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Industrial Coatings at Extreme Conditions

Srinath Subramanian‡, Clara Pérez Hornero§, Lars Thorslund Pedersen§, Søren Kiil‡*

*: Corresponding author. Tel.: +45-4525-2827, E-mail address: sk@kt.dtu.dk
‡: Department of Chemical and Biochemical Engineering, Technical University of Denmark, DTU, Building 229, DK-2800 Kgs. Lyngby, Denmark
§: Hempel A/S, Lundtoftegårdsvej 91, DK-2800 Kgs. Lyngby, Denmark

Abstract

With the gradual depletion of oil wells operable at relatively lower temperatures and pressures, the upstream oil industry relies on High Pressure High Temperature (HPHT) wells to source crude oil and gas. HPHT well extraction and processing require anticorrosive coatings applied on substrates such as downhole piping and pressure vessels that can withstand such temperature and pressures. Very little information is available regarding the degradation mechanisms of currently used solvent-borne epoxy coatings in these conditions. Cyclic stress tests at lower temperatures (25-85 °C) [1] resulted in coating fractures and holes from collapsed blisters originating from thermal shocks.

To improve coating formulations, it is important to understand the mechanisms of coating degradation at such conditions with respect to the chemical and physical processes involved. It is thus essential to understand the effects of temperature and pressure as well as the chemical degradation caused by liquids (e.g. saline water), hydrocarbons and gases such as methane, carbon dioxide and hydrogen sulfide. In this work, experimental studies have been conducted with coated metal substrates exposed to high temperatures (up to 200 °C) and high pressures (up to 180 bar). The test apparatus can be supplied with gases such as methane, hydrogen sulfide and carbon dioxide in the presence of liquids such as saline water and hydrocarbons to mimic the conditions found in industrial downhole piping. The coating samples can also be subjected to periods of cyclic exposure to these conditions using the associated controller in the device.

Preliminary Experiments

Steel panels coated with amine-cured epoxy and novolac epoxy based formulations were immersed in a liquid containing two phases: water (3.5 wt. % NaCl) and hydrocarbons (n-paraffin+p-xylene) at 200 °C and 164 bar. High pressure nitrogen was used to pressurize the exposure chamber. It was found that novolac-based coatings suffered minimal degradation even after 80 hours of exposure. A sticky layer was observed on the surface of the epoxy and epoxy-novolac based coatings [2]. Figure 1 shows an exposed coated steel panel alongside an unexposed one. The coating was epoxy-based and amine cured. Exposure time was 30 hours at 170 °C and 150 bar pressure with water and hydrocarbon phases in the reactor as described above. The sticky material was found on the interface between water and hydrocarbons. Figure 2 shows magnified images of the unexposed sample alongside three distinct exposure areas (compare with Figure 1). Epoxy-based coatings suffered degradations such as osmotic blisters which appear to intensify with time. Preliminary tests at low temperatures and high pressures indicate that high pressures may not have any significant impact on the degradation of coatings. Corrosion on the steel-coating interface could be observed in the interfacial region between hydrocarbons and salt water indicating the presence of oxygen inside the coating, despite the initial flushing performed using low pressure nitrogen.

