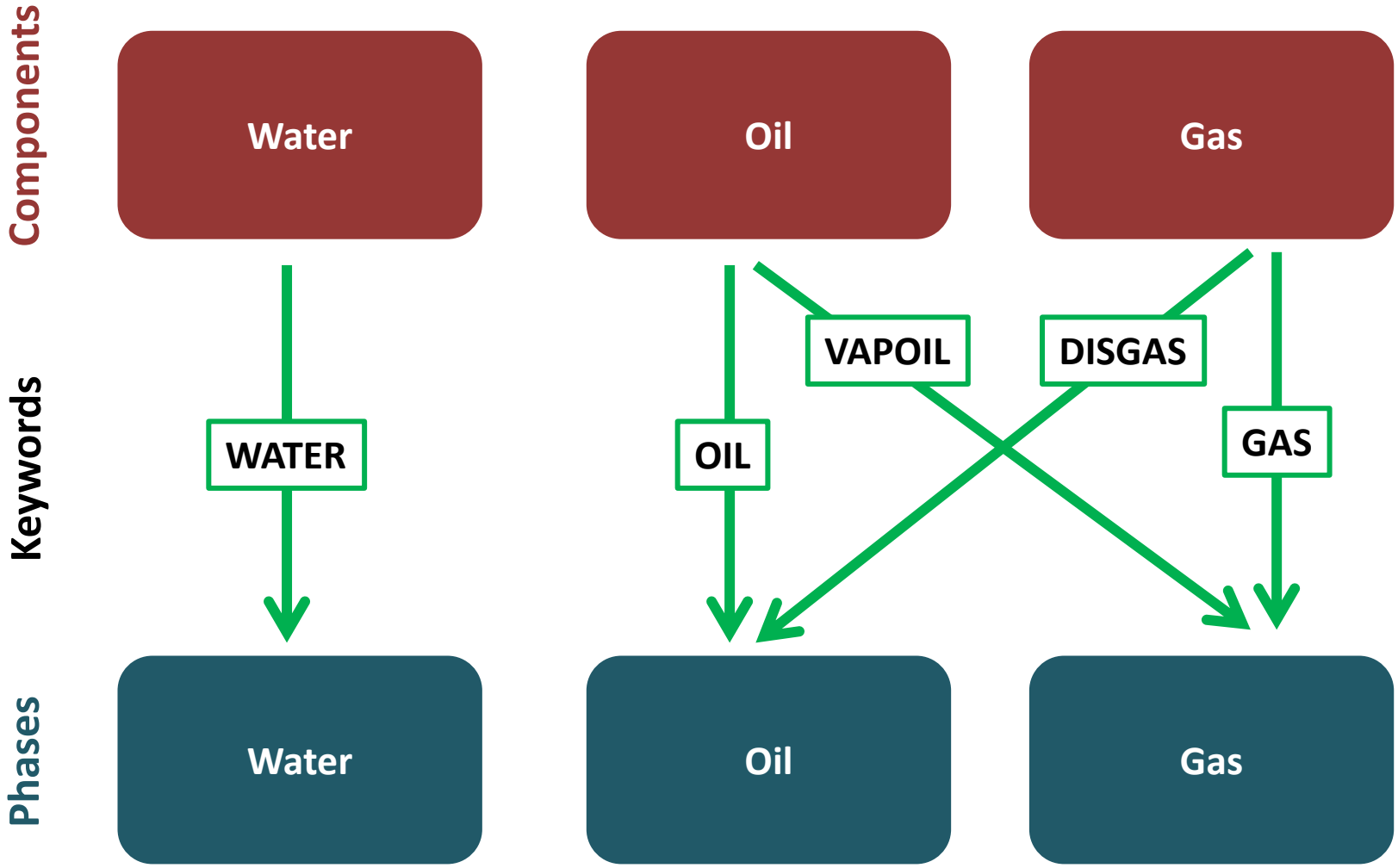
MULTFLT syntax

```
-- within MAKE-ENDMAKE brackets

MULTFLT
  name1  mult1 /
  name2  mult2 /
  name3  mult3 /
  ...
/

================================================================================

    name# - character ID of the fault;
    mult# - transmissibility multiplier across the fault.
```

