Geothermal Well Integrity Study

Report For

Study Team: WGI, WEP, BakerRisk

Agenda

- Introduction of the study and all involved
- Statement of Project objectives
- Outline of main deliverables
- Conclusions
- Recommendations HAZID / Well Integrity Management
- Further studies required
- Next step/ongoing study – Corrosion and Asset Management

Introduction of all involved in the study

- **Study team**
  - **WOODGROUP Intetech**
    - Ogo Ikenwilo (Project Manager)
    - Liane Smith
  - **WEP**
    - Henny Cornelissen
  - **BakerRisk**
    - Robert Magraw
- **Independent reviewer (TNO)**
  - Paul Hopmans

Objectives of the study

- Determine what standard will be used as guideline for the study
- Describe typical wells
- Define context for hazard identification
- Hazard identification and risk assessment
- Preparation of a Risk matrix
- Identification of WBEs, failure mechanisms, monitoring guidelines
- Well integrity assessment for drilling and operational phases
- Barrier Philosophy
- Operating and maintenance philosophy
- Independent review and feedback
- Recommendations/Guidelines for Geothermal Wells

Introduction to the study

- Well Integrity Management for geothermal wells in the Netherlands has historically been based on Oil and Gas Industry standards and procedures; this study was commissioned to adapt those standards to the geothermal sector.

- ISO 16530 was selected to be used as a guideline for the study.

- Well integrity management is one of the current themes of the Agenda.

- The first geothermal wells in the Netherlands were completed in 2007 and to date, 15 low enthalpy geothermal doublets have been drilled.

Description of typical wells

- The Dutch Geothermal Energy sector makes use of geothermal heat as a renewable energy. The heat extraction scheme, known as the geothermal space heating doublet, combines a production well lifting, via an electro submersible pump (ESP) set, the hot fluid to a surface heat exchanger and where needed an injection well pumping the heat depleted brine back into the source reservoir.

