Development of a Well Impairment Model for Predicting Geothermal Clogging

Ahmed Hussain

DIMOPREC project
09/04/2021

TU Delft

Introduction

1. Introduction and roll call.
2. Aim and activities of the work packages (WP).
3. Deliverables from and progress in the WP's.
   A. A. Hussain: (numerical) model
   B. N. Essaf: decision procedures and workflow (focused on Pb scaling)
   C. Veegeo: skid
   D. Deltares: experiences in other scaling programs
4. Impact of COVID/change of schedules.
5. Cooperation between the partners.
6. Dissemination.
7. A.O.B.

1 - Introduction and roll call

- Short introduction of all participants
  - Name / affiliation / function

2 - Aim and activities of the work packages (WP) (1/3)

+ 2 ½ months (started March 16^{th} 2020)

WP of Fase [3]	Korte beschrijving	Categorie: IO of EO[4]	Uitvoerders (met namen)[5]	Resultaat	Geplande begin- en einddatum[6]
WP 1 Screening and evaluation of selected Dutch geothermal doublets					
1a	Evaluation and screening	IO, EO	TU Delft, VeeGeo, Deltares	Upgrading the mineral database with available kinetic and reaction parameters for candidate Dutch geothermal fields.	1-20 – 5-20
1b	Statistically quantification	IO	TU Delft	*Development of relevant statistically procedure for problem simplification based on task1.a*	3-20 – 10-20
WP 2 Full-field modelling, workflow and quantifying					
2a	Model based quantitative criteria	IO	TU Delft, Deltares	*Generic analytical model and analysis based on quantitative criteria to evaluate the importance of kinetics of geo-chemical reactions, An innovative approach to simplify the numerical simulation*	5-20 – 10-20
2b	Full-field predictive model & workflow	IO	TU Delft, Deltares	*Numerical model development and work flow providing governing mechanism in field scale, Presenting quantitative key parameters and operational strategies being relative to avoid or treat clogging*	6-20 – 9-21
WP 3 3 Demonstration and implementation for Dutch geothermal reservoirs					
3a	Case studies for test and validation	IO, EO	TU Delft, VeeGeo, Deltares	Presenting the optimized operational parameters for relevant minerals to minimize the risk of precipitation, Detailed validated geo-chemical mechanisms of the selected pilot areas	9-20 – 10-21
3b	Development of generic decision-making tool and workflow	IO	TU Delft, VeeGeo, Deltares	Generalization of results from pilot areas to options for national development, Development and presenting a generic decision-making tool to control clogging in Dutch geothermal doublets	9-20 – 9-21
3c	Development of a corrosion skid specific for field testing	IO, EO	TU Delft, VeeGeo, Deltares	testing of scale formation and influence on scaling rates	1-21 – 10-21
WP 4 Project management, coordination and dissemination					
4a	Project coordination	IO, EO	TU Delft	The Project Agreement agreed and signed by all project members (TU Delft)	1-20 – 12-21
4b	Project management and control	IO, EO	TU Delft	For all WP's, the dissemination and reports on final results (TU Delft, all), The periodical overview of the project (TU Delft, all partners, every 12 months)	1-20 – 12-21
4c	Dissemination	IO	TU Delft, VeeGeo, Deltares	Presentation of the project and its findings during international conferences and in scientific peer-reviewed publications – conference proceedings, bibliographic data of scientific papers, workshops, Reporting every 12 months	1-20 – 12-21

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2 - Aim and activities of the work packages (WP) Status September 2020 (2/3)

WP of Fase [3]	Korte beschrijving	Categorie: IO of EO[4]	Uitvoerders (met namen)[5]	Resultaat	Geplande begin- en einddatum[6] / Status September 2020
WP 1 Screening and evaluation of selected Dutch geothermal doublets					
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2a	Model based quantitative criteria	IO **Ongoing**	TU Delft, Deltares	*Generic analytical model and analysis based on quantitative criteria to evaluate the importance of kinetics of geo-chemical reactions, An innovative approach to simplify the numerical simulation*	5-20 – 10-20
2b	Full-field predictive model & workflow	IO **Ongoing**	TU Delft, Deltares	*Numerical model development and work flow providing governing mechanism in field scale, Presenting quantitative key parameters and operational strategies being relative to avoid or treat clogging*	6-20 – 9-21
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3c	Development of a corrosion skid specific for field testing	IO, EO **Ongoing**	TU Delft, VeeGeo, Deltares	testing of scale formation and influence on scaling rates	1-21 – 10-21
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✓ 4c	Dissemination **Sent extended abstract to EAGE conference**	IO	TU Delft, VeeGeo, Deltares	Presentation of the project and its findings during international conferences and in scientific peer-reviewed publications – conference proceedings, bibliographic data of scientific papers, workshops, Reporting every 12 months	1-20 – 12-21

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2 - Aim and activities of the work packages (WP) Status March 2021 (3/3)

WP of Fase [3]	Korte beschrijving	Categorie: IO of EO[4]	Uitvoerders (met namen)[5]	Resultaat	Geplande begin- en einddatum[6] Status March 2021
WP 1 Screening and evaluation of selected Dutch geothermal doublets					
✓ 1a	Evaluation and screening	IO, EO	TU Delft, VeeGeo, Deltares	Upgrading the mineral database with available kinetic and reaction parameters for candidate Dutch geother[…] fields.	1-20 – 5-20 Start after WP 2↓
1b	Statistically quantification	IO	TU Delft	*Development of relevant statistically procedure for problem simplification based on task1.a*	3-20 – 10-20
WP 2 Full-field modelling, workflow and quantifying					
2a	Model based quantitative criteria	Ongoing (sent abstract)	[…]J Delft, Deltares	*Generic analytical model and analysis bas[…] quantitative criteria to evaluate the importance of kinetics of geo-chemical reactions, An innovative approach to simplify the numerical simulation*	WP 2 start moved ahead ↓ 5-20 – 10-20
2b	Full-field predictive model & workflow	Ongoing (sent abstract)	[…]J Delft, Deltares	*Numerical model development and work flow providing governing mechanism in field scale, Presenting quantitative key parameters and operational strategies being relative to avoid or treat clogging*	6-20 – 9-21
WP 3 3 Demonstration and implementation for Dutch geothermal reservoirs					
3a	Case studies for test and validation	Ongoing (Najoua)	TU Delft, VeeGeo, Deltares	Presenting the optimized operational parameters for relevant minerals to minimize the risk of precipitation, Detailed validated geo-chemical mechanisms of the selected pilot areas	9-20 – 10-21
3b	Development of generic decision-making tool and workflow	Ongoing (Najoua)	TU Delft, VeeGeo, Deltares	Generalization of results from pilot areas to options for national development, Development and presenting a generic decision-making tool to control clogging in Dutch geothermal doublets	9-20 – 9-21
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✓ 4a	Project coordination	IO, EO	TU Delft	The Project Agreement agreed and signed by all project members (TU Delft)	1-20 – 12-21
4b	Project management and control	IO, EO See submissions on RVO site	TU Delft	For all WP's, the dissemination and reports on final results (TU Delft, all), The periodical overview of the project (TU Delft, all partners, every 12 months)	1-20 – 12-21
✓ 4c	Dissemination Abstract and presentation at EGU 2021 conference	IO	TU Delft, VeeGeo, Deltares	Presentation of the project and its findings during international conferences and in scientific peer-reviewed publications – conference proceedings, bibliographic data of scientific papers, workshops, Reporting every 12 months	1-20 – 12-21

