WP3 : Low-T Geothermal Source

MATChING
MATERIALS & TECHNOLOGIES FOR PERFORMANCE IMPROVEMENT OF COOLING SYSTEMS IN POWER PLANTS

3.1. Coatings for geothermal pipes

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HORIZON 2020

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T3.1 Coating demonstration for low T geothermal Source

Subtask 3.1.1 Coatings and base material selection and optimization.

- Definition of relevant combinations substrates/coatings (also surface treatments if necessary).

Subtask 3.1.2 Laboratory testing

- Selection of the coating candidates to be tested at Balmatt´s facility. (Coatings, susbtrates, application procedure)

Subtask 3.1.3 Demonstration and on-site evaluation of the selected coatings

- Testing at Balmatt´s facility

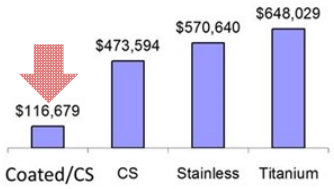
WP3. Hybrid cooling systems for Low-T geothermal source

T3.1 Coating demonstration for low T geothermal Source

Objective

To reduce the installation costs, we investigate the **application of coatings for upgrading the corrosion resistance of carbon steel and AISI 316L** in place of expensive, corrosion resistant alloys.

Material Group	Tested Metals	PRE %	Cost (relative to steel)
Carbon steel	P265G, P235G, P110, L80, N80	-	1
Stainless steels & Alloys	316L	27	8.3
	318LN	34	7.1
	904L (Super austenitic)	36	19.4
	2507 (Duplex)	41	12.6
	Alloy 31 (Super-Duplex)	52	33
Titanium	Grade 2: 99.9%Ti	-	16.2



Estimated life cycle cost

As alternative for the high alloying materials in MATChING we selected CS P265G and SS AISI 316L

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• The Mock-up test designed at DTI, is based on the NACE TM0185, ASTM G111-97 and ASTM E 1068-85, and simulate the operational conditions at the Balmatt site (test duration 540 h).

Initial Characterization (adhesion, rusting, blistering) → **Mock up (540 h)** → After LOTU characterization (adhesion, rusting, blistering) → Preliminary validation: ISO 2409:2007 (adhesion), ASTM D714-02 (blistering), ISO 4628-3 (rusting)

Fail → Discarded

Pass → **Electrochemical Impedance Spectroscopy**
- Electrolyte permeation
- Coating deffectivenes
- Substrate corrosion

	LOTU (mock-up)	In situ Balmatt	
Temperature	130 °C	125-130 °C	
Pressure	30-40 bars	~40 bars	
Media	Synthetic brine	Balmatt brine	
Partial pressure of CO_2	-	CO_2 in the gas mixture	76,5 Vol. %
pH	5.55	~5.50	
Stirring	600 rpm	Flow rate	100-200 $m^3 h^{-1}$
Exposure time	~24 days (570h)	Flow velocity	1 $m s^{-1}$

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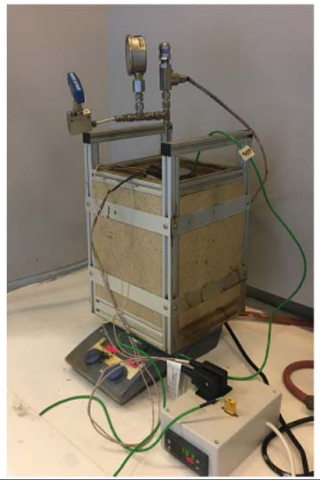
T3.1 Coating demonstration for low T geothermal Source

Laboratory testing, Mock-up (LOTU)



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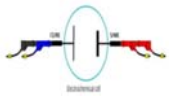
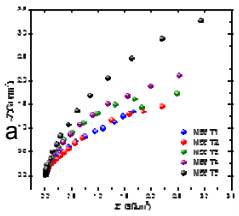
Coating validation by EIS

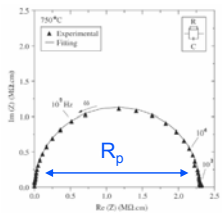
By EIS, The protective performance of the coatings is commonly assessed by estimating the **polarization resistance (Rp).**

Depending on the Rp value, the protective character of the coatings can be ranked as:



R_p >10^8 Ω·cm² excellent protection without noticeable penetration of electrolyte.
R_p 10^7-10^8 Ω·cm² good protection minimal electrolyte absorption.
R_p 10^6-10^7 Ω·cm² doubtful, the electrolyte creates a path the metal surface but there is not active corrosion yet
R_p <10^6 Ω·cm² poor, the coating is non protective,





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Coatings on stainless steel (AISI 316L)

