[PS]Scaling Assessment, Inhibition and Monitoring of Geothermal Wells*

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Abstract

The formation of inorganic, sparingly soluble salts from aqueous brines during geothermal energy production, is known as 'scale' and is one of the major flow assurance problems. Scale forms and deposits under supersaturated conditions, wherever the mixing of the incompatible types of water, formation water from the bottom hole and the injected seawater, takes place. Or when temperature or pressure changes are severe enough to produce a supersaturated solution. The deposited scale adheres on the surfaces of the producing well tubing and on parts of water handling equipment, where it builds up in time and leads to problems in reservoirs, pumps, valves and topside facilities. The rapid increase of the mineral deposits leads to inevitable damage of the equipment parts. As a consequence, suspension of production is necessary for the recovery or replacement of damaged parts. Steel pipes are known to be susceptible for scale deposition. The formation of scaling on the inner surface of casings depends on the scaling tendency of the water and the surface chemistry and morphology of the casing. Many mitigation strategies have been proposed: coatings, scale inhibitors, acids washes, etc. The scaling tendency can only be lowered by a chemical intervention on the production fluids: reduce the supersaturation of the salts in the water by inhibitors that form chemical complexes with the scaling ions.

We show that the amount of scaling that is deposited on a substrate depends on three parameters:

• Surface energy of the casing, compared to the one of the scaling crystals and the water environment: the more the surface energy resembles the scaling crystals, the more scale will be deposited and stick to the surface, because of the high interfacial forces.

• Roughness of the surface: higher roughness leads to lower the scale deposition. The lowest adhesion force is found when the roughness is high, the interfacial tension is low, and the radius of the roughness is low. This case is for the adhesion between scale and surface. So if scale is formed in the bulk solution, the adhesion is low for a rough surface. However, a different process will occur when the scale is growing on a rough surface. There, we have seen that scaling is favored when the roughness is high.

• The bulk modulus of the surface: a lower bulk modulus results in lower forces that are needed to remove the scale crystals from the surface.

These parameters were used for the development of a single parameter that can describe the scaling tendency of a surface. A more long-term solution for scaling prevention is the implementation of a casing material that is intrinsically better resistant against scaling. A new class of pipes that may show intrinsically improved scaling performances is glass fiber reinforced composites. The inner surface of the pipes consists of the polymer matrix of epoxy or polyethylene and will have a different surface energy than steel pipes. Several sets of experiments were done on steel and polymer matrix casings under static scaling conditions. The scale that formed was a combination of heterogeneous nucleated on the surface and homogeneous nucleated in the bulk solution. The latter scale was removed by rinsing the samples and an adhesive tape after drying to only assess the scale that was grown on the surface. Moreover, we have shown that the measurement of the light reflection from the scaled surface is a good way of assessing the amount of scaling. With the results collected in this study, it is possible: to predict the scaling tendency under specific conditions, to measure the scale to validate the predictions and to assist the development of material for pipelines to lower scaling risks.