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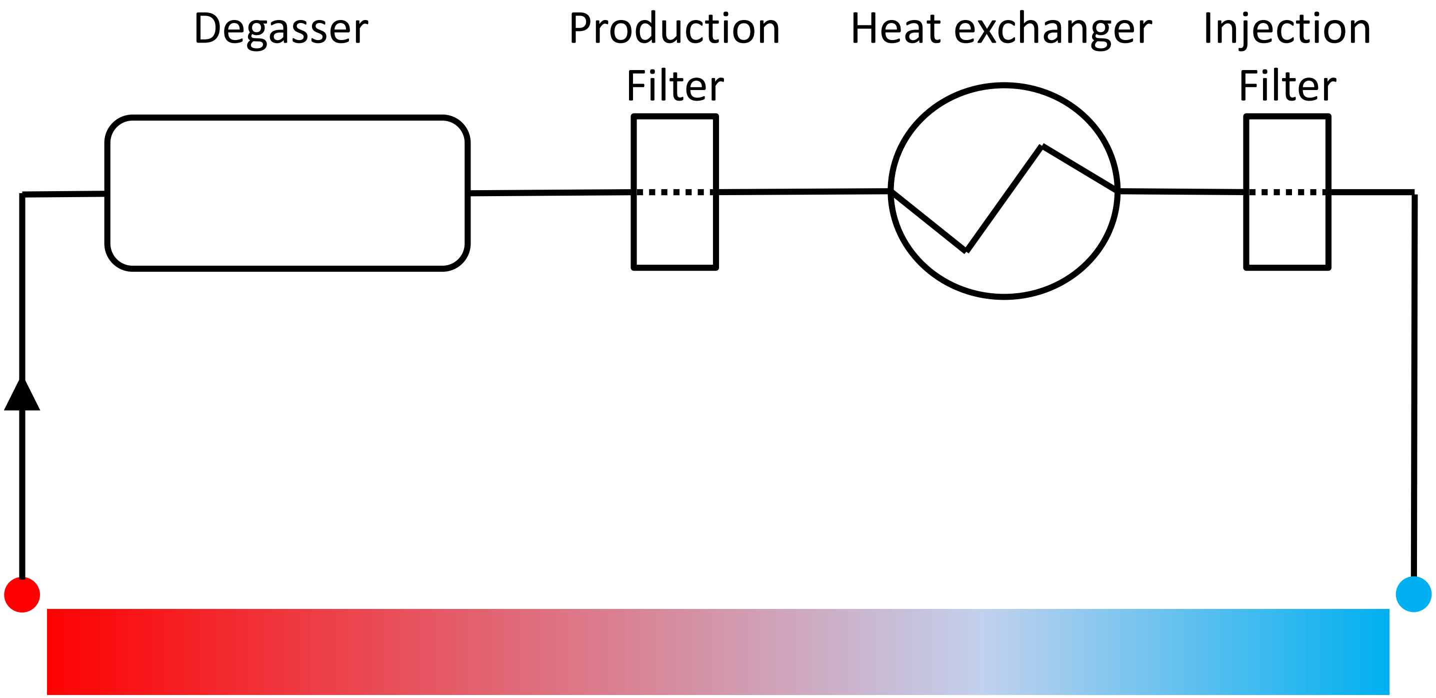
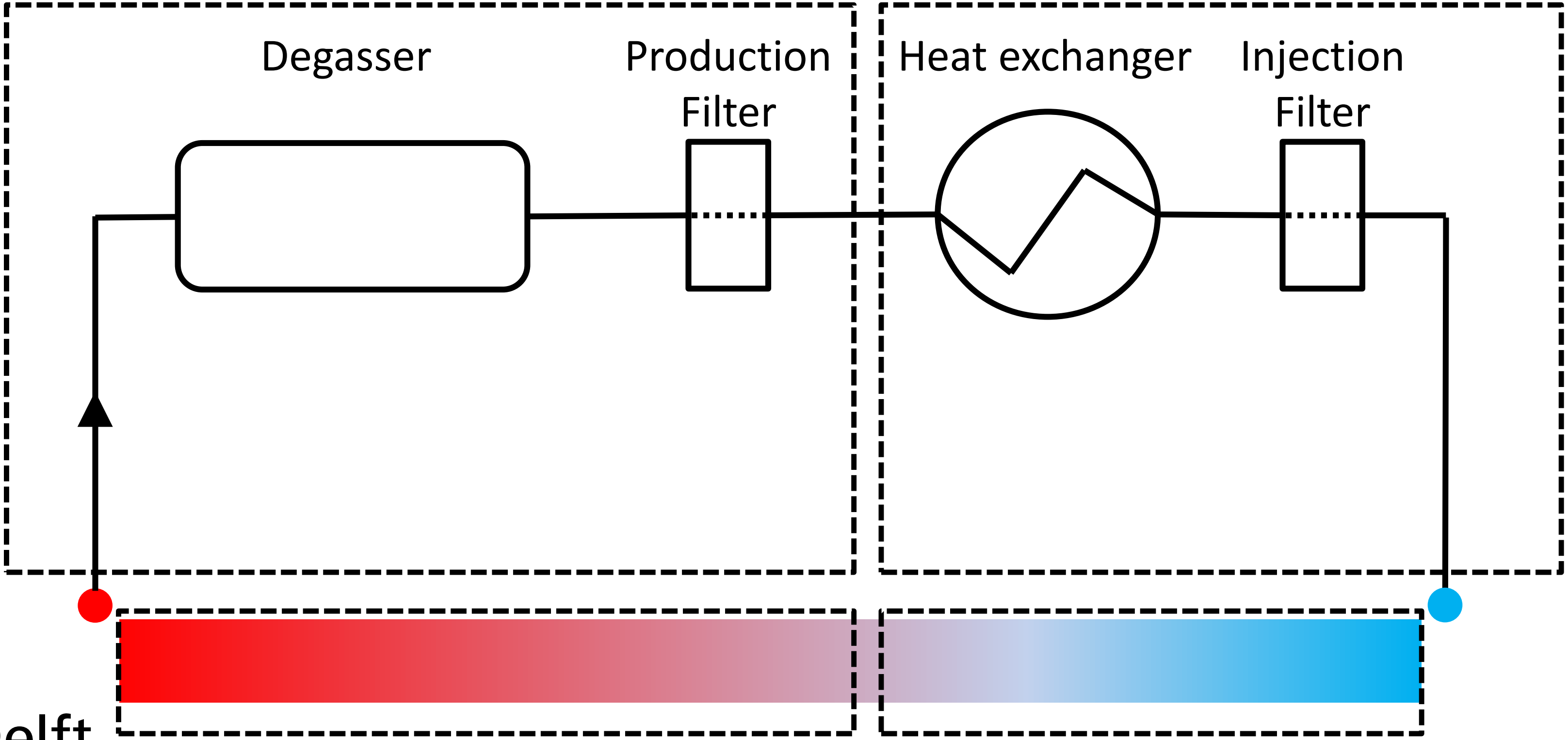
3 - Deliverables from and progress in the WP's

A. Hussain (TU Delft)

Scaling in geothermal projects: regions of interest



Scaling in geothermal projects: regions of interest



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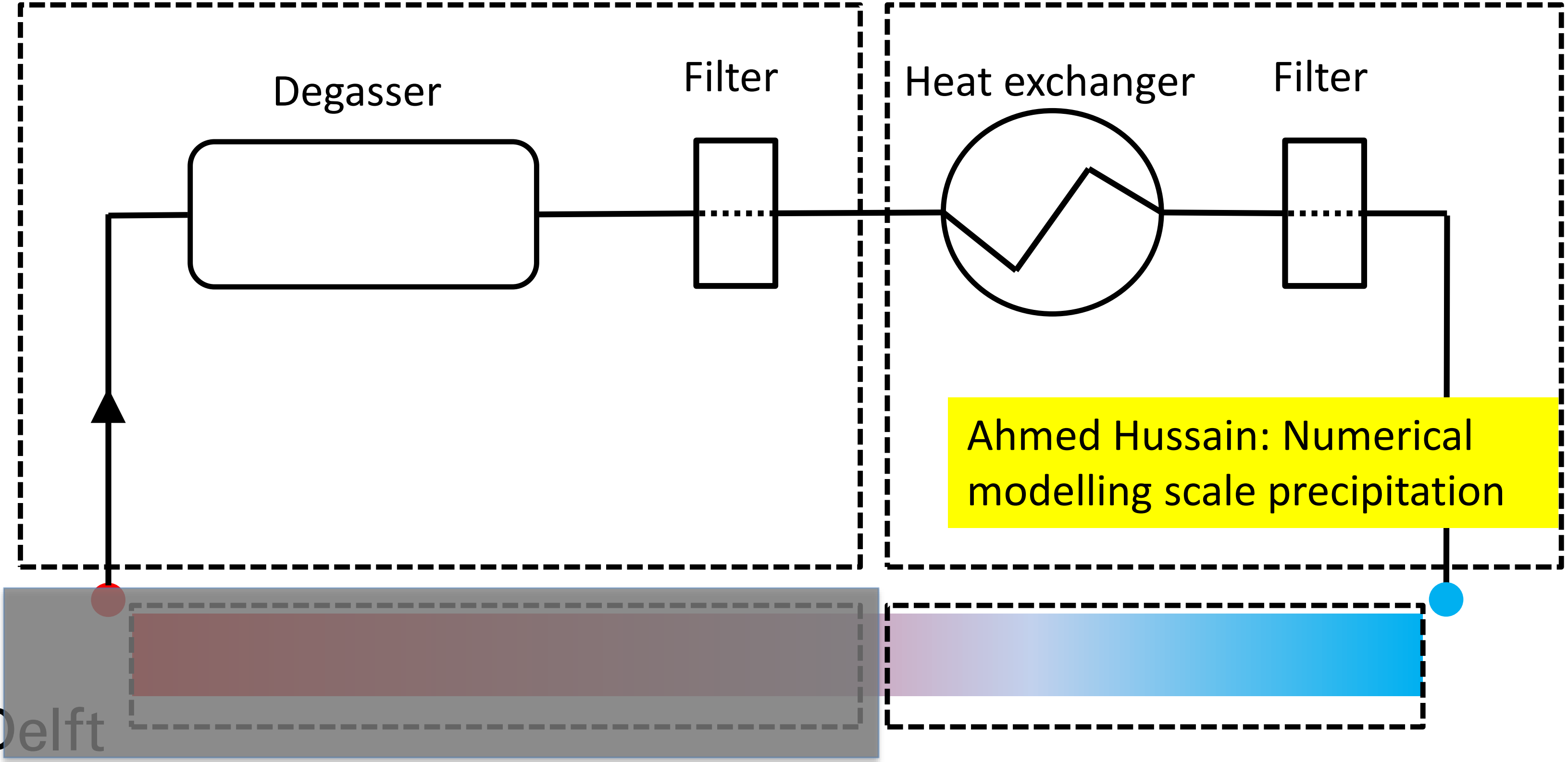

