Enhanced Geothermal Systems (EGS) - Potential and Stimulation treatments

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1. Introduction

Conventional geothermal resources cover a wide range of uses for power production and direct use under profitable conditions. A large scientific and industrial community has been involved in developing Enhanced Geothermal Systems (EGS) in unconventional reservoirs (e.g.Tester et al., 2006). Optimum economic utilization of reservoirs can be achieved with profound analysis of the geological system and adequate planning (including reservoir modelling), and understanding of the processes and interaction of the “borehole – reservoir” system. This concept involves different tracks for enlarging access to heat at depth by improving exploration methods, drilling and reservoir assessment technology for deep geothermal resources, and the stimulation of low permeability reservoirs.

Stimulation treatments must be performed to enhance the productivity of low permeability geothermal reservoirs by inducing artificial fluid pathways. The subjects which have to be addressed in conjunction with the EGS concept include quantification of reservoir parameters using laboratory experiments as well as borehole measurements to monitor the reservoir characteristics. The aim is to study the long-term hydraulic flow, rock-fluid interaction, mechanical-hydraulic and thermal-hydraulic coupled processes, the recent stress field, and borehole stability. In conjunction with operational work, the aforementioned issues support mitigation strategies to avoid reservoir and storage impairment and hence lead to an increase in productivity and sustainability during later use.

2. Potential of EGS resources

EGS resources and reservoirs are more difficult to localise and to assess in contrast to conventional high-temperature steam reservoirs in volcanic environments. While volcanic resources are clearly indicated by obvious effects at the surface (e.g. geysers, fumaroles, etc.), unconventional and EGS resources leave mainly indirect traces (e.g. increased surface heat flow). Usually, they are water-dominated systems and characterised by a wide range of production temperatures. The lower temperature limit in unconventional reservoirs is defined by the current technical limitations in conversion of heat into electric energy. An EGS is defined by artificial improvement of the hydraulic conductivity of the reservoir (Fig. 1).

The site investigation covers the initial phase of an unconventional project. It provides an investigation scheme for possible EGS resources and reservoirs and includes a validation of appropriate exploration techniques in different geo-environments. The site investigation is subdivided in a first phase of site screening, describing best practice for the localization of a geothermal site. A scale-dependent workflow has been developed for this purpose (Huenges, 2010). It describes a step-by-step procedure, how to locate a reservoir using different geoscientific techniques. It introduces different tools and approaches to investigate resources on continental scale. While downscaling to regional and local scales, tools and approaches are adopted to the respective scale and the information of interest on the specific scale. A second phase on site characterisation shall increase the understanding of physical and chemical processes in the reservoir and define the key properties influencing the productivity of the reservoir. This provides an overview of the necessary evaluation and relevant geoscientific tools to characterise the thermal, hydraulic and chemical conditions of an EGS reservoir. Special emphasis should be given to the potential of predictive modelling of the enhancement of the hydraulic conditions of the later reservoir and performance assessment during production governed by the development of thermal, hydraulic and chemical condition in the later reservoir.

