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Technical Paper

Simulating, testing and validating thermoplastic compostie pipes resistance to rapid gas decompression effects for Pre-salf fields

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Abstract

Rapid gas decompression (RGD) resistance is an important characteristic to be assessed for polymers used as a barrier / liner of a pipeline conveying gas. The Oil & Gas industry has standardized straightforward test methods based in field experience and academic research, to assess polymer materials resistance against the extreme decompression rates that can occur in pipeline applications. This is particularly of interest for non-metallics products such as Thermoplastic Composites Pipes (TCP) which are composed of different thermoplastic layers and can be sensitive to this phenomenon. However, TCP are difficult to test according to standard protocol due the long durations implied by the TCP structure. This difficulty can be alleviated by testing a more conservative geometry and informing the testing by modelling. The outcome is a method better suited to TCP while precisely quantifying the TCP structure behavior to demonstrate suitability for high pressure gas transport.

Keywords: TCP. Riser. RGD. pre-salt. CO2

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1. Introduction

Rapid gas decompression (RGD) resistance is an important characteristic to be assessed for polymers used as a barrier / liner of a pipeline conveying gas. The Oil & Gas industry has standardized test methods based in field experience and academic research to assess polymer materials resistance against the extreme decompression rates that can occur in pipeline applications. This is particularly of interest for non-metallics products such as Thermoplastic Composites Pipes (TCP) which are composed of different thermoplastic layers and can be sensitive to this phenomenon. However, TCP are challenging to test according to standard protocol due the long durations implied by the TCP structure. This difficulty can be alleviated by testing a more conservative geometry and informing the testing by modelling. The outcome is a method better suited to TCP. This method precisely quantifies the TCP structure behavior which is validated by comparing simulation with experimental data while demonstrating suitability for high pressure gas transport applications.

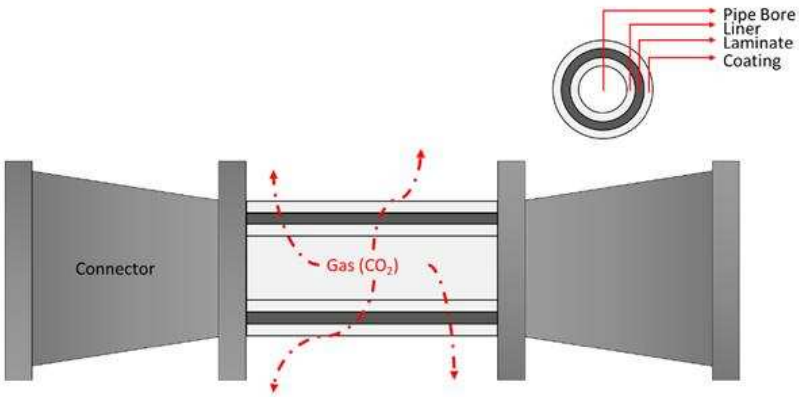
2. Summary

Rapid Gas Decompression (RGD) effects are a modification of a material properties in relation to a sudden change (reduction) of pressure. Rapid Gas Decompression resistance is of particular interest in the Oil & Gas industry in the context of non-metallics materials: elastomers and polymers. These materials under specific condition can exhibit large reduction in bulk density. At a small scale, gases present in a service fluid get absorbed in polymeric materials. When pressure is reduced these gases will expand and under the right conditions will overcome the internal mechanical resistance of the material resulting in the formation of microvoids. In the most severe cases, the microvoids will coalesce into bubbles and be characterized as blisters.
This phenomenon is closely related to the solubility of service fluids components into non-metallics. Pre-salt fields in Brazil have a notoriously high CO_2 content and need high pressure systems (~10ksi). Under such condition, CO_2 shows a significant solubility in several thermoplastic polymer systems. In order to demonstrate the fit-for-purposeness of a polymer system for pre-salt field, it is critical to demonstrate its resistance to rapid-gas decompression effects.

3. RGD test background

The potential effects caused by RGD cycles depends on the polymer saturation level related to gas absorption and desorption by the polymer matrix. Solubility and time to saturation depends on the thickness of a structure's cross section and the boundary conditions of the media (Pressure, temperature, gas composition and decompression rate). The TCP structure consists of fully bonded layers of polymer and fibre reinforced polymers. The time to saturation of the full structure can be considerable long. Figure 1 shows a typical TCP structure with its three constituent layers: liner, laminate and coating.

Figure 1 – Example of TCP Structure



Source: Produced by the authors

3.1. Practical applications and experimental approaches

RGD test procedure as defined in API 17J (American Petroleum Institute, 2014), requires at least 95% of saturation of the polymer matrix prior the execution of the decompression cycles. Time to saturation can be predicted using the test boundary conditions and diffusion coefficient calculations.

