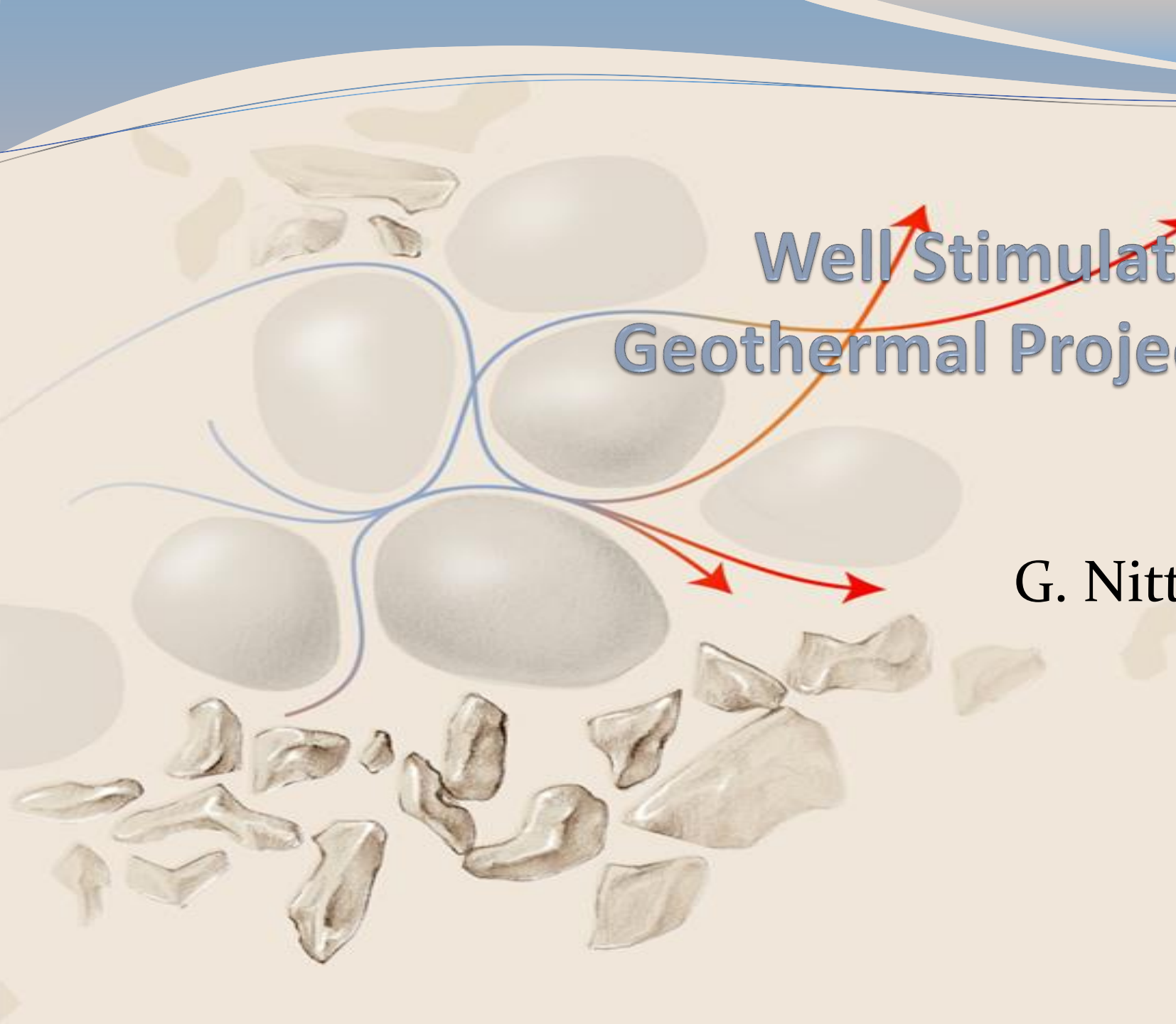

Well Stimulation Techniques for Geothermal Projects in Sedimentary Basins

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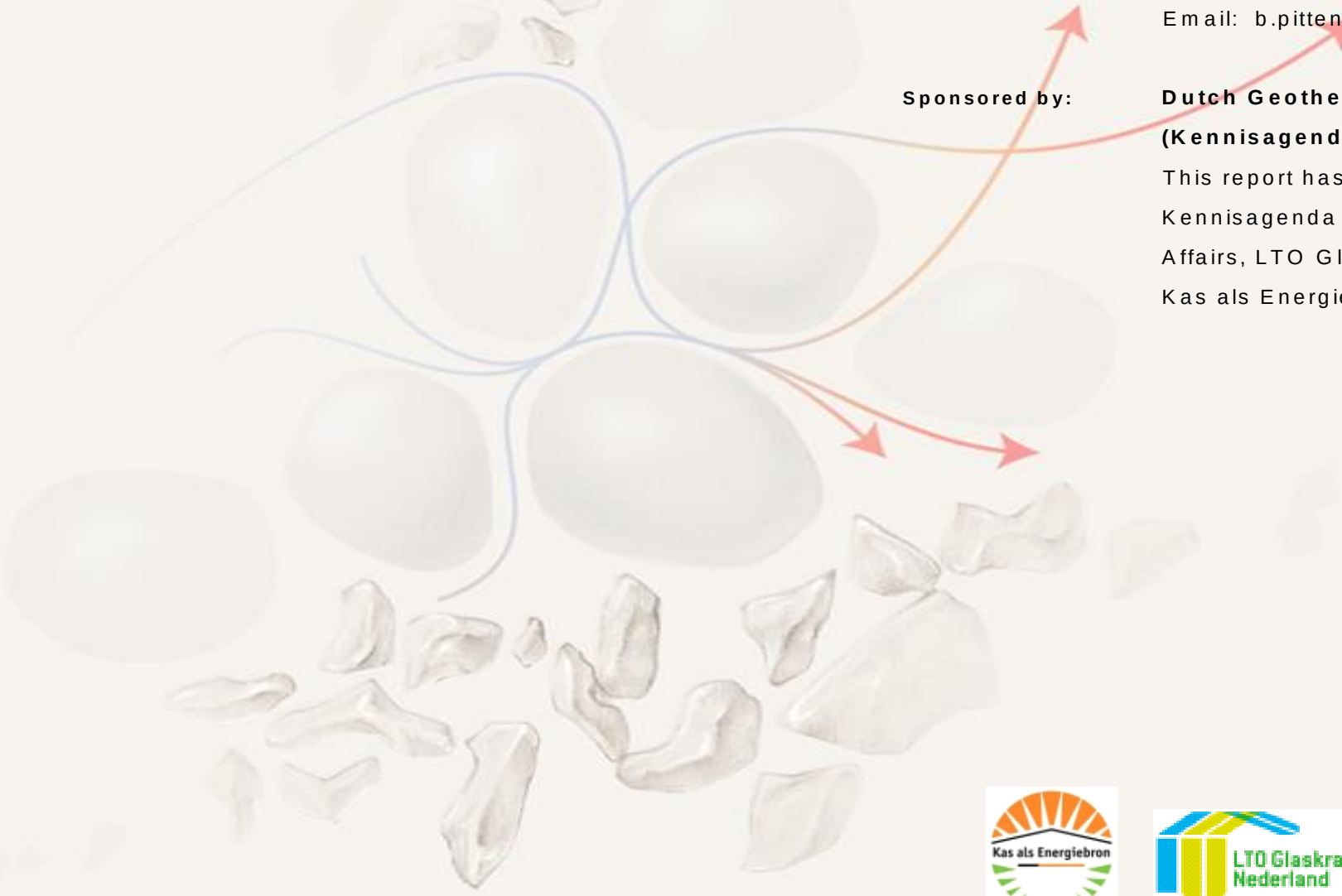

Kas als Energiebron

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Ministerie van Economische Zaken

if

WELL STIMULATION

- What is well stimulation?
  - Any activity that enhances productivity of a well by affecting the near well bore area
    - Matrix treatments – restore natural productivity
    - Hydraulic fracturing – enhance natural productivity
    - Acoustic methods – remove near wellbore damage
    - (Re)Perforation?