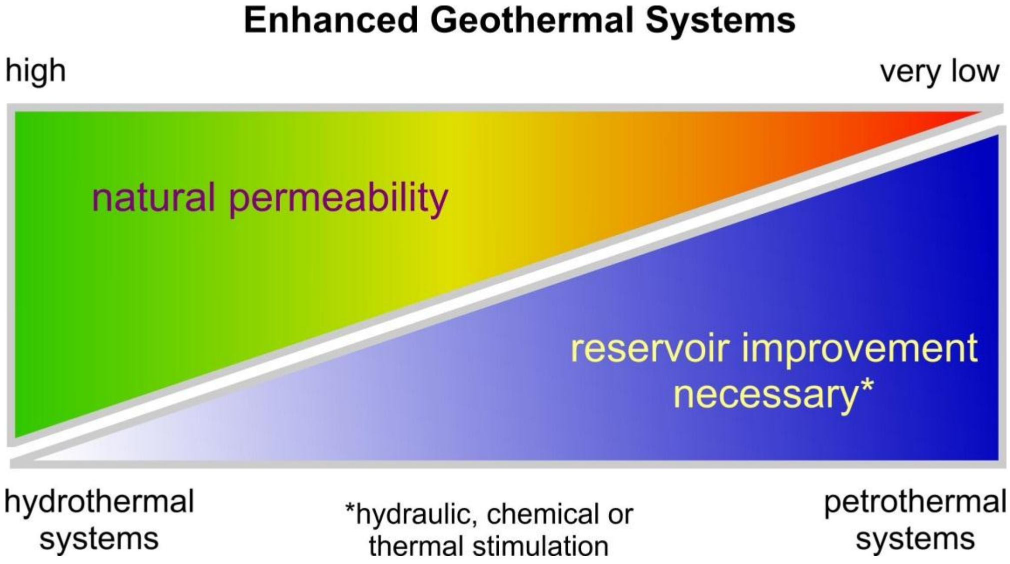

Figure 1: Potential for the enhancement of hydrothermal and petrothermal systems to develop an EGS

Geothermal energy in EGS is assessed using geothermal brine as carrier fluid in a number of wells for production and re-injection. In particular, the number and depth of wells strongly influences the financial planning. The energy is usually planned to be assessed in a doublet system with a production and re-injection well (Landau, Gross Schönebeck, Unterhaching, etc.). Energetically more complex systems are being developed using two or more wells, for example a triplet system in Soultz or an economically optimised multiple-well design (Huenges, 2010).

The high financial investment for well drilling goes along with a high risk of finding a non-productive reservoir or a reservoir in which production flow rates and temperatures obtained are not economically viable. The workflow has been developed to provide a best practice procedure offering an evaluation of the efficiency of different tools in different geological environments in order to minimize this risk. Other risks can also be identified. Excluding accident risks during drilling of borehole, the risk of high magnitude seismic events occurrence during hydraulic stimulation must be carefully taken into account, as public acceptance can be considered as a key factor of achievement of unconventional geothermal reservoir assessment.

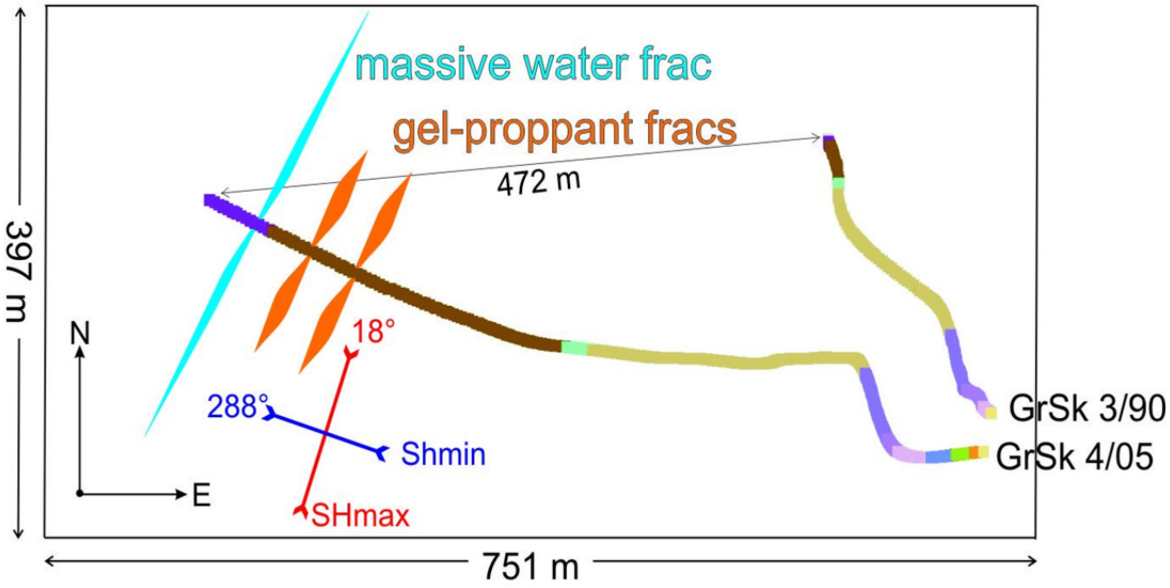

Figure 2: Multiple fracture treatments in the well GrSk4/05 of the Groß Schönebeck site in the North-German Basin. This well was drilled in the direction of minimum principle stress.

3. Stimulation concepts

Research at various sites confirmed that shearing rather than tensile fracturing is the dominant process (Baria et al., 1999). Natural joints, favourably aligned with the principal stress directions, fail in shear. As a consequence, formations with high stress anisotropy and hence, a high shear stress, should be best candidates for hydraulic fracturing in low permeable rock.