4. RGD test background

The following work has for objectives, firstly to present the behavior of gas (CO_2) transportation throughout the layers of a TCP structure with regards to saturation times and mass uptake. These are important parameters to perform RGD test in accordance with API standard. Afterwards, the variation results of mechanical properties are compared, using simulation and laboratory test results of polymeric and composite materials to validate the presented simulation analyses.

4.1. Simulation

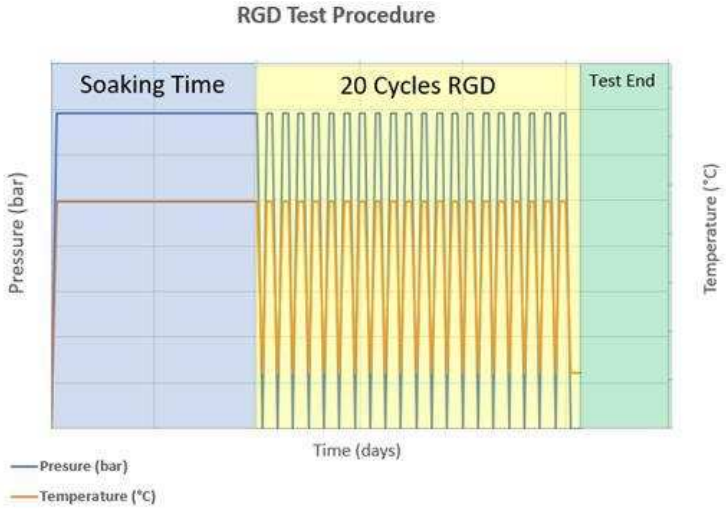
In order to predict the time to saturation of a generic TCP structure (4" as example) and predict the gas absorption and desorption behavior during a RGD test in accordance with API standards for a full-scale samples and small-scale sample (ring shape), CheFEM is used. CheFEM is a solubility and permeation prediction tool (Composite Analytica, 2019). It is based on calibrated Sanchez-Lacombe Equation of State (Sanchez & Lacombe, 1978) and William-Landel-Ferry based shift functions (Ashter, 2014). Using this tool, the permeation rates and saturation times are determined for a representative set of conditions.

The features for simulation of a full TCP structure and the boundary conditions have been selected according API 17J standard where:

- TCP Sample: Full-scale pipe (pressurized internally)
- Ring Sample: Ring shaped sample (Pressurized by immersion);
- Fluid mixtures: 100% CO_2;
- Soak time: Time to reach at least 95% of saturation;
- Test cycles: 20 consecutive cycles as presented in Figure 2;
- Decompression rate: 70 bar/min;
- Temperature: 93°C;
- Pressure: 690 bar;

The complete RGD procedure can be represented as per Figure 2 diagram.

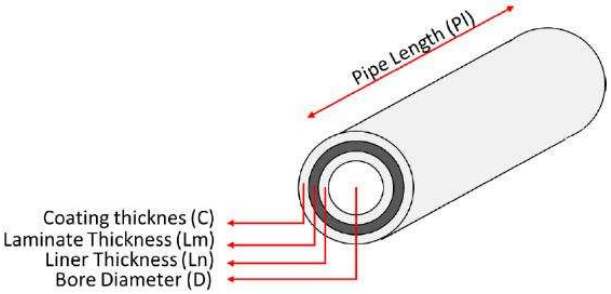
Figure 2 – RGD test diagram



Source: Produced by the authors

The TCP Layers composition and dimensions, presented in Figure 3:

Figure 3 – Reference for TCP geometry

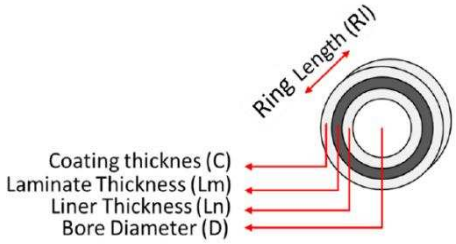


Source: Produced by the authors

- • D: 101.4 mm
- • Ln: 8.2 mm (PVDF)
- • Lm: 18 mm (CF-PVDF)
- • C: 6.5 mm (PVDF)
- • Pl: 1000 mm

Ring sample geometry dimensions, presented in Figure 4:

Figure 4 – Reference for ring sample geometry



Source: Produced by the authors

- D: 101,4 mm
- Ln: 8.2 mm (PVDF)
- Lm: 18 mm (CF-PVDF)
- C: 6,5 mm (PVDF)
- Rl: 10 mm

4.2. Experimental data

In order to confirm the accuracy of the results obtained by simulation, experimental data has been used to compare simulation and material test results. For this purpose, two materials have been mechanically tested after exposure in CO_2 by means of tensile test. A PVDF grade used for liner extrusion, and CF-PVDF grade, used for laminate construction. The mechanical test data outcomes are sued for such comparison. The test parameters are presented in Table 1. Those tests have also been simulated using CheFEM tool.