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INTRODUCTION

The formation of inorganic, sparingly soluble salts from aqueous brines during geothermal energy production, is known as scale. Scale deposition damages the downhole equipment and decreases in flow rate lead to a loss in production. Moreover, the mineral deposition leads to inevitable damage of the equipment parts. As a consequence, suspension of production activities is necessary for the recovery or replacement of damaged parts.
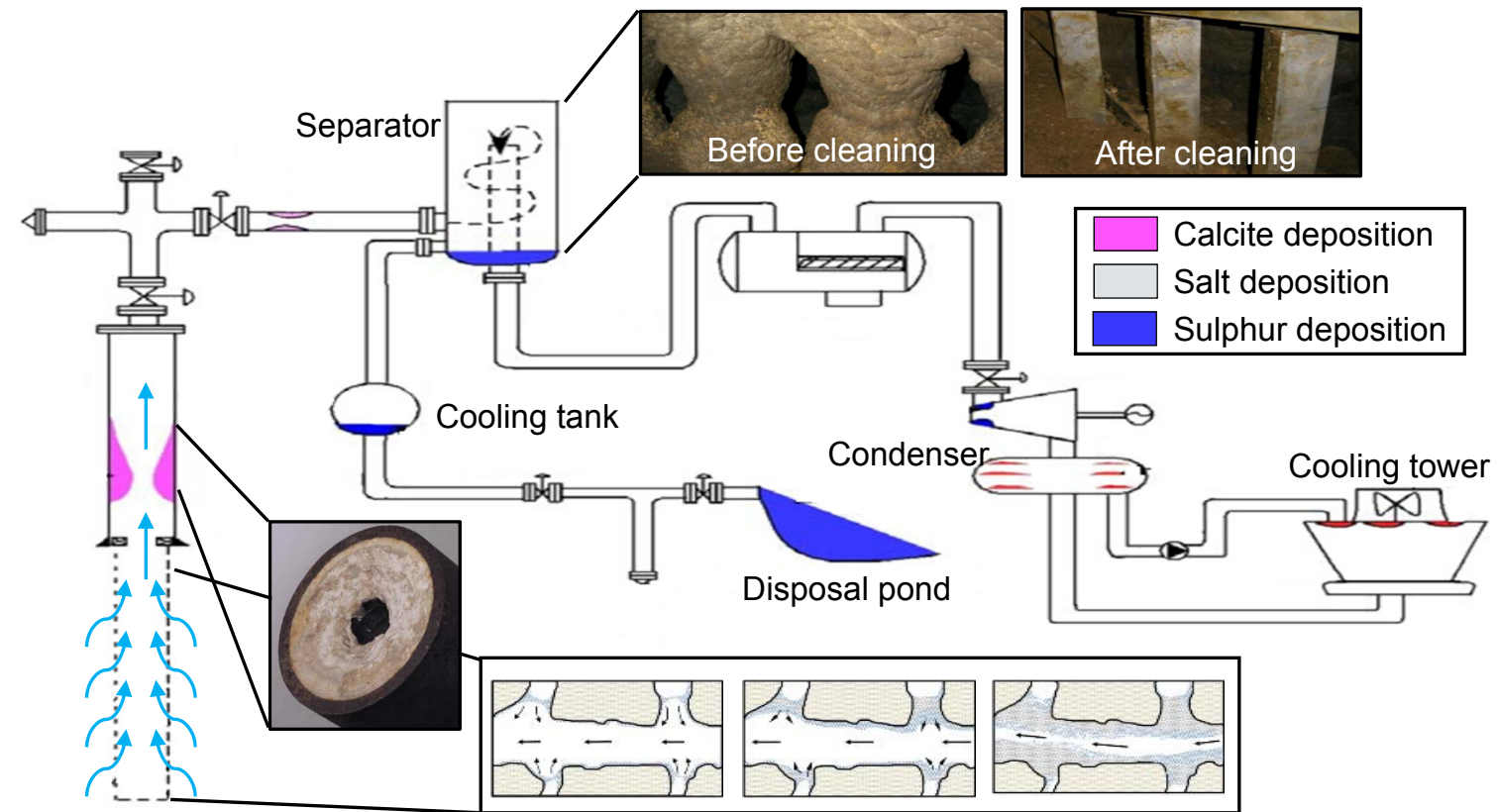