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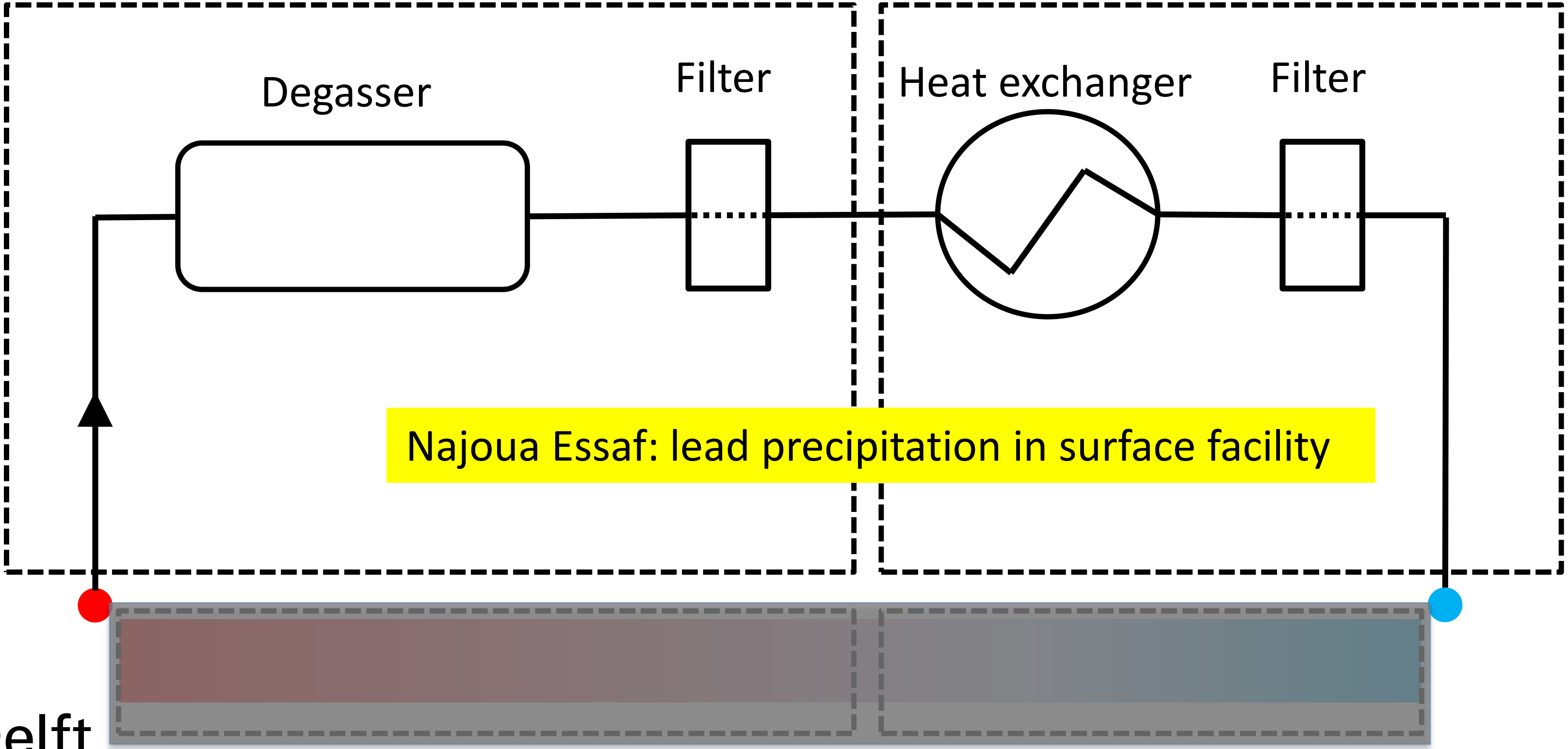
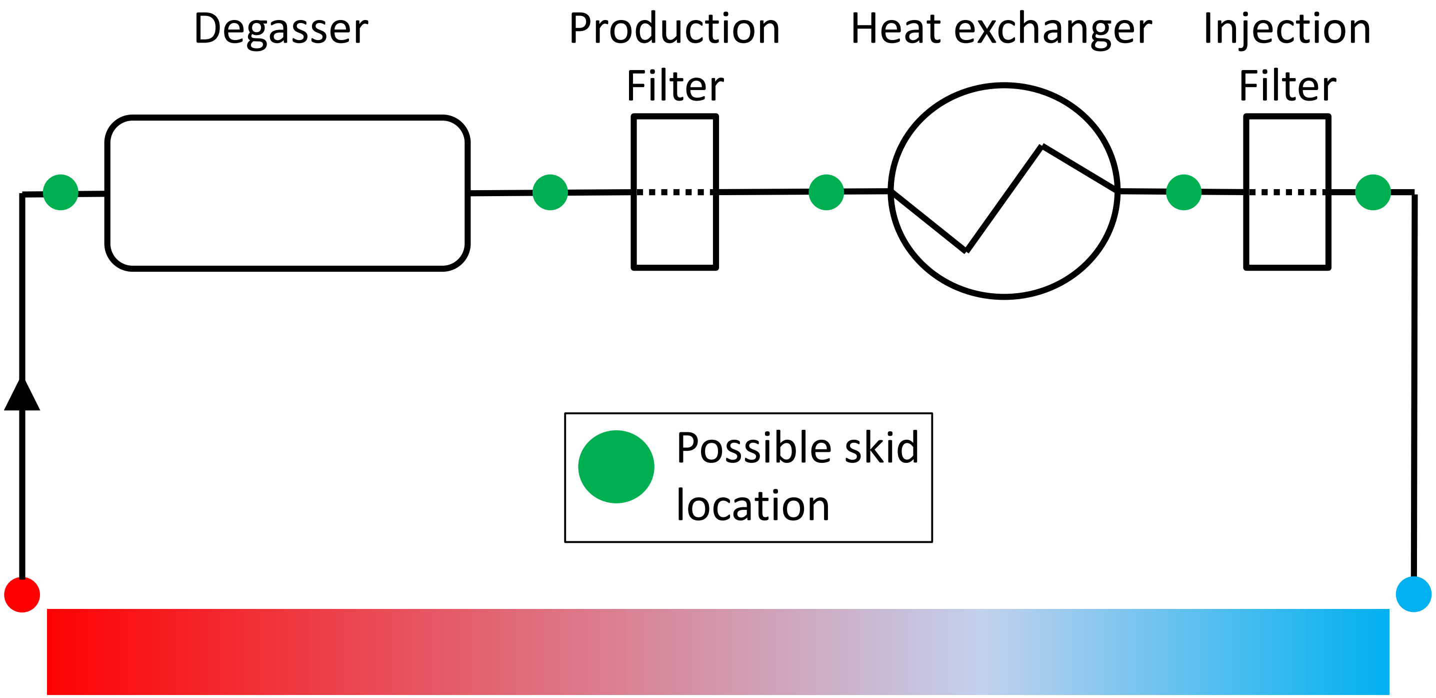


Scaling in geothermal projects: regions of interest



Numerically modelling: optimize for computation expense

- Three reaction speed categories:
  - ‘Slow’: can neglect reaction altogether
  - ‘Intermediate’: take into account reaction speed
  - ‘Fast’: can assume reaction occurs instantaneously

- Why categories: can reduce computation time → can consider more scaling reactions with practical simulation time.

Definitions of scaling reaction categories

Region of interest: 10m from injection-well

Injection well radius: 0.05m

- Slow
  - @ 10m from injection-well less than 1% of the total scaling has occurred
- Fast
  - @ 0.0005m from injection well more than 99% of the total scaling has occurred
- Intermediate
  - Between ‘Fast’ and ‘Slow’

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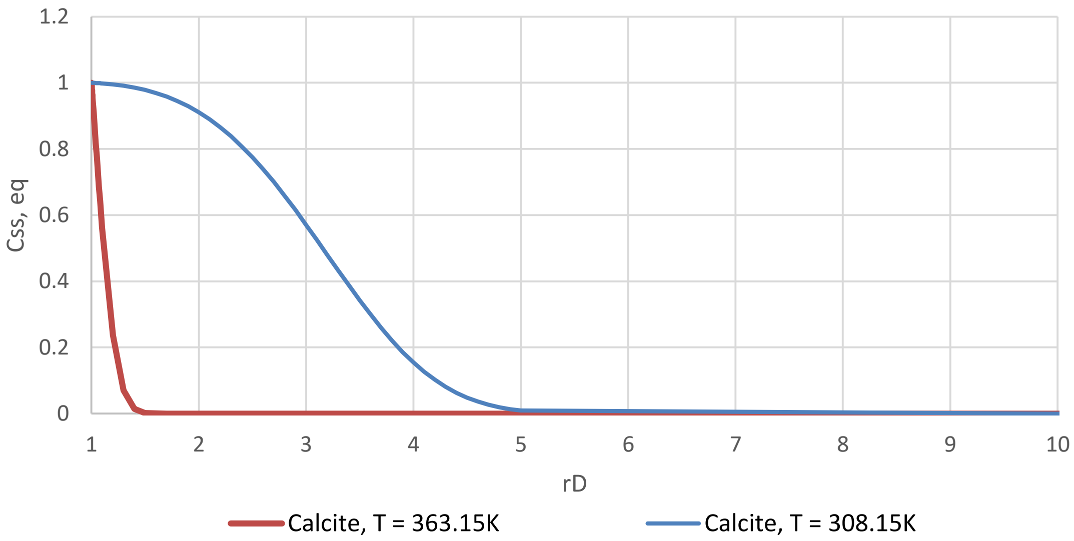
QC stage → compare simulation results to analytic solution

