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Management of Geological and Drilling Risks of Geothermal Projects in the Netherlands

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ABSTRACT

In this paper a recommended workflow and methodology of geological and drilling risk management is shown and discussed with data of the Erica geothermal project in the Netherlands. Drilling boreholes for development of geothermal energy with depths of 2000 to 3500 m is a relatively new/recent activity in the Netherlands. Ten geothermal doublets have been drilled so far since 2007 in the Netherlands. Several drillings have been completed with lower geothermal flows than expected. Furthermore, unexpected dissolved gas contents up to 1.5 Nm^3 gas per m^3 water have been measured at one project while at another project oil is being coproduced. Also several sidetracks due to swelling clays, mud losses and lost-in-hole equipment have been required to reach the aquifer. A few projects that have been realised are suffering from scaling and/or corrosion problems. These problems have been mitigated, but as a consequence due to these events the geothermal project costs have increased rather unexpectedly.

For the detailed Erica geothermal design and budget planning a geological risk study was used to investigate and calculate the geological and drilling risks to establish the financial risk budget for the drilling. Geological risks are generally difficult to influence while drilling risks can be managed or influenced when proper and effective measures are taken. As a result of the local geological setting, several risks issues have been identified: permeability, depth top reservoir, temperature, overpressure, salinity, salt plugging, initial and residual gas, dissolved gas, H_2S and shallow gas. The parameters that have impact on the calculation of geothermal power (P_t) are taken into account in the uncertainty analysis: permeability, depth and temperature of the reservoir. Other parameters that influence the project budget and can also have impact on the geothermal power are taken into account in the risk management.

1. INTRODUCTION

A geological study in Drenthe SE resulted in a geothermal design within the Lower Volpriehausen Sandstone (Triassic) where the geological properties were sufficient for an economical geothermal project (Fig. 1). The geothermal heat is planned for a cluster of greenery houses. Detailed petrophysical analysis showed a high concentration of salt in Triassic formation water and a special integrated study was carried to evaluate the porosity in the Triassic sandstone aquifer (Heijnen et al., 2010). A geological risk study was carried out for well trajectory planning and a Dutch guarantee fund application. In this project phase the heat recovery was optimized by two horizontal well trajectories and the reservoir geological model resulted in a flow of 15MW_{th} geothermal energy.

For expensive projects like deep drillings it is good practice to carry out a risk study that quantifies risks. Risks can be technical, legal, budgetary, organisational and related to public acceptance. These risks have to be known before the start of drilling operations. The occurrence of unwanted/unexpected events and there countermeasures can lead to significant extra costs of more than 20% of total project costs. For this paper we propose a risk management work flow that focuses on the technical risks of a deep onshore geothermal drilling project.

The risk management of a geothermal project is comparable with a hydrocarbon prospect. For geothermal prospects the numerical risk analysis can be limited to reservoir characteristics as uncertainties in temperature, effective thickness, permeability and sedimentary heterogeneity. A methodology and workflow of risk management is proposed for geothermal projects. Geological and drilling risks can be identified and expected project risk can be calculated using a risk analysis, expected probability of occurrence and calculation of costs of realistic measures. The technical design of the surface geothermal installation shall be improved by using this methodology in an early project phase. It is advised to have contingency plans ready at the start of each geothermal drilling project. Detailed risk management and implementing measures shall lead to a more reliable drilling budget. In this paper a recommended workflow and methodology of geological and drilling risk management is shown and discussed with data of the Erica geothermal project in the Netherlands.

2. ERICA GEOTHERMAL PROJECT

The provincial town Emmen is located in the northeastern part of the Netherlands, near the border with Germany, see figure 1. The present zone of interest comprises two designated areas of greenhouse development sized 100 and 180 ha respectively. The area is located within the Northwest European basin and its geological history has been influenced by sedimentation rates, tectonic phases and sea level changes. The region of southeastern Drenthe is located within the northeastern part of the Lower Saxony Basin. The area has undergone inversion during the Laramide and Subhercynian tectonic phases. The oldest penetrated sediments in the area are the source rocks of Late Carboniferous age. The subsurface of the area consists of different types of sediments with several unconformities and NW-SE oriented faults.

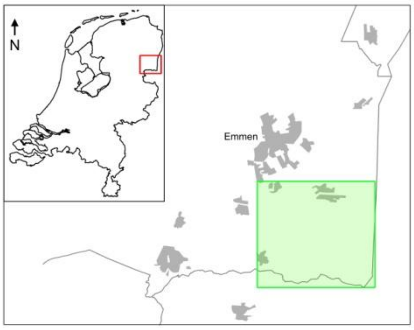

Figure 1: The location of the research area near Emmen.