- What is it not?
  - Reservoir enhancement like steam drive or water flooding
  - Removal of scale, wax, etc. from the tubing

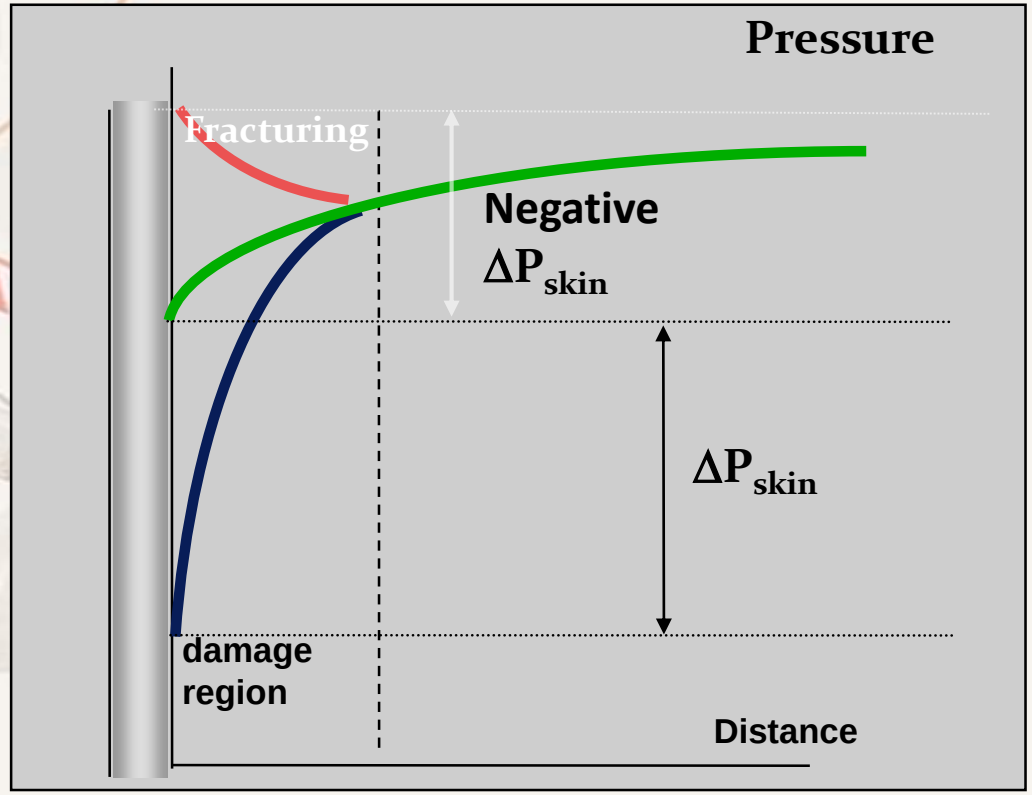
Determine skin factor

Skin is a dimensionless representation of near well-bore pressure drop caused by damage, plugging, etc..

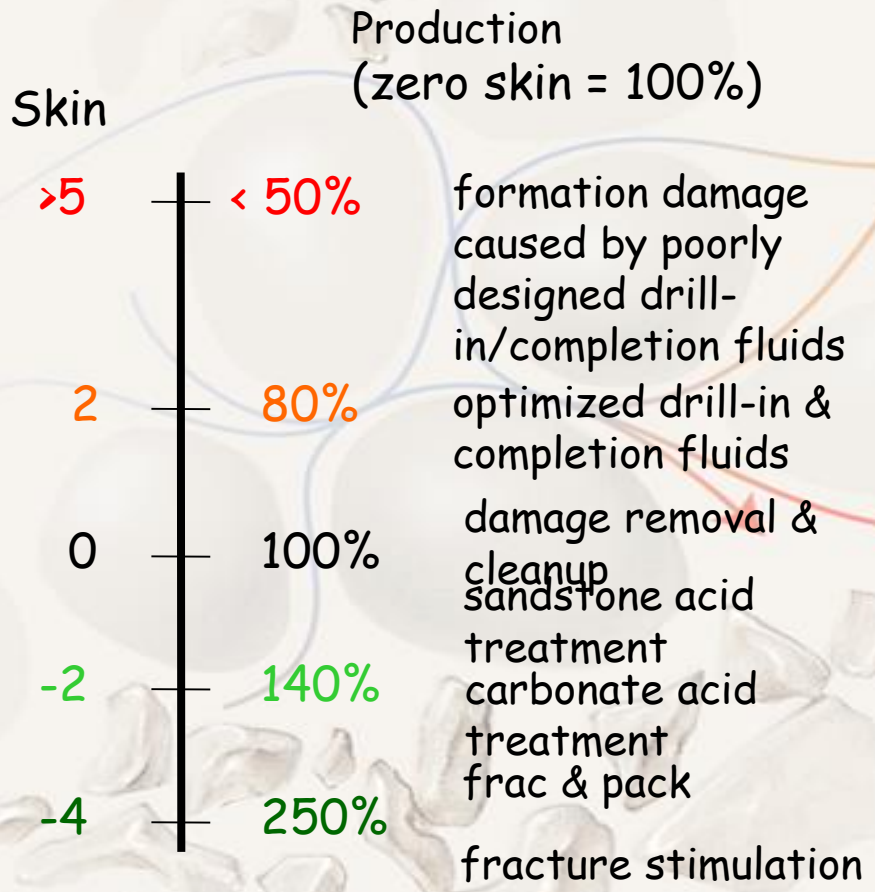
$$Q_o = \frac{2\pi k_o h\,(p_r - p_{wf})}{\mu_o B_o \ln\left(\frac{r_e}{r_w} - 0.75 + S\right)}$$

$$\Delta P_{skin} = \frac{Q \cdot \mu}{2\pi \cdot kh} \cdot S$$

Total skin S (and *kh*) can be measured in a welltest



Production & Skin: Semi-Steady State



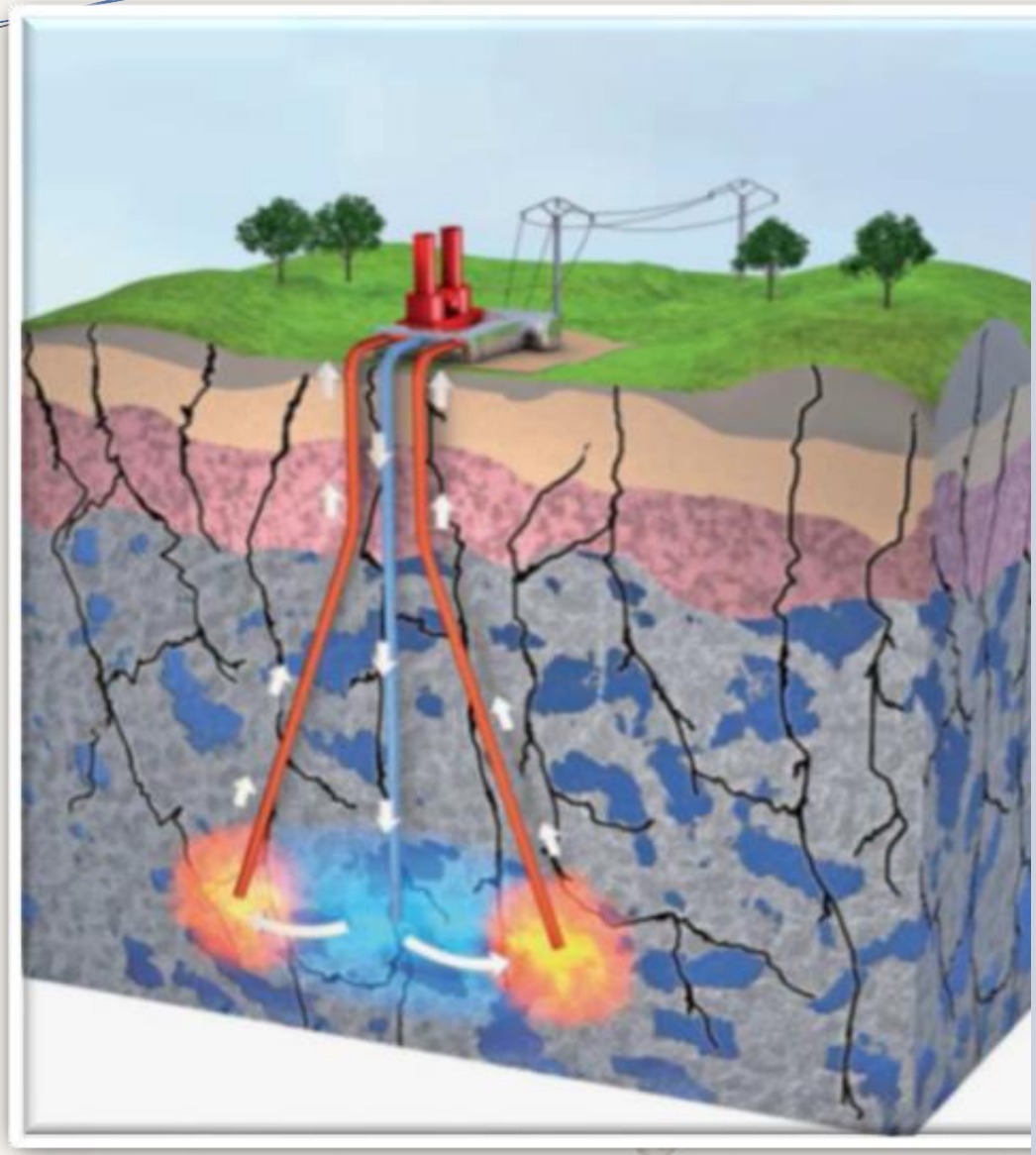
Flow Efficiency (FE or WIQI)