A method to increase the effective fracture area is the isolation of intervals in the borehole and the successive stimulation of these intervals (Zimmermann et al., 2010). With this approach a larger effective fracture area can be obtained than with one massive stimulation over a long open hole section (Fig. 2). Such strategy is also favourable to reduce the risk of creating larger seismic events of critically stressed reservoirs.

Cases of induced seismicity have been reported from hydraulic stimulation programs in geothermal wells (e.g. Majer et al., 2007), but not all geological formations are prone to these events. Induced seismic events, which could be felt at the surface, have been reported from hard rock environments. Since the permeability in these formations is a fracture-permeability, the pressures generated to fracture the formation can only diffuse through the fracture and fault network, which will lead to a reduction in effective stress. In sedimentary environments, due to their matrix porosity and permeability, elevated pressures will not focus on fracture and fault pathways, but diffuse through the porous matrix. A potentially considerable sedimentary coverage of a hydraulically stimulated hard rock formation will also damp induced seismic events.

Controlling the fracture propagation in the reservoir while stimulating or circulating is an important issue for all projects in low permeable rock (Baria et al., 2006). Microseismic monitoring gives 3D time-resolved pictures of event location and magnitude from which the fractured rock volume can be inferred. This method has evolved to the key technique to map the reservoir in HDR projects (Wallroth et al., 1996; Niitsuma, 2004). In EGS current projects (Soultz, France; Cooper Basin, Australia) the microseismic event distribution serves for the determination of the target area for new wells. More recently, microseismic monitoring has become important to detect and to control larger seismic events, which might occur during stimulation in seismically active areas (Bommer et al., 2005; Majer et al., 2007).

Waterfrac treatments are applied in low permeable or impermeable rocks with high amounts of water to produce large-scale fractures with low width compared to the gel-proppant treatments (Mayerhofer et al., 1997). In general, waterfrac treatments produce long fractures in the range of a few 100 meters with low apertures of approximately 1mm and hence low conductivity. The success of the treatment depends on the self-propping of the fractures, i.e. fractures remaining residually open after pressure release. This characteristic is strongly attributed to the potential of shear displacement.

The flow rate during waterfrac treatments can be constant during the whole treatment or vary in a cyclic manner (Fig. 3) with several high flow rates followed by low stages (Zimmermann et al., 2010). Simulations have shown that the impact of high flow rates for the fracture performance is better, even if the intervals are limited in time, compared to a constant flow rate.

Enhancing the treatment design comprises adding some abrasive agent in the fluid during the high flow rates such as sand or proppants (Walker et al, 1998). This will help to support the sustainability of conductivity of the fractures created. Using a proppant suspending agent like a linear gel, which gives the proppant mechanical suspension while travelling through the frac, will allow the proppant to travel to the tip of the fracture (Mayerhofer et al., 2000).

Gel-proppant treatments are used to stimulate reservoirs with cross-linked gels consisting of polymers to obtain high viscosities in the range of up to 1 Pa s in conjunction with proppants of a certain mesh size (typically 0.5 to 1 mm; e.g. Legarth et al., 2005). These gels enclose a so called breaker to undo the cross-linking after the proppants are placed in the fracture. These treatments can be applied in a wide range of formations with varying permeability and a good control of stimulation parameters (Cleary, 1994). Placing the appropriate concentration and type of proppant in the fracture are critical parameters for the success of the hydraulic fracturing treatment (Zimmermann & Reinicke, 2010). The produced fractures have a short length of about 50-100m, but a higher aperture of up to 10mm compared to the waterfracs. It is especially used to bypass the wellbore skin in high permeable environments. In general, this kind of treatment is more expensive than a waterfrac treatment.

Typically, the gel-proppant treatments start with a datafrac (also called minifrac) (Fig. 4) to obtain information about friction and tortuosity of the perforated interval. In this datafrac one would first pump an linear gel (medium viscosity gel with viscosity in the range of 0.1 Pa s) which would give an indication if any near-wellbore problems exist which could potentially adversely affect the placement of the frac treatment. This would then be followed by pumping a cross-linked gel which would give an idea of leakoff (i.e. fluid loss due to the permeability of the rock) as well as help predict closure pressures, fracture geometry and if there is any indication of pressure dependent leakoff.