The basis of the risk inventory forms the previously published multi-disciplinary study by Heijnen et al. (2010). The questions raised during this investigation concerned the depth of the target formations, their properties and most importantly their potential of extracting geothermal energy for heating greenhouses. These questions have been answered by integration of the geology, geophysics and petrophysics as shown in figure 2. The study included well trajectory planning and a Dutch guarantee fund application. In this project phase the heat recovery was optimized by two horizontal well trajectories and the reservoir geological model resulted in a flow of 15MW$_t$. The main target is the Volpriehausen Sandstone Member of the Buntsandstein at a depth of approximately 2600 m (see figure 2).

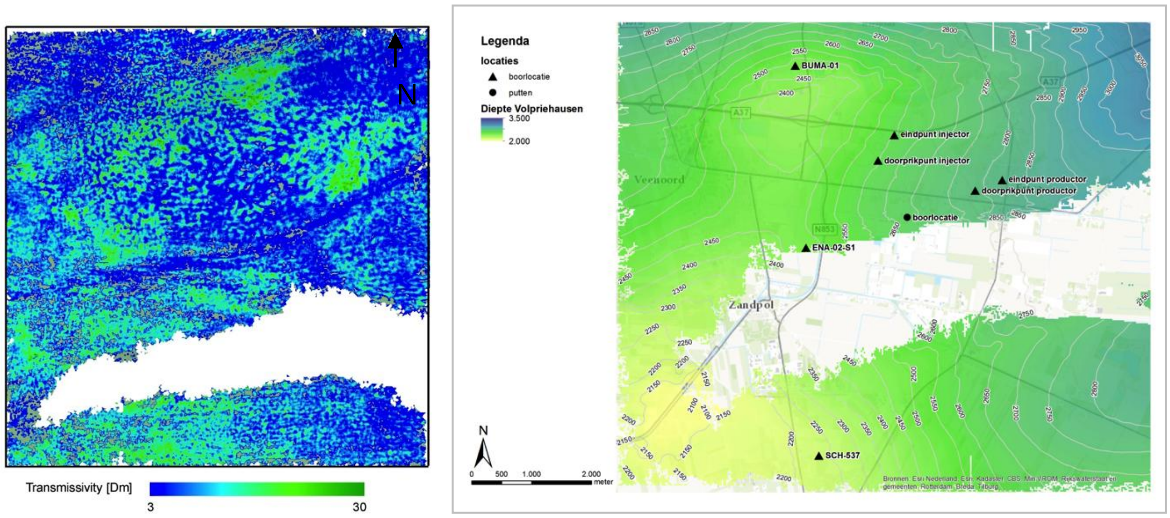

Figure 2: The transmissivity (Dm) of the proposed geothermal Lower Volpriehausen geothermal reservoir was calculated with log and 3D seismic data analysis (left). From the surface location horizontal wells at aquifer depth are drilled in NE direction into top Volpriehausen reservoir(right) (Heijnen et al., 2010).

A geological risk study was used for the detailed Erica geothermal design and budget planning to investigate and calculate the geological and drilling risks to establish the financial risk budget for the drilling phase. Geological risks are generally difficult to influence while drilling risks can be managed or influenced when proper and effective measures are taken. As a result of the local geological setting several risks issues have been identified: permeability, depth top reservoir, temperature, overpressure, salinity, salt plugging, initial and residual gas, the presence of H_2S, dissolved methane and shallow gas. The parameters that have impact on the calculation of thermal power (Pt) such as permeability, depth and temperature are taken into account in the uncertainty analysis. The other parameters that affect the project budget and which can also have impact on the geothermal power are taken into account in the risk management. Of these risks, overpressure of the reservoir, the salinity of the formation water and initial salt plugging of the reservoir are the highest. The salinity of the formation water amounts up to 280.000 ppm NaCl equivalent. Cores taken in the nearby Roswinkel gas wells show initial salt plugging at the Solling Sandstone level while TDT logs of these wells show salt scaling as a result of nine years of gas production within the Volpriehausen Sandstone. These data clearly show that permeability reduction as a result of salt plugging within the pores, or due to salt scaling during production, are serious risks. While for the second risk mitigation measures can be taken, the first risk will most likely result in a stop of the project. Unfortunately, seismic acoustic impedance data could not be used to differentiate salt plugged area within the target zone since these data showed that acoustic response of an area with high porosity and salt plugging can result in the same acoustic value as an area with lower porosity but which is filled with natural gas.