$$WIQI = \frac{Q_{damage}}{Q_0} = \frac{7}{7 + S_{damage}}$$

Production increase after treatment

$$PIF = \frac{7 + S_{before}}{7 + S_{after}}$$

Causes of Damage



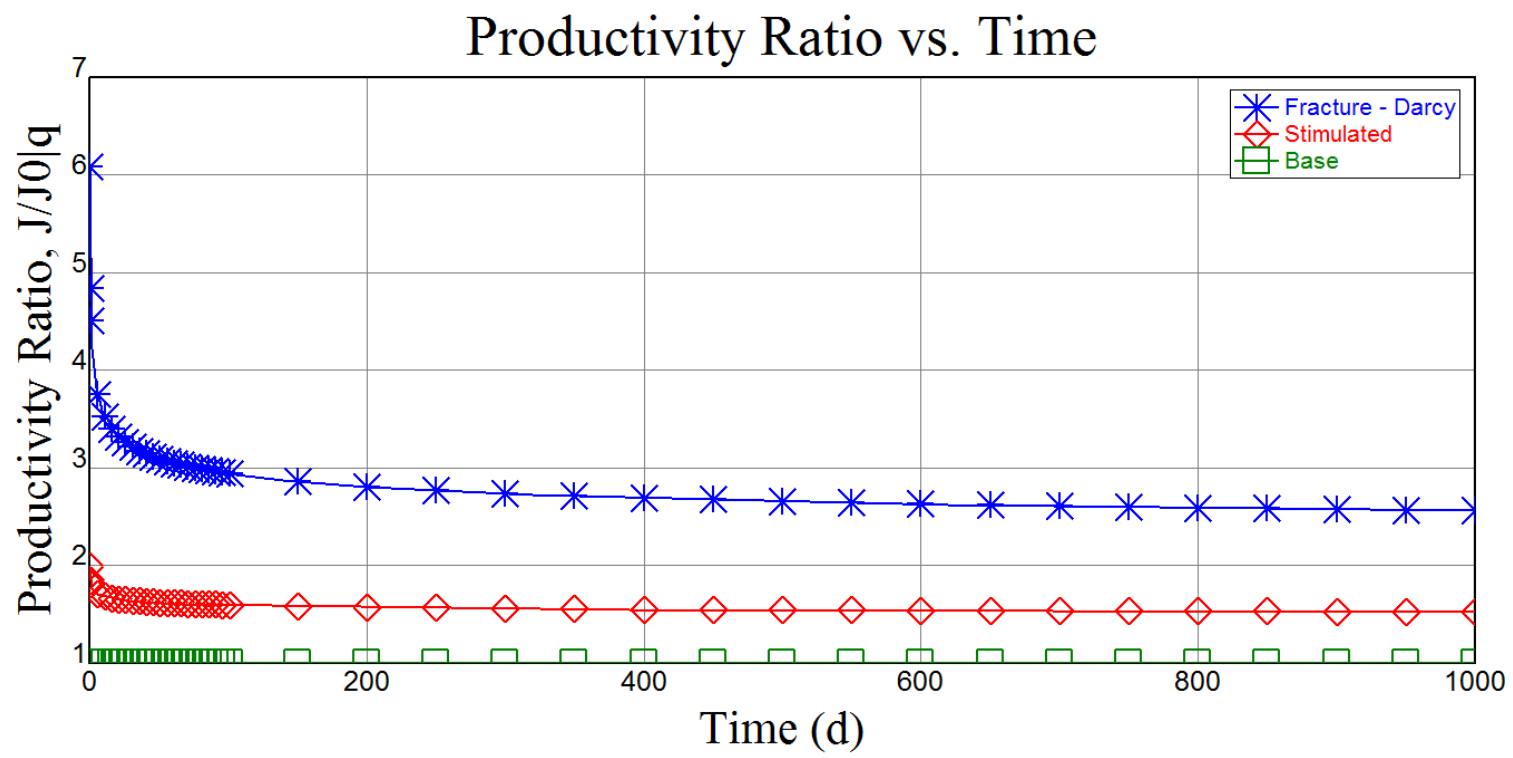
Damage in near borehole reservoir (injector and/or producer) or screen plugging

- Initial damage because of drilling mud or wrong treatment
- Initial damage because of wrong treatment
- Production of fines
- Injection of particles (corrosion, fines, wallskin, scaling particles)
- Scaling

Consequence

- increased drawdown in producer à more pump energy needed + less optimal ESP design (efficiency, depth)
- Increased injection pressure in injector à more pump energy needed + closer to max. injection criterium

