High performance coatings for protecting carbon steel and low alloying stainless steel in low enthalpy geothermal fluids

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HEAT EXCHANGER FOULING & CLEANING CONFERENCE

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H2020 MATChING

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

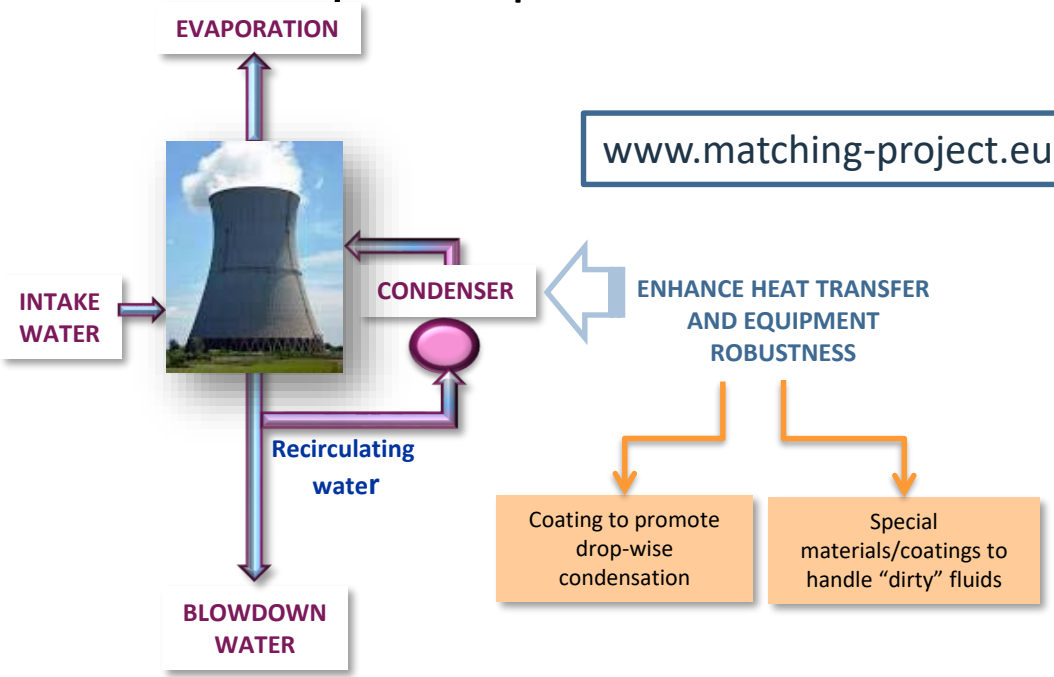
MATChING is the acronym of “Materials & technologies for performance improvement of cooling systems in power plants”

Users group:
>10 additional global partners

14 Partners from 6 EU Countries: 4 from Italy, 4 from Belgium,3 from Spain, 2 from Netherlands and 1 from Denmark

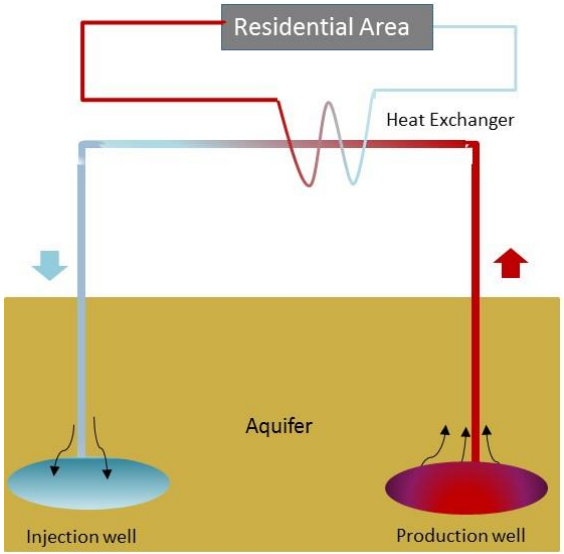
H2020 MATChING (DTI Coatings)