- Before cleaning
- After cleaning

Calcite deposition
Salt deposition
Sulphur deposition

Separator
Cooling tank
Condenser
Cooling tower
Disposal pond

Fig. 1. Locations of solid deposition in reservoir and in subsurface and topside facilities.
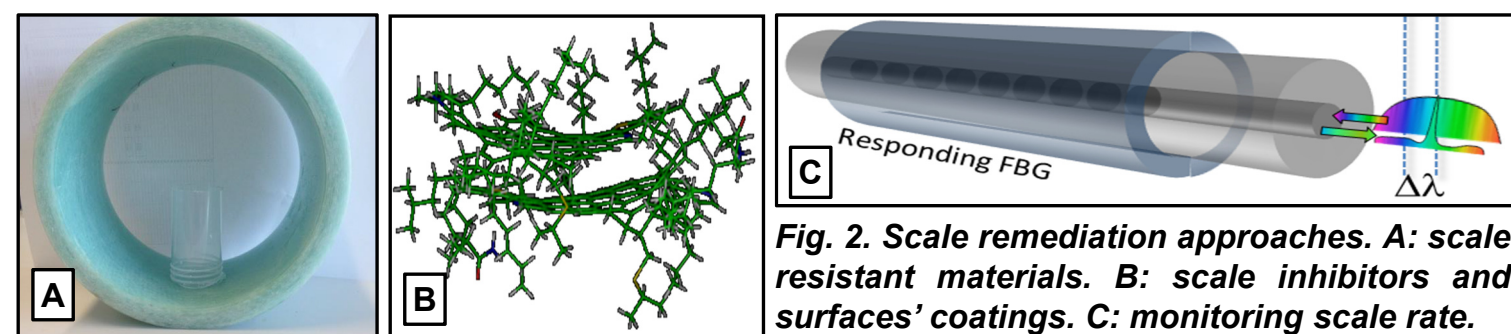

Responding FBG
$\Delta\lambda$

Fig. 2. Scale remediation approaches. A: scale resistant materials. B: scale inhibitors and surfaces' coatings. C: monitoring scale rate.

METHOD

The mechanism of surface scale is **not** based on nucleation followed by precipitation. The main process is **direct nucleation and growth** of the crystals on the surfaces.
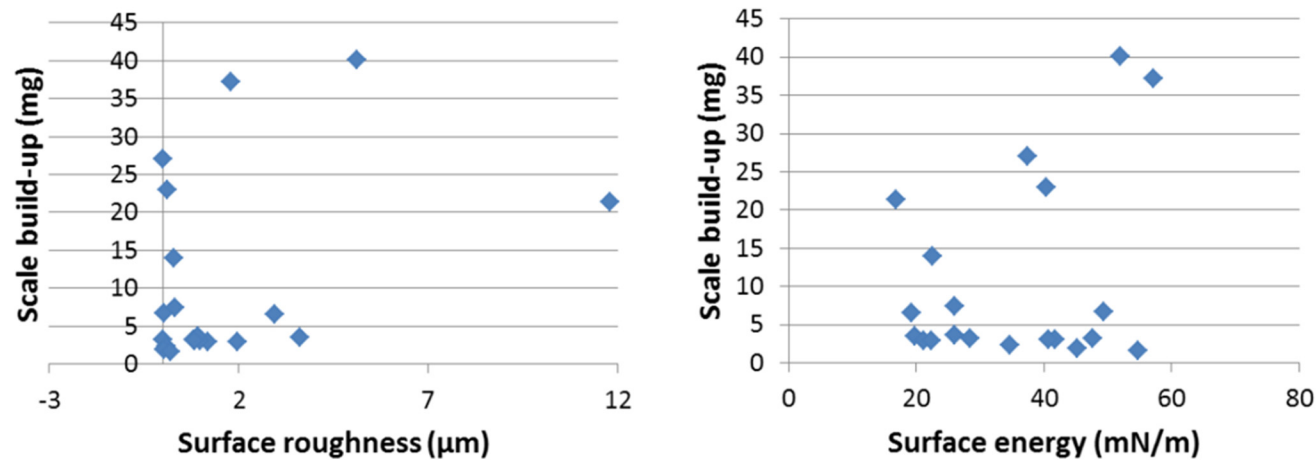

Fig. 3. Scale build-up as a function of surface roughness and energy.

There is **no clear correlation between** scale build-up and one single parameters (surface roughness and surface energy).

GOAL

Define and quantify the influence of the surfaces on scale deposition.

Change the 3 surfaces parameters that influence more the deposition of scale.

- The **SURFACE ENERGY** is varied by incorporating of hydrophobic and hydrophilic groups in the coatings.
- The **SURFACE ROUGHNESS** variation is introduced by implementing nanotexturing of the coating surface by imprinting.
- The **SURFACE BULK MODULUS** is changed by using different polymer coatings and different pipe's material.

IDEA

APPROACH

1. Surface characterization
2. Prediction of scaling
3. Measurements to validate predictions
4. Proposals to modify surfaces

Static experiments were performed with low-carbon and cold-rolled steel panels that have substrates with a **large range of surface roughness** and glass-filled polymer composites that have **low interfacial tension and surface roughness**.