Productivity improvement



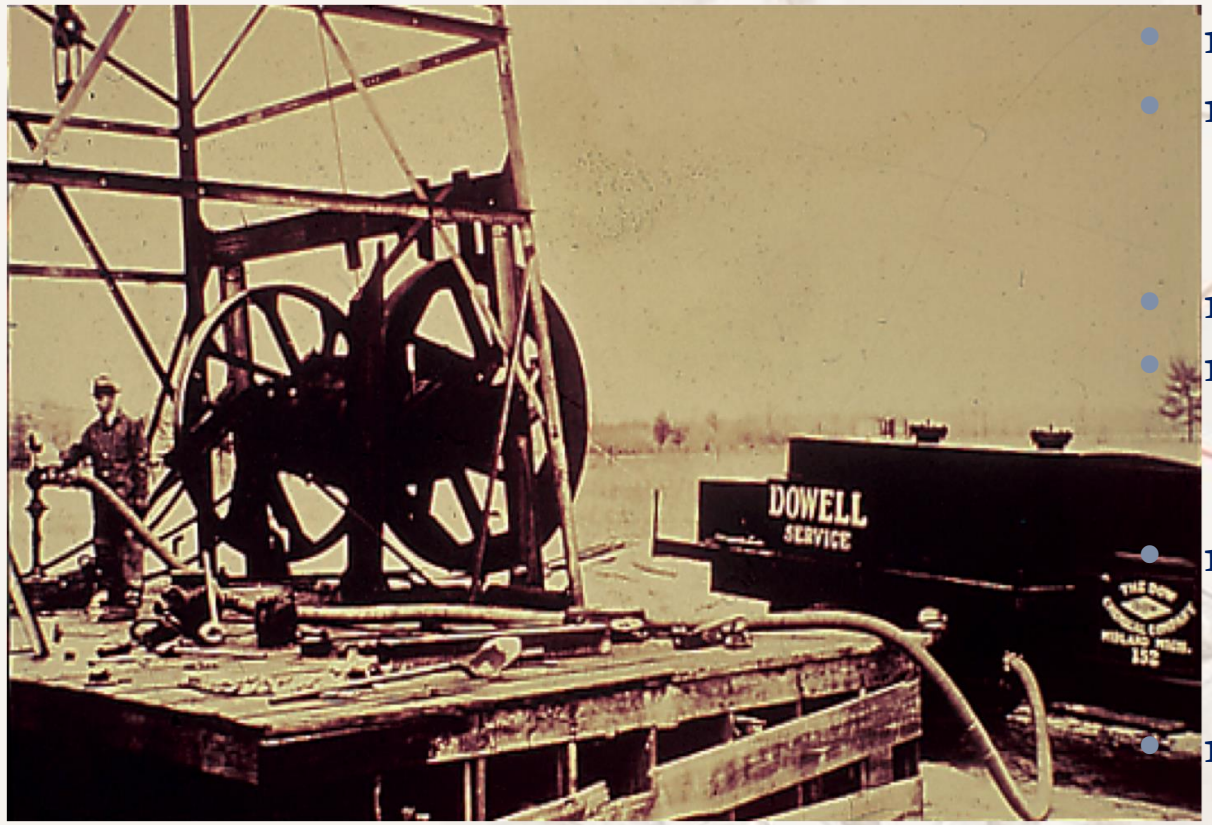
- For the injection well it means **higher injection rates** without **increasing the surface pressure**

Acidizing

- Removing near-borehole drilling mud damage
- Removing carbonates in near-borehole reservoir
- Removing scaling

History

Acidising treatments



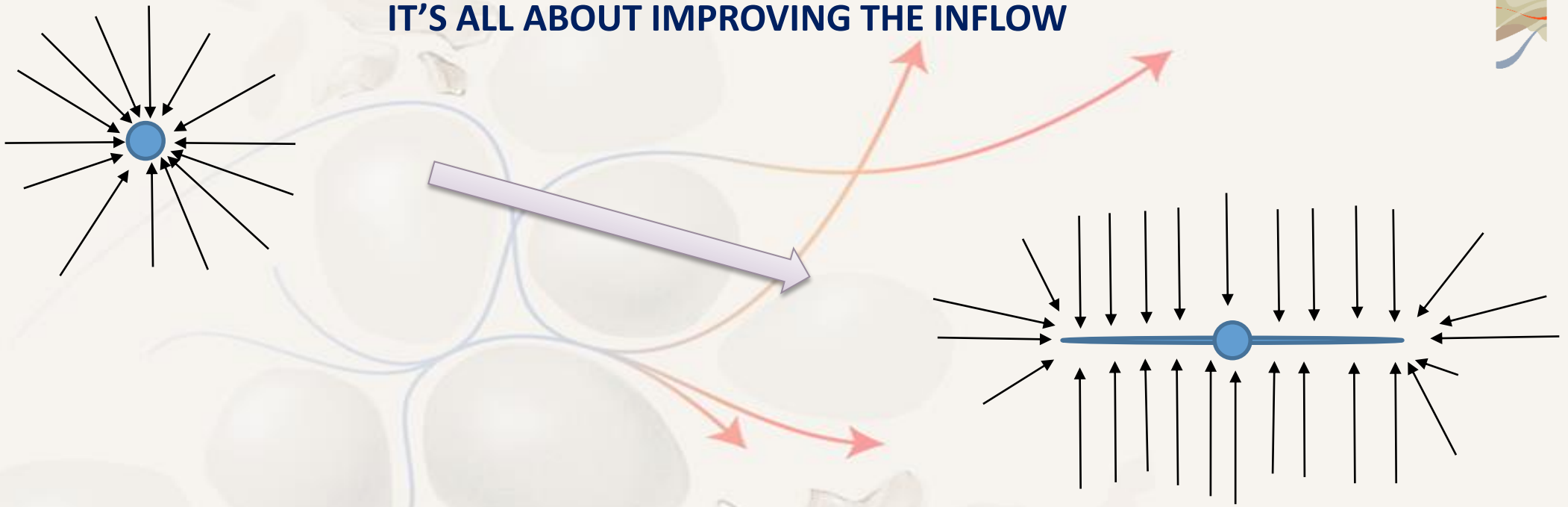
Acidizing in early days

- 1895 First acid job
  - Successful HCl treatments by the Ohio Oil company
  - Corrosion problems
- 1932 HCl with arsenic corrosion inhibitor
- 1933 first HF treatment in sandstone
  - disappointing due to formation plugging – precipitates
- 1940 First HF/HCl treatment
- 1950/60's Numerous treatments
  - Additives to combat shortcomings
  - Better theoretical understanding
- 1970's Alternative HF/HCl systems
  - Fluoboric acid
  - Self Generating mud acids, etc
- 1980's Diversion and placement techniques
  - Foams
  - Coiled tubing
- 1990's Computerised design and execution support