Example: injection of supersaturated calcite solution into reservoir

Calcium concentration vs r, both dimensionless

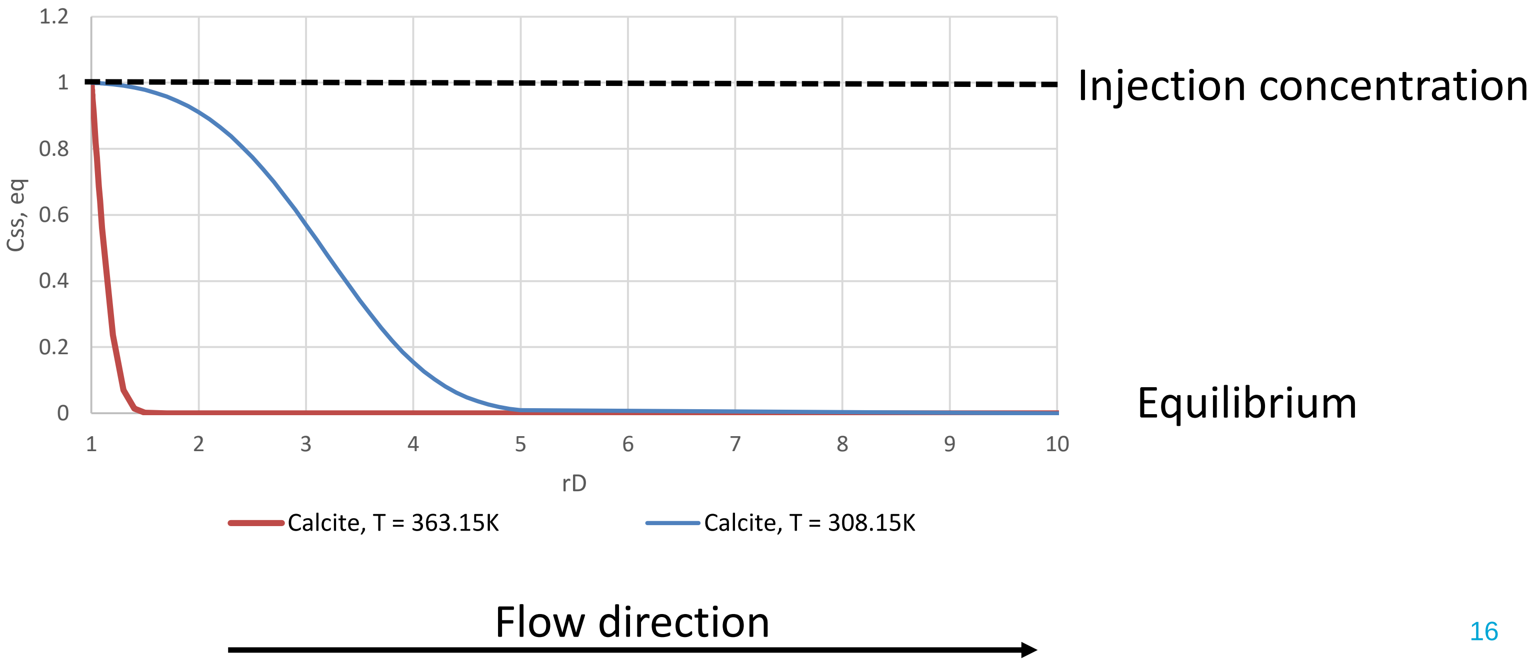


Flow direction

QC stage → compare simulation results to analytic solution

Example: injection of supersaturated calcite solution into reservoir

Calcium concentration vs r, both dimensionless



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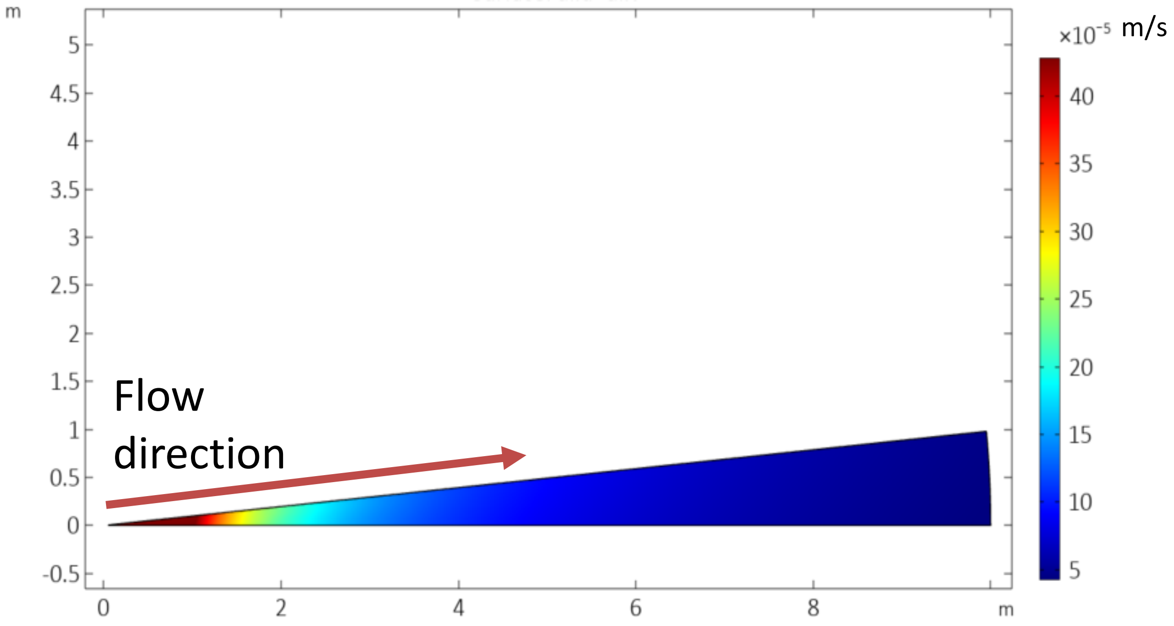
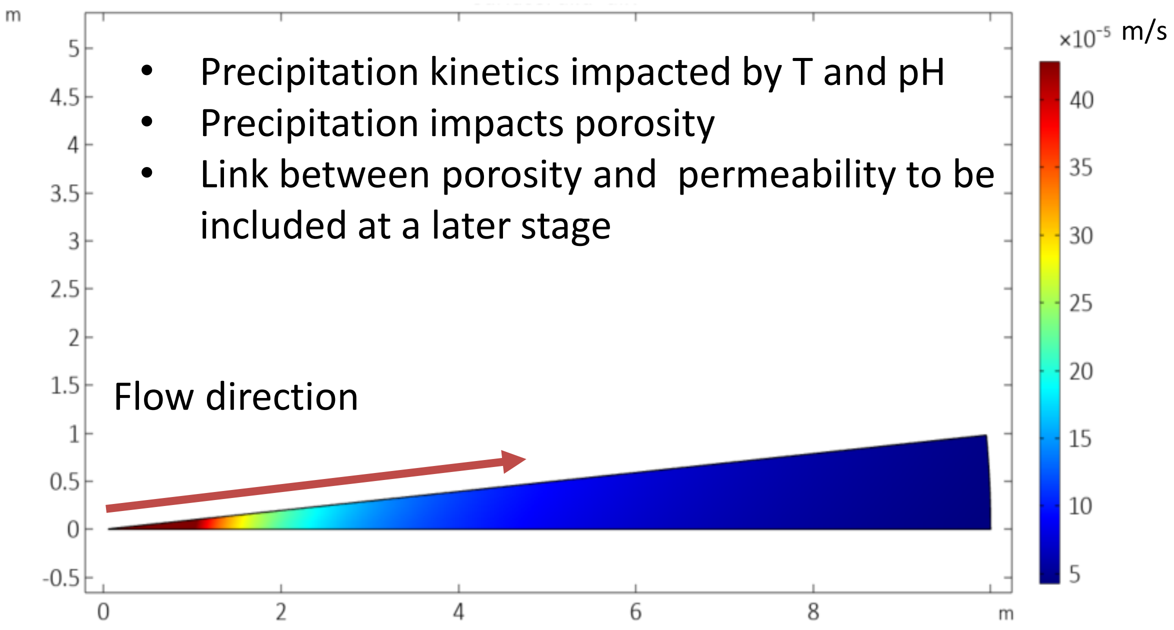
QC stage → compare simulation results to analytic solution
2D model, radial

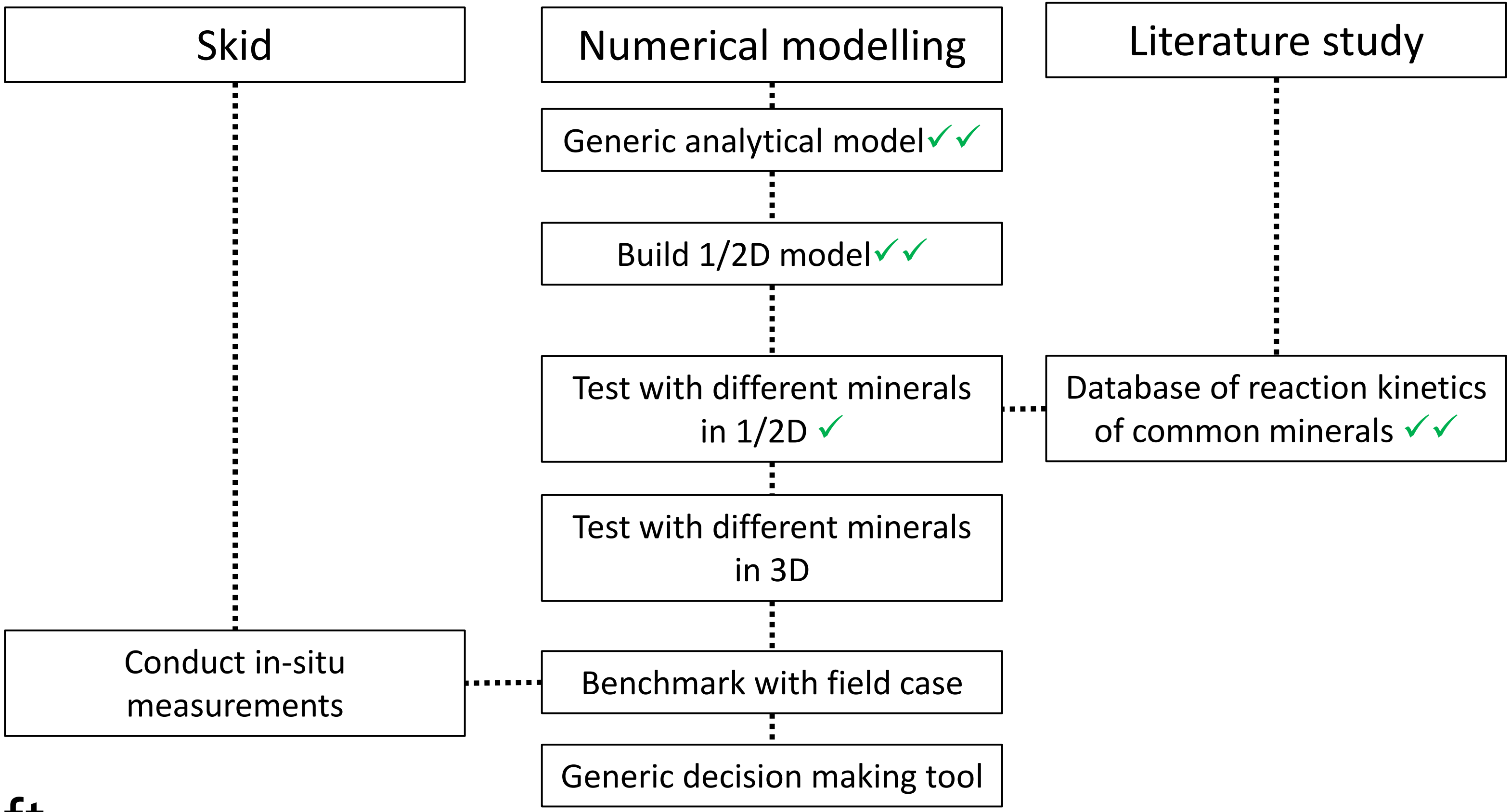


QC stage → compare simulation results to analytic solution 2D model, radial

- Precipitation kinetics impacted by T and pH
- Precipitation impacts porosity
- Link between porosity and permeability to be included at a later stage



Flowchart activities Ahmed



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3 - Deliverables from and progress in the WP’s

N. Essaf (TU Delft)

TUDelft

Rijksdienst voor Ondernemend Nederland

VEEGEO Geothermal Energy

DIMOPREC

Deltares

Lead scale in geothermal systems

Najoua Essaf
TU Delft - Master Geo-Energy Engineering
Veegeo

TU Delft

MSc research project

- Location: province South-Holland
- Installation description:
  - Synthetic material (GRE) for tubing/piping vs metal in other Dutch projects
- Scaling
  - More radioactive lead-210 scaling found than in other projects
  - No scaling inhibitor
- Aim of the research
  - Mitigation strategies for lead-210 scaling