- Thermal power plants

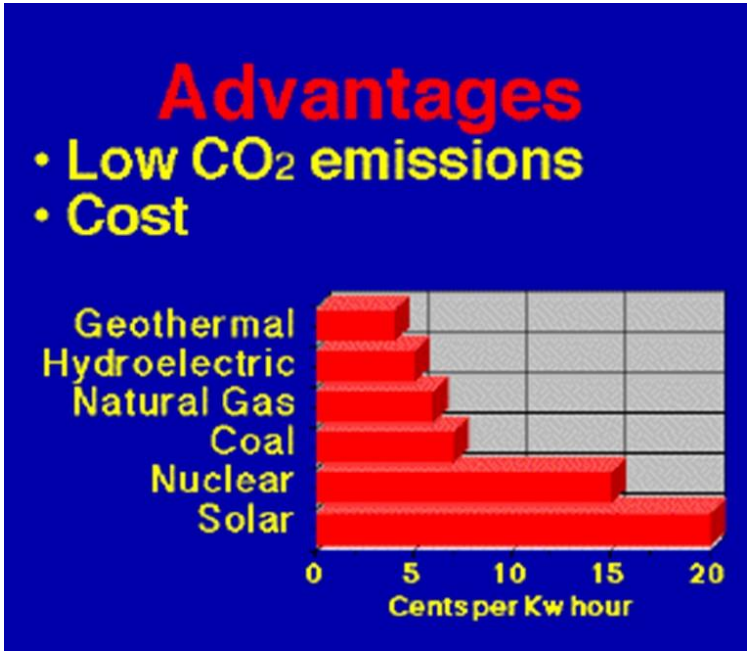


www.matching-project.eu

- Geothermal Installations



Geothermal Energy-Advantages



http://www.earthsci.org/mineral/energy/geother/geother.htm

European Parliament recognize geothermal energy's essential role in the "European energy transition towards net-zero greenhouse emission in 2050"

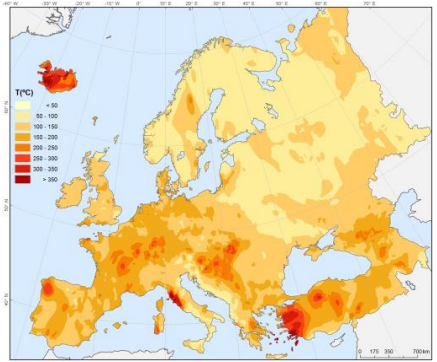
https://www.eesc.europa.eu/en/agenda/our-events/events/civil-society-and-path-carbon-neutral-europe-2050

Geothermal Energy – Technological Issues

Corrosion & Scaling are the major issues in the exploitation of geothermal sources.

Nature and aggressivenes of the brines is site dependent

Material solutions have to be adapted for the particular characteristics of the geothermal site