The mainfrac treatment followed after these pretesting is an injection of gel-proppants with a stepwise increase of proppant concentration with a high viscous cross-linked gel into the fracture. The result of the treatment, i.e. the propagation of the fracture, mainly depends on the slurry rate and the concentration of proppants added and their variation as a function of time.

An adjustment during the treatment is possible and often necessary to avoid a screen-out of the well. One can adjust the treatment varying the flow rate and the proppant concentration in case the pressure progression suspect a failure of the treatment.

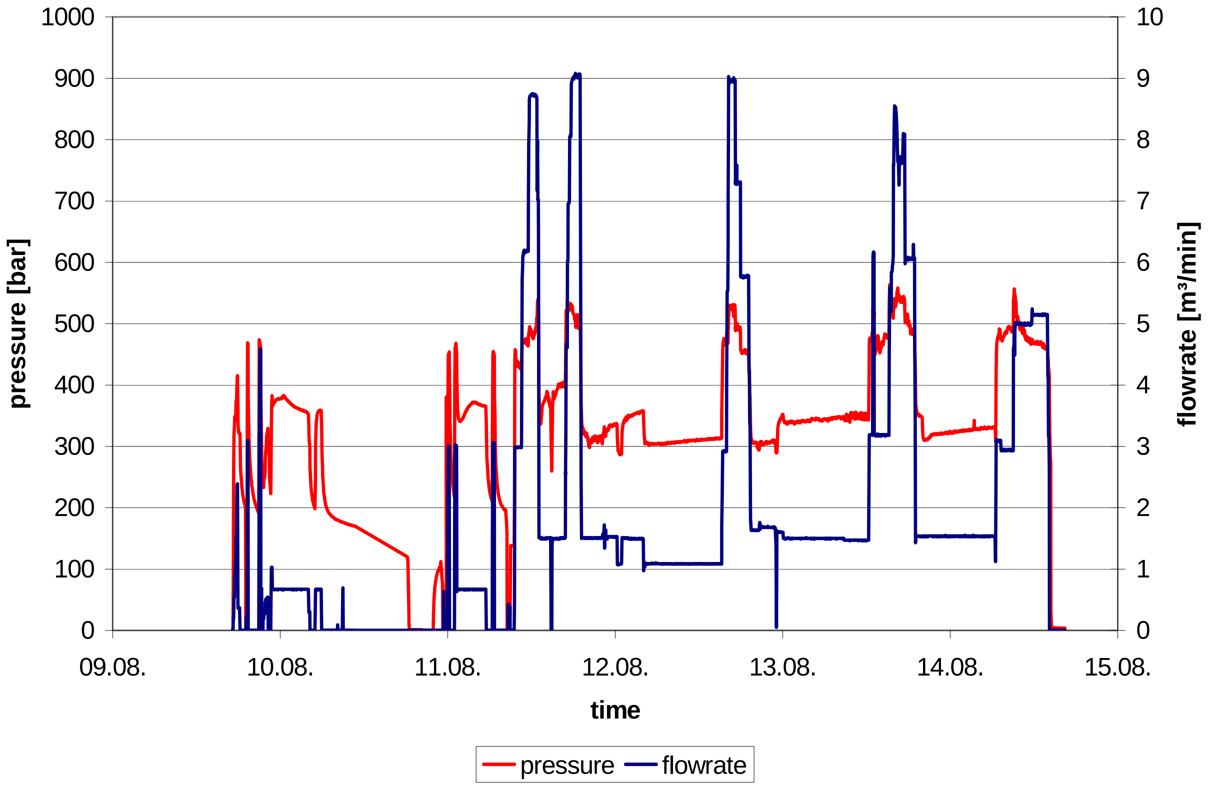

Figure 3: Waterfrac treatment with cyclic variation of flow rate (Zimmermann et al., 2010)

In hybrid frac treatments (Rushing & Sullivan, 2003), water or linear gel is pumped first to generate fracture length. Then a gel-pad with cross-linked gel is injected, followed by proppants or sand of a certain mesh size with a cross-linked gel to fill the fracture. This method can be applied to low-permeable reservoirs and provide sustainable production rates.