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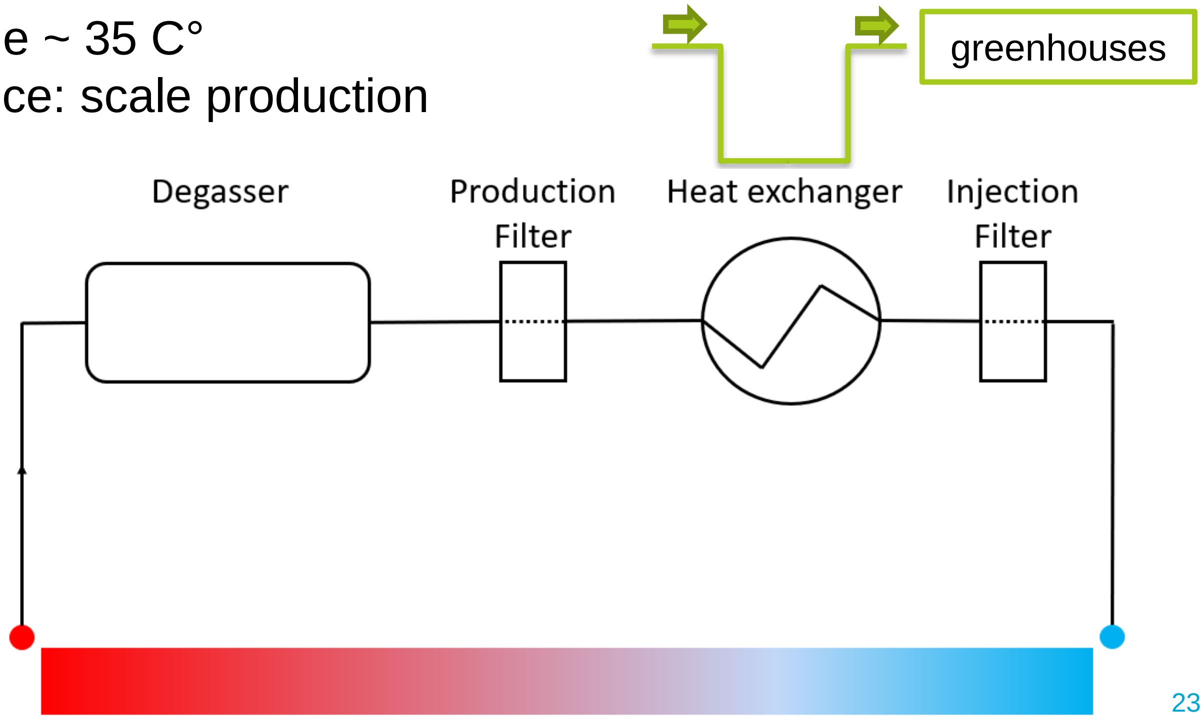
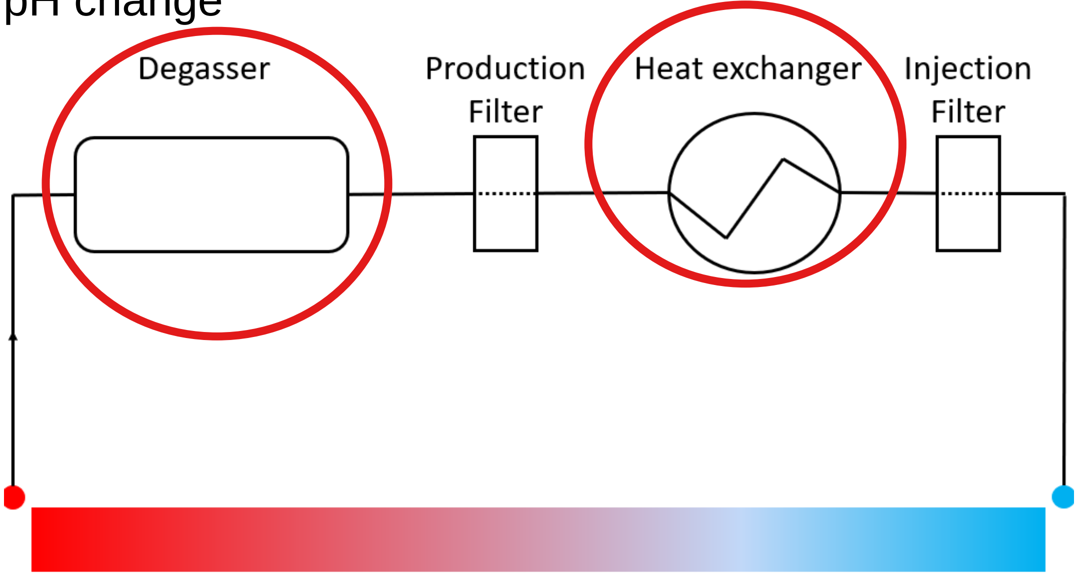
Schematic overview of the installation

- Heat used for greenhouses
- Hot brine ~87 C
- Cooled brine ~ 35 C°
- Consequence: scale production



Schematic overview of the installation

- Degasser
  - C_nH_n(~93%), CO_2(~5%), N_2(~2%) extraction
  - Pressure change
  - pH change
- Heat exchanger
  - Heat extraction from brine
  - T_{prod} 87 °C , T_{inj} 35 °C



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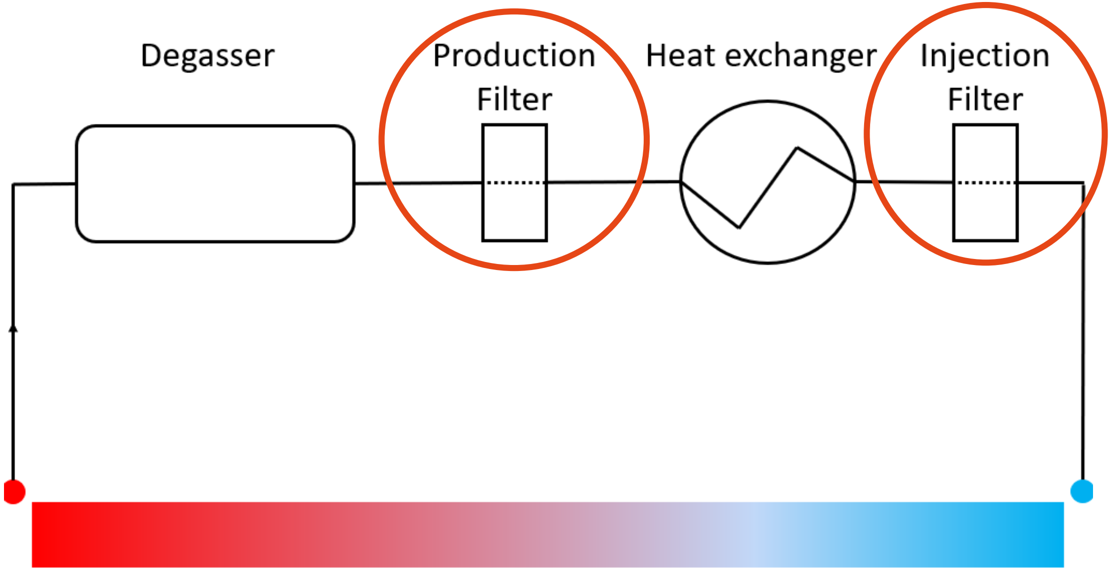
Schematic overview of the installation

- Through time fluctuation in production water composition
- Reason: Water originates from various parts of the reservoir rock
- Scale is captured at the production and injection filter
- Scale compositions from the different filters are mostly similar
- However, some mineral percentages may differ considerably



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Mineral scale composition at injection well

XRD analysis

Tabelle 1: Qualitativer und quantitativer Mineralphasenbestand [%].

		wt.%
Quarz	SiO_2	25,3
Magnesioferrit	Fe_2MgO_4	8,8
Hämatit	Fe_2O_3	1,7
Talk	$Mg_3(OH)_2(Si_4O_{10})$	3,5
Galenit	PbS	15,1
Blei	Pb	6,9
Fluorit	CaF_2	6,8
Halit	NaCl	5,7
Chalkopyrit	$CuFeS_2$	4,4
Lepidokrokit	FeO(OH)	8,3
Zink	Zn	2,0
Montetrisait	$Cu_6(SO_4)(OH)_{10}\cdot 2\ H_2O$	2,9
Goethit	FeO(OH)	6,8
Muskovit	$KAl_3(OH)_2Si_4O_{10}$	1,9

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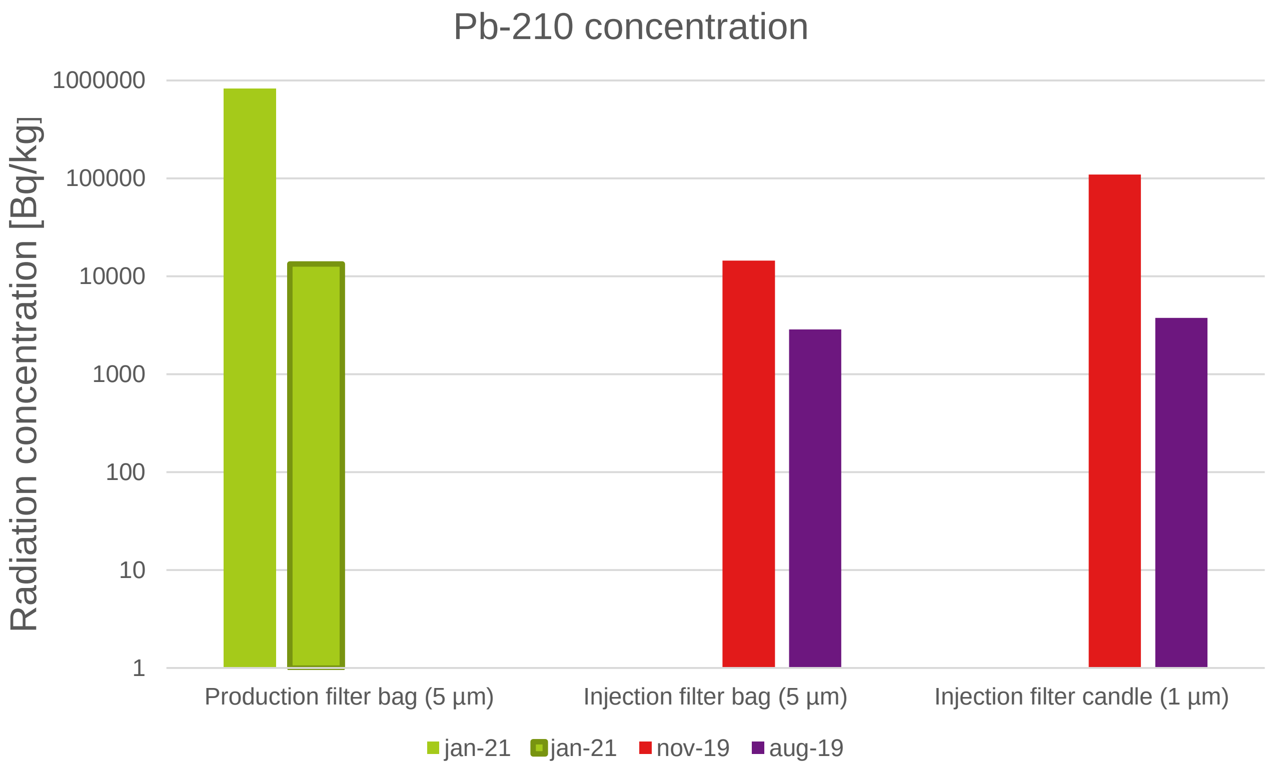
Lead concentration at different points in the facility



