RP3.4-01: Retrofitting Pipelines by In Situ Coating – Research Summary

Australia has thousands of kilometres of buried steel pipelines currently used for transporting natural gas. If repurposed for hydrogen transport, these pipelines face the risk of hydrogen embrittlement, which compromises their safety and reliability. Mitigating the effects of hydrogen embrittlement on steel infrastructure is essential to ensure the secure and dependable transportation of hydrogen through these pipelines.

This project aimed to develop an internal coating for steel pipes to prevent hydrogen embrittlement. The coating must be applicable in situ to buried pipelines and capable of preventing hydrogen ingress into the steel. Additionally, the coating materials must be cost-effective. The project encompassed three stages focused on evaluating the hydrogen permeability, rheological properties and hydrogen radical scavenging ability of different coating materials.

Stage 1:

Hydrogen permeability of various coating materials were investigated and compared. This included twelve commercially available coatings and coatings fabricated in-house from purchased chemicals. Crosslinked poly vinyl alcohol (PVA) exhibited the lowest hydrogen permeability, two orders of magnitude lower than that of commercially available coatings, demonstrating the strongest potential as the coating material. A theoretical model of the unsteady state hydrogen diffusion process through coated steel was developed to evaluate the effectiveness of coating materials in preventing hydrogen embrittlement. The model revealed that a 2mm-thick crosslinked PVA coating can extend the time to reach concentration equilibrium to seven years with a 44% reduction in the final hydrogen concentration on the steel surface.

Stage 2:

The rheological properties of the coating solution are crucial for internal application onto existing pipelines. A novel polymeric coating using crosslinked PVA and Poly(ethylene glycol) diglycidyl ether (PEGDGE) was developed, featuring low hydrogen permeability and suitable shear-thinning properties for application to existing pipelines. The effects of the molecular weight of PVA and PEGDGE, their reaction ratios and catalyst concentrations on the properties of the crosslinked materials were investigated. A very low hydrogen permeability was achieved by optimising these parameters. This material also exhibited the required shear-thinning behaviour after reaction for 120 hours. A patent was filed with this coating composition.

There is more work still required to further develop this concept into a viable coating method. The coating utilized an alkaline catalyst which may introduce corrosion during application. The adhesion of the coating needs to be enhanced. Further research was carried out in Phase 2 of this project, focusing on different catalysts, coating adhesion and rheology modifiers.

Stage 3:

It is known that steel embrittlement is caused by the ingress of hydrogen radicals, rather than hydrogen molecules, that form at the steel surface. In this stage, the potential to scavenge these hydrogen radicals was investigated. The project examined the hydrogen radical scavenging ability of polydopamine (PDA) in the gas phase, demonstrating its potential to react with hydrogen radicals. The reaction mechanism of PDA with the hydrogen radicals was studied through experiments and modelling. The findings enhanced our understanding of the mechanisms underlying hydrogen radical scavenging capability, providing valuable insights for potential applications in coatings designed to prevent hydrogen embrittlement. A provisional patent was filed for this coating composition.

This project has made significant progress in addressing the challenge of hydrogen embrittlement in steel pipelines by developing innovative coating solutions. The promising results underscore the potential of these coatings to enhance the safety and reliability of hydrogen transportation through existing pipelines. Nonetheless, further research is required to enhance the performance of these coatings and translate these experimental findings into commercial applications. In Phase 2 of this project, different catalyst conditions were examined, and the addition of rheology modifiers was studied.

Future work should focus on investigating the impact of reduced hydrogen concentration on the embrittlement process to determine the concentration threshold that triggers embrittlement. Additionally, more research is needed to understand the precise mechanism of hydrogen molecule dissociation into hydrogen radicals on steel surfaces. It is particularly important to confirm whether the dissociated hydrogen radicals would preferentially react with a radical scavenger embedded in a coating rather than binding to the steel. Finally, both coatings need to be tested while adhered to steel surfaces when exposed to high hydrogen pressures, to confirm whether embrittlement is indeed reduced.

The project has attracted interest from a range of coating suppliers and there is the potential for the coating patents to be licenced through one of these companies.

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