BLACKOIL module

EOS module BLACKOIL

T=const



Options vs. EOS modules

	SIMPLMOD	T2EOS1	BINMIXT	BLACKOIL	GASSTORE
CAPPRES	Yes	No	No	Yes	Yes
HCROCK	Yes	Yes	Yes	No	Yes
HCFLUID	No	Yes	No	No	No
ISOTHERM	Yes	Yes	No	No	Yes
ADDPHASE	Yes	Not tested	Yes	Not tested	Not tested
EQL-ENDEQL (initial equilibration)	No	No	No	Yes	Yes
EOSNUM regions	Yes	No	No	Yes	No

Mathematical model

$$\frac{\partial}{\partial t}\left(\phi \sum_{i=w,o,g} \rho_i c_{i(j)} s_i\right) + \mathrm{div}\left(\sum_{i=w,o,g} \rho_i c_{i(j)} \mathbf{w}_i\right) = 0, \quad j = w,o,g$$

$$\mathbf{w}_i = -K \frac{K_{ri}}{\mu_i} \, \mathbf{grad} P_i - \rho_i \mathbf{g} \ , \quad i = w,o,g$$

$$K_{rw} = K_{rw}(s_w), \quad K_{ro} = K_{ro}(s_w, s_g), \quad K_{rg} = K_{rg}(s_g)$$

$$P_g - P_o = P_{c,go}(s_g), \quad P_o - P_w = P_{c,ow}(s_w)$$

$$c_{w(o)} \equiv 0, \quad c_{w(g)} \equiv 0$$

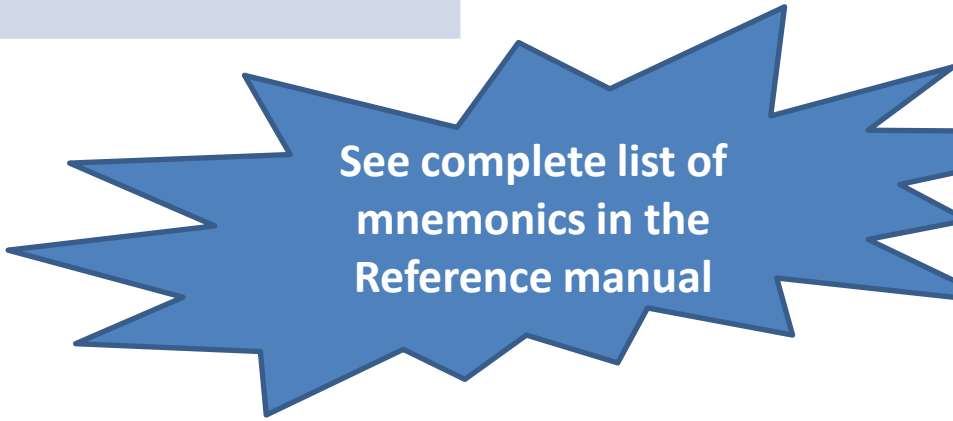
$$\mathrm{WATER} \Rightarrow s_w \neq 0; \quad \mathrm{OIL} \Rightarrow s_o \neq 0; \quad \mathrm{GAS} \Rightarrow s_g \neq 0;$$

$$\mathrm{DISGAS} \Rightarrow c_{o(g)} \neq 0; \quad \mathrm{VAPOIL} \Rightarrow c_{g(o)} \neq 0.$$