3. UNCERTAINTY ANALYSIS OF GEOTHERMAL ENERGY

In an early phase of the project a geological uncertainty analysis of the expected geothermal power has been executed by calculation and variation of the most important parameters such as rock porosity, permeability, N/G thickness, reservoir temperature, production and injection temperature following the flow chart and physical laws of geothermal energy (Table 1). A stochastic risk analysis of the reservoir geothermal power was carried out which resulted in a geothermal power of 15.1 MW$_t$ which is expected with 90% certainty. This means that there is 90% chance that the expected thermal power is 15.1 MW or higher with a CoP of 12.2. The power was calculated using the formulas 1 and 2 and the input parameters listed in table 1.

$$P_t = q.dT \cdot \frac{C_w}{3600} \qquad (1)$$

where *Pt* is the potential geothermal energy in MW_t, *q* is the geothermal flow in m^3/h, *dT* is the temperature difference between the produced and injected water in °C and *Cw* is the volumetric heat of water in $MJ/m^3 \cdot K$.

$$P_{t,net} = E_{res} - E_{pump} \qquad (2)$$

$$CoP = \frac{E_{res}}{E_{pump}} \qquad (3)$$

where *Pt,net* is the amount of net thermal power, *Eres* is the thermal energy extracted from the reservoir, *Epump* is the energy needed for the pump(s) and *CoP* is the Coefficient of Performance.

Input			Output	
Reservoir parameter	*Unit*	*Calculated variation*	*Expected geothermal power*	P_t
Salinity	g/l	210 (L) 280 (M) 300 (U)	p90	15.1 MW_t
Geothermal gradient	ºC/m	0.0276	p50	18.9 MWt
Permeability	mD	200 (L) 430 (M) 510 (U)	p10	21.4 MW_t
N/G thickness	m	0.79 (L) 0.9 (M) 1.0 (U)		
Aquifer top (producer)	m TVD	2748		
Aquifer top (injection)	m TVD	2583		
Reservoir temperature	ºC	100.8		
Injection temperature	ºC	42.0		

Table 1: Input and output parameters of the uncertainty analysis of Erica geothermal power where L is the lower case, M is the expected or mid case and U is the upper case. The p90 refers to chance that the amount of thermal power is equal or higher than the listed amount.

4. RISK MANAGEMENT AND METHODOLOGY

Drilling boreholes for development of geothermal energy with depths of 2000 to 3500 m is a relatively new/recent activity in the Netherlands. Several of the ten realized systems have been completed with lower geothermal flows than expected. Furthermore, unexpected high dissolved gas contents up to 1.5 Nm^3/m^3 water have been measured at one location while in another project co-produced. Also several side tracks due to swelling clays, mud losses and lost-in-hole equipment have been required to reach the aquifer. A few projects that have been realised are suffering from scaling and/or corrosion problems. Consequently, due to these events the project costs have increased rather unexpectedly. It is therefore important to quantify these risks beforehand and take them into account in the business case.

Risks can be technical, legal, budgetary, organisational and related to public acceptance. These risks have to be known before the start of drilling operations. The occurrence of unwanted/unexpected events and their mitigationmeasures can lead to significant extra costs of more than 20% of total project costs. The risk management of a geothermal project located in a sedimentary basin is comparable with a hydrocarbon prospect. For geothermal prospects the numerical risk analysis can be limited to reservoir characteristics such as uncertainties in temperature, effective thickness, permeability and sedimentary heterogeneity. Source rock, structural trap, and timing of migration (common issues in hydrocarbon exploration) are no primary issues in geothermal projects. The following methodology and workflow of risk management is proposed for geothermal projects:

Step 1: **Risk inventory**: subsurface and drilling risk inventory and investigation based on available literature, maps, borehole logs, seismic dataset, rock and water samples and conceptual drilling trajectories.

Step 2: **Risk description and measures (impact)**: geological and drilling risks that effect (i) geothermal flow (reservoir), (ii) drilling operations and (iii) geothermal surface installation are described and effective measures are defined where possible.

Step 3: **Risk matrix (probability of impact)**: expert judgement of the risk factor with expected value of the proposed measure in euro’s or time are summarized in a risk matrix.

Step 4: **Risk owner**: when the risk, source and impact is known, the ownership of the risk is identified and registered.

Step 5: **Risk decision tree**: visualisation in a decision tree with risks and probabilities as a sequence in a chronological flow chart.

Step 6: **Update** risk register when risk or costs change or risk event did not occur.

The second advantage of a managing risk register is the optimisation of the geological drilling target and the surface installation in an early phase of the project. Table 2 gives a proposed scheme of applying risk factors that are used also in hydrocarbon industry (Otis & Schneidemann, 1997).

Category	Probability / risk factor	Description
Very high risk	> 0.85	More factors conform the risk
High risk	0.50 – 0.85	One or more factors are doubtful to confirm the risk
Average risk	0.50	A number of factors are unknown or data is doubtful
Low risk	0.15-0.50	All factors have positive indication to exclude the risk
Very low risk	< 0.15	Sufficient proof to exclude the risk

Table 2: Risk factors used in this work flow (Otis & Schniedemann, 1997).

