Introduction to the STRESOIL project

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Introduction

Accelerated remediation technologies are currently being introduced in Europe, primarily from USA. The primary goal of the STRESOIL project is to combine integrated methods of site characterisation, determination of the transport properties of fractured porous media and numerical simulation of contaminant fate in fractured reservoirs, with *on site* stimulation technologies for the implementation of accelerated *in situ* remediation of low permeability fractured contaminated soils.

Project objectives.

To obtain this goal 6 work packages have been formulated (Fig. 1). A detailed geological characterization of a fractured site was carried out, (2) Stimulation scenarios using hydraulic fracturing has been installed and tested on five highly contaminated areas (cells), (3) viable remediation technologies has been selected and installed on two of the stimulated cells, (4) an existing numerical simulator of the contaminant transport in fractured media (PolluSIM) are being updated to simulate remediation processes in stimulated fractured media and asses the NAPL fate in long-term basis, (5) monitoring the contaminant fate with the use of advanced techniques of chemical and microbiological characterizations of the soil has been implemented, in order to evaluate termal treatment and bio-ventilation as remediation technologies, map the spatial/temporal distribution of NAPL compound concentrations over the site, calibrate the numerical simulator, and evaluate the efficiency of the stimulation / remediation strategy in short-term basis, and (6) finally a cost benefit analysis will be carried out to assess the feasibility of the methodology.

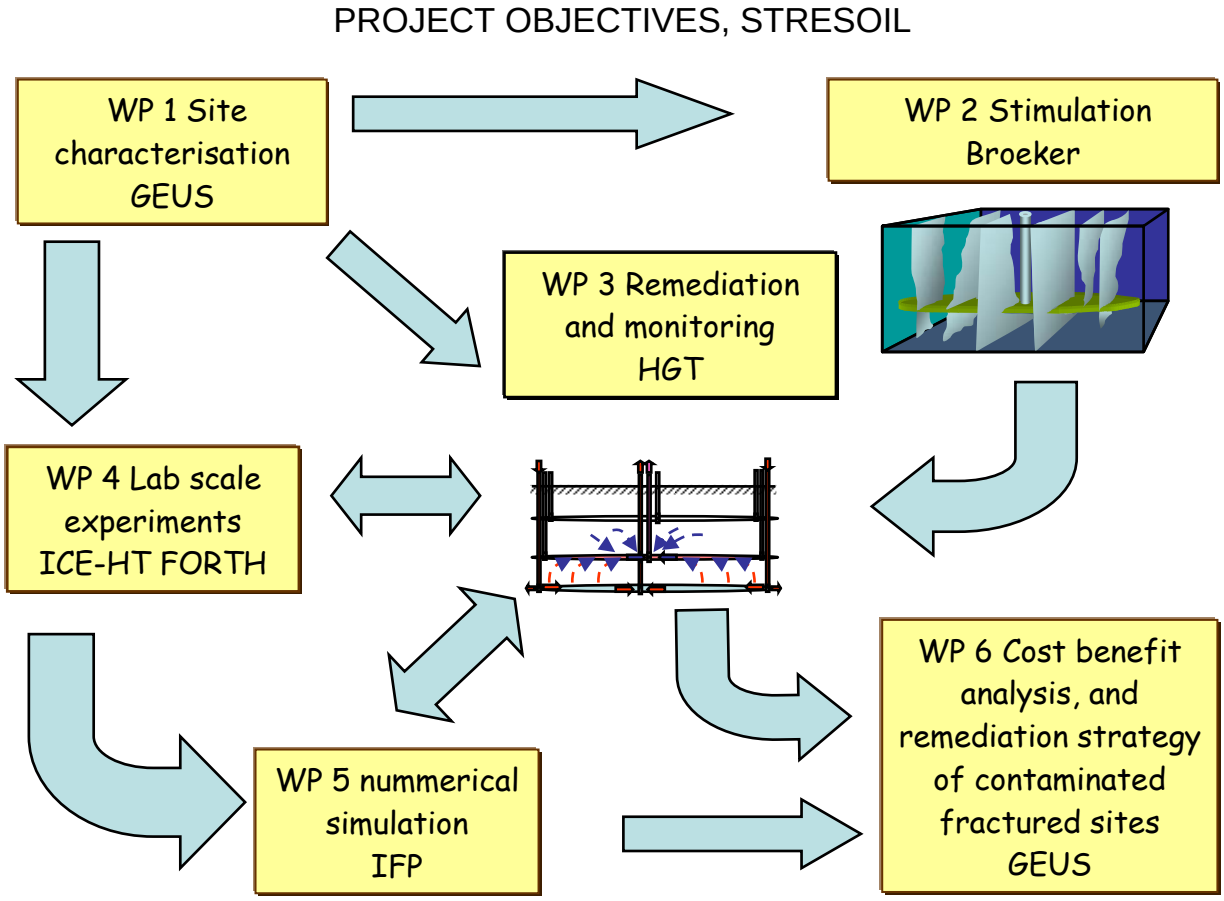

Figure 1. Project objectives and interconnection between the different workpackages.