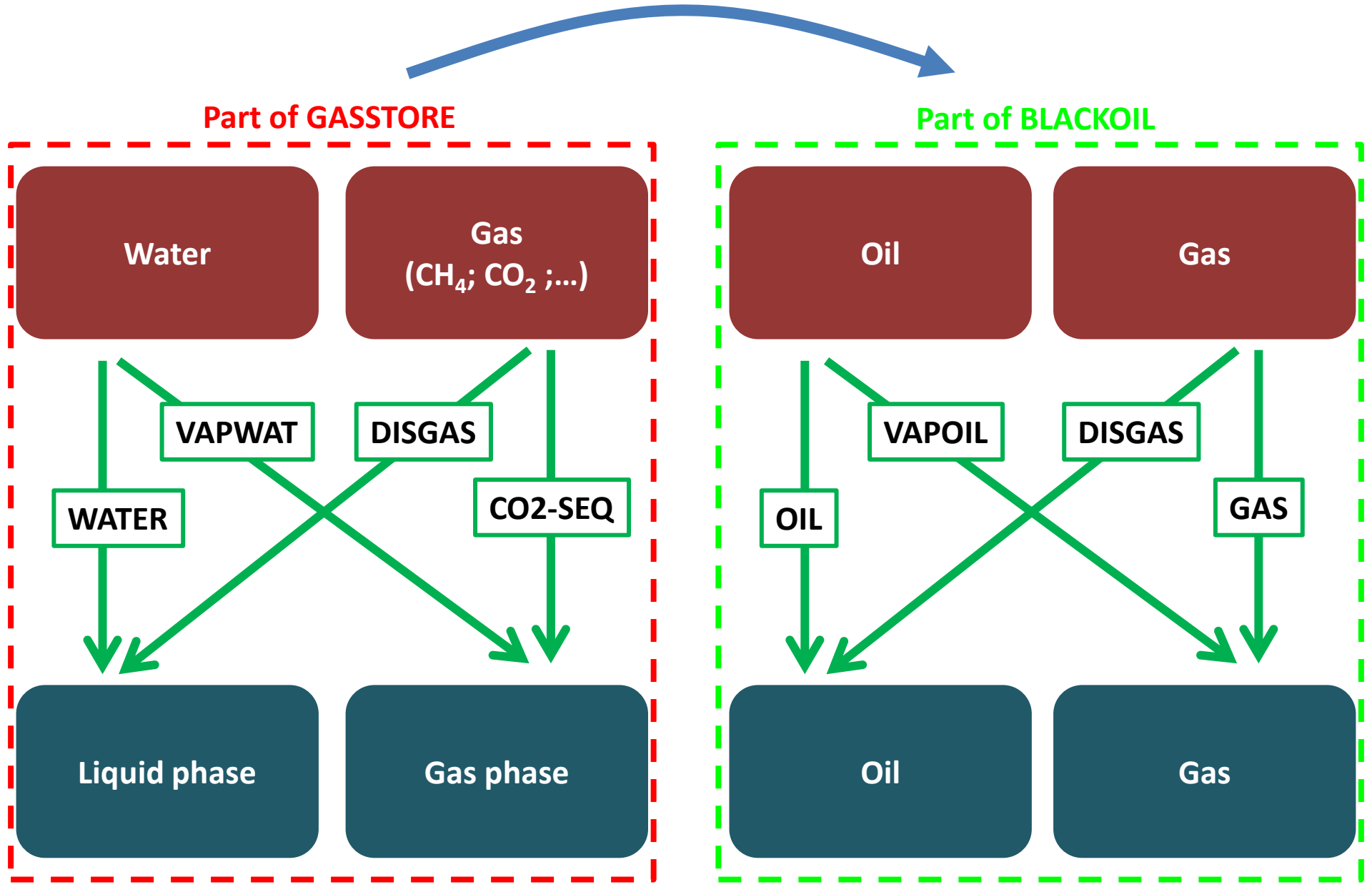
+ equations of state

Mnemonics (BLACKOIL)

Mnemonic	Description
SGAS	Saturation of gas phase
SOIL	Saturation of oil phase
SWAT	Saturation of water phase
RS	Gas-oil ratio
RV	Oil-gas pressure
PBUB	Bubble pressure
PDEW	Dew pressure



Exporting
GASSTORE to BLACKOIL


Part of GASSTORE
Water
Gas
(CH_4; CO_2 ;…)
VAPWAT
DISGAS
WATER
CO2-SEQ
Liquid phase
Gas phase
Part of BLACKOIL
Oil
Gas
VAPOIL
DISGAS
OIL
GAS
Oil
Gas