Table 1 – PVDF and CF-PVDF Exposure and mechanical tests parameter

Material	Exposure Time	Exposure Temperature	Exposure Pressure	Mechanical Test	Test Method
PVDF	90 days	130 °C	500 bar	Tensile Test	ASTM-D3039
CF-PVDF	112 days	93 °C	300 bar	Tensile Test	ASTM-D3039

Source: Produced by the author.

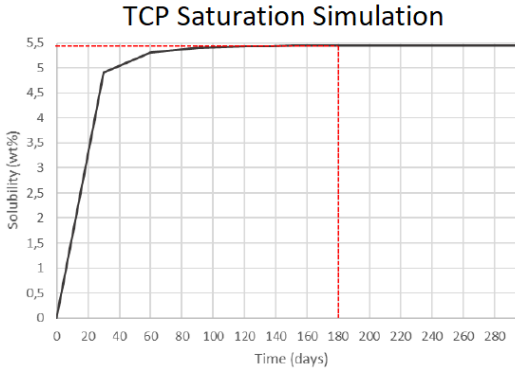
5. Results

This section presents the results acquired running the simulation on CheFEM toll for the presented conditions and the experimental test for pure PVDF polymer, representing the liner, and CF-PVDF materials, with respect to the laminate layer.

5.1. Simulation Results

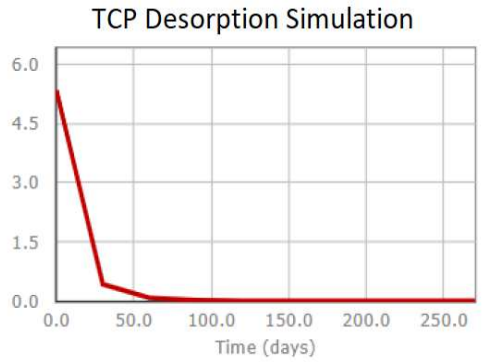
After the conclusion of the simulation of full-scale sample (**Error! Reference source not found.**), the time for saturation and desaturation was observed and are shown in **Error! Reference source not found.** and **Error! Reference source not found.** respectively for the TCP full-scale sample .

Figure 5 – Results of gas absorption



Source: Produced by the author.

Figure 6 – Results of gas desorption



Source: Produced by the author.

The simulation results are presented in Table 2 and shows the conditions to perform an API RGD procedure.

Table 2 – TCP Full-scale sample simulation outcomes

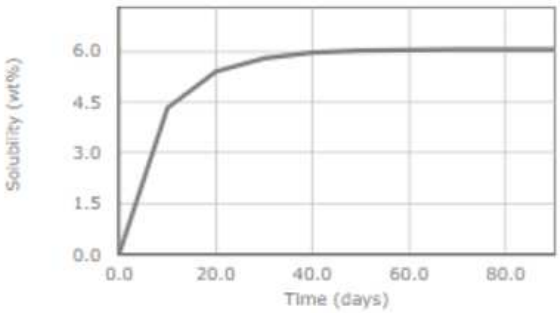
Parameter	Value	Unit
Saturation (soaking) Time	180	Days
Time to desaturate w/ depressurization rate per cycle	50-100	Days
Number of Cycles	20	-
Time to perform RGD cycles	20*50 = 1000	Days
Time to test	1180	Days

Source: Produced by the author.

The time to perform the RGD test of a full-scale TCP sample overgoes the 3 years of duration.

For comparison, the simulation of a ring sample, immersed in CO_2 environment has been carried out under the conditions described in section 4.1. The results obtained shows that the sample obtained 95% of saturation after 40 days and the desorption occurs with the decompression. Suitable time to perform an RGD test procedure.

