Danish Hydrocarbon Research and Technology Centre
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Programme: Well Production and Technology

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Bio-active self-healing cement in oil well applications

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The bio-active self-healing cement project aims to apply a microbially-engineered system for *in-situ* calcium carbonate precipitation in deep sub-seafloor environments. We hypothesize that such self-healing cement can prevent the development of microstructural cracks during the lifecycle of the cement that could potentially compromise the integrity of the well-construction.

We will present results showing the feasibility of obtaining self-healing properties of oilwell cement by dosing it with lightweight expanded clay aggregates (LECA) impregnated with endospores of the alkaliphilic bacterium *Bacillus alkalinitrilicus* along with suitable growth substrates and a calcium source.

Various size fractions of LECA beads ranging from <63 – 500 micron in size and percentages by weight of cement (1 – 10%) have been selected to investigate the optimum dosage without compromising the compressive strength of the cement. Key findings of the bio-active self-healing cement with embedded LECA beads were showing promising results: that self-healing after continuous sulphate attack (over a year exposure time) was occurring; that the size fraction of the LECA beads chosen as the primary carrier for the endospores, nutrients and the calcium source did not compromise the unconfined compressive strength (UCS) up to a certain dosage threshold. Currently we are testing and optimising the healing capacity of the bio-active self-healing cement by determining the nutrient loading and leaching kinetics of LECA beads along with the bacterial survival and growth kinetics in LECA.

In addition, non-destructive micro x-ray computed tomography could visualise for the first time the crack self-healing repairing phenomenon at sub-micron scale (<0.98 µm resolution). This is important when evaluating the crack self-healing capacity in a flow loop-setup which will be later in the year conducted in an in-house built simulation unit at DTU Civil Engineering Department.

Furthermore, ideas for upscaling the impregnation process to produce bigger quantities has been considered and ideas are presented.

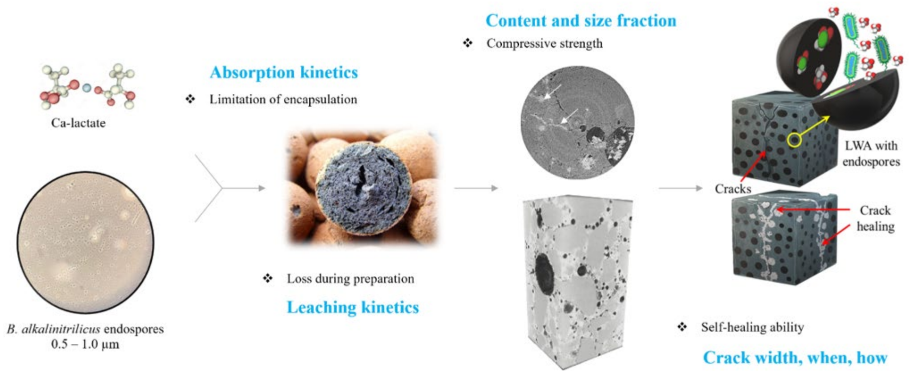

Figure 1: Strategy to design and test a microbially-engineered self-healing cement system.

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Extended Reach Intervention with Stabilizing Supports

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In the current study we test the feasibility of some novel stabilizing solutions to extend the reach of coiled tubing (CT) inside the horizontal oil wellbores, beyond what the existing tools and methods have been able to accomplish in the field [1],[2]. It has been shown through numerical and analytical investigations that by decreasing the radial clearance between CT and well casing, the critical helical buckling load of CT can be increased; thereby extending its reach and preventing a premature lock up[3]. Liljenhjerte *et al.* (2021) [3] developed a new TFA algorithm to determine the optimal distribution ofstabilizing initiatives that can prevent buckling of CT during the run in hole (RIH) process. To investigate this strategy, a lab scale prototype of the horizontal section of wellbore and CT is used (Figure 1). The radial clearance between the CT and well casing in this set-up is reduced by using various suitable injectable materials (Figure 2(b)). In this lab scale set- up, the buckling behavior of CT, compressed under a predetermined force in the presence and absence of a support materialis analyzed. The results show an increase of up to 130% in the load carrying capacity of an aluminum CT (OD= 6mm, thickness = 1mm) in the presence of a support material. A reduction of the radial clearance between the CT and the wellboreseems to be a promising stabilizing initiative that can increase the critical helical buckling load and extend the reach of CTto a desired operational depth.

Figure 1: (a) Lab scale set-up of the CT and well casing, **(b)** steel CT buckling inside the PMMA casing

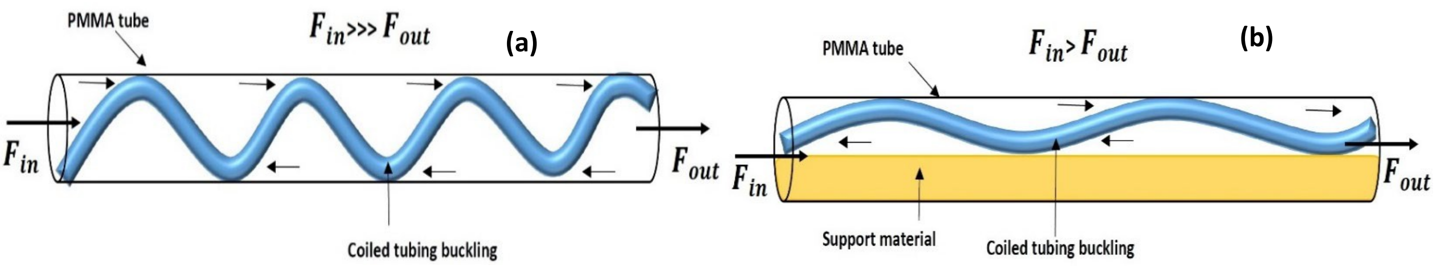

Figure 2: Schematic representation of **(a)** coiled tubing buckling inside PMMA tube and **(b)** coiled tubing buckling inside PMMA tube filled with support material. FF_{iiii} is 'Force in' and FF_{oooooo} is 'Force out'.

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[3] J. Liljenhjerte and J. V. Nygaard, “Evaluating stabilizing initiatives to extend coiled tubing reach,” *J. Pet. Sci. Eng.*, vol. 205, p. 108905, 2021, doi: 10.1016/j.petrol.2021.108905.

Quantification of cracking in oil well cement and the effects onzonal isolation

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The formation of cracks and interfacial damage at the primary cement sheath compromises the overall structural stability, imperviousness, and durability of the system. These cracks also provide a flow path forfluids through the cement sheath, leading to leaks of hydrocarbons to the environment. Therefore, it is necessary to investigate the possible flow paths due to crack formation in the i) interface between the cement and casing, ii) interface between cement and rock formation, and iii) in the radial direction of the cement sheath. The mechanisms that may provoke cracking have been investigated, and the detection anddevelopment of the cracks have been measured using digital image correlation (DIC). A testing campaign isbeing performed to estimate the leaks in oil wells through those cracks.