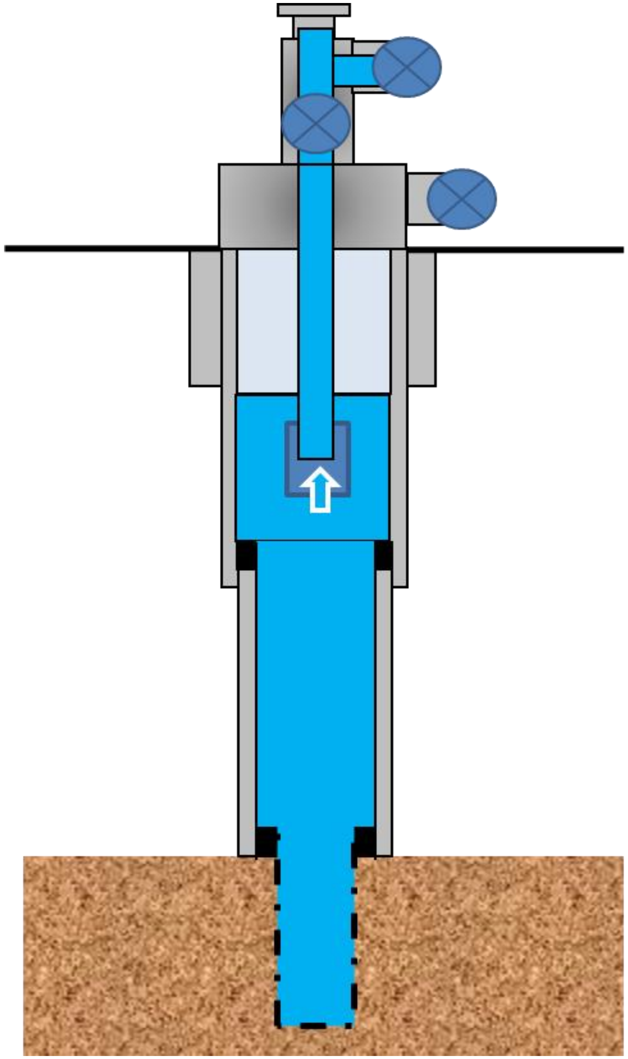


Diagram of a typical Dutch Geothermal Well

HAZID study highlights

- Hazard identification and risk assessment
  - Main Drilling HAZID Risks
    - Shallow gas release leading to loss of containment/fire
    - Stuck Pipe
    - Flooding and noise pollution
  - Main Operational HAZID Risks
    - Gas separating from brine solution causing corrosion and resulting in loss of containment/fire
    - Produced and precipitating solids resulting in blockages both in the well bore and of the formation Injectivitiy issues) and scale formation
- Preparation of a Risk matrix
- Risk assessment of Operating wells (Recommendation)
  - Consideration should also be given to conducting a similar HAZID and risk assessment for each operating well doublet to confirm the risks specific to the location have been considered and are adequately mitigated.
  - MOC/Periodic review should be considered throughout the well life cycle.

Proposed Risk Matrix

Consequence						Increasing Probability				
Severity Rating	People	Environment	Assets	Reputation	Social	A	B	C	D	E
						10^{-6} to 10^{-4} occurrence / year	10^{-4} to 10^{-3} occurrence / year	10^{-3} to 10^{-1} occurrence / year	10^{-1} to 1 occurrence / year	> 1 occurrence / year
						Rare occurrence	Unlikely occurrence	Credible occurrence	Probable occurrence	Likely occurrence
						Never heard of in the Global industry	Heard of in the Global industry	Incident has occurred in DAGO	Happens several times per year in DAGO	Happens several times per year in DAGO
1	No/negligible health effect/injury	No effect	No damage	No impact	No impact					
2	Minor/Slight health effect/injury	Slight effect	Slight damage	Slight impact	Local impact		Manage for continuous improvement			
3	Major health effect/injury	Localised effect	Localized damage	Considerable impact	Regional impact			Incorporate risk reduction measures		
4	Permanent disability/up to 3 fatalities	Major effect	Major damage	National impact	National impact				Intolerable	
5	More than 3 fatalities	Massive effect	Extensive damage	International impact	International impact					

Summary Risk Matrix for Geothermal Operations in the Netherlands

WBE identification and performance standard

- The barrier and well integrity management aspect of this study is aimed mainly at safety in the drilling phase and containment in the operational phase.

- Identification of WBEs, failure mechanisms, monitoring guidelines

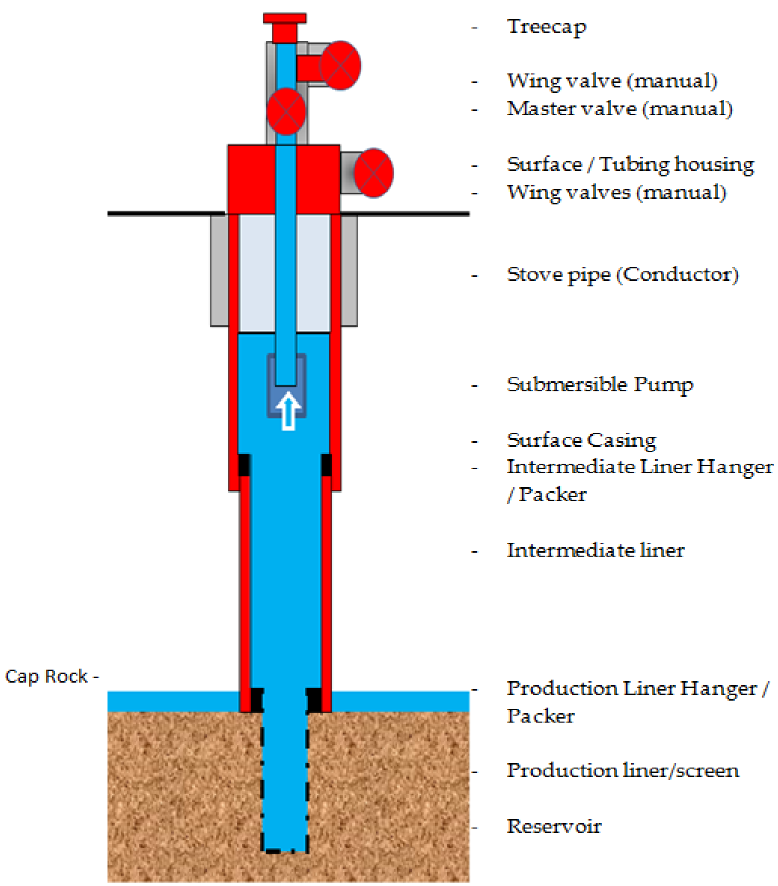
- **Types of Barriers**
  - **Drilling / Well Testing Barriers**
    - ✓ Fluid Column, BOP stack, Cement, Casing, Liner Hanger, Wellhead
  - **Well Operation Barriers**
    - ✓ Formation water, Wellhead/Xmas Tree Valves, Cement, Casing, Liner Hanger
  - **Intervention / Work Over Barriers**
    - ✓ Formation water, Plug, Casing, Liner Hanger, Cement
  - **Suspension and Abandonment Barriers**
    - ✓ Plugs, Casing, Cement, Liner Hanger