Thermal stimulation has been actively used in high enthalpy geothermal fields in volcanic and metamorphic settings to increase the productivity of wells (e.g. Charlez et al., 1996). The injection of cold water leads to a cooling of the rock in the near well bore environment, or adjacent to existing natural or induced fractures. The cooling of the rock matrix induces a tensile component of stress (thermo elastic stress) near the injection well or adjacent to the injection surface. The value of this thermally induced tensile stress depends on the shape of the cooled region, the thermal and elastic rock properties, the difference between the down hole and surface water temperatures, as well as the injection rate. Various numerical models have been developed to explain and predict thermally induced fracturing in sedimentary rocks. Conditions are also discussed, under which secondary fractures perpendicular to the primary main fracture may open.

Matrix acidizing treatments are designed to remove near wellbore damage, primarily associated with plugging of pores by siliceous particles as the consequence of drilling, completion or stimulation (Economides and Nolte, 2000). Matrix stimulation is accomplished by injecting a fluid with low pH (e.g. acid) to dissolve and/or disperse materials that impair well production and is mainly used to treat the near-wellbore region (Zimmermann et al., 2011). In a matrix acidizing treatment, the acid used is injected at a pressure low enough to prevent formation fracturing (Rae and di Lullo, 2003).

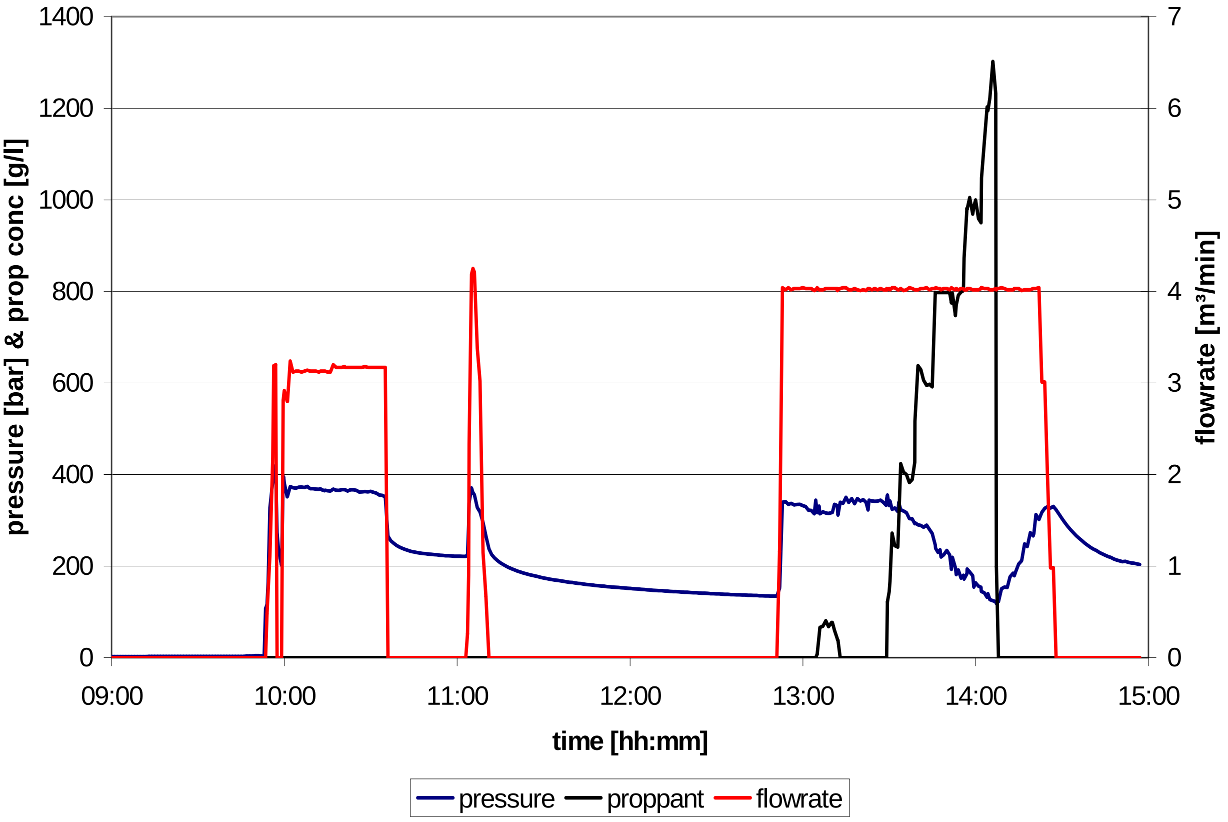

Figure 4. Gel-proppant treatment including a pretest (datafrac), step rate test and then main treatment, where proppants in conjunction with gel is transported into the fractures (Zimmermann & Reinicke, 2010)

Acid fracturing combines hydraulic fracturing and acid injection. The goal is to produce a conductive fracture, with the exception that the conductivity is achieved by acid etching instead of hydraulic fracturing (Economides and Nolte, 2000).