GASSTORE to BLACKOIL

GASSTORE option	BLACKOIL option
OIL	WATER
GAS	CO2-SEQ; CH4;…
DISGAS	DISGAS
VAPOIL	VAPWAT

GSTOBO keyword

GSTOBO syntax

```
-- in PROPS section

GSTOBO
  filename temp xsm smol presst tempst dliqst dgasst opt /
  pres1 pres2 pres3 pres4 ... /

================================================================================

  filename - name of the output file;
  temp     - reservoir temperature (degree Kelvin);
  xsm      - salt mass fraction;
  smol     - molality (mol/kg). This item is used if xsm is not specified;
  presst   - pressure at surface (stock tank) conditions (default 1 atm);
  tempst   - temperature at surface (stock tank) conditions (degree Kelvin)
             (default 293.15 K);
  dliqst   - liquid phase density at surface (stock tank) conditions. If not
             specified by user then dliqst is calculated at presst and
             tempst;
```

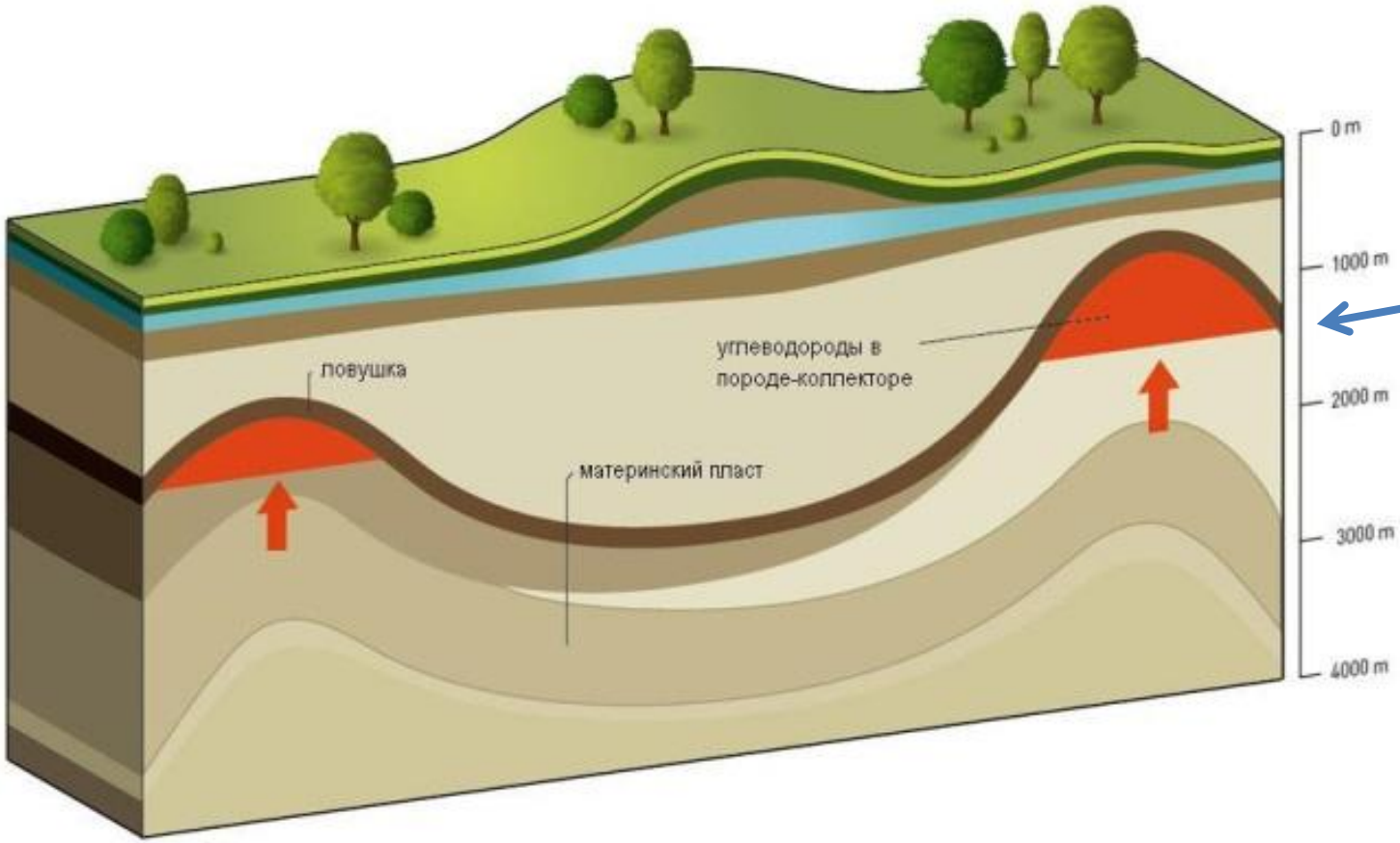
Scenario 8; exercise

Export black oil PVT tables for modelling Scenario 8 with the BLACKOIL module with options OIL, GAS and DISGAS (not VAPOIL); Resimulate scenario 8 using BLACKOIL module

RUN-file (scenario 8; BLACKOIL)

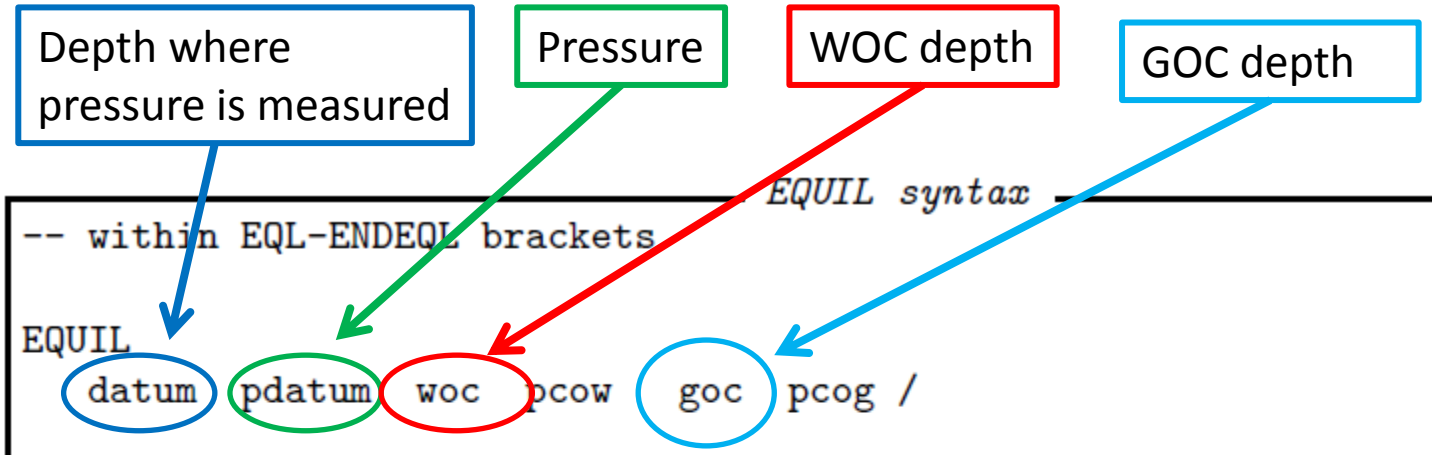
1. Open RUN-file in text editor
2. Run the simulation
3. Open LOG-file to see results

Water-oil contact



Water-oil contact depth (WOC)

Keyword EQUIL



EQUIL syntax

```
-- within EQL-ENDEQL brackets

EQUIL
   datum  pdatum  woc   pcow   goc   pcog /

=============================================================================

      datum     - datum depth;
      pdatum    - pressure at the datum depth;
      woc       - water-oil contact depth;
      pcow      - capillary pressure at water-oil contact;
      goc       - gas-oil contact depth;
      pcog      - capillary pressure at gas-oil contact.
```