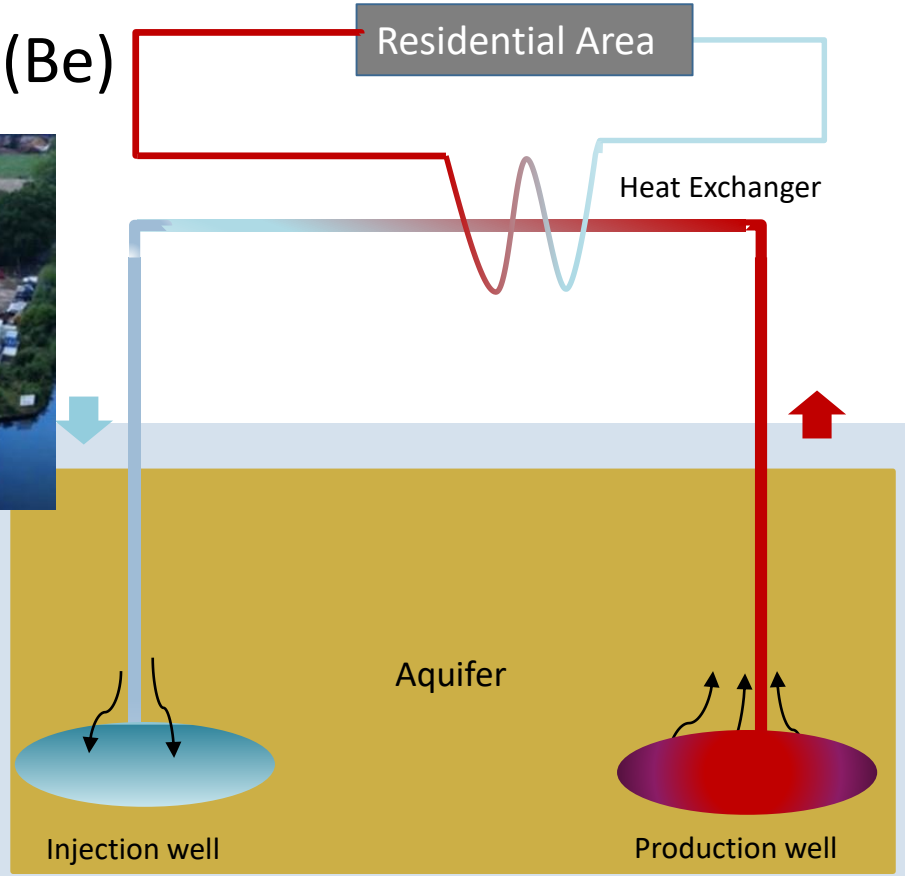


C.R Chamorro et al. Energy, 65, 2014, 250-263

The geothermal Site of Balmatt (Be)

Balmatt Brines*

Production T **125-128 C**
P: **40 bars**
Brine type **Na-(Ca)-Cl**
Salinity: **165 g/l**
Gas brine volume ratio is 2.5
CO2: 75 vol.%, other CH4
pH unseparated fluid (with the CO2) is **5.4**



**S Bos, B Laenen. Development of the first deep geothermal doublet in the Campine Basin of Belgium. European Geologist 43, May 2017*

Geothermal Energy – Technological Issues

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

Typical solutions

MATChING alternatives: P265G and AISI 316L

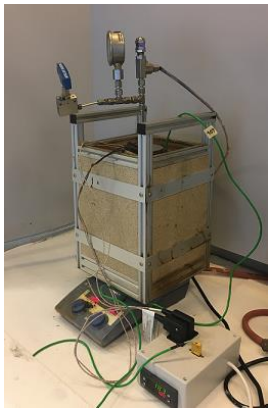
High performance coatings

For **cost-effectiveness** we considered existing commercial coatings and combinations of commercial and newly developed

Coating	Type	Substrate	Dry film thickness (µm)	S.E (mN/m)
F1	Fluoropolymer based	P265G,AISI 316L	75	<24
F2	Fluoropolymer based	P265G,AISI 316L	100-120	<24
Ph	Phenolic based	P265G,AISI 316L	250-270	~30
EP1	Composite epoxy/sol-gel coating	P265G	250-300	<24
EP2	Composite epoxy/sol-gel coating	AISI 316L	150	<24

Testing Strategy

Mock-up test



	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 $m s^{-1}$

- No standard laboratory procedures to test anti-corrosion coatings in geothermal fluids.

- The 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).

Coating Evaluation

Physical analysis
- Visual
- Adhesion
- Blistering
- Rusting

Ok

Physico-chemical
Electrochemical impedance Spectroscopy (EIS)

Ok

VALIDATION
DEMO

No

Discarded

No

Discarded

Coating Evaluation

Physical analysis

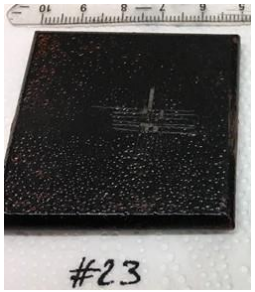
Parameter	Standard	Pass criterion
Adhesion	ISO2409:2007 (thickness<250 µm), ASTM D 3359-02 (thickness >250 µm).	Rating 1 or less
Blistering	ASTM D714-02.	Rating 8F or no blisters
Rusting	ISO 4628-3.	Surface free of rusting (rating 0)