- The substrate is **coated** with the surface modifier.
- Calcium carbonate starts to form after an induction period.
- The scaling solution is left for 1 hour at room temperature.
- The cylinders are removed and the substrates are **washed**, to remove the unreacted chemicals.
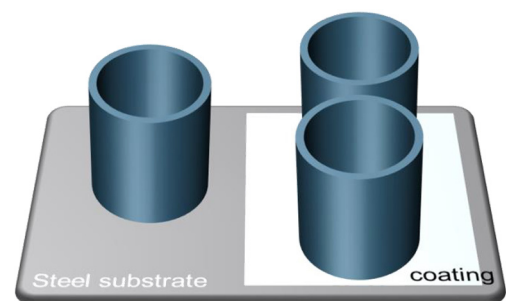- The polymer tube on the untreated steel was used as **reference measurement**.

Fig. 4. Experimental set-up.

The **specular light reflection from the surface** was monitored: the reflected light from the non-treated steel surface was used as reference, and the absorbance of the scaling layer was calculated.
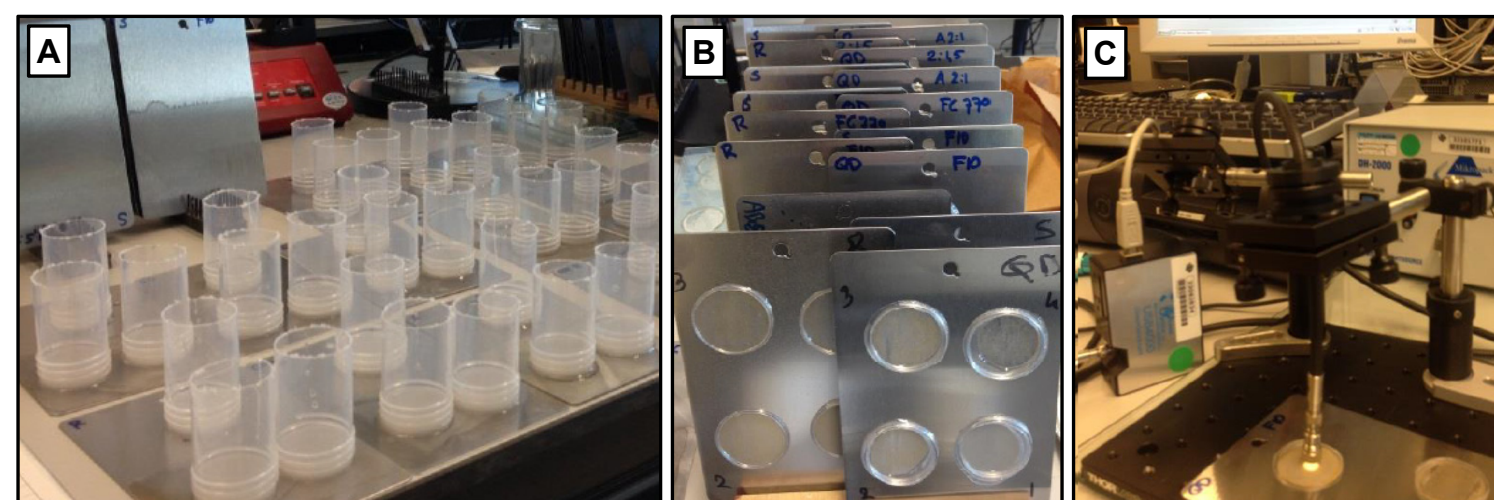

Fig. 5. A: 30 different combinations of substrate and surface modifiers were tested. B: samples after scale deposition. C: light reflection measurements.