ID	t_1						t_5						Corrosion resistance
	R_1 ($M\Omega cm^2$)	C_1 ($nFcm^{-2}$)	R_2 ($M\Omega cm^2$)	C_2 ($nFcm^{-2}$)	Z_ω ($M\Omega cm^2$)	R_p ($M\Omega cm^2$)	R_1 ($M\Omega cm^2$)	C_1 ($nFcm^{-2}$)	R_2 ($M\Omega cm^2$)	C_2 (μFcm^{-2})	Z_ω ($M\Omega cm^2$)	R_p ($M\Omega cm^2$)	
1	0.50	0.35	8.10	27.48		8.60	0.50	0.43	9.1	66.32		9.6	Poor
2	13057	0.13				13057	247700	0.14				247700	Excellent
3	73053	0.12				73053	68900	0.12				68900	Excellent
4	1900	0.13				1900	600	0.14				600	Good
5	5700	0.13				5700	5700	0.13				5700	Good
7	0.01	0.89	0.13	5.98	1.04	0.14	0.01	0.93	0.27	10.7	6.21	0.28	Poor
8	1096×10^3	0.21				1096×10^3	1096×10^3	0.22				1096×10^3	Excellent
9	2.58	0.26	420	89.7		422.58	2.21	0.25	410	41.5		412.21	Doubtful
10	0.63	0.54	15.40	5.19		16.03	0.53	4.68	0.02	703.97		0.55	Poor
11	0.68	0.55				0.68	0.06	0.62	0.26	354		0.32	Poor
12	0.06	0.24	0.55	387		0.61	0.01	0.27	0.04	1.06		0.05	Poor
REF	866×10^{-6}	1220	0.002	5.91		0.002	915×10^{-6}	2310	0.002	17.3		0.002	-

Coatings on CS

ID	t_1						t_5						Corrosion resistance
	R_1 ($M\Omega cm^2$)	C_1 ($nFcm^{-2}$)	R_2 ($M\Omega cm^2$)	C_2 ($nFcm^{-2}$)	Z_ω ($M\Omega cm^2$)	R_p ($M\Omega cm^2$)	R_1 ($M\Omega cm^2$)	C_1 ($nFcm^{-2}$)	R_2 ($M\Omega cm^2$)	C_2 (μFcm^{-2})	Z_ω ($M\Omega cm^2$)	R_p ($M\Omega cm^2$)	
4 (M44)	98100	0.08				98100	99000	0.08				99000	Excellent
6 (M45)	1300	0.03				1300	2320	0.04				2320	Good
10 (M46)	5.45	0.47	157	3.37		162	0.27	1.27	1.39	1.80		1.66	Doubtful
12 (M48)	0.03	0.52	0.66	22700		0.69	0.02	0.59	0.19	9.56		0.02	Poor
13 (M49)	10200	0.12				10200	7050	0.13				7050	Good
REF	38×10^{-6}	20600	0.002	195000		38×10^{-6}	33×10^{-6}	23800	0.003	428		33×10^{-6}	-

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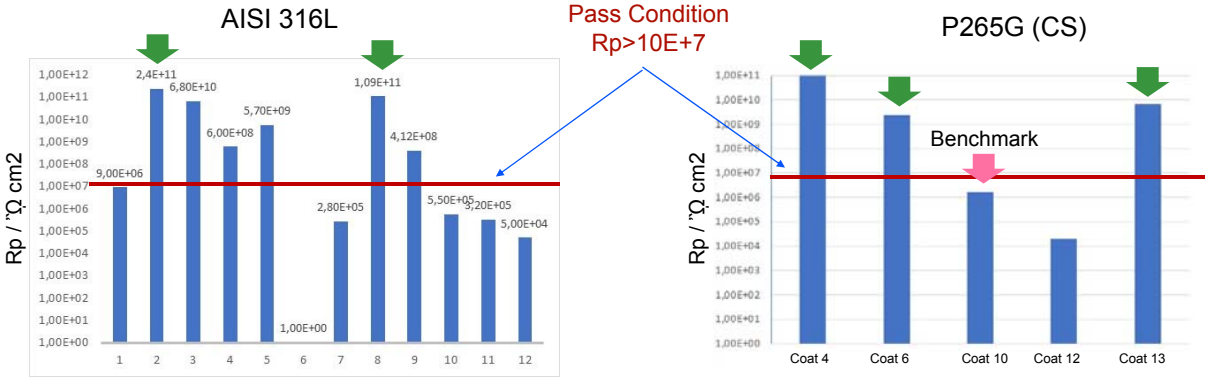

