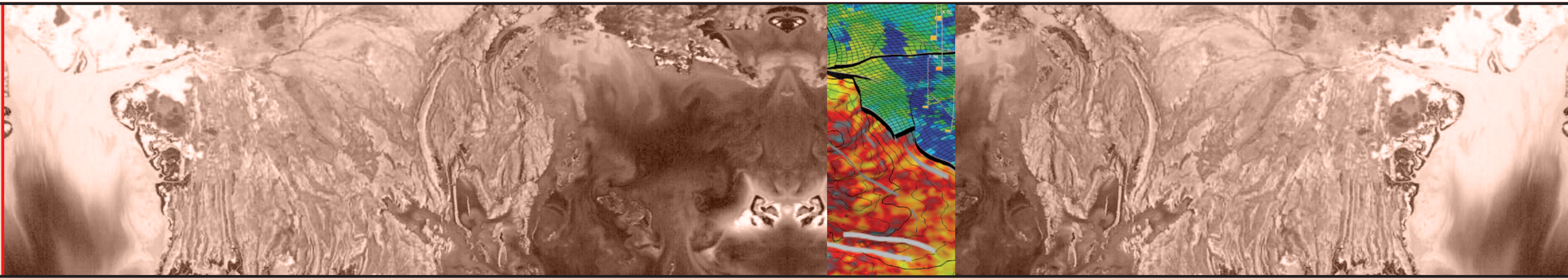
RESERVOIR ENGINEERING



RESERVOIR ENGINEERING

THE MULTIPHASE FLOW BEHAVIOUR OF NATURALLY FRACTURED RESERVOIRS (RE17)

STEPHAN K. MATTHÄI

State-of-the-art characterisation, modelling and simulation of Naturally Fractured Reservoirs (NFRs).

INSTRUCTOR

STEPHAN K. MATTHÄI is the chair of reservoir engineering at the Mining University of Leoben, Austria, and is a consultant to the Oil & Gas industry, as well as government institutions. He is a frequent keynote speaker and co-organisor of SPE, EAGE, and other international conferences. Before coming to Austria, he was a senior lecturer of computational hydrodynamics at Imperial College London, UK, and he holds a M.Sc. from Tübingen University, Germany, and a PhD degree from the Research School of Earth Sciences at the Australian National University. He also conducted postdoctoral research at the American Universities Cornell and Stanford, as well as at the Swiss Federal Institute of Technology (ETH Zürich). His publications range from "The Formation of Hydrothermal Gold Deposits" to the "Upscaling of Two-Phase Flow in Naturally Fractured Reservoir," American Association of Petroleum Geologist Bulletin 93 (11): 1621-1232. His current team of postdoctoral researchers and graduate students investigates multiphase flow in NFRs during GOGD (Gas Oil Gravity Drainage) in carbonates and wettability alteration in heterogeneous porous media. The efforts of the team contribute directly to multidisciplinary field and numerical simulation studies. He is also the originator of the Complex System's Modelling Platform (CSMP++). This software library (API) facilitates the solution of multi-physics (thermal – hydrologic – mechanic –chemical = THMC) problems in geometrically complex models; one particular domain of application is Discrete Fracture and Matrix modelling and simulation of NFRs. CSMP++ enjoys a growing international user community, incorporating the latest research developments from many well-known universities.

VIENNA, AUSTRIA

The city's cultural heritage is mainly musical, the great classical composers like Strauss, Brahms, Beethoven, Schubert, Haydn and Mozart all having lived and performed here. Today the Vienna Philharmonic Orchestra and the State Opera House help keep alive the city's tradition by offering more classical music performances a year than any other city in the world. Vienna is a city of music, but it is also synonymous with gourmet fare, cream cakes, superb coffee, the angelic strains of the Vienna Boys' Choir and the proud prancing of the Lipizzaner stallions at the world-famous Spanish Riding School. Vienna started out as a Celtic settlement on the banks of the Danube and became one of the Roman's most important central European fortifications. Its central location on the strategic Danube river contributed to the city becoming a mighty empire, reaching its peak during the tumultuous reign of the dazzling Hapsburg dynasty. At the end of the 19th century the golden age of empire began to decline as Vienna's coffee houses filled with radical intellectuals like Freud, Klimt and Mahler. Most of the city's tourist attractions are within the largely pedestrianised inner city area, which was once enclosed by the city walls. The walls have been replaced with the Ringstrasse, a wide ring road. Further out in the suburbs is the thrilling Prater amusement park with its massive ferris wheel, and the opulent Schoenbrunn summer palace. Visitors also should not miss a trip to the Vienna Woods, peppered with ancient 'Heurigen' (wine taverns).