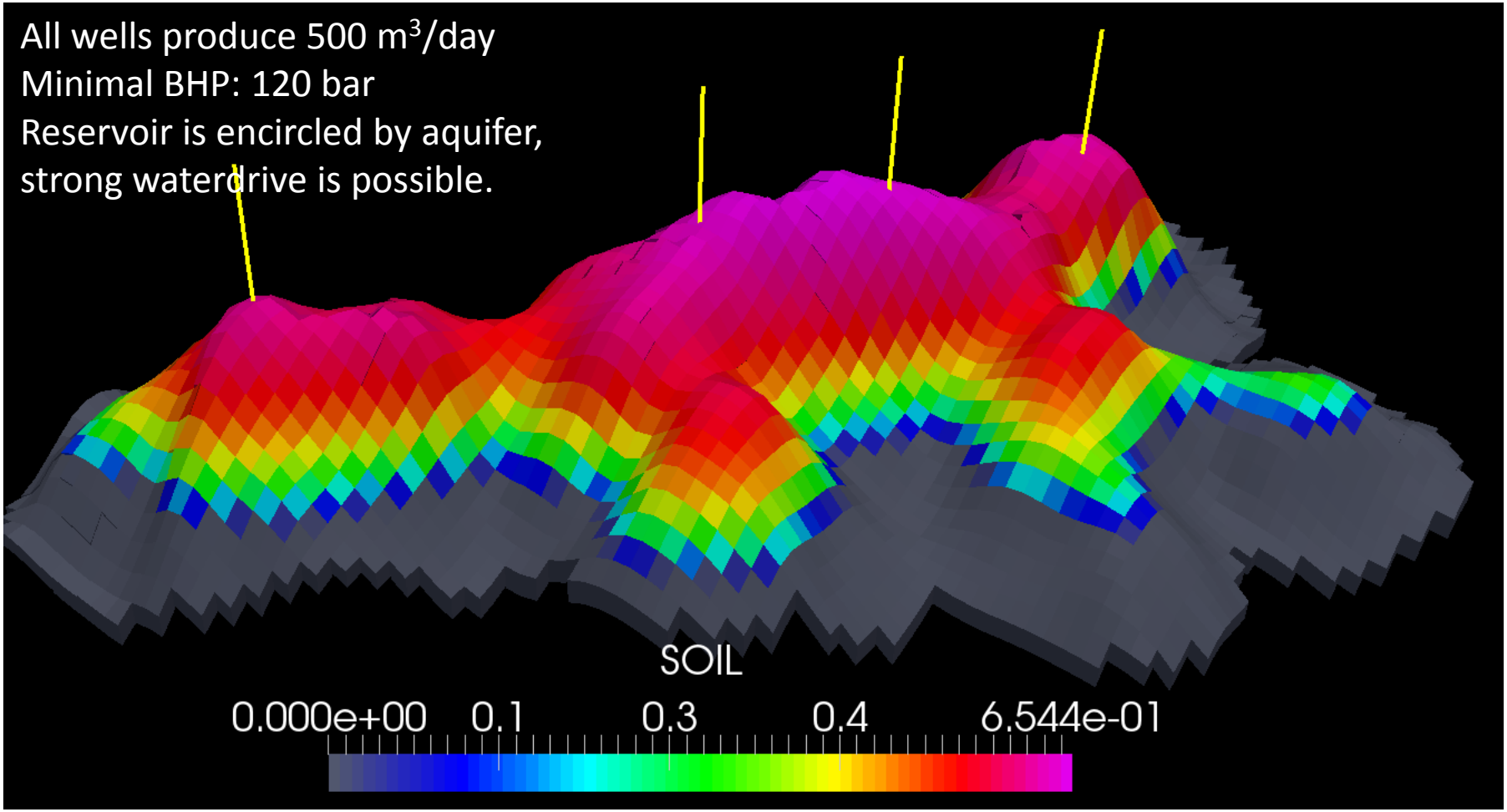
RUN-file (scenario 8; BLACKOIL2)