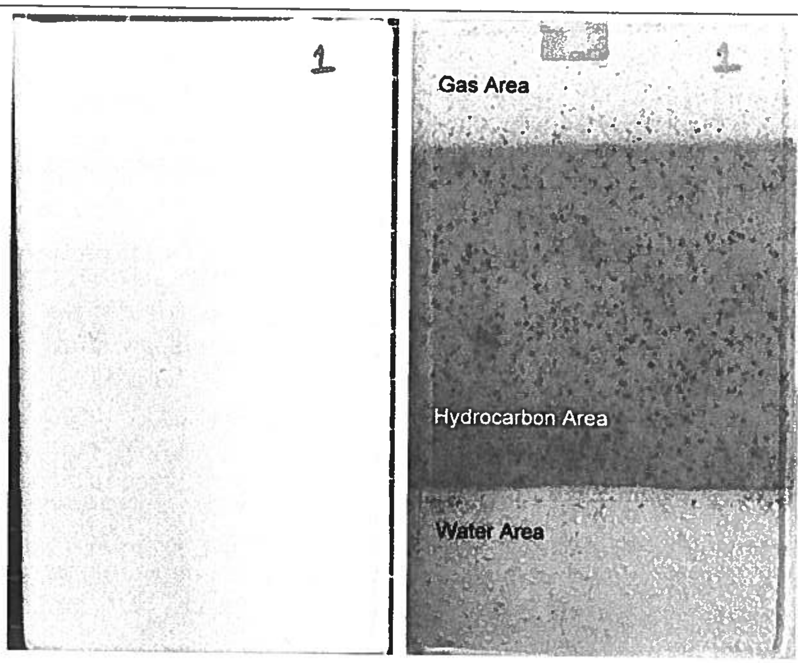

Figure 1: Unexposed coated steel panel (left) vs. exposed panel (right). The panels were exposed to a mixture of water (3.5% wt. NaCl) and hydrocarbons (equal volume mixture of n-paraffin and p-xylene) at 170 °C and 150 bar for 30 hours. The different areas of exposure are indicated on the samples. The small rectangular mark at the top of the panel (right) is due to the sample holder. The glossy part on the left panel is reflection from the incident light.

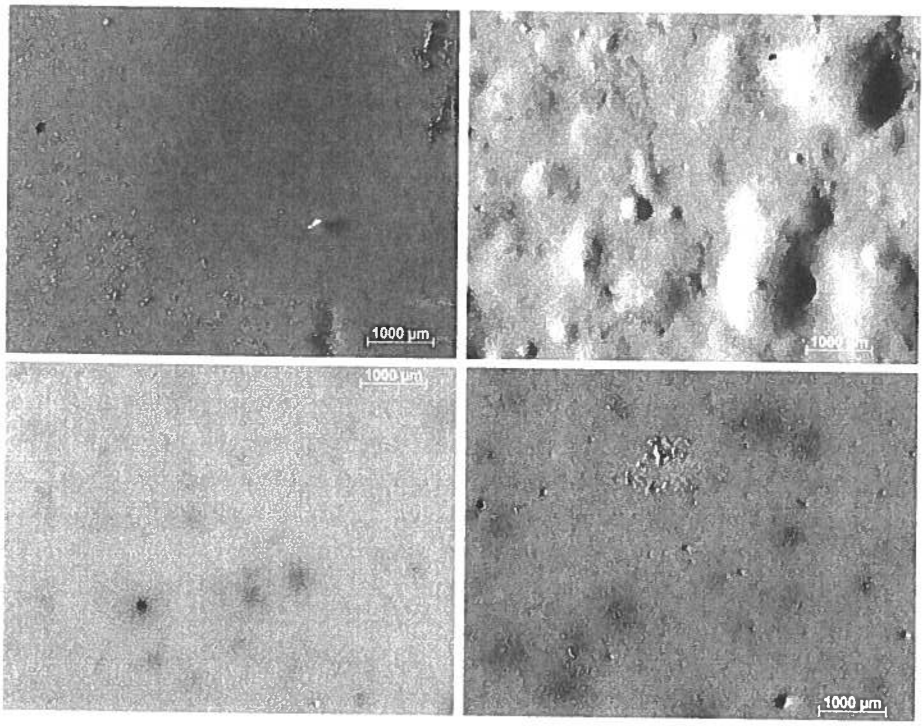

Figure 2: Magnified views of exposed sample areas vs. unexposed sample. The samples are – unexposed (top left), exposed areas - water area (top right), gas area (bottom left) and hydrocarbon area (bottom right). Blistering can be seen in the water exposed areas.

Further Experimental Work

Investigations regarding the chemical analysis of the sticky material is currently underway. Experimental investigations to separate the effects of temperature and pressure on coating degradation and also identify the physical mechanisms of degradation in epoxy-based coatings will be performed. Subsequently, the effects of gases such as methane, carbon dioxide and hydrogen sulfide will be investigated.

References

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[2] P. R. Mahler, "Industrial Coatings at Extreme Conditions " MSc Masters Thesis, Chemical & Biochemical Engineering, Technical University of Denmark, Copenhagen, 2015.