4. GEOLOGICAL AND DRILLING RISKS OF A GEOTERMAL PROJECT

The risk matrix is filled with risks, causes, measures and costs of measures (consequences) for the identified geological and drilling risks (Table 3). The resulting financial risks are simply calculated as the product of *probability x costs*. The issues in the risk matrix are ranked following the expected risk value per issue and direct measures can be taken during operations because costs can now calculated, foreseen and reserved within the project budget. The proposed risk methodology fits into project management tools PRINCE or IPM (Integrated Project Management).

The occurrence of reservoir overpressure, scaling or corrosive fluids, H_2S, reservoir salt plugging, tool stuck-in-hole and reservoir formation damage have been identified as high risk factors for this example project budget (other projects may have another risk matrix). The expected reservoir overpressure at surface, based on pressure data from nearby wells, amounts to100-120bar. The water quality issues, H_2S contents and data for the salt plugging analysis are based also on data from nearby situated wells. The risk of induced earthquakes, sealing faults, shallow gas and subsidence has been checked on and are considered to be minimal. A geological risk that cannot be influenced is salt plugging.

Risk	Description	Prob-ability	Consequence	Possible mitigation measures	Expected costs estimation	Expected risk probability times costs
Geological risks						
Reservoir overpressure	100-120 bar above hydrostatic at surface.	0.85	Higher reservoir production rate. ESP not needed Higher injection pressure needed.	Improved engineering of the casing, well head and surface installation. Controlled injection program pressure limit.	€ 500,000	€ 425,000
Salinity	Saturated formation water (Mg, Na and Cl).	0.5	Scaling in casing and surface installations. More energy needed for injection.	Water and chemicals to dissolve salts. Tube to BH in production well to add water or inhibitors.	€ 300,000	€ 150,000
Salt plugging	Salt crystals in rock pores and pore throats.	0.5	Low to no reservoir flow rate at production well.	Reservoir stimulation is <u>partly</u> or <u>not</u> possible. Coverage by insurance or guarantee fund.	Insurance or SEI costs are usually taken in the budget.	Insurance or SEI costs are usually taken in the budget.
H_2S	High H_2S is measured during drilling operation.	0.5	Corrosion of steel and health risk.	Internal coating on steel; Definition of extra HSE conditions. Tube to BH in production well to add inhibitor.	€ 300,000	€ 150,000
Gas or oil field	Free gas or oil in reservoir or reservoir pockets.	~0	Project stops in case producible gas/oil.	Geothermal drilling targets is planned in non-closed structure.	~0	~0
Dissolved gas in formation water	Dissolved gas in formation water.	0.85	Dissolved gas can form bubbles that cause flow problems in the installation and in the injection well.	Keep pressure above bubble point; Engineering and construction of a degasser/separator.	€ 300,000	€ 255,000

Risk	Description	Prob-ability	Consequence	Possible mitigation measures	Expected costs estimation	Expected risk probability times costs
Drilling risks						
Equipment lost or stuck-in-hole	Swelling clay, stuck in fault, total mud losses or by dog leg.	0.5	Drill string or tool are lost and project delay.	Design well trajectory with minimal risk; Use experienced drilling company with certified personal. Use inhibitors and drill a sidetrack.	Fishing and drilling side track in 16 days: € 650,000 Lost tool set: € 250,000 to € 500,000	€ 600,000
Drill fluid invasion in reservoir	Mud cake and reservoir invasion.	0.5	The reservoir produces less geothermal flow (power).	Hole cleaning and extra application of soluble LCM's in reservoir section and/or use acids.	€ 100,000 to € 300,000	€ 50,000 to € 150,000 (excl. loss of geothermal power)

Table 3: Risk matrix with the risks, probabilities, measures and expected costs of the Erica example project. All cost in this table refer to drilling in an urban area in western Europe.

The salt plugging and the drilling risk of equipment loss and drill fluid reservoir invasion have been identified as the highest risks in this project (Table 3). For this specific geothermal project a financial risk reservation is recommended for geological risks of € 1,000,000 (excluding the insurance fee or SEI costs). For the drilling risks, an extra financial reservation of € 750,000 is recommended. Since high costs are involved for drilling, it is recommended to apply this risk management methodology for geothermal drilling projects in sedimentary basins.

4. CONCLUSION

Geological and drilling risks can be identified and expected project risk can be calculated using a risk analysis, expected probability of occurrence and calculation of costs of realistic measures. The technical design of the surface geothermal installation shall be improved by using this methodology in an early project phase. It is advised to have contingency plans ready at the start of each geothermal drilling project. Detailed risk management and implementing measures shall lead to a more reliable drilling cost budget.

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