Acidizing 2000's

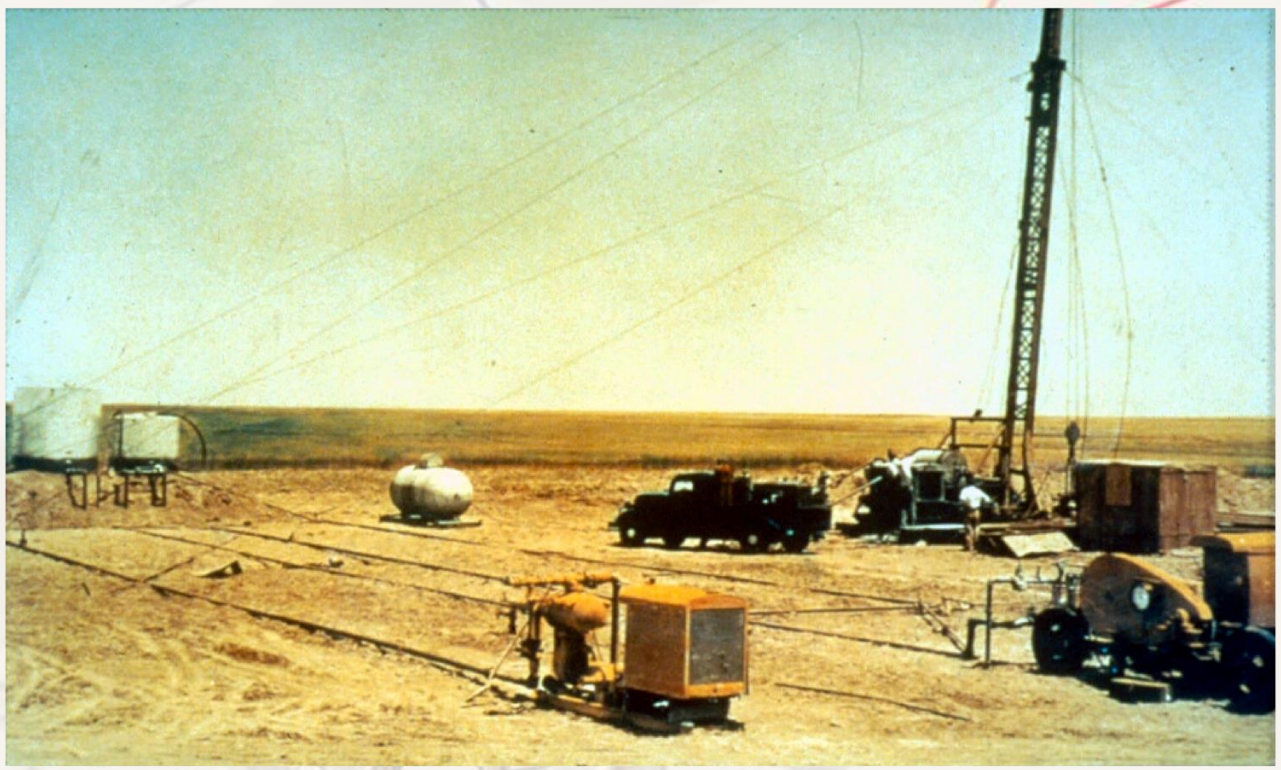
Hydraulic fracturing

IT'S ALL ABOUT IMPROVING THE INFLOW

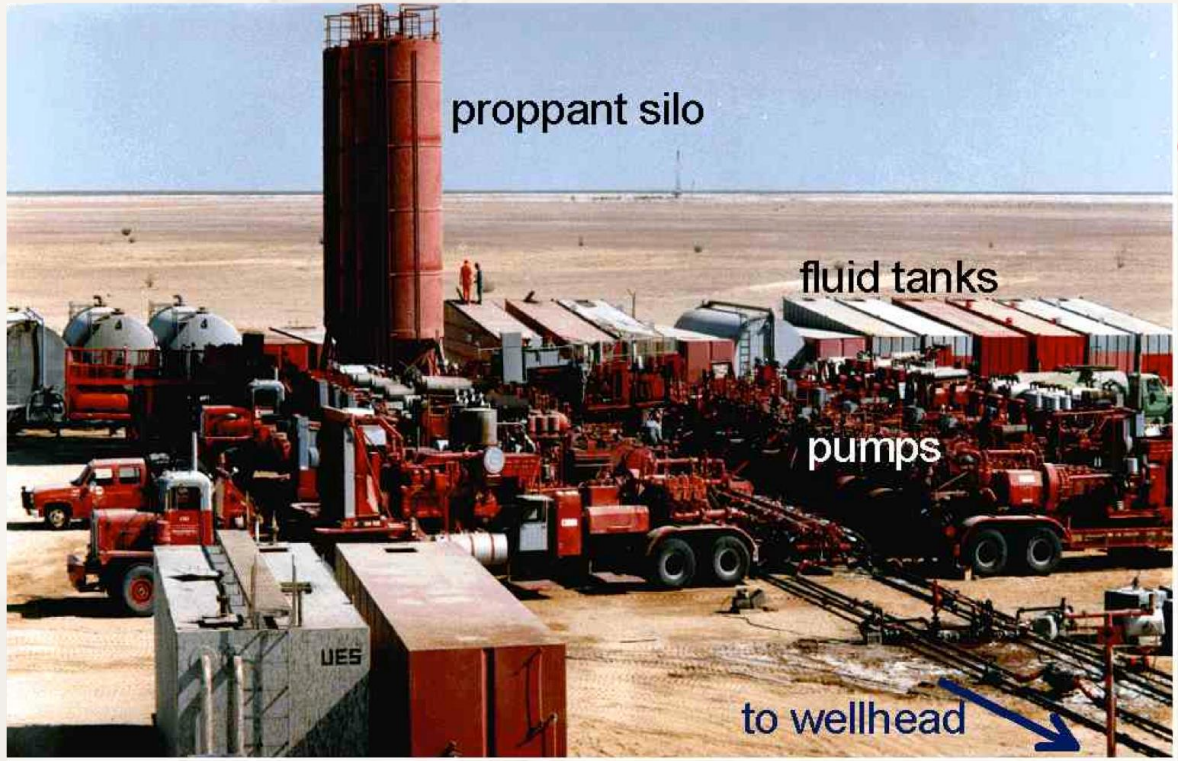


Optimum connection between reservoir and well

First Hydraulic Fracture Treatment - 1947



Nowadays



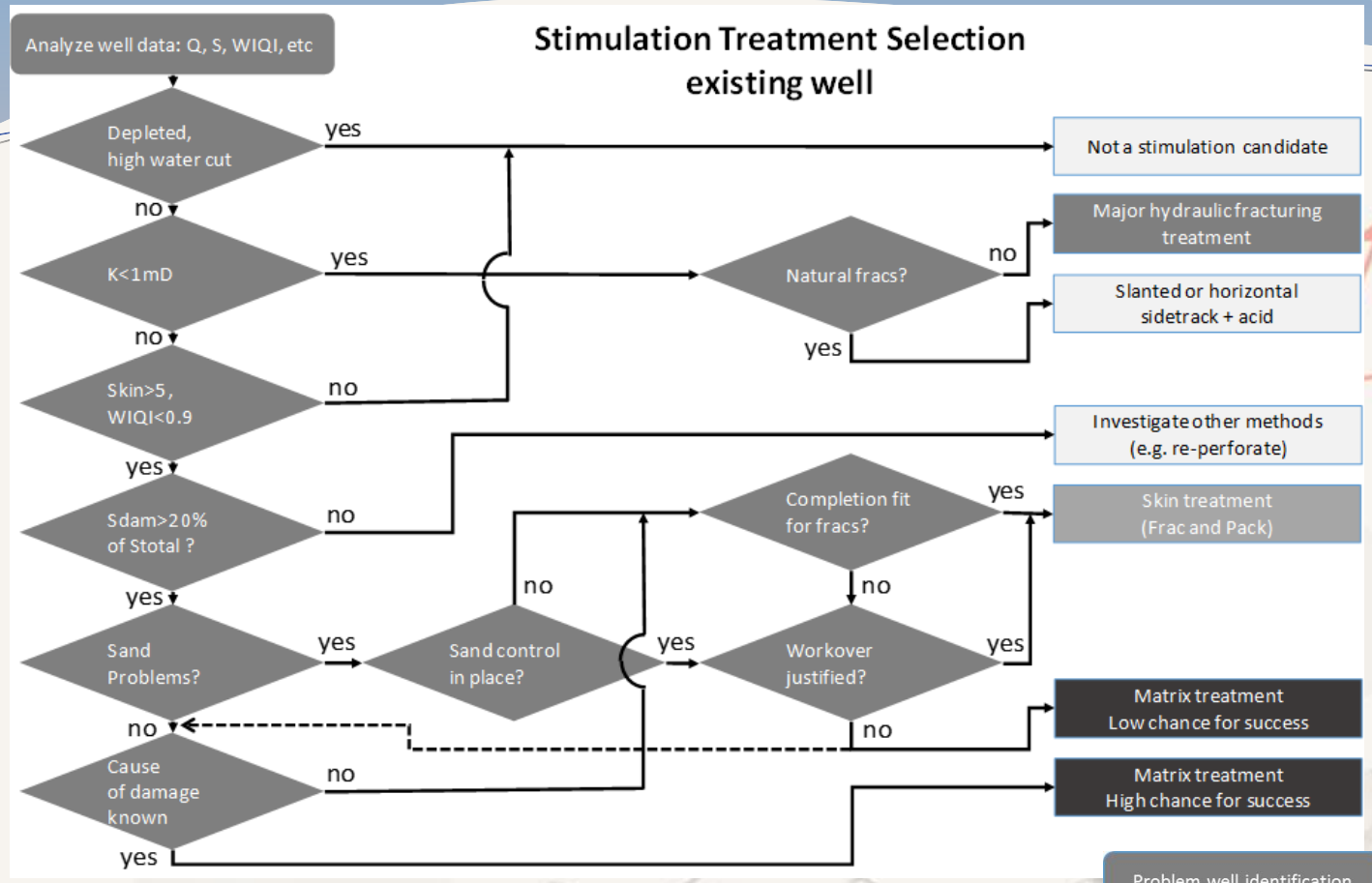
Type of Fracturing treatments

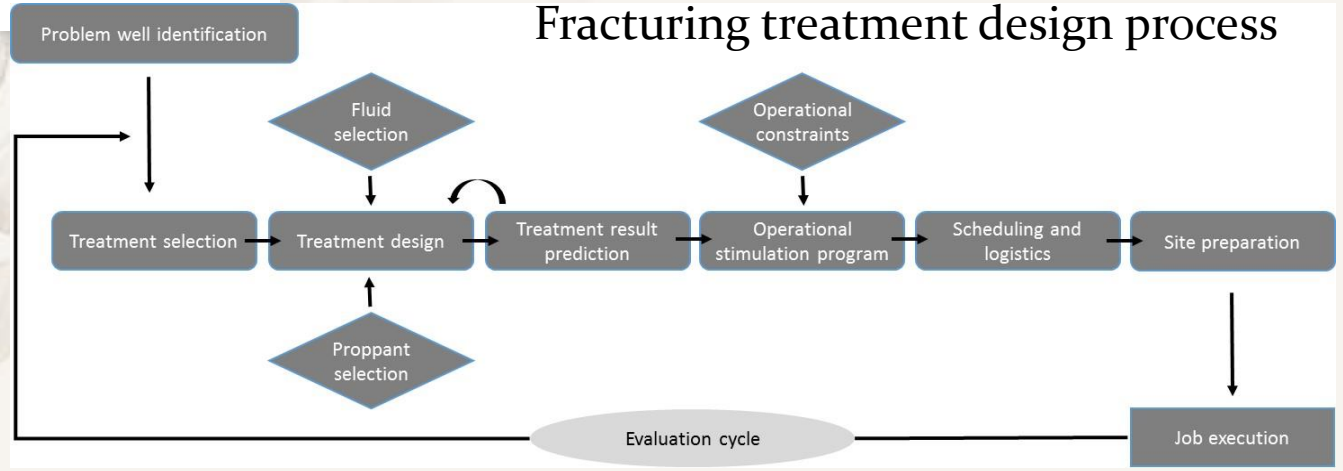
- **Skin Frac**
- **Frac & Pack**
- Massive Hydraulic Frac
- Multiple vertical fracs
- Multiple horizontal hole fracs
- Acid frac

Objectives for the booklet

- **Identify** methods to enhance and optimize the inflow performance
- **Select candidates** for stimulation treatments
- **Understand** the design and execution of stimulation treatments

Contents


Stimulation Treatment Selection
existing well
Analyze well data: Q, S, WIQI, etc
Depleted, high water cut
yes
Not a stimulation candidate
no
K<1mD
yes
Natural fracs?
no
Major hydraulic fracturing treatment
yes
Slanted or horizontal sidetrack + acid
no
Skin>5, WIQI<0.9
no
Investigate other methods (e.g. re-perforate)
yes
Sdam>20% of Stotal ?
no
Completion fit for fracs?
yes
Skin treatment (Frac and Pack)
yes
Sand Problems?
yes
Sand control in place?
yes
Workover justified?
yes
no
no
no
Matrix treatment Low chance for success
no
Cause of damage known
no
Matrix treatment High chance for success
yes


Fracturing treatment design process
Problem well identification
Fluid selection
Operational constraints
Treatment selection
Treatment design
Treatment result prediction