5 ways to register

1. Internet: www.hoteng.com
2. E-Mail: training@hoteng.com
3. Fax: +43 3842 430531
4. Tel.: +43 3842 43053-33
5. Mail: HOT Engineering GmbH, Parkstrasse 6, A-8700 Leoben, Austria

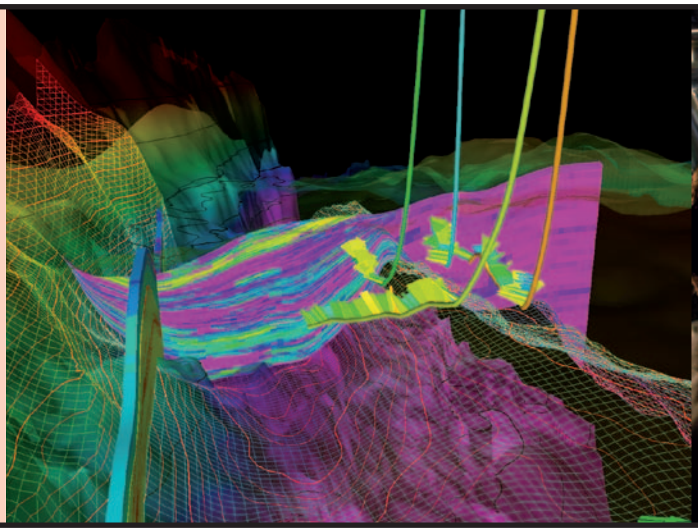
NATURALLY FRACTURED RESERVOIRS (RE17)

Subject is the state-of-the-art in characterisation, modelling and simulation of Naturally Fractured Reservoirs (NFRs), their properties including constitutive relationships for matrix and fracture multiphase flow as well as fracture-matrix transfer and the variation of flow properties with scale. Also covered will be flow-based upscaling of permeability and relative permeability in view of emergent flow structures and instabilities such as fracture-assisted viscous fingering. This analysis will be supported by findings from cm- to hm-scale physical experiments and numerical simulations. Observations and dynamic data are used to address NFR behaviour on the field-scale.

The information shared in this course underpins a novel NFR characterisation and reservoir simulation workflow that begins with statistical fracture characterisation in the subsurface, including geomechanical techniques for the prediction of fracture geometrical arrangement, connectivity, and aperture, and taking into account the in situ stress state. It will be shown how the latter can be inferred from the lithostatic load, borehole breakouts and drilling-induced tensile fractures. The discussed workflow progresses with the computation of grid-block scale fracture – matrix ensemble properties and concludes with field-scale simulation of NFRs.

The course also tries to establish what dynamic data reveal about the role of fractures or faults in any particular NFR and how these diagnostics should be used to guide data collection, history matching, and predictive simulations.

Many of the conclusions drawn in this course rest on results from Discrete Fracture and (rock)-Matrix (DFM) simulations carried out on unstructured hybrid FEM-FVM scale models. Therefore, the foundations of the DFM and simplifications made / associated assumptions are explained as well. Subsequently, the DFM approach is compared and contrasted with existing fracture modelling and flow simulation techniques, including an analysis and discussion of the pros and cons of field-scale dual porosity modelling.



RESERVOIR ENGINEERING

WHO SHOULD ATTEND

Reservoir engineers and geoscientists working on fractured reservoirs. A basic understanding of reservoir characterisation and modelling, multiphase fluid flow in porous media, and numerical methods.

OUTLINE

MECHANICS, STATISTICS AND PERMEABILITY OF NATURALLY FRACTURED RESERVOIRS

Naturally Fractured Reservoirs and THMC processes
Combined thermal-, flow-, mechanical- and chemical processes make NFRs hard to predict because they are closely coupled, nonlinear and linked across different length scales. This introductory section makes a dynamic behaviour inventory, reviews conventional reservoir engineering approaches highlighting their shortcomings, building a case for the novel characterisation and simulation approaches presented in this course.

Fracture mechanics relevant to porous rocks
This section introduces geomechanical concepts relevant for an understanding of fracture processes:
- Morphology of single fractures
- Failure criteria and modes
- Fracture-growth and crack-tip stresses
- Damage and process zones
- Strain localisation in elasto–plastic media
- Fractures compared with other deformation structures
- Relevant terminology of fracture mechanics.

Fracture pattern formation and aperture distributions under in situ conditions
Characteristic fracture patterns develop when growing fractures interact with each other, pre-existing fractures, layer interfaces, and / or other material heterogeneities as soon as associated stress perturbations overlap.
- Morphology of interacting fractures and implications for their 3D shape
- Effect of facies architecture and compositional layering on fracturing
- Frictional sliding reactivation of pre-existing fractures in shear
- Fracture aperture
- The state of stress in NFRs and its effect on fracture aperture distributions
- The role of critically stressed fractures for flow localisation in NFRs

Fracture statistics and their measurement
- Fracture spacing and length distributions
- Fracture connectivity and percolation clusters
- Statistical properties of matrix blocks
- Geologically constrained fracture modelling: stochastic, rule based, and geomechanical.