Flow chart

A. **Production filter-bag**: When lead scaling is mostly found at the production filter, it could be a result of changes in the degasser or upstream from the degasser (well / reservoir)

B. **Injection filter-bag:** When lead scaling is mostly found at the injection filter-bag, it could be a result of the heat exchanger or upstream (slower reaction)

C. **Injection filter-candle:** When lead scaling is mostly found at the injection filter-candle, it could be a result of the heat exchanger or upstream (slower reaction). The lead scaling could then consist of particles <5 µm and > 1 µm

D. **Different sections**: Having lead scaling evenly spread over the different sections within the installation can be (among other) caused by a slower reaction that forms gradually within the brine

- Mitigation strategies depend on the cause. Possible mitigation: 1) adding inhibitor, 2) control physical changes (p, T, Q) of the installation 3) other

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Done so far

- Data analyses
  - Filter data
  - Well logs (density, gamma ray, resistivity)
- Literature research
  - Paragenesis of lead carbonate and lead sulfate
  - Potential mineralization forms under changing pressure and temperature conditions
- Relating findings to the field of interest
- Flow chart

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Conclusions so far

- Lead-210 produced from reservoir
- Pressure, pH value and temperature can influence the reaction rate and solubility.
  - Both degasser and heat exchanger may be important for lead scaling

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Upcoming activities

- New measurements on pH value (including from skid)
- New analyses based on new filter data
  - Filters are placed and changed simultaneously → to exclude external factors (e.g., brine composition fluctuations over time or changes in process conditions)
- Modelling geochemical processes (PHREEQC) on the geothermal project to confirm conclusions are in line with theory

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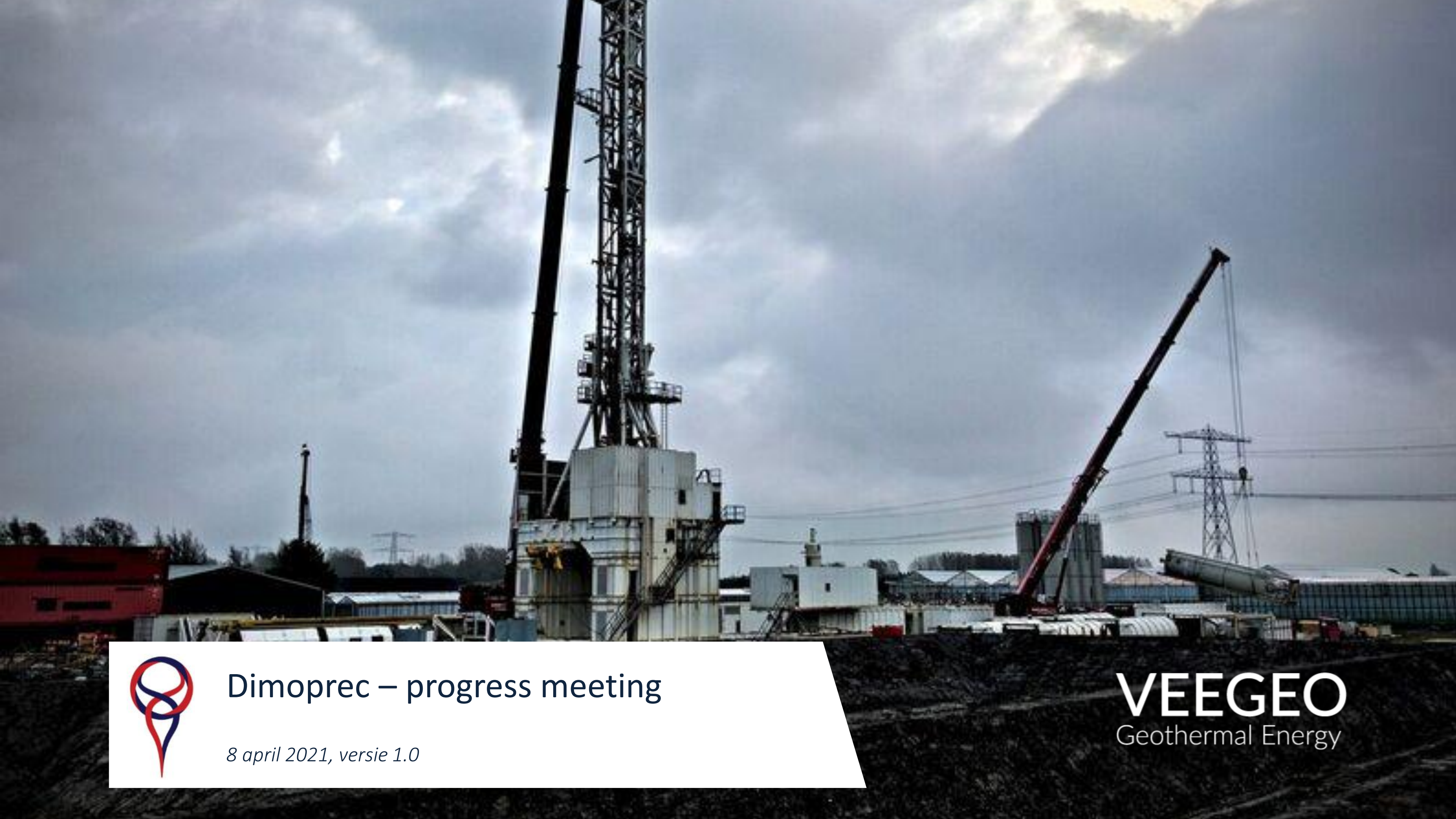
Questions?

3 - Deliverables from and progress in the WP’s

Veegeo

TU Delft



Dimoprec – progress meeting

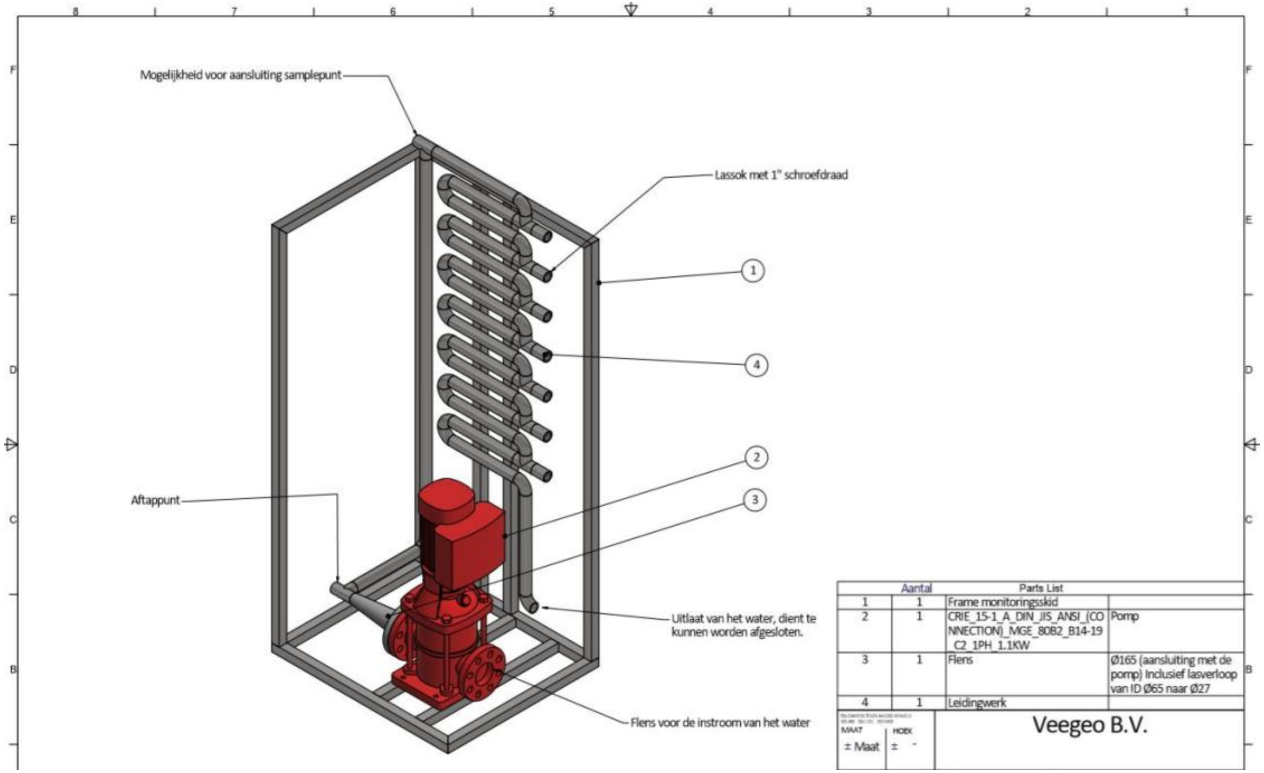
8 april 2021, versie 1.0

VEEGEO
Geothermal Energy

VEEGEO SKID

- The Veegeo SKID is a mobile sidestream for geochemical analyses
- One of its kind - specifically designed to test at geothermal facilities
- Geochemical analyses such as water tests, coupons, corrosivity etc.

Design and characteristics



	Aantal	Parts List	
1	1	Frame monitoringsskid	
2	1	CRIE_15-1_A_DIN_JIS_ANSI_(CONNECTION)_MGE_80B2_B14-19_C2_1PH_1.1KW	Pomp
3	1	Flens	Ø165 (aansluiting met de pomp) Inclusief lasverloop van ID Ø65 naar Ø27
4	1	Leidingwerk	

Design and characteristics

Design and characteristics

Progress so far

Fase	Progress
Design	*Completed*
RFQ	*Completed*
Building	*Completed*
Pressure tested	*Completed*
Transport to location	*Completed*
Choose point of connection	*Completed*
Connection to installation	*50 %*
Basic field test	*0 %*

Next steps

- Finish installation and calibration at location
- Basic field test
- Model result field test design (planned to start in autumn):
  - What are the model results?
  - What do we verify?
    - Coupling of model and field measurements; specifications
    - Organisation of skid field-data acquisition, comparison of fluid and mineral analysis vs model results

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Geothermal Energy

www.veegeo.nl

4 - Impact of COVID/change of schedules

Covid-19 related reasons:

- **Illness:** personal experience with COVID-19 resulted in absence for some time and concentration problems the period afterwards.
- **Laptop**: longer delivery time for laptop: laptop arrived 3 months after start of project. Could not work properly on my old personal laptop.
- **Field access**: very limited access to geothermal fields: cannot collect samples, investigate facilities nor investigate practical limitation.
- **COVID- connection problems**: must conduct simulations with a VPN network license: cannot reliably conduct modelling work overnight due to disconnection of VPN after some hours. Therefore, only simulations during day time, limiting modelling efficiency.