Operational stimulation program
Scheduling and logistics
Site preparation
Proppant selection
Evaluation cycle
Job execution

Differences between geothermal and oil & gas wells

- **Temperature**
- **Treatment fluid composition**
- **Reservoir fluid chemistry**
- **Flows**
- **Investment versus gains**
- **Specific set up with respect to well configuration**

Appendices

- Appendix I causes of formation damage and their cure
- Appendix II definitions of skin components
- Appendix III general fluid name cross reference list
- Appendix IV maximum injection rate for matrix treatments
- Appendix V Minifrac or Datafrac Procedure
- Appendix VI layout checklist
- Appendix VII health safety and environmental aspects
- Appendix VIII procedures and working plans needed for stimulation activities in NL

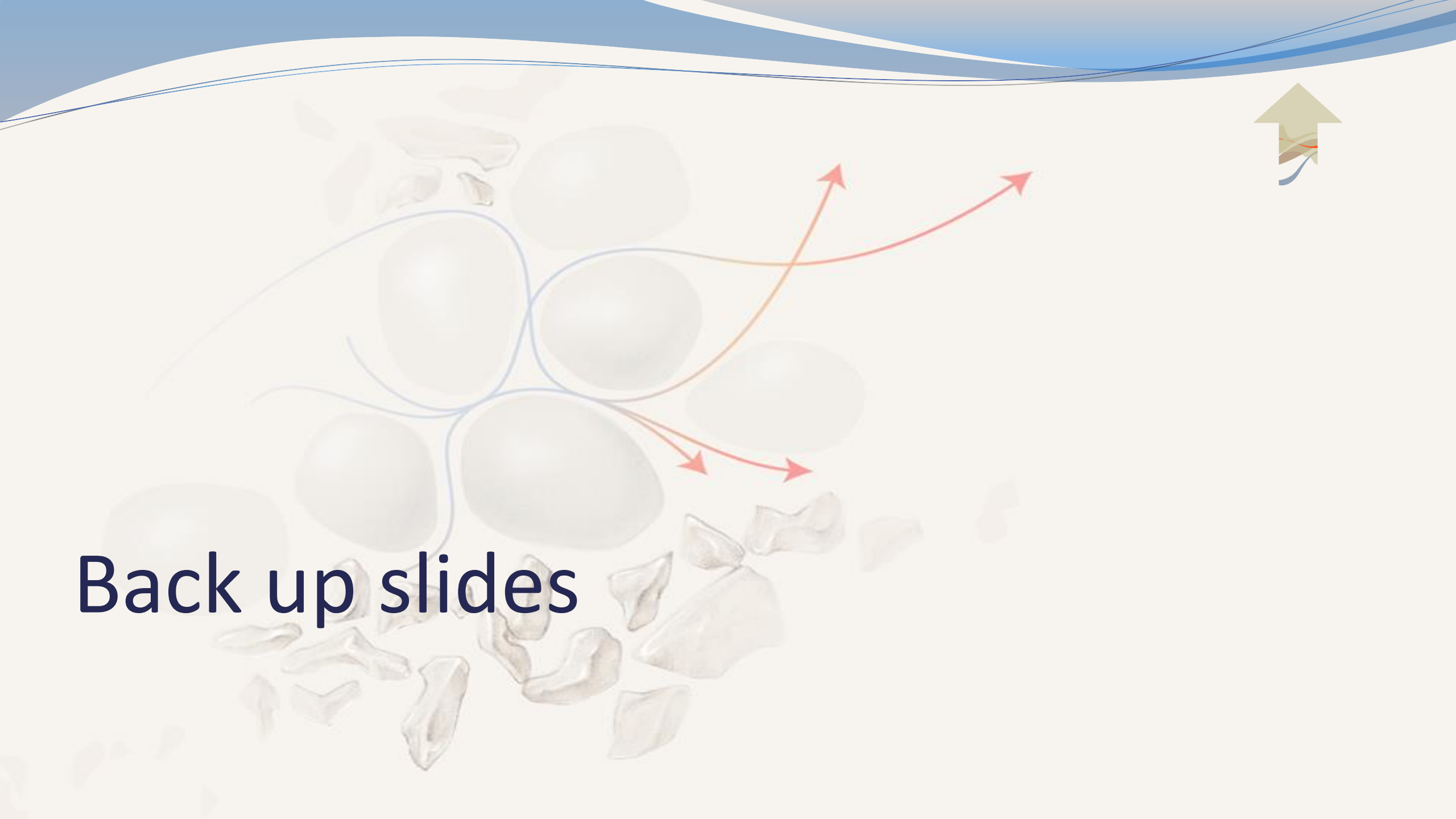
Scope of this technical overview

- Technical recommendations
  - matrix stimulation (acidizing)
  - hydraulic fracturing
  - acid fracturing
  - Some other stimulation techniques are described briefly
- Limitations of the guidelines
  - Stimulation of geothermal doublets in permeable reservoirs
  - Written for operators, consultancies and contractors in the geothermal industry
- The technical guidelines in this report are not to be used for:
  - A detailed stimulation treatment design or job execution program
  - Well design, well completion or drilling programs
  - Cost calculations/consideration: prices or costs are not included in these technical guidelines