Figure 7 – Results gas absorption for small scale sample

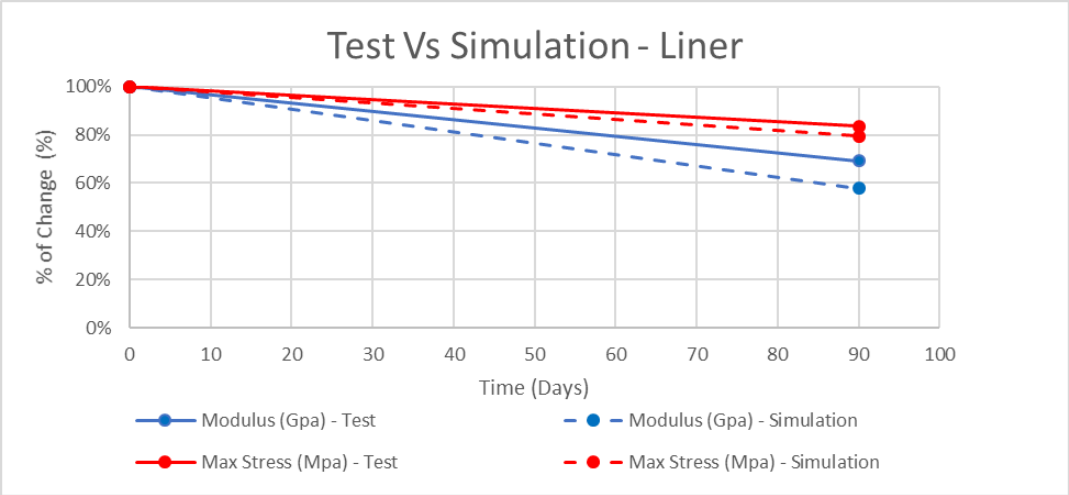


Source: Produced by the author.

5.2. Comparison of test results against simulation

Figure 8 presents the comparison between the tensile test results of the liner material before and after exposure in CO_2 for 90 days under the condition presented in Table 1. As can be observed, simulation complies with test data for the liner material. The variation in the maximum stress are round 31% for the test while the simulation showed a drop of 42%, the Modulus present a drop of 17% in the test where simulation shows 21%. This leads to a difference of 9% for the maximum stress obtained values and 4% for the variation of modulus results.

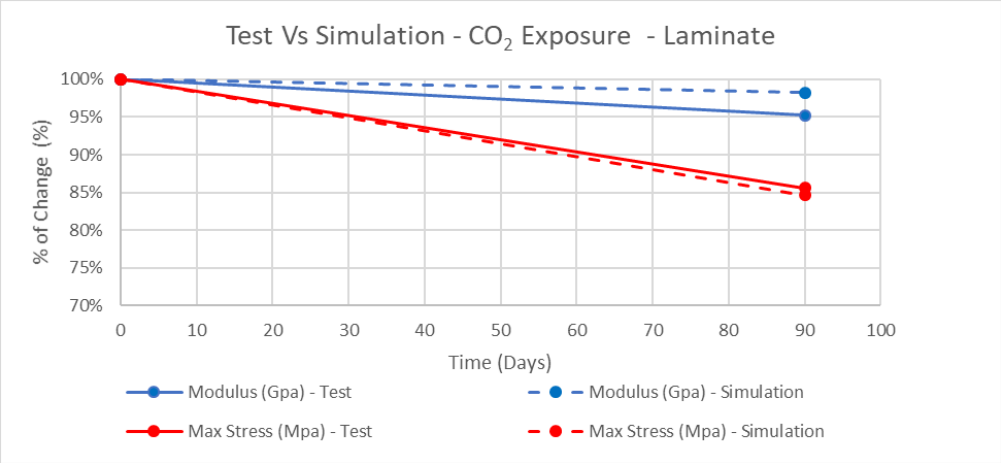
Figure 8 – Comparison between test and simulation – Liner material



Source: Produced by the authors

Error! Reference source not found. presents the comparison between the tensile test results of the composite material before and after exposure in CO_2 for 112 days under the condition presented in **Error! Reference source not found.**. As can be observed, simulation resulted in very similar results compared to test data of the laminate for both parameters, maximum stress and modulus. The difference between the variations of maximum stress are around just 1%, while the difference between the drop in the modulus is just 3%.

Figure 9 – Comparison between test and simulation – Laminate material



Source: Produced by the authors

The comparison between test a simulation, for composite and polymer materials, showed a very consistent, it demonstrates the relevance of CheFEM for material performance evaluations in CO2 environments at elevated pressures and temperatures.

6. Conclusion

The presented analysis demonstrates that it is not possible to apply the RGD protocol as defined by the API 17J within a feasible timeframe in a complete TCP structure. The long time necessary to saturate and desaturate liner and laminate shows the general TCP resistance to permeation. For RGD assessment, a conservative test method is proposed. This protocol is still representative to evaluate all TCP layers and the interfaces between them using small-scale samples, immersed in the desired fluid. In the end, the same acceptance criterion from API standards can be used.

7. Final Considerations

The RGD test method proposed herein is an alternative to full-scale test procedure as proposed by API standards. Because a model is validated through this process, the results obtained on the described sample dimensions (4-inch TCP structure) is representative for other TCP geometries if the materials used for the layers construction are the same (manufacturer and grades). It is also very

important to highlight that the level of absorption of CO_2 for laminate and coating layers are very conservative once they will be physically isolated from the pipe bore.
The result of comparing test data with CheFEM simulations outlines the importance the use of prediction tools as a helpful method to assess composite and polymeric for the Oil and Gas market, saving money and time. As demonstrated here, combining predictions with well proved test approaches benefits the understanding of the material, the product and emphasizes the relevance of specific test methods.

8. Acknowledgments

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