1. Open RUN-file in text editor
2. Run the simulation
3. Open LOG-file to see results

Scenario 9

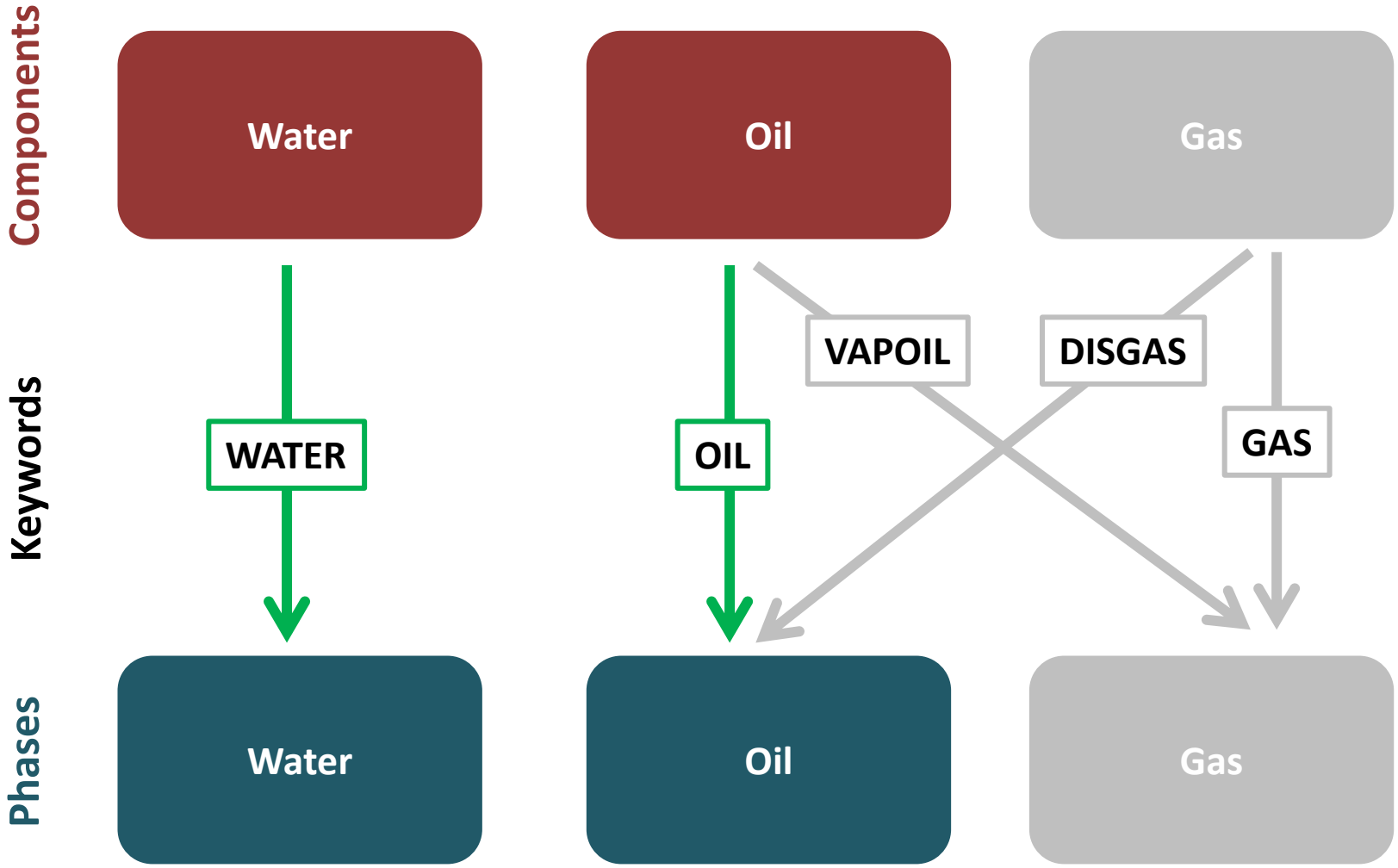
Scenario 9

Water-oil contact is at the depth 2310 m, pressure 230 bar.