Scope of this technical overview

- Other techniques
  - There are less commonly used techniques applicable in the geothermal industry. These techniques are described in less detail
- Legal aspects of stimulation
  - Not meant to be guidelines for legislative purposes
  - In most countries the authorities have issued documents dealing with the rules and regulations with respect to well stimulation, specifically fracturing.
  - In the Netherlands SodM (Staatstoezicht op de Mijnen) has recently issued an inventory of fracturing (including acid fracturing) in which the controlling role of SodM is explained.
  - In Germany fraccing permits are arranged by state authorities (Bergamts). The state Lower Saxony has issued several documents specifying the conditions under which fracturing might be allowed
  - In the UK the DOE (Department of Energy) is the controlling authority.
  - A summary of the Dutch regulations is given

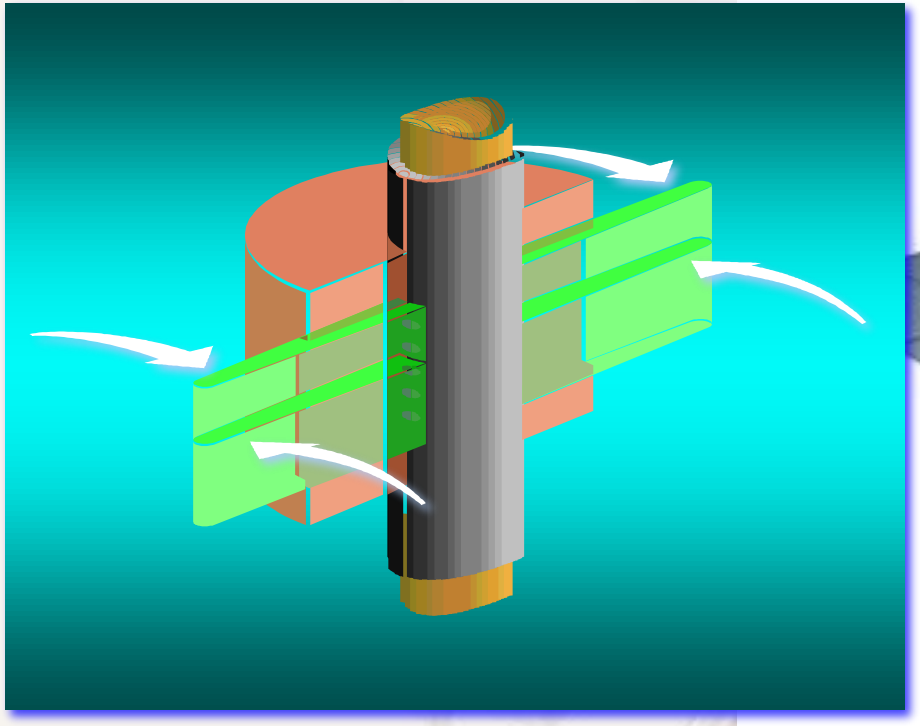
Dank U voor Uw aandacht

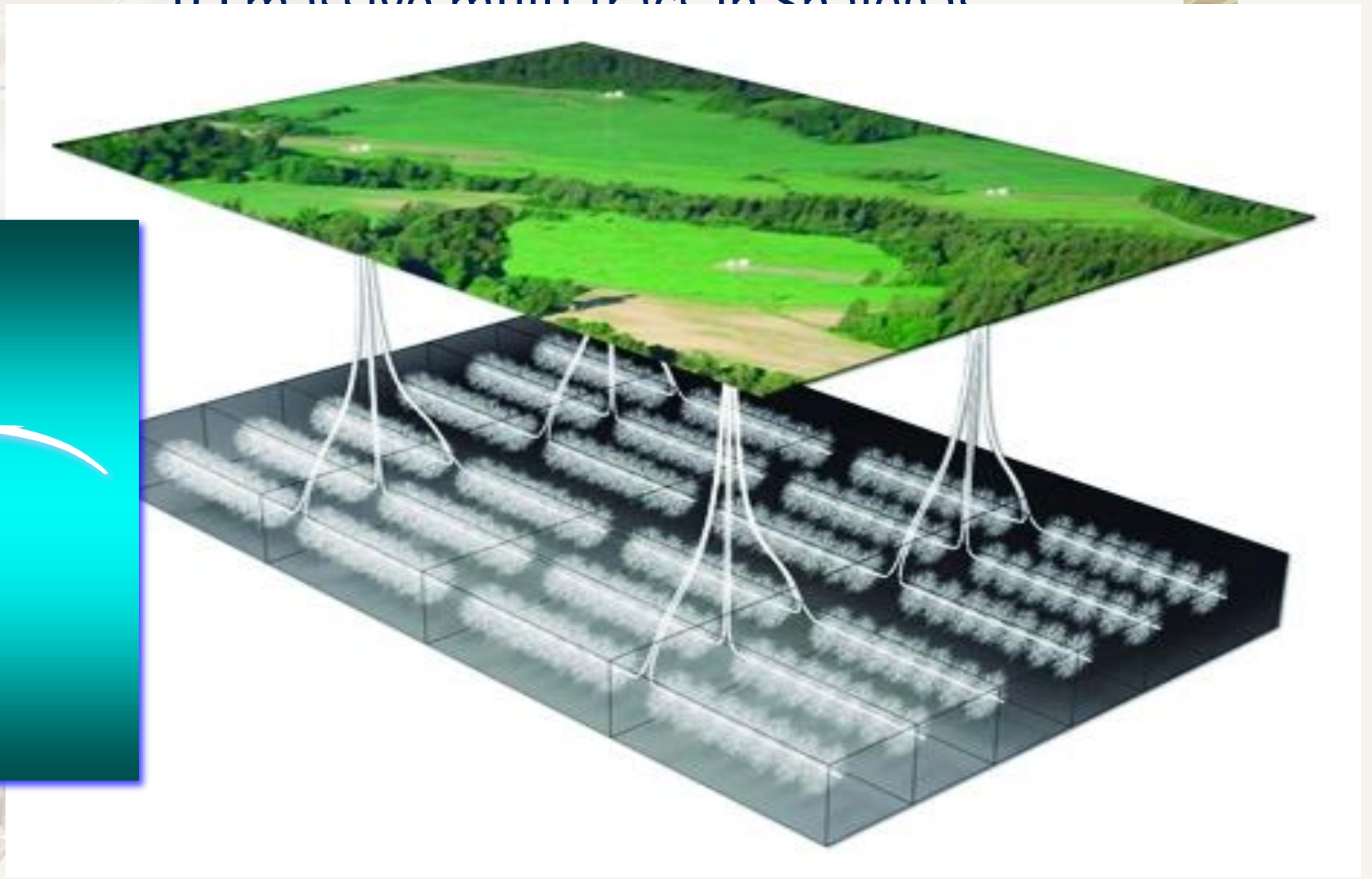


Back up slides

FROM SMALL FRAC & PACKS IN HIGH PERMEABILITY SANDSTONES

TO massive multi fracs in Shalegas

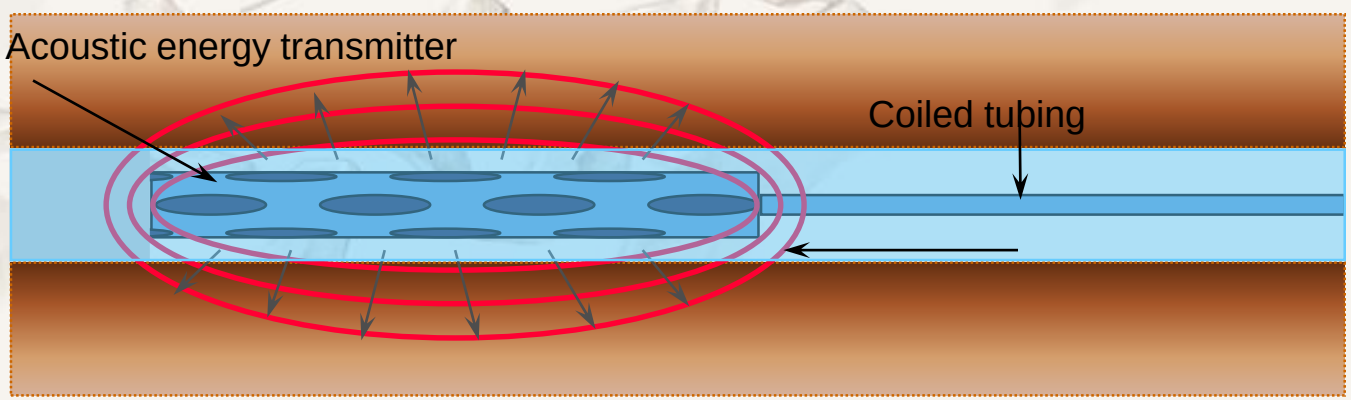




Acoustic well stimulation

- Damage removal
  - Fines in near wellbore
  - Drilling Filter-cake
  - (In)organic deposits
- Screen cleaning