RESULTS

The roughness of the different substrates (3 steel panels and 1 epoxy tube) was measured using an Optical Imaging Profiler (Fig. 6, Table 1). Moreover, an area of ~500x500 mm² was scanned using a confocal microscope (Fig. 7 and 8).
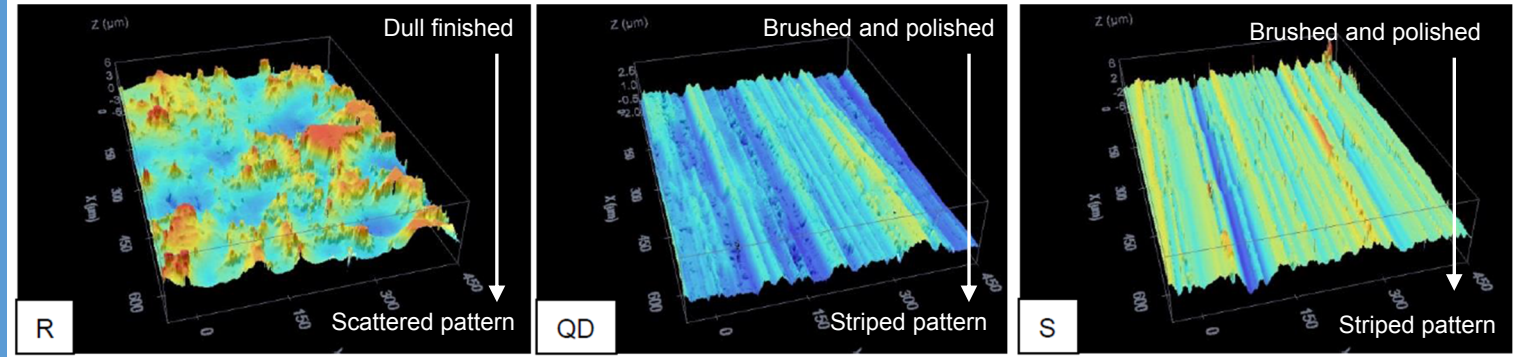

Dull finished / Scattered pattern
Brushed and polished / Striped pattern
Brushed and polished / Striped pattern

Fig. 6. Roughness measurements of the substrates of the 3 steel panels.

Sample	Finish	Roughness [mm]	Area of peaks	Area increase
QD	Smooth	0.38	0.81	1.01
R	Dull	1.18	0.49	1.07
S	Ground	1.02	0.78	1.35
GFR epoxy	No	0.044	0.93	1.01

Table 1. Measurements of the substrates of the 3 steel panels and of the glass fibers reinforce epoxy.
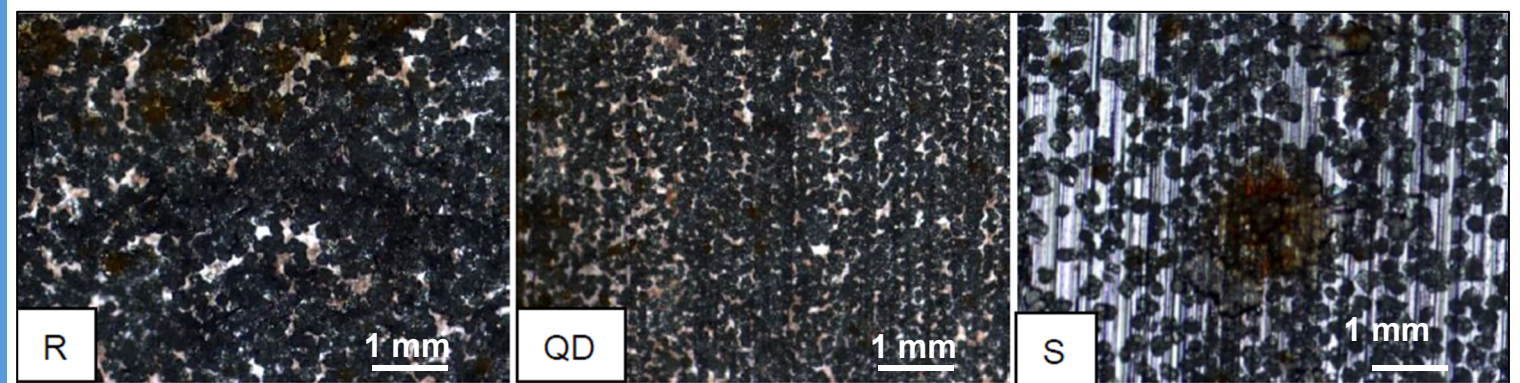