Barrier Philosophy

- **The barrier philosophy for the geothermal wells drilled to date is based on this current situation**
  - Co – production of gas and oil that does not lead to a self flowing well condition is expected to be the most common situation that will be encountered in the low enthalpy geothermal wells in the Netherlands.
- Ba**rrier Strategy**
  - **Dual Barrier Strategy**
    - ✓ During normal operation of a standard low enthalpy geothermal well in the Netherlands, the well relies on the hydrostatic fluid column and the hardware barrier as two barriers.
    - ✓ The basis for reliance on the fluid column as a barrier element is the fact that without the ESP running, no water production to the surface will arise.
- **Requirements for Barrier Integrity**
  - The barrier shall be defined and failure criteria shall be determined
  - The integrity of barriers shall be confirmed upon installation and at regular intervals as per the type of barrier
  - It shall be possible to test well barriers. Testing methods and intervals shall be determined.
  - The position/ status of the barriers shall be known at all times.
- **Description of possible failure modes of barriers**

Barrier Philosophy

XYZ Operator			
Well:	Prepared by:	Date:	Primary Well Barrier to the reservoir (blue)
Well type:	Approved by:	Date:	Secondary Well Barrier to the reservoir (red)
Date Original Well Completed:		Tree is rated to:	
Date Workover 1 Completed:		Wellhead is rated to:	
Date Workover 2 Completed:		Tubing is rated to:	
Drawing Ref:		Drawing Rev:	
Current Well Status: *Producing*	Date:		



Barrier Element Table	
Barrier Element	**Element Verification**
Primary Well barrier to Reservoir	
Cap Rock	Xxx Equivalent mud gradient from LOT or FIT s.g
Formation/Well Fluid	Fluid S.G. and static fluid level
Secondary Well Barrier to the reservoir	
X-mas Tree Cap	PT to xxx. Leak detection
X-mas Tree Wing Valve	PT to xxx. Leak detection
Production Liner Hanger / Packer	PT to xxx w/ MW yy s.g
Intermediate Liner Cement	TOC at TOL – Cement quality Logging (e.g. CBL):
Intermediate Liner	PT to xxx w/ MW yy s.g. Caliper or wall thickness logging
Intermediate Liner Hanger / Packer	PT to xxx w/ MW yy s.g
Surface Casing	PT to xxx w/ MW yy s.g. Caliper or wall thickness logging
Surface Casing / Tubing Housing	PT to xxx w/ MW yy s.g. Leak detection
Wellhead Wing Valve	PT to xxx w/ MW yy s.g. Leak detection
Master Valve	PT to xxx w/ MW yy s.g. Leak detection
Well Integrity Notes:	
1. Xxxxxxxx	