Possible configuration

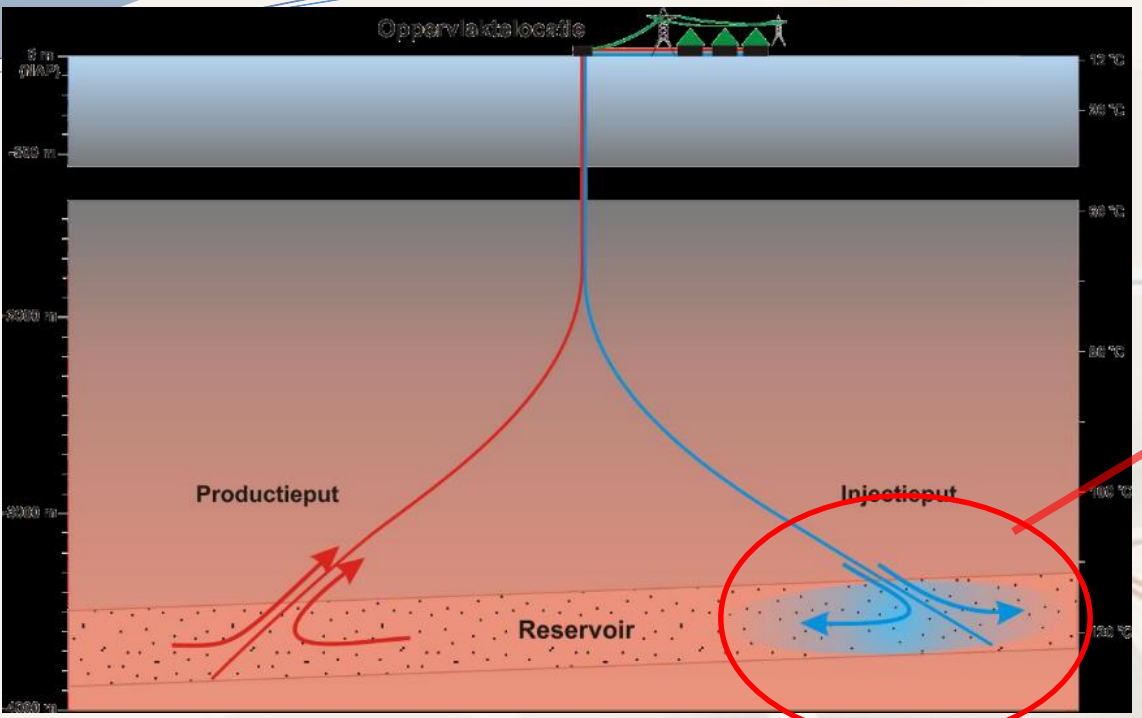


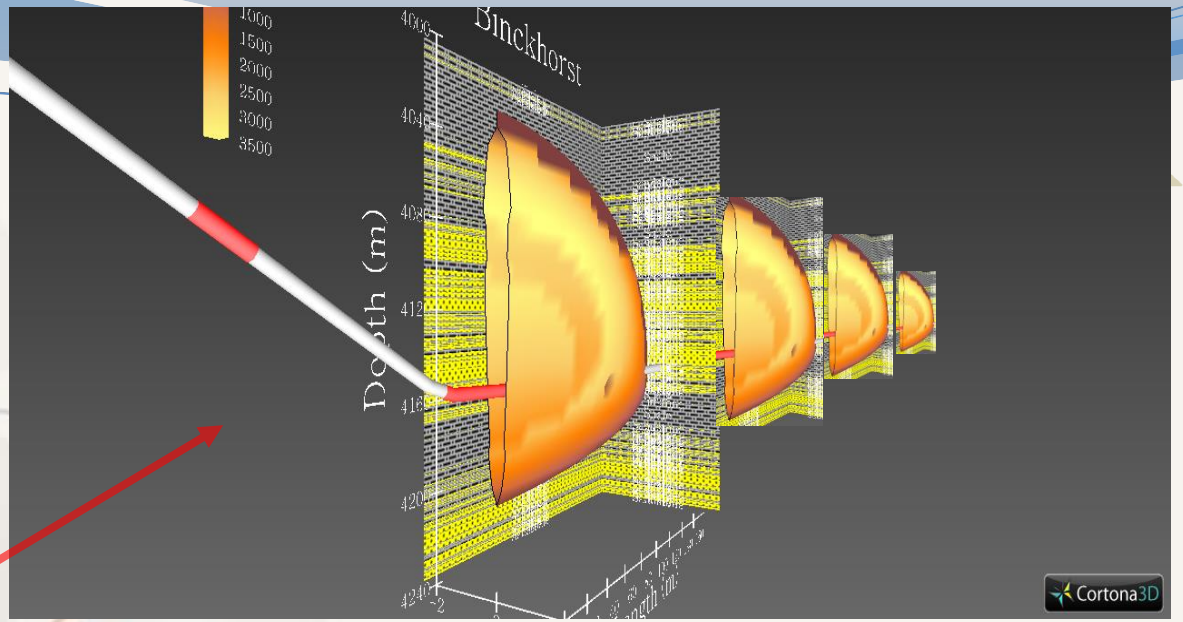
Candidate Selection Acid Treatments
requirements as 'rules' in spreadsheet

Hydrocarbon saturation	**30 % or more** **Highly d*epleted wells are poor acidizing candidates (from economic point of view).***
Water cut	**50 % or less (can be higher if water can be handled)** ***Acid will preferentially stimulate water zone***
Gross reservoir height	**no limit, but diversion needed in longer wellbores**
Permeability	**Gas > 1 mD, Oil/water > 10 mD** ***Low perm reservoirs need a frac, not acid***
Reservoir pressure	**Gas: two times the abandonment pressure** **Oil : 80 % depletion**
Production system & tubing	**Current production not more than 80 % of maximum capacity of facilities** ***Must be able to handle increased production***

Differences between geothermal and oil & gas wells

- **Fracturing in geothermal and shale gas**
  - Frac length for geothermal projects in sedimentary basins 10 to 300m
  - Frac length for shale gas production can be more than 1000m
- **Fluid volumes**
  - matrix treatments of geothermal 50 – 75 m3 of acid or less.
  - fracturing of geothermal wells are normally in the order of 500 m3 or less per fracture.
  - in shale gas and shale oil, 2500 m3 or more per fracture are quite common.
- **Number of fracs**
  - in geothermal doublets the general norm is one or two with a maximum of four per well
  - in shale gas often a large number of fracture treatments per well.
- **Exploitation**
  - shale gas wells have a limited lifetime of a few years. After its lifetime a new well needs to be drilled, including the needed fracturing activities.
  - geothermal wells are meant to produce for 15 to 30 years or even more.
- **Enviromental impact**
  - Staatstoezicht op de Mijnen (legal authority of Economic Affairs in the Netherlands) just published an evaluation on regular oil & gas fracking activities in the Netherlands (252 wells and 338 fracs since 1950). The conclusion is that no harmful effects have occurred.





Doublets, Triplets

SoDM rule does in general not apply for dedicated fracture treatments