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The consortium

The STRESOIL consortium consists of five partners:
Geological Survey of Denmark and Greenland (GEUS) are coordinating the project as well as being lead partner for two work packages: WP1 the geological characterisation and WP 6 Cost benefit analysis.
The Danish Drilling company Broeker that has developed the stimulation technology in cooperation with the American Company FRx is lead partner on WP2.
The polish company Hydrogeotechnika are site owners and lead partner on WP3 concerning the remediation and monitoring technology.
ICE-HT-FORTH from Greece is lead partner on lab scale experiments and determination of transport properties in soil and fractures.
Institute Francais de Petrole (IFP) is Lead partner on WP 5 regarding development of numerical tools for simulating the NAPL fate during the experiment.

The site

The selected experimental site is situated on the former Kluczewo airport in Poland. The Kluczewo airport is situated approximately 4-5 km west of the lake Miedwie and south of the city Stargard Szczecinski in the North-Western part of Poland (Fig.2). Germany (1927-1945) and Soviet Union (1946-1992) used the airport for primary military purposes. The site is characterised by different types of generally low-permeable glacial deposits overlying a regional sandy aquifer, which is heavily contaminated by jet fuel. The Airport is thus the second largest ground-water reservoir contaminated by fuel in Poland.

Figure 2. Location of the Kluczewo airbase.

Work performed and results so far

During the first year of the project, field-scale studies were performed on the site. Integrated methods of multi-scale characterisation of fractured media were employed and regional and local hydrogeological / geological models were established. The glacial deposits constitute three different units of till, of which an upper water-lain clay till and a lower basal till are fractured. The units are separated by a flow-till with multiple thin sand stringers. The fracture networks were classified and quantified.

Chemical analyses of soil and groundwater were carried out in order to characterise and quantify the level of contamination. The microbiological activity was investigated in order to evaluate the soil/water capacity for NAPL biodegradation and use bio-stimulation as a site treatment method.

21 hydraulic fractures were established on five experimental cells. One cell was used to measure hydraulic properties and two cells were selected for remediation experiments. Two remediation technologies were selected to be installed: (1) steam injection, and (2) bio-remediation enhanced by air ventilation and two non-fractured cells were prepared for bio-remediation experiments for comparative analysis of the performance of the stimulation technique.

The single-phase transport properties (permeability, formation factor) of disturbed soil samples were measured. An experimental setup was established and tested for determining the effective multiphase transport coefficients of the different types of soils.

During the second year of the project a general geological characterisation and mapping of the distribution and fate of NAPL over the site for the development of fracture network / matrix porosity model has been completed. A conceptual 3D-fracture network model was constructed and the statistical properties of the fracture/matrix framework were calculated. A detailed analysis of the contaminant fate prior to the remediation experiments in the steam injection cell, and the bio ventilation cell were completed in September 2005 (t_0-sampling) and the results showed that the major pollutant entrapped in the soil of the Kluczewo airport is a kerosene cut, and there is a general increase in the concentration towards the groundwater table.

Microbiological characterisation of the site was completed in the spring 2006 and it appears clearly that despite the good intrinsic capacity of the micro flora to mineralise the jet fuel under optimal conditions (accessibility and nitrogen), its capacity to degrade the hydrocarbons associated to the specific soil matrix from the site is very limited. This makes the possibility for a successful biological treatment rather limited.

Guidelines for establishment of hydraulic fractures at the Kluczewo site, including investigations of soil mechanics and rheological properties of the fluids/gel used in hydraulic fracturing are in progress, and hydraulic characterisation of cell 2 has been completed. It was not possible to quantify the increase in the influence radius after establishment of hydraulic fractures at 2.5, 3.5 and 4.5 m depth in Cell 2, but a substantial change in the air pressure distribution in the total soil volume in Cell 2 has certainly been observed. There is strong indication that the sand-filled fractures have been by-passing the observation points, properly in an upward dipping angle, and that the injected air travelled through the sand-filled fractures to areas of lower permeability zones.

During the t_0 -sampling of the two cells the hydraulic fractures were carefully mapped, and combined with the uplift data from the injection of the hydraulic fractures, a detailed 3D-model of the hydraulic fracture distribution were constructed for each cell. The 3D-models and field-scale tests formed the basis for lab-scale experiments necessary for determine the transport properties and remediation performance.