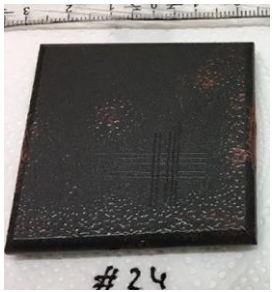
Ok coatings → Physico-chemical analysis

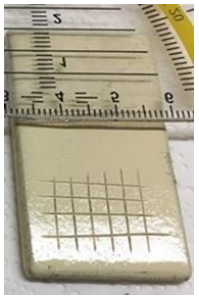
Coating Performance - P265G

Physical evaluation

Coating	F1	F2	Ph	EP1
Adhesion rating	5	0	0	0
S.E (mN/m)	-	-	44	25
Blister	6 MD	6 M	None	None
Rust	3	3	0	0
Comment	Failed	Failed	Pass	Pass



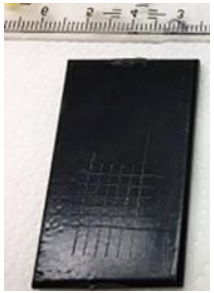


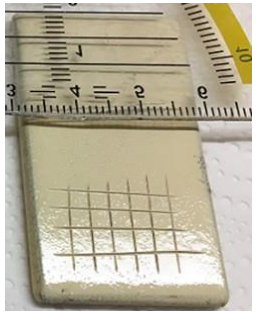


Coating Performance – AISI 316L

Physical evaluation

Coating	F1	F2	Ph	EP2
Adhesion rating	0	0	0	0
S.E (mN/m)	<24	<24	44	25
Blister	None	None	None	None
Rust	0	0	0	0
Comment	Pass	Pass	Pass	Pass



Coating Evaluation

Physico-chemical analysis (EIS)

- PGSTAT20 AUTOLAB from Ecochemie®
- synthetic brines, r.t, open to air and continuous stirring
- 100 kHz - 0.1 Hz (5 points per decade), AC 200 mV (rms)
- Two-electrode configuration

Electrochemcial Impedance Spectroscopy

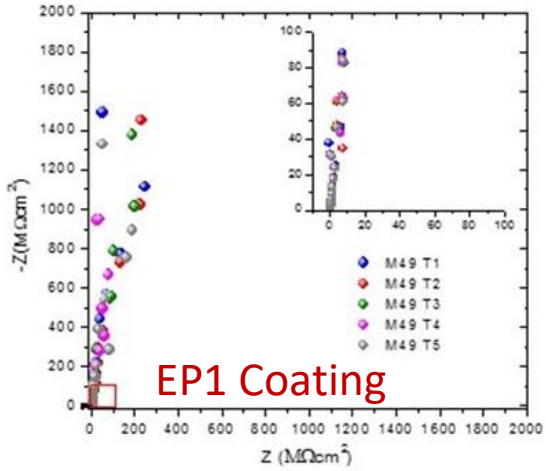
- Electrolyte permeation
- Coating deffectivenes
- Substrate corrosion

- The protective performance assessed by estimating the impedance analysis at 0.1Hz

$|Z| > 10^8$ Ω·cm² excellent
$|Z|$ 10^7-10^8 Ω·cm² good
$|Z|$ 10^6-10^7 Ω·cm² doubtful
$|Z| < 10^6$ Ω·cm² poor

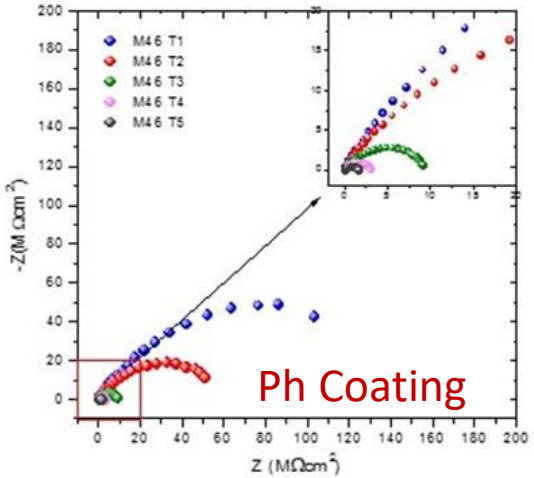
Coating Performance – EIS analysis

Very protective coating



- Capacitive behaviour
- The high impedance and stability over time indicate excellent barrier properties