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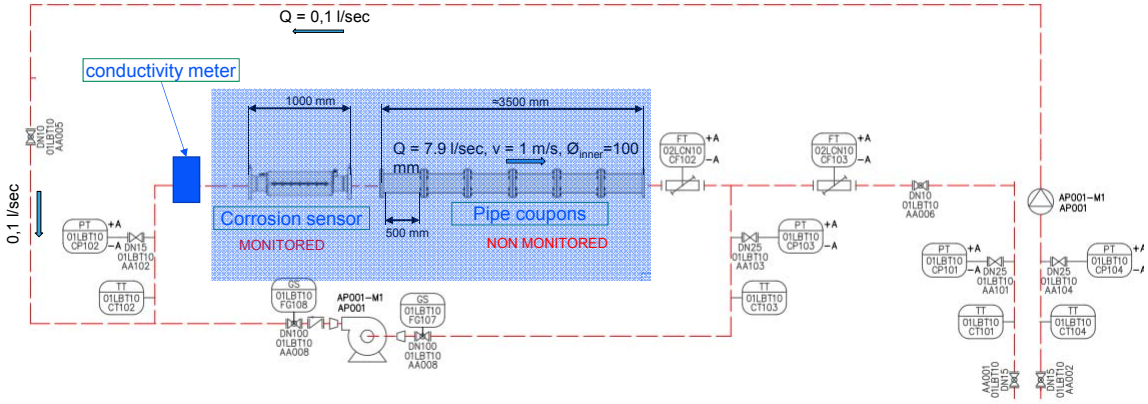
Demonstration and on site evaluation of the selected coatings

In total 6 coatings will be evaluated (2 on stainless steel and 4 on carbon steel)



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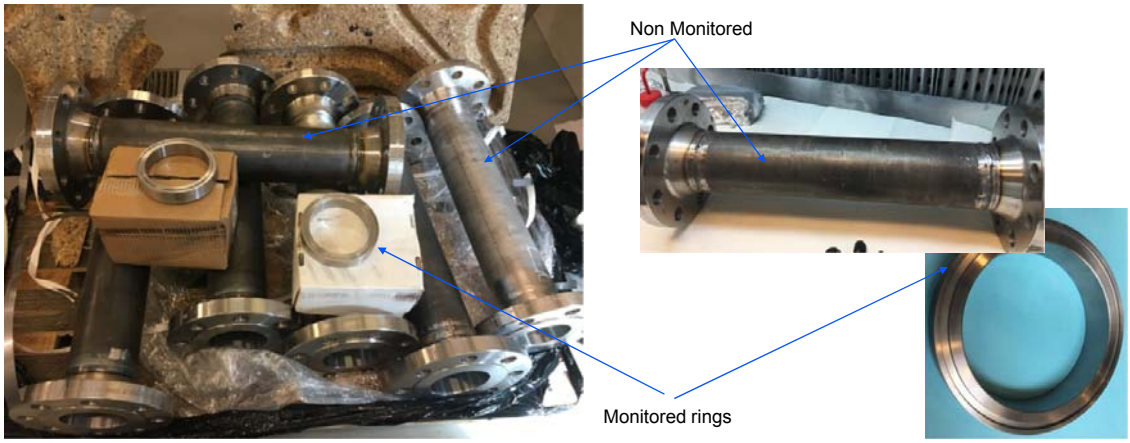

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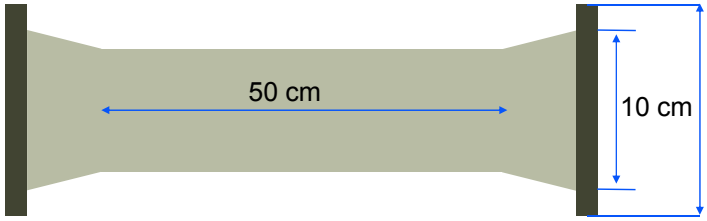
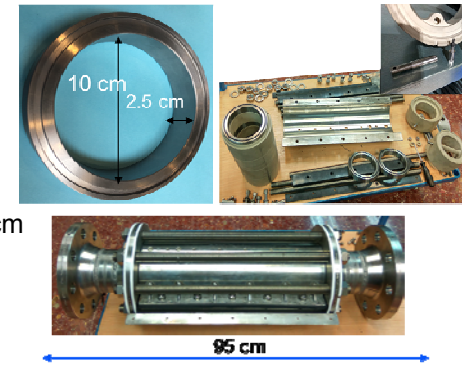
T3.1 Coating demonstration for low T geothermal Source

Sections for Demonstration

Long tube dimensions (non monitored section)



Monitored sections



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Long Sections

Coatings 8, 4, 6 and 10 were applied at the coatings manufacturers facilities according to their specific procedures.
Coating 2 and 13 were applied at DTI by spray application (monitored sections) and by flushing (non monitored sections). Coatings 2 and 13 are comprised on different coating layer, per each coating layer the mixing ratios, dilution viscosity, curing time and temperatures were followed as per product specifications.