The technical solution for the two remediation experiments were designed, constructed, installed and tested in the period September - December 2005 (Fig. 3a and 3b).

Figure 3a: Air pressure permeability test

Figure 3b: Air pressure-flow test

Steam injection experiment

Due to extreme weather conditions in the winter 2005/2006 the testing of the steam injection equipment was postponed until April 2006. In March-April the steam-injection equipment was tested and calibrated. After some problems with the power supply (underground power cables were stolen during the Easter vacation) the steam injection field experiment was initiated on April 18 (Fig. 4). The remediation continued until August 2006 and a number of different injection scenarios was

implemented during the experiment, in order to optimize its efficiency. In September the T_2 sampling was carried out and the whole cell has been excavated and the hydraulic fractures mapped and prepared for the field excursion during the STRESOIL workshop on 28-29 September 2006.

Bio venting experiment

A number of hydraulic tests were performed in the bio venting cell in order to measure the performance of the hydraulic fractures and a strategy for the remediation set-up and performance of this cell was outlined during the winter and spring 2005/2006. Finally, on 19th of June the bio venting experiments was initiated and both experiments are running satisfactorily. The experiments are carefully monitored and samples of condensate from the steam injection as well as samples of gas from the bio venting cell are collected according to a carefully outlined protocol. The Bio-remediation is scheduled to continue for a 9-12 month period depending on the potential extension of the project.

Figure 4: Testing of the steam remediation set-up

A new method was developed for the characterization of the pore structure of soil matrix by combining BSEM images, datasets from Hg porosimetry tests, and inverse modelling algorithms. The method was applied successfully for the determination of the geometrical/topological properties of 5 soil samples collected from all units of Kluczewo site. The micro structural properties were introduced into analytic equations derived with the aid of the critical path analysis of percolation theory to estimate the absolute permeability and electrical formation factor of the various zones of the soil. The predicted transport properties were comparable to corresponding laboratory measurements on soil columns).

The multiphase transport coefficients (relative permeability curves, capillary pressure curve and longitudinal dispersion coefficient) of soils originating from Unit 3 and interface of Units 2/3 were measured by performing immiscible and miscible displacement experiments on disturbed and undisturbed soil columns (fig. 5). This was done by monitoring the electrical resistance across successive segments and over selected cross-sections of the soil and using inverse modelling algorithms to match the numerical predictions to experimental datasets.

Evaluation of the hydrocarbon transfer to the aqueous phase showed that the environmental impact of contaminated soil is closely related to the intrinsic water solubility of the hydrocarbons and to their volatility through the atmosphere. The work done leads to the conclusion that the contaminated soil sampled from Kluczewo airport is mainly polluted by a kerosene cut. Depending on the depth, this kerosene cut may have been significantly weathered while entrapped in the soil. The project has now compiled an extensive database concerning the composition of the jet fuel present at the site, its weathering in the time and the impact of the hydrocarbons on the water.

Based on the tectonic fracture aperture analysis the effective medium approximation was employed to calculate the absolute permeability of natural fractures whereas 2-D networks of elliptical channels

were constructed in the computer to simulate the oil/water drainage and calculate the capillary pressure and relative permeability curves.

Single-phase and two-phase flow tests were performed on a column packed with the sand used for installing hydraulic fractures in order to determine the absolute permeability and relative permeability functions of the porous material that fills in the hydraulic fractures.

Figure 5: Photographs showing details of the connection of electrodes inserted in undisturbed soil samples with external conductivity meter.

The up-to-date measured/calculated transport properties of the soil matrix, natural fractures, and hydraulic fractures (WP-4) along with results of the fracture network characterization (WP-1) were used for the development of an improved numerical tool that simulates the NAPL fate in a stimulated fractured medium under various scenarios of bio-ventilation.

The first conclusions of this work are:

- It was easy to satisfy both air pressure and air flow rate in the injection well (green fracture) versus the production well (red well) with the single medium simulator.
- The numerical simulation indicates that the flow rate of produced air is about 54 % of the injected air whereas according to the measurements the percentage was only 27%. This means that there is no preferential pathway between the red fracture and the green fracture.
- The connection between the two hydraulic fractures is excluded since there is no preferential path between the red fracture and the green fracture.

The operational conditions for the field experiment have been set up and improved according to the predictive simulations in single medium.

Future work

The last year of the project concerns primarily monitoring the bio-venting cell and analysing the data from the two experiments in order to update a numerical simulator and create numerical databases for evaluation of the efficiency of the remediation technologies. Important contributions from the project will be guidelines and protocols describing the methodologies and technologies.

Aknowledgement

This work was performed under FP6, Global Change of Ecosystems, project no: SSPI-CT-2003-004017 (project acronym: STRESOIL) supported by the European Commission