Total delay: circa three months

4 - Impact of COVID/change of schedules

Work package descriptions	Total PM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
		1st Year													2nd Year														Final reporting
		Project Months						Lost time estimates									Lost time estimates									Lost time estimates			
		1	2	3	4	5	6		7	8	9	10	11	12	13	14		15	16	17	18	19	20	21	22		23	24	25
WP 1 Screening and Realization of selected Dutch geothermal doublets	6.0								M1									M2									M3		M4
Task 1,a: Evaluation and screening	3.2	0.3	0.6	0.6	0.6	0.3		0.6		Do what is possible							0.2												D
						D			D1a																				
Task 1,b: Statically quantification of relevant kinetic data	4.2			0.3	0.6	0.6	0.6	0.1	0.6	0.6	0.3	Do what is possible					0.5												D
	total wp										D							D1.b											
WP 2 Full-scale modelling, workflow and quantifying	9.7																												
Task 2,a: Model based quantitative criteria	3.2					0.5	0.6	0.4	0.6	0.6	0.3	Do what is possible					0.2												D
											D							D2a											
Task 2,b: Full-scale model & workflow	8.1						0.2	0.0	0.2	0.3	0.6	0.6	0.6	0.6	0.6	0.6	1.0	0.6	0.6	0.6	0.3	0.3	0.2	0.2		?			D
	total wp															D								D			D2b		
WP 3 Assessing and quantifying a demonstration and implementation framework for Dutch geothermal reservoirs	13.7																												
Task 3,a: Case studies for test and validation	4.6										0.1		0.1		0.1	0.5	?	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.3	?			D
																									D		D3a		
Task 3,b: Derivation of generic decision-making tool and workflow	4.5										0.1		0.1		0.5	0.5	?	0.5	0.5	0.5	0.5	0.5	0.5	0.3		?			D
																								D			D3b		
Task 3,c: Development of a corrosion skid specific for testing	4.6															0.3	?	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	?	0.3		D
	total wp																								D		D3c		
WP 4 Project management, coordination and dissemination	1.6																												
Task 4,a: Project coordination	0.9	0.1		0.1			0.1	0.0			0.1			0.1			0.0	0.1			0.1			0.1		0.0		0.1	D
Task 4,b: Project management and control	0.4			0.1							0.1						0.0	0.1										0.1	D
Task 4,c: Dissemination	0.3													0.1							0.1					0.0		0.1	D
	total wp																0.0												
TOTAL Person-months revised	59.0	0.4	0.6	1.1	1.2	1.4	1.5	1.1	1.4	1.5	1.6	0.6	0.8	0.8	1.2	1.9	1.9	2.3	2.1	2.1	2.0	1.8	1.7	1.6	0.8		0.3	0.3	
TOTAL Person-months original	56	Project Months																											
Reporting		1	2	3	4	5	6		7	8	9	10	11	12	13	14		15	16	17	18	19	20	21	22		23	24	26
									Meeting									Meeting									Meeting		

5 - Cooperation between the partners

- Weekly meeting regarding progress and administration
  - K-H. Wolf
  - A. Hussain

- Weekly meeting regarding progress MSc project Najoua Essaf and available field data from Veegeo:
  - K-H. Wolf
  - H. Claringbould
  - A. Reerink
  - N. Essaf
  - A. Hussain

- Bi-weekly meeting regarding the modelling work between Deltares and TU Delft. Attendance:
  - B. Meulenbroek
  - W. Van der Star
  - N. Khoshnevis
  - A. Hussain

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6 - Recent/upcoming dissemination

- **Presentation at EGU 2021 (April 28th)**:

Modelling Mineral-Scaling in Geothermal Reservoirs Using Both a Local Equilibrium and a Kinetics Approach

Hussain, A., Khoshnevis, N., Meulenbroek, B., Van der Star, W., Bruining, H., Claringbould, J., Reerink, A., and Wolf, K.-H.: Modelling Mineral-Scaling in Geothermal Reservoirs Using Both a Local Equilibrium and a Kinetics Approach, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-16033, https://doi.org/10.5194/egusphere-egu21-16033, 2021.

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7 - AOB

Back-up slides

Numerically modelling: optimize for expensive

- Different methods of modelling scaling:
  - Kinetic approach (KA)
    - Takes into account the reaction speed
    - (Pro) Closest to reality
    - (Con) Numerically expensive

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Numerically modelling: optimize for expensive

- Different methods of modelling scaling:
  - Kinetic approach (KA)
    - Takes into account the reaction speed
    - (Pro) Closest to reality
    - (Con) Numerically expensive
  - Local equilibrium approach (LEA)
    - Assumes reaction occurs immediately
    - (Pro) Numerically less expensive
    - (Con) Does not take into account reaction speed
  - Neglect

Numerically modelling: optimize for expensive

- Different methods of modelling scaling:
  - Kinetic approach (KA)
    - Takes into account the reaction speed
    - (Pro) Closest to reality
    - (Con) Numerically expensive
  - Local equilibrium approach (LEA)
  - Neglect

Back-up slides Najoua

Different scale composition / lead concentration at different points in the facility

Production filter

Reference date: 07 January 2021

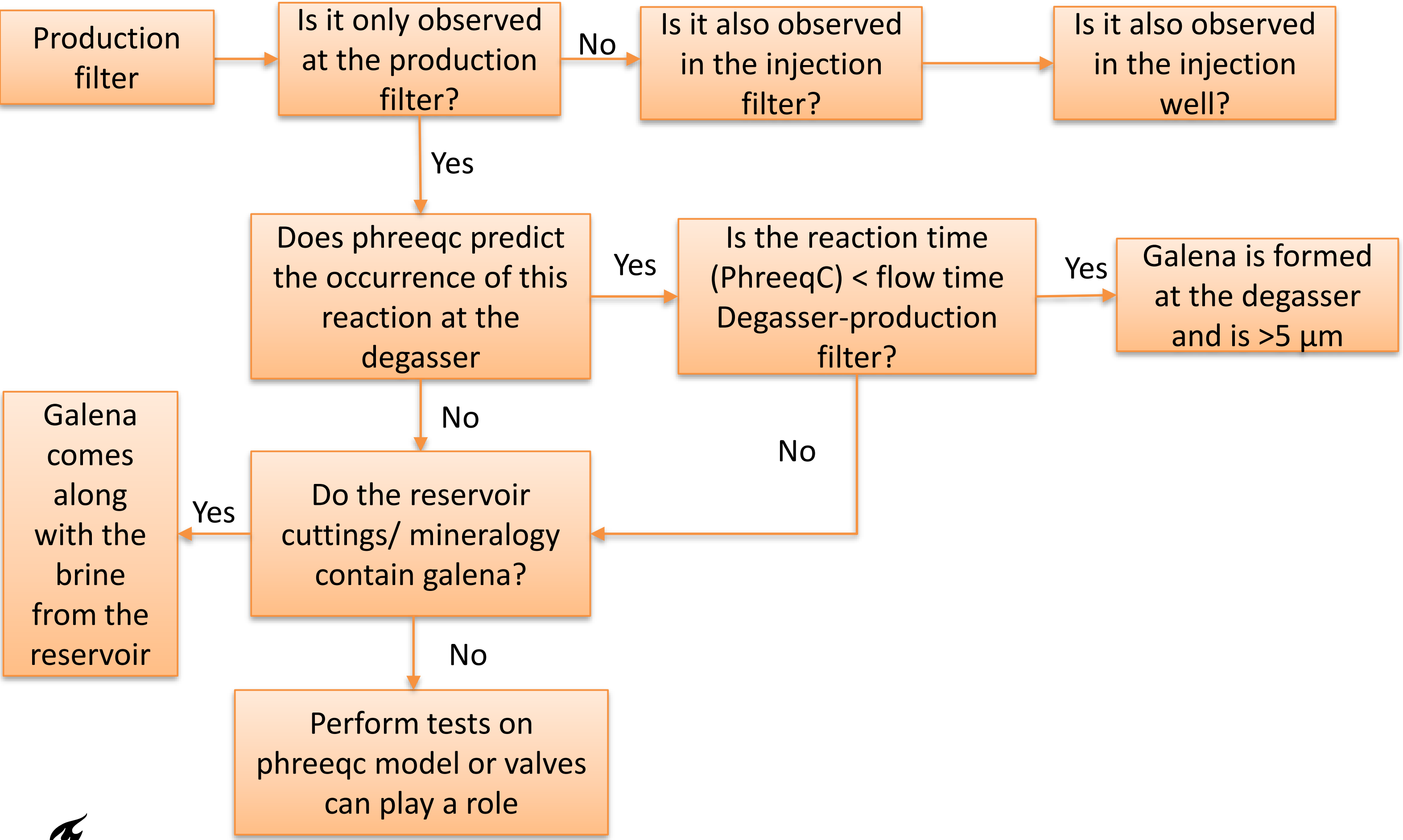
Analytical results			No. 1		No. 2	
Name of the sample			CPM 525		CPM 188	
Specification			Zakkenfilter		Zakkenfilter	
Nuclide		Units	Result	U [%]	Result	U [%]
U-238-series						
U-238	γ	Bq/kg	< 107	-	< 28	-
Ra-226	γ	Bq/kg	211	30	70	30
Pb-210	γ	Bq/kg	820000	19	13300	23
U-235-series						
U-235	γ	Bq/kg	< 13	-	< 4,5	-
Th-232-series						
Ra-228	γ	Bq/kg	154	17	43	46
Th-228	γ	Bq/kg	604	10	432	10
Further Radionuclides						
K-40	γ	Bq/kg	< 60	-	126	60
Physical parameters						
Dry matter		%	49,1		86,2	
Dry Mass		g	13,39		8,744	
Measured Time		s	49485		48718	
Further parameters						
Geometry		ml	135		75	
Diameter		mm	90		76	
Detector Brand			Canberra		Canberra	
Detector Type			n		n	