EOS module BLACKOIL

T=const



RUN-file (scenario 9)

1. Open RUN-file in text editor
2. Run the simulation
3. Open LOG-file to see results

WELLSTOP keyword

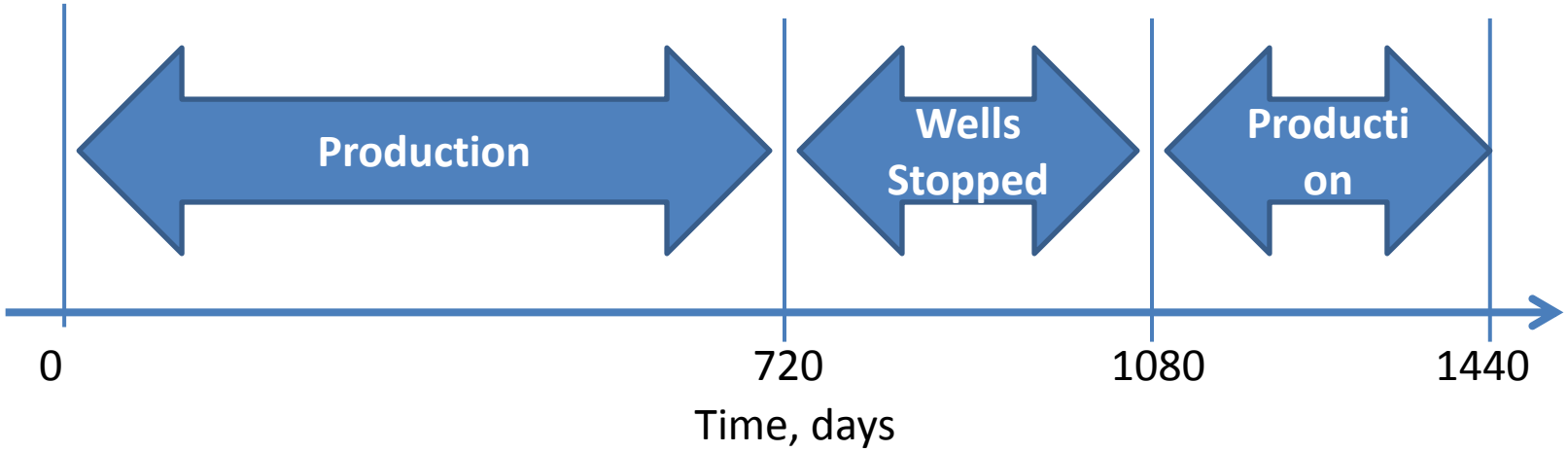
Stops a well

WELLSTOP syntax

```
-- in SCHEDULE section

WELLSTOP
   name1 /
   name2 /
   name3 /
   ...
/

================================================================================

   name#  - well name or well name template.
```

Scenario 9 (exercise 1)

Resimulate scenario 9 with the following schedule



Scenario 9 (exercise 1)

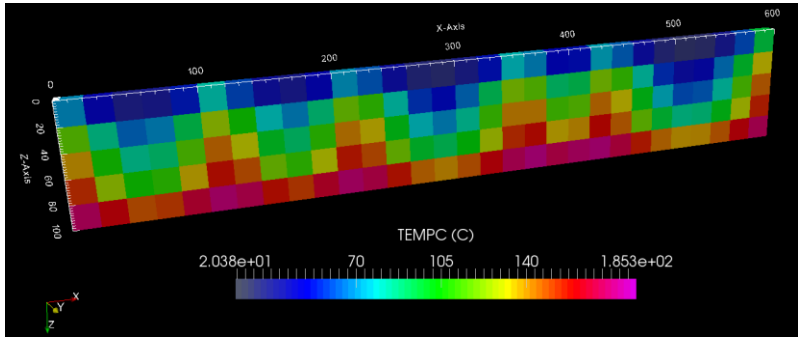
Resimulate scenario 9 modelling injection of water through two injection wells. Injection starts at 720 days. Simulate until 1080 days.

Параметры скважин:

INJE1: I=30, J=27, k=2-5, Q=500 m^3/day, P_{max}=260 bar

INJE2: I=20, J=47, k=2-5, Q=500 m^3/day, P_{max}=260 bar

Next day



- BINMIXT module
- Local grid refinements (LGRs)
- Boundary conditions at Earth surface (onshore/offshore)
- Crossflow