Fig. 7. Microscopic view of the substrates of the 3 steel panels. The black dots indicate the calcium carbonate crystals. R and QD panels present the same amount on scale but with different crystals' size. QD panels present the higher nucleation. S panels present the lower amount of deposited scale.
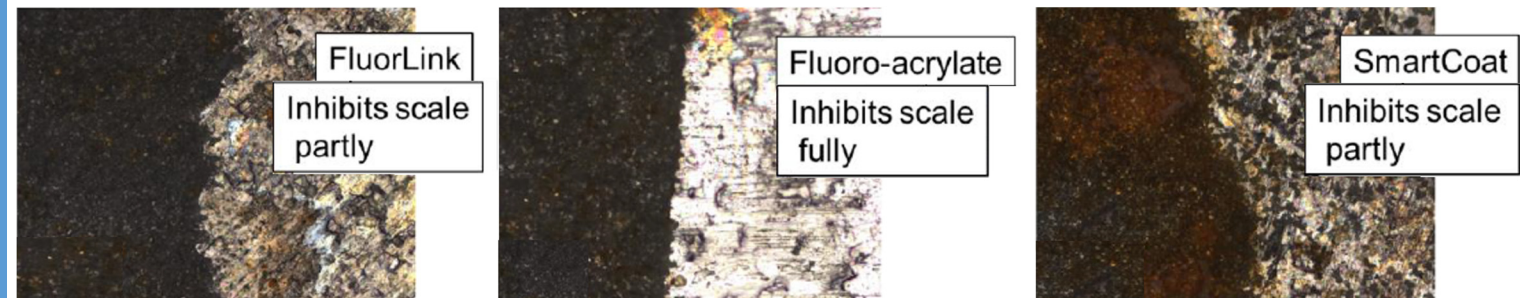

FluorLink — Inhibits scale partly
Fluoro-acrylate — Inhibits scale fully
SmartCoat — Inhibits scale partly

Fig. 8. Scaling formation on coated steel surfaces for 3 different coatings.

The specular light reflection was measured at 650 μm with a spectrophotometer.
Absorbance of the scale layer, after removal of the not deposited scale, is given by:

$$A_{tape} = -log\left(\frac{I_{scale}}{I_{steel}}\right)$$

I_{scale} = reflected light of the scale
I_{steel} = reflected light of the reference surface

Considering only this parameter did not show a clear trend between of the amount of scale that deposited. ➜ We included the **roughness** (r_1, r_2) and the difference of the **energy** (γ_{13}, γ_{23}, γ_{13}).

$$W_{adh} = \gamma_{13} + \gamma_{23}\,r_2 - \gamma_{12}\,r_1$$

γ_{13} = interfacial energy scale and water
γ_{23} = interfacial energy substrate and water
γ_{12} = interfacial energy scale and substrate