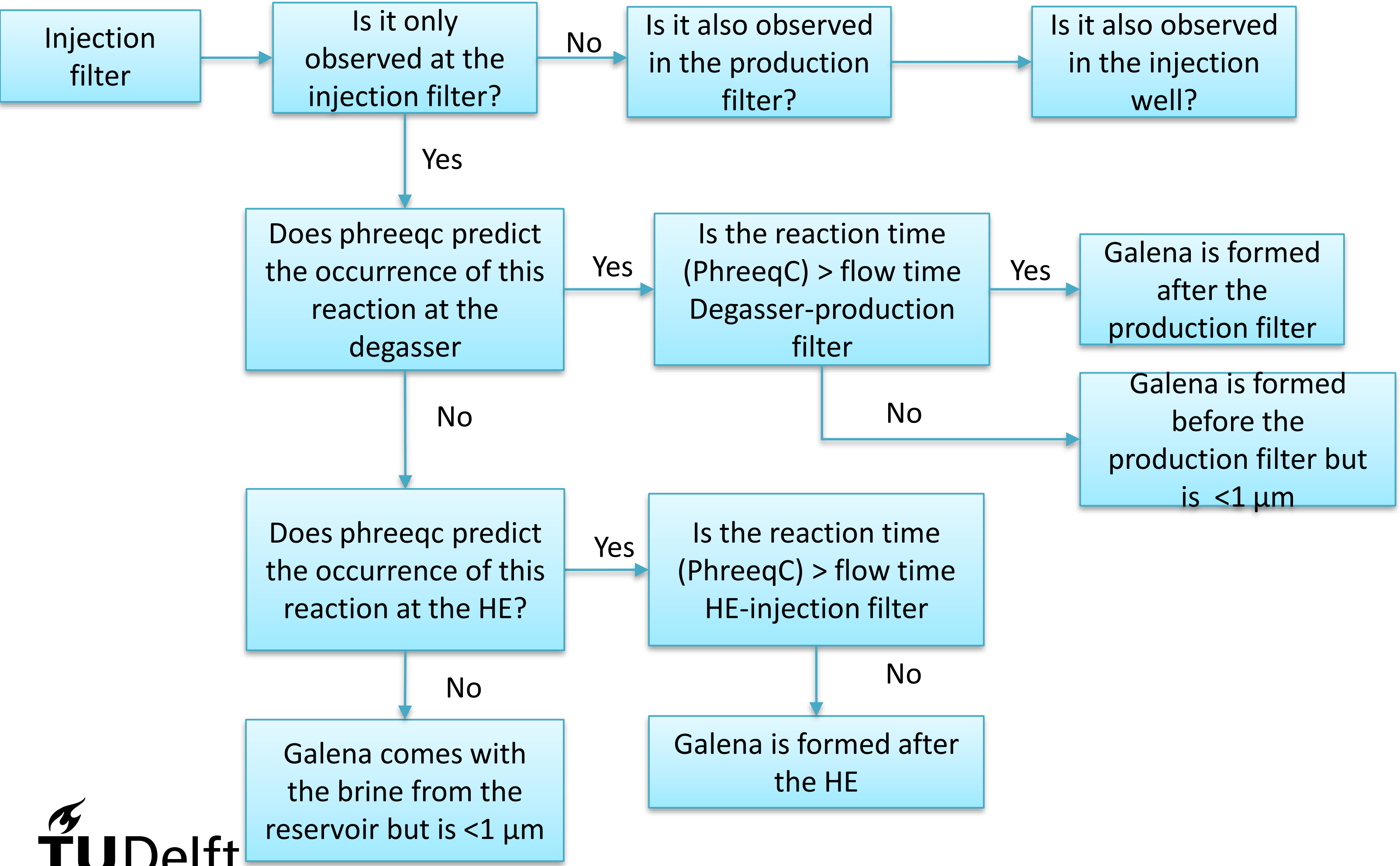
Injection filter

Reference date: 26 November 2019

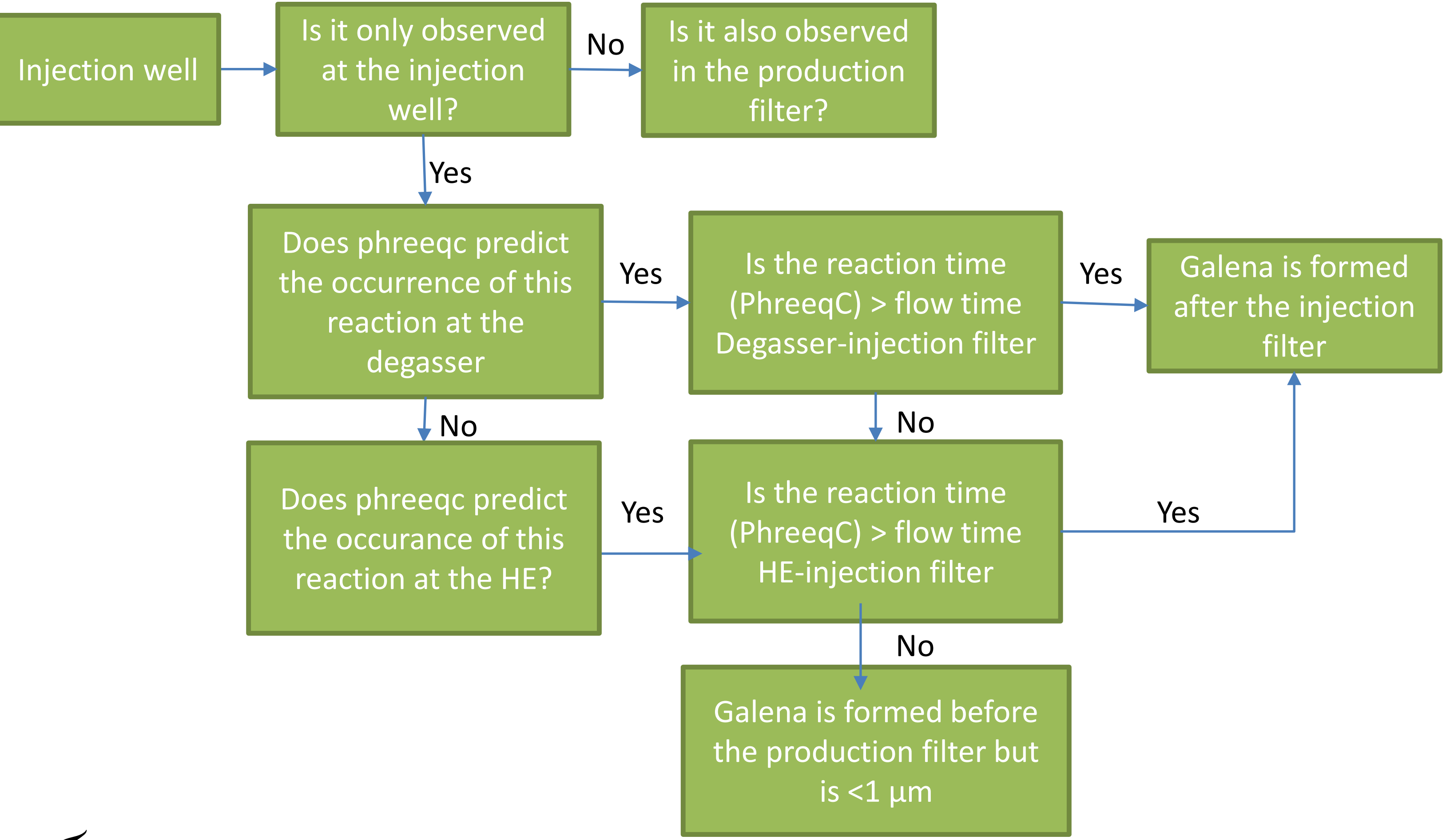
Analytical results			No. 1		No. 2		No. 3	
Specification			Zakkenfilter 800 CPM		Kaarsfilter 800 CPM		Vloeistof injectietubing 100 CPM	
Nuclide		Units	Result	U [%]	Result	U [%]	Result	U [%]
U-238-series								
U-238	γ	Bq/kg	< 10	-	< 51	-	< 97	-
Ra-226	γ	Bq/kg	27	30	183	60	261	50
Pb-210	γ	Bq/kg	14400	20	109000	20	190000	15
U-235-series								
U-235	γ	Bq/kg	< 1,2	-	< 7,1	-	< 7,6	-
Th-232-series								
Ra-228	γ	Bq/kg	32	17	120	22	173	31
Th-228	γ	Bq/kg	50	12	170	14	78	26
Further Radionuclides								
K-40	γ	Bq/kg	44	50	< 138	-	< 323	-
Physical parameters								
Dry matter		%	24		97		8,4	
Dry mass		g	28,780		3,92		0,81	
Measured Time		s	63177		65967		47801	
Further parameters								
Geometry		ml	FIL		135		75	
Diameter		mm	49		90		74	
Detector Brand			Canberra		Canberra		Canberra	
Detector Type			n		n		n	

TU Delft


Production filter
Is it only observed at the production filter?
No
Is it also observed in the injection filter?
Is it also observed in the injection well?
Yes
Does phreeqc predict the occurrence of this reaction at the degasser
Yes
Is the reaction time (PhreeqC) < flow time Degasser-production filter?
Yes
Galena is formed at the degasser and is >5 µm
No
No
Galena comes along with the brine from the reservoir
Yes
Do the reservoir cuttings/ mineralogy contain galena?
No
Perform tests on phreeqc model or valves can play a role


Injection filter
Is it only observed at the injection filter?
No
Is it also observed in the production filter?
Is it also observed in the injection well?
Yes
Does phreeqc predict the occurrence of this reaction at the degasser
Yes
Is the reaction time (PhreeqC) > flow time Degasser-production filter
Yes
Galena is formed after the production filter
No
Galena is formed before the production filter but is <1 μm
No
Does phreeqc predict the occurrence of this reaction at the HE?
Yes
Is the reaction time (PhreeqC) > flow time HE-injection filter
No
Galena is formed after the HE
No
Galena comes with the brine from the reservoir but is <1 μm

TU Delft


Injection well
Is it only observed at the injection well?
No
Is it also observed in the production filter?
Yes
Does phreeqc predict the occurrence of this reaction at the degasser
Yes
Is the reaction time (PhreeqC) > flow time Degasser-injection filter
Yes
Galena is formed after the injection filter
No
No
Does phreeqc predict the occurance of this reaction at the HE?
Yes
Is the reaction time (PhreeqC) > flow time HE-injection filter
Yes
No
Galena is formed before the production filter but is <1 µm