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Monitored Sections

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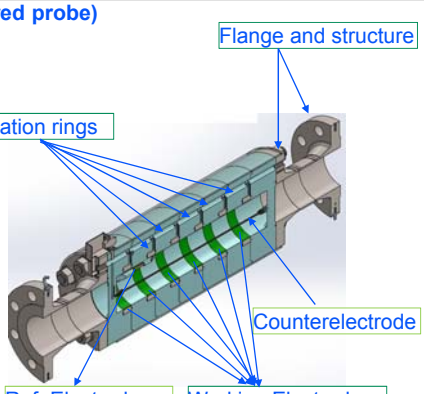
Monitored Sections

Design of the corrosion sensor (monitored probe)



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- Active sensor with on-line electrochemical measurements
- Inner diameter 100 mm
- Materials:
  - 4 working electrodes on CS and 2 on 316L
  - ID coated
  - Flanges and structure: AISI 316.
  - Isolation rings: PEEK
  - Auxiliary electrodes: platinized titanium

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Laboratory testing of the monitored probe for insitu coating testing by EIS

Requirements for Balmatt installation:

Location requisites:
- Max 10 meters from the sensor.
- Ambient temperature below 30ºC
- Avoid direct impact of the sun
-Flat surface 1 x 1 meter to deploy the unit

Internet:
- Ethernet connection (RJ45) with access to internet

Test includes:
1. Tightness of the probe under pressure and temperature
2. Verification of electrical connections welds quality, shortcircuits avoidance.
3. Electrochemical measurements (possible artifacts, electrodes response)

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Long Sections

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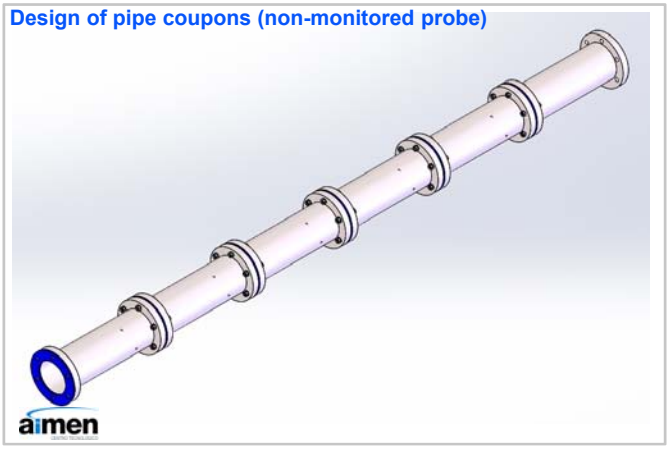
Demonstration and on site evaluation of the selected coatings

Design of pipe coupons (non-monitored probe)



- Independent tube sections 500mm long
- Inner diameter: 100 mm
- Materials (6):
  - 4 tubes on CS and 2 on AISI 316L.
  - ID coated (same coatings as for the monitored section)
- No on-line measurements implemented. Analysis of the coatings at the end of the experiment

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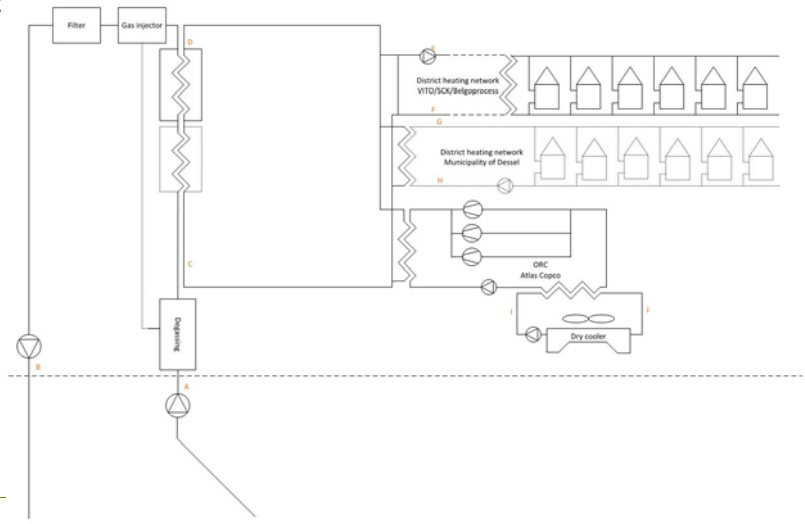
Balmatt project



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Balmatt project

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Demonstration and on site evaluation of the selected coatings

- Picture of test section – under construction
- Pipe coupons and corrosion sensor in one loop fed by low flow brine
- Temperature, pressure and flow meters
- pH meter and conductivity measured

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