Well Barrier Schematic

Operating and Maintenance philosophy

- Monitoring of barriers / Operational Well Integrity
- Wellhead/Xmas Tree maintenance
  - Strategy
  - Frequency
  - Pressure testing
  - Test failure/Valve leakage
- Well Barrier Acceptance Criteria
  - ISO 16530-2 refers to 2 cc per inch diameter per minute as acceptance criteria, a 7 valve would be allowed to leak 14 cc/ min which is quite stringent for a water well with low pressure delta, so the 400 cc/ min is more acceptable norm for water Geothermal wells. SODM to decide which ALR to adopt.
- Fluid Sampling / Corrosion & Scale monitoring
- Checklists (well operating envelope and barriers) for the different well life cycles was developed

Data Management

- Categories of data to be collected
  - ✓ Well design data
  - ✓ Well construction data
  - ✓ Well operation data
  - ✓ Well suspension and abandonment data

- Data storage and management
  - ✓ Various electronic formats can be used in the first instance (e.g. Excel etc.)
  - ✓ Appropriate software is recommended as a repository of information but can go way beyond that..
  - ✓ Knowledge sharing amongst operators, lessons learnt etc.

Innovations for Drilling and Well Completions

- Composite/Non – Metallic Tubulars
- Rod driven pumps
- Installation of a tieback string
- Internally coated casings
- Lined casings
- Use of Y – tool

Independent review and feedback (Main issues)

Issue	Study team view	Independent reviewer response	Report Update
Formation water as a barrier	Deemed not to comply with the ISO standard due to; ➢ Monitoring ➢ Testing ➢ Ability to adjust fluid properties	Compares the scenario to the drilling fluid used as the primary barrier during drilling and so complies to the ISO standard	Updated the report to reflect a dual barrier instead of a single barrier
Acceptable leak rate for well valves	2 cc/inch /min was proposed	Recommend to adopt 400 cc/min rule for SCSSSV as per API 598	Updated. We think that 2cc/min is reasonable but DAGO/SSM can decide if 400 cc/min is ALARP.
Valve maintenance frequency	12 months cycle	24 or 36 months	Not updated We think that 12 months is reasonable based on the lack of redundancies and the small inventory of valves. Operators can adopt a risk based deferment of maintenance activities.

Study Conclusions

- **Low enthalpy wells**
  - The Dutch geothermal wells exploited so far have all been non-artesian; not capable of natural flow to the surface, despite many having some co-produced dissolved gas.

- **Well Barrier Elements**
  - Well Barrier Elements for the full well cycle were identified and performance standards established so far as is practicable.

- **Well Barrier philosophy**
  - Well Integrity is managed on a dual barrier philosophy based on the hydrostatic fluid level as the primary barrier.

- **ISO 16530/NORSOK D010 standards; specific extensions for geothermal needed**
  - ✓ For the existing doublets in NL, the fluid column is seen as barrier. This requires an extension of the ISO / NORSOK standards, with specific performance standards written for this scenario.

Recommendations

- **Drilling HAZID**
  - Independent examination system and external reviewers
  - Insurance for unforeseen or unpreventable disasters
  - Rigorous drilling consent/programme review to consider all/most eventualities.

- **Operations HAZID**
  - These relate mainly to corrosion issues; a comprehensive review of the entire well system to optimize and minimize cost for best corrosion mitigation over the well life.
  - Problems of corrosion, scaling and solids precipitation can be managed in practice by modelling or monitoring to anticipate their severity and by targeted chemical treatment at dosage rates dependent on flow rates.
  - The need to gather more data to better inform well design, material selection, data logging and sharing of information between operators was recommended.