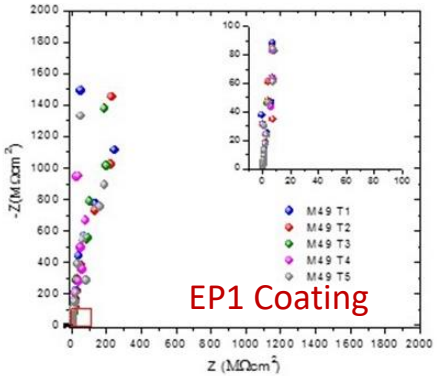
Non protective coating

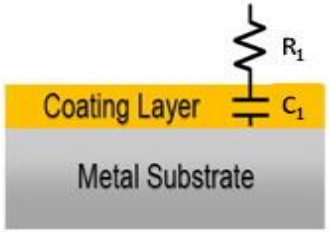


- The Nyquist plot changed gradually from a circular arc to a semicircle, radius decreased over time (less barrier properties)

Coating Performance – EIS analysis

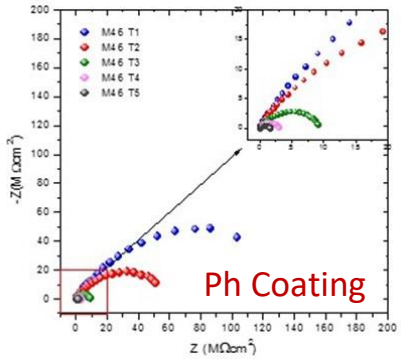
Very protective coatings

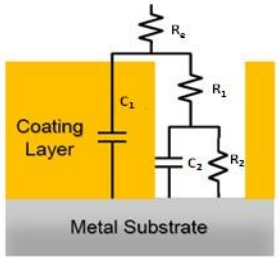




The EEC has a single time constant associated to the coating barrier properties. The coating adheres perfectly to the metal substrate, no surface imperfections.

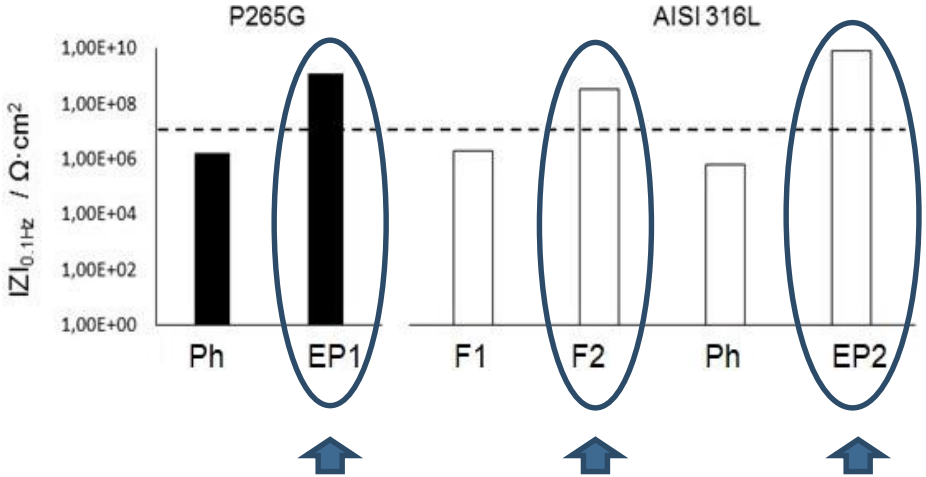
Non protective coatings





The EEC has two time constants:
The 1st time constant →Coating barrier properties
The 2nd time constant → electrolyte permeated into the coating/metal interface (corrosion process at the substrate interface.