Fracture permeability and anisotropy of fractured rock
- Permeability of individual fractures
- Permeability variation with scale
- Fracture-matrix ensemble permeability estimated in numerical experiments
  - Equivalent permeability of stochastic fracture models near the fracture percolation threshold
  - Equivalent permeability of geomechanical discrete fracture models at different states of fracture development
- Effective permeability versus fracture-matrix flux ratio

Parameterisation of fracture-matrix dual continua models with (static) field data
- Review of the Baerenblatt model
- Statistics and importance of block radius
- The physical meaning of the shape factor
- Implications of fracture aperture for fracture permeability and its statistics

Fractures versus faults
Are you actually dealing with an NFR a wide fault zone?
- Fault geometry, displacement (profiles), segmentation, relays and fault rocks
- Fault properties as a function of displacement
- Fracture corridors
- Fault permeability

Fracture development and modification due to chemical reactions
- Volume strain and fracturation in response to chemical reactions,
- Dolomitisation and dedolomitisation and their role in fracture development,
- Carbonate precipitation and dissolution,
- Stylolites.

FLUID FLOW IN NATURALLY FRACTURED RESERVOIRS

Much of the material presented is derived from single- and two-phase flow Discrete Fracture and (rock)-Matrix (DFM) numerical simulations carried out with a hybrid simulator combining Finite-Element (FEM) with finite-volume (FVM) methods. As in other engineering disciplines, computer-aided design (CAD) models and unstructured grids are used as input to this simulator. To understand the differences of this workflow to standard simulation approaches and the remaining simplifications / underpinning assumptions, the DFM method is introduced here.
- DFM model concept
- Numerical foundations required to understand the DFM method
- CAD / boundary-representation based fracture modelling
- Differences to Petrel and other geomodelling approaches

Unstructured spatially adaptive discretisation of DFM simulation models: hybrid FEMFVM formulation for DFM simulation
Solution of pressure and saturation equations with the finite element – node-centered finite-volume method using an operator splitting approach and unstructured grids.
- Representation of fractures and faults in unstructured meshes
- Spatially adaptive discretisation (meshing)
- Error metric to control solution accuracy / mesh refinement

Constitutive relationships for multiphase fracture flow and fracture matrix transfer
- Fracture flow and relative permeability
- Capillary pressure - saturation relationships
- Ensemble relative permeability
- Rate dependence and counter-current imbibition

Single-phase flow in fractured rock
- Flow localisation
- Fracture –matrix flux ratio
- Time to tracer breakthrough
- Comparison of DFM results with tracer tests
- Diagnostic capabilities of tracer tests

Single-phase transport through fractured rock
- Time to tracer breakthrough
- Comparison of DFM simulation results with tracer tests
- Diagnostic capabilities of tracer tests

Multiphase flow in fractures and rock matrix
DFM insights into the balance of viscous, gravitational and capillary forces.
- Breakthrough, total mobility evolution and recovery by water flooding
- Dependence of injection front shape and advance on mobility ratio
- Saturation at breakthrough
- Flow localisation, its measurement and its relation to saturation at breakthrough
- Role of capillary forces

Flow-based upscaling of fracture-matrix ensemble relative permeability
- Upscaling informed by fracture-matrix flux ratio and fraction of invaded fracture – matrix interface area as a function of Pore Volumes Injected (PVI)
- Accounting for the interplay between viscous and capillary forces
- Rate dependence of upscaled relative permeability and monotonic fractional flow functions
- Comparison of new model with DFM simulations on the sector scale
- Incorporation of new parameters into conventional NFR characterisation and modelling workflow; shortcomings of existing simulators and workarounds.

Illustration of 10 NFR modelling and simulation pitfalls
- Conventional simulation approaches in the light of the presented findings

ENGINEERING OF NATURALLY FRACTURED RESERVOIRS AND CASE STUDIES

Dynamic characterisation of fractures by well testing and downscaling

Inverse modelling
What the sum of observations tells about the characteristics of a particular NFR, which data should be collected from it, and how it should be characterised and simulated.
- Dynamic data and well tests using inert and reactive tracers
- Forecasting recovery and water production from individual wells
- Ideas on how to maximise recovery

Critical review of status quo in NFR modelling and simulation
It is assumed that dual porosity / dual permeability models and associated well test interpretation and reservoir simulation techniques are the most widely used in reservoir engineering of Type II NFRs. What are the implications and what alternatives do we have?
- The “standard” NFR engineering / workflow
- Dual continuum models and fracture-matrix transfer functions
- Alternative approaches

Field Studies of Naturally Fractured Reservoirs and potential nuclear waste repositories

Hydrologic / geomechanic site characterisation at Äspö (Sweden) and Yucca Mtn (NE, USA) and implications for (Nelson) Type I NFRs hosted by basement rocks. Special case of reservoirs in the vicinity of fault zones (Santa Maria basin, CA, USA)

Type II NFRs and their recovery achieved by different engineering methods
Case studies from well characterised fields including chalk reservoirs (Austin chalk in Spraberry Trend, west Texas, USA, Ekofisk, North Sea), limestone/ dolomite reservoirs (Ghawar), and siliciclastic reservoirs (Clair, North Sea).