Recommendations (Elements of Well Integrity Management)

- **Well Integrity Assessment method – Well Failure Matrix (WFM)**
  - **Objectives**
    - ✓ Identify all well barrier elements (WBE)
    - ✓ Decide how the integrity of each WBE will be confirmed
    - ✓ Define the acceptance criteria for each WBE for each type of integrity check
    - ✓ Assign a risk ranking to each single WBE failure event and to combination events. The risk ranking is a semi-quantitative value which considers the well type and well location.
  - **Application**
    - ✓ Primarily used during the operational phase
  - **Advantages**
    - ✓ Is systematic and comprehensive, and should identify all WBE assessment tests.
    - ✓ Is effective for considering both technical faults and human errors (failure to conduct required tests).
    - ✓ Can be automated in software to provide a real time risk ranking which could also be useful for benchmarking of wells in different locations.

Recommendations (Elements of Well Integrity Management)

- **Roles and Responsibility (RACI chart)**
  - Roles and responsibility for Well Integrity need definition at each location

- **Well Integrity training**
  - There is need for customised geothermal wells specific well integrity training for all personnel involved. This should be standardised, kept up to date and made available to DAGO and their contractors. Frequency for refreshers should be agreed with DAGO and documented

- **Well by Well Integrity Review**
  - Well by well review based on the findings of this document is recommended

- **Well Integrity Management System Audit**
  - A well integrity audit is recommended to be carried out by an independent auditor and frequency can be proposed by DAGO and approved by SSM

Recommendations (Elements of Well Integrity Management)

- **Well Integrity Software System**
  - ✓ Provide real time management of all data related to well integrity
  - ✓ Meet the full requirements for Well Integrity Management including real time risk analysis from collected data.
  - ✓ Provide for the collection, storage, presentation and evaluation of fluid monitoring data needed for corrosion and scaling risk analysis (a need identified by the HAZID)
  - ✓ Evaluate the corrosion and scaling risks of the wells as the environment conditions in them change over time (fluid composition, temperature and pressure).
  - ✓ Track chemical usage relative to corrosion and scaling risks and as a means to minimise chemicals volumes and costs
  - ✓ Interface to any existing databases
  - ✓ Meet internal and external reporting requirements
  - ✓ Meet well review requirements
  - ✓ Provides the basis for continuous improvement by capturing lessons learnt

Recommendations (Independent Reviewer)

- On closed annuli, positive pressure may be applied (for e.g. Nitrogen cushion) to quickly detect leaks.

- Annulus alarm and shutdown system to be set up with trigger pressures where possible is encouraged.

- Creation of a project specific risk register that is updated through the well life cycle will be very beneficial to the management of integrity for geothermal wells.

- Well by Well Integrity Review
  - This shall be implemented not more than 12 months after the report has been issued (Independent reviewer recommendation)

Further proposed actions and studies

- Further studies and research recommended to further develop the Dutch geothermal sector are;
  - Corrosion risk assessment and mitigation study.
  - Tubing and casing material selection life cycle cost study, casing coating selection.
  - Composite/Non-metallic tubulars - The long term performance of this product for casing needs investigation.
  - Asset integrity management guidance for the complete surface facilities.
  - Review of common well integrity challenges with potential mitigation steps set-out for evaluation in any specific case.

Next step – Asset Integrity Management (ongoing study)

STRAND A

- Analysis of corrosion threats, materials selection and mitigation options applicable to Dutch geothermal wells.
- Include a flow chart of decision making and Integrity Operating Windows (operating limits)
- Include an example to illustrate the use of life-cycle-costing in well materials selection
- Provide guidance on corrosion risks for surface facilities, with mitigation options

STRAND B

- Use existing experience and lessons learned from other industries such as Oil and Gas and apply them to geothermal systems in a practical and effective manner.
- Produce a guideline document to define best practices for Asset Management and give geothermal operators guidance on creation of lean Asset Management plans which optimize production and safety yet reduce cost.
- The guideline shall cover the entire asset life cycle and include topics such as Design, Operation, Integrity, Inspection, Maintenance, Safety and Management of Change.
- Generally, facilitate knowledge –sharing and knowledge transfer in the area of asset management for geothermal energy systems in the Netherlands.

THANK YOU FOR LISTENING

- COMMENTS AND QUESTIONS