4. Conclusion

Some lessons were learned from the experiences of the stimulation concepts applied to develop an EGS. The achievements of hydraulic fracturing treatments and gel-proppant treatments indicate that the stimulation methods should be designed individually depending on the reservoir rock properties, stratigraphic sequences, and structural geological setting to achieve best results. If hydraulic fracturing is performed, the sustainability of fracture openings must be assured. In case of generating mostly tensile fractures with minor shear displacement, supporting procedures like adding meshed sand or proppants should be performed to keep the fractures open. This is especially the case for production wells with reduced formation pressure during production. During the stimulation treatments, the propagation of fractures and the final extension can be controlled by the flow rate, the treatment duration, and the utilization of fluids with different viscosities (linear or cross-linked gels). This opens the possibility to control the propagation of the fracture in height and length and leads to an optimal connection to the reservoir rocks. Designing a special concept of the well path, including sub horizontal sections in the reservoir and special alignment according to the stress field, offers the possibility for multiple fracture treatments in a well to develop the geothermal field.

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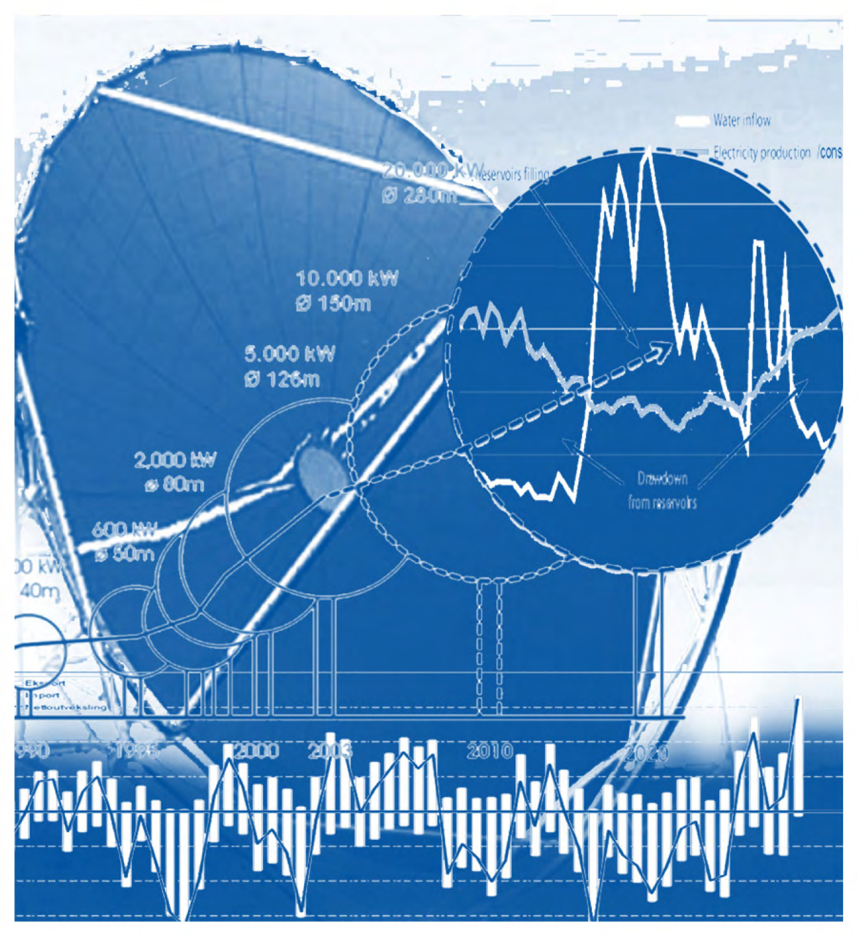

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