The steel substrates could be described by a **single scaling relation**: the work of adhesion (W_{adh}). When comparing the scaling on the epoxy tube and the steel plates, the scaling on the tube is much lower than on the steel plates.
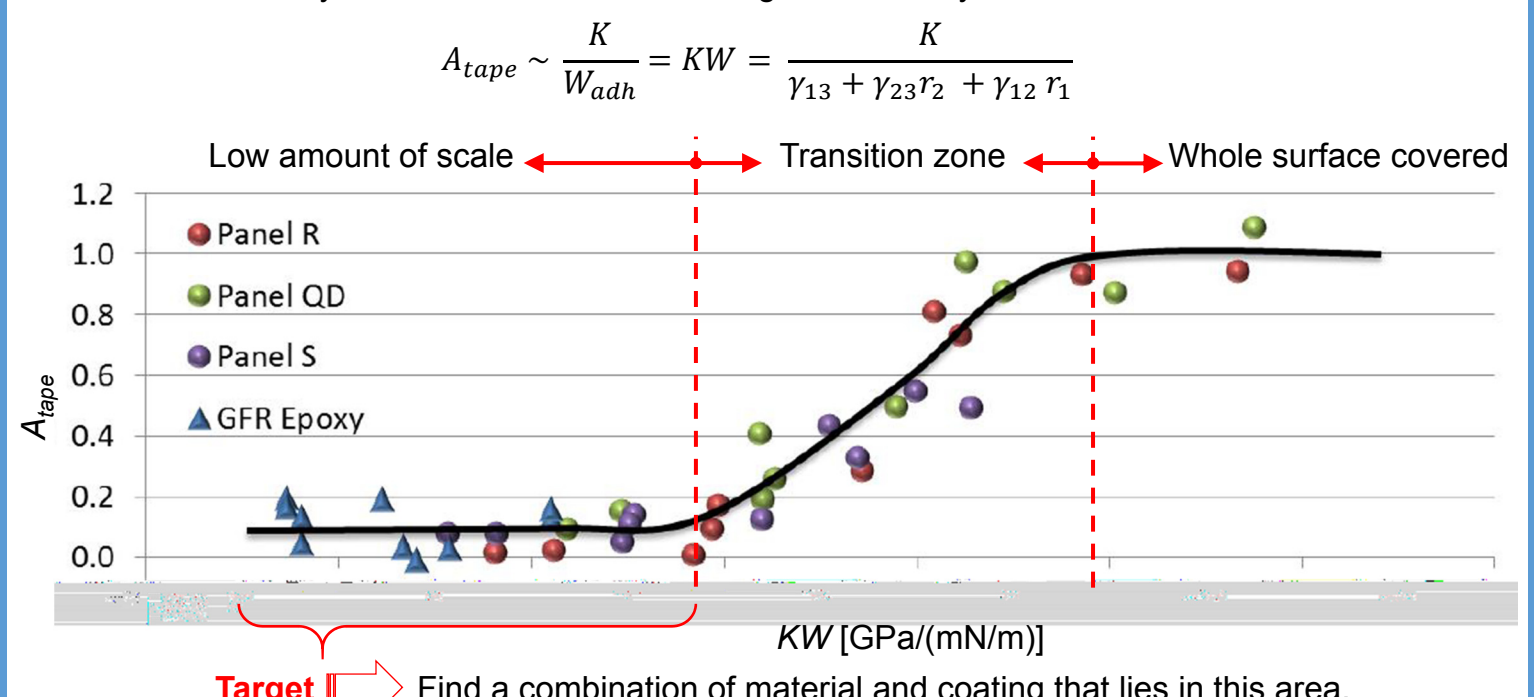This is not caused by the difference in surface roughness, but by the **hardness** of the substrates.

$$A_{tape} \sim \frac{K}{W_{adh}} = KW = \frac{K}{\gamma_{13} + \gamma_{23}r_2 + \gamma_{12}r_1}$$

Low amount of scale — Transition zone — Whole surface covered

- Panel R
- Panel QD
- Panel S
- GFR Epoxy

A_{tape}
KW [GPa/(mN/m)]

Target ➜ Find a combination of material and coating that lies in this area.

Fig. 9. Comparison of the scaling on the three steel substrates and the glass fiber reinforced epoxy substrates.

ONGOING WORK

Complete scale management set up

- Dynamic experiments
- Achieve an in depth understanding of scale mechanisms
- Test inhibitors
- Test coatings
- Test new materials for pipelines
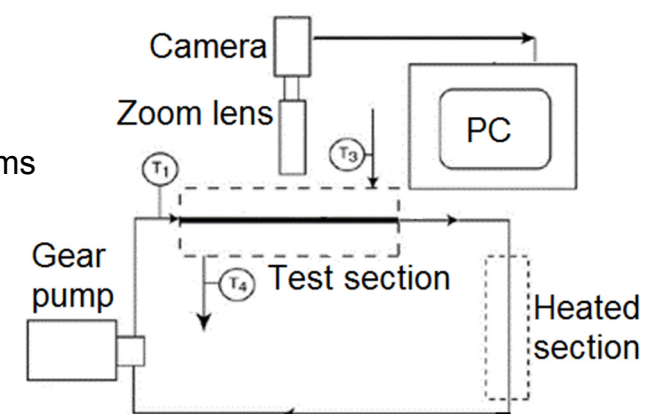- Test combinations of scale mitigation techniques

Camera
Zoom lens
PC
Gear pump
Test section
Heated section

Fig. 10. Simplified representation of the scale management set up.

CONTACTS

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