Coating Performance – EIS Analysis



- Coatings EP1, F2 and EP2 have very good barrier properties

- Ph and F1, have low |Z|, suggesting that the electrolyte reached the metal (not yet visual evidences of coating degradation)

Coating Performance – Thermal resistance

$$Rf = \frac{d_f}{k_f}$$

Rf is the thermal resistance on a specific side of the heat exchanger (m^2 K/W), d_f is the average thickness of the coating layer (m) and *kf* is the thermal conductivity of the coating (W/m·K).

$$k_f = \frac{x_1 + x_2 + \cdots x_i}{\frac{x_1}{k_1} + \frac{x_2}{k_2} + \cdots \frac{x_i}{k_i}}$$

kf is the thermal conductivity of the coating, $x_1 \ldots x_i$ are the thicknesses of the different layers and $k_1 \ldots k_i$ their respective thermal conductivities.

Coating Performance – Thermal resistance

Coat.	Thickness (µm)	Thermal conductivity (W/m K)	Thermal resistance, *Rf* (m^2K/W)
F2	100	~ 0.25	0.0004
EP1	250	~ 0.63	0.0004
EP2	150	~ 0.58	0.00025

- The HX were designed with a fouling factor (*Rf*) of 0.0004 m^2K/W.
- The coatings impact the thermal conductivity by a lower or similar factor than the design *Rf*.
- The coatings prevent corrosion and the fouling situation is likely to be improved.

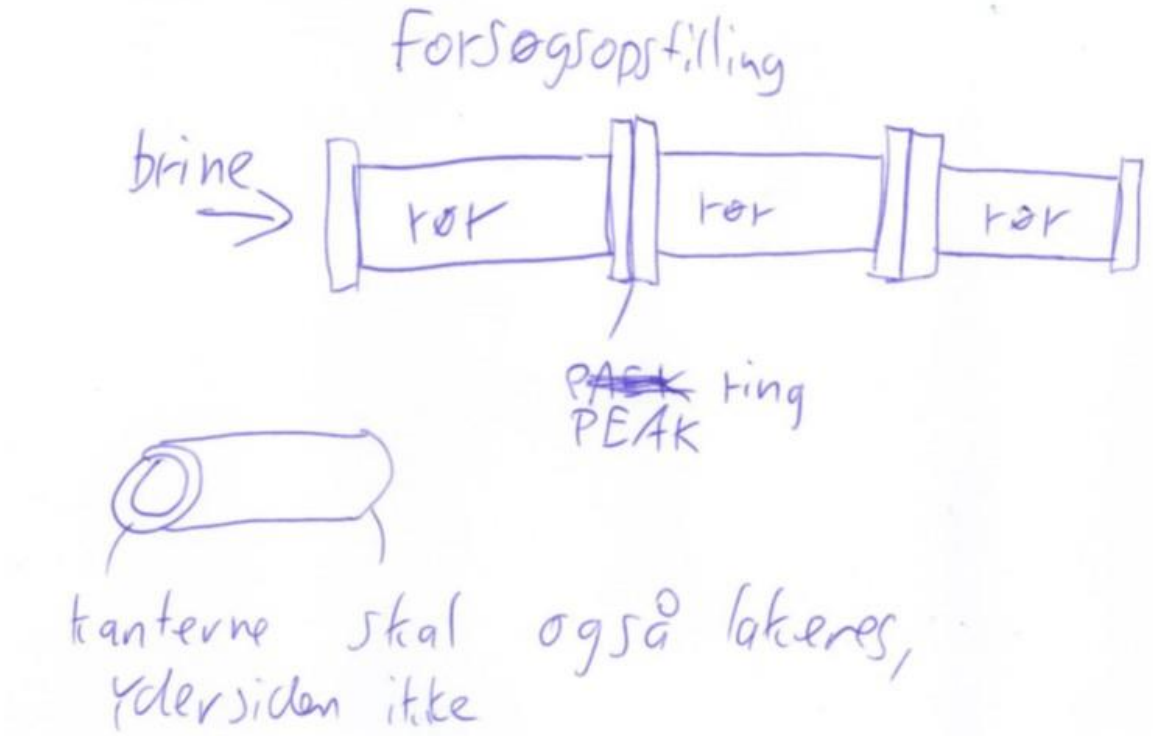
Conclusions

Coatings EP1 on carbon steel and F2 and EP2 on stainless steel:

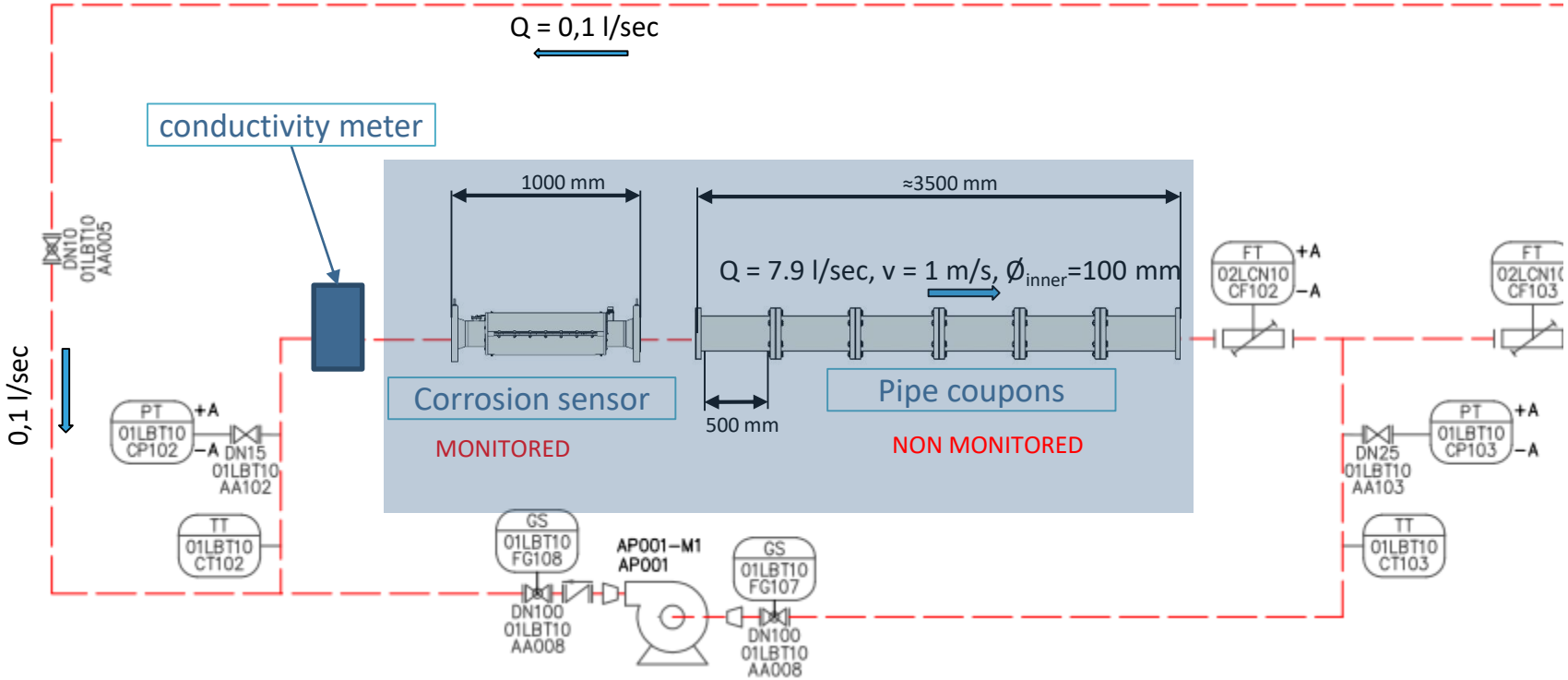
- Effectively protect the substrates against corrosion.
- Retain very low S.E and smooth surface
- Limited impact on the heat transfer resistance

Do the laboratory test correlate well with the field performance? Ongoing demonstration test will answer the question

Demonstration



Demonstration



Demonstration

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QUESTIONS?

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