

Carbon Steel Corrosion on Production Environment, Evaluating The Impact of CO₂ Partial Pressure, BSW And Oil Characteristics on Tubular Life Extend

Merlin C. E. Bandeira, Rogaciano M. Moreira,
Felipe S. Assunção and Oscar R. Mattos
LNDC/COPPE/UFRJ
Av. Pedro Calmon s/n, Cidade Universitária
Ilha do Fundão
Rio de Janeiro/RJ, 21941-596
Brazil

Gustavo L. Vaz, Jefferson R. Oliveira, Ilson
Palmieri and Bruno Diehl Neto
Cenpes/Petrobras
Av. Horácio Macedo, 950
Cidade Universitária
Ilha do Fundão
Rio de Janeiro/RJ, 21941-915
Brazil

ABSTRACT

The high productivity of pre-salt exploratory wells led to a re-evaluation of Petrobras' model of offshore oil production and exploration. We present here the study that allowed the conversion of exploratory wells into producers, based on the corrosion resistance of carbon steel in different scenarios of pre-salt field production. The aim of the test program was to evaluate the influence of the produced water content (BSW), CO₂ partial pressure and oil characteristics on the carbon steel corrosion resistance. General corrosion analysis showed that for brine content below 40% corrosion rates ca. 0.05 mm/year for 28-day tests. Higher CO₂ partial pressure did not lead to increased corrosiveness, unlike shear stress. There was localized corrosion in most of the evaluated test conditions, confirming the importance of using laboratory techniques that allow such analysis. Localized as well as generalized corrosion kinetics decrease over time, confirming that laboratory tests, even when replicating field conditions, are more conservative as the operation time of the production columns will be extremely longer than laboratory test times. Based on results of this test program it was possible to extend the operation of exploratory wells adopting as safety criteria for well abandonment the produced water content (i.e. BS&W content) and additionally monitoring the internal pressure of production tubing.

Key words: pre-salt; BSW; carbon steel; rotating cage

INTRODUCTION

The production tubing of PETROBRAS exploratory wells is usually completed in carbon steel or low alloy steel as they operate for a short period, unlike columns in the production wells, which are completed with CRAs and designed for approximately 30 years. Due to high productivity of the pre-salt

exploratory wells the idea of converting them into producing wells was considered, however it was necessary to establish safety criteria and operating limits since carbon steel is susceptible to CO₂ corrosion on referred field conditions.

It is known that the water content in the oil directly influences the corrosiveness of the medium, but it is complex to estimate, based on existing knowledge, the corrosion rate only as a function of BSW (percentage of water and sediment), since each oil may have different characteristics, which are not incorporated in corrosion rate simulation softwares¹⁻³.

Some models consider the effect of oil wettability on corrosion rates⁴, but not all oil characteristics. According to studies published in the 80s by Jasinski and Effird⁵ using experimental data where the carbon steel was exposed only to the brine leads to huge errors when trying to estimate corrosion performance of structures exposed to environments containing mixtures of brine/oil. Although those studies presented consistent results, conservatism persists and the vast majority of laboratory studies to guide field decisions are conducted in 100% aqueous environments.

This type of approach in material selection in most cases leads to the selection of CRA rather than low alloy steels, given the high corrosion rate in brine-only environments. Considering the conservatism of the data used for the selection of tubulars in oil production and the high productivity of pre-salt exploration wells Petrobras reviewed its production model of offshore oil exploration. Knowing the results of previous works⁵⁻¹² that showed the influence of oil type and BSW on carbon steel corrosion, the need for a specific study for the new pre-salt fields was evident. The test conditions of the literature data⁴⁻¹¹, as well as the characteristics of the oil itself, were different from the fields for which it was needed to estimate the corrosion rate of carbon steel and therefore a fit-for-purpose testing program was required.

It is clear the intention of different research groups to identify, in the complex mixture of crude oil, what is the influence of the various categories of compounds on carbon steel corrosion. Effird⁸ cited data showing a relationship between TAN (Total Acid Number) and the wettability of the respective oil, where there was a tendency that the higher the TAN the lower the wettability and consequently the lower corrosion rate. However, this is a complex study given the diversity of composition among the producing fields.

Other researchers¹² claim that since key factors responsible for the inhibiting properties of crude oils and their interactions are consistent, it is very difficult to model the effect from fundamental principles and laboratory testing seems to be the most practical approach. However, some oil companies have decided not to take credit for the inhibiting properties of the oil until a methodology is representative of the field environment.

As reported in Stroe's work¹³ the lack of a well-established correlation between the physicochemical composition/properties of oils and their impact on tubular component corrosion leads to a neglect of the eventual protective effect of the oil. The same author also points out that corrosion assessment method should consider the effects of localized corrosion and not just uniform corrosion. As mentioned above, the high productivity of exploratory wells in the pre-salt fields motivated laboratory scale studies, to safely guide decision for the life extension of exploration well.¹⁴

The present work consists of the development of simple and objective response methodology and laboratory procedures that simulate the thermodynamic flow parameters inside the production column. Therefore, it was mandatory to evaluate the effect of BSW on the corrosion rate (localized and uniform) for each exploratory well considering the corrosive severity of fluids (oil and brine emulsion) and flow conditions in the production environment. In order to achieve it the experimental conditions must be as close as possible to those in the field.

The well report data¹⁵ with physical chemical properties, fluid dynamics computational simulation (MARLIM II software),¹⁶ thermodynamic simulation of system properties (OLI Systems)¹ and improvement of the RC technique for high pressure measurements were addressed. The results provided data on the safe corrosiveness performance of carbon steel tubular components on exploratory wells, considering both localized and uniform corrosion focusing on the BSW effect associated with the characteristics of each oil production environment and their susceptibility to CO₂ corrosion. By the experimental procedure development and further analyses of the carbon steel corrosion results, it was possible to convert exploratory wells into producing wells during a limited lifetime.

EXPERIMENTAL PROCEDURE

The methodology for atmospheric pressure rotating cage testing described in ASTM G202¹⁷ are also used to evaluate corrosion inhibitors, compare material performance and inhibitor dosage under different conditions (brine composition, crude oil and gas mixture). It is a simple experimental system, which test simultaneously several flat specimens under different flow conditions to represent those in the field. Furthermore, it is worth noting that the flat geometry of coupons allows not only uniform corrosion by mass loss measurements in accordance with ASTM G1¹⁸ but also localized corrosion by confocal microscopy analysis. Several coupons tested in a single investigation minimizing experimental error and improving representativeness of results.

The performed tests with Rotating Cage (RC) investigate API 5CT P110 carbon steel specimens taken from production tubular material samples evaluating three production scenarios. Table 1 presents the composition of the crude oils studied and table 2 list field conditions evaluated.

Formation water and oil mixture in the conditioning vessel to remove the oxygen by CO₂ purge. Stirring and heating promote the system emulsification. Simultaneously N₂ purged the autoclave containing the cage with the specimens. After that, the fluid was transferred from the conditioning vessel to the test vessel and the CO₂ saturated the system at atmospheric pressure, 60 °C, 500 RPM and gas flow rate of 100 mL/min with 1h/L solution. The autoclave pressurization establishes the fraction of gases corresponding to the partial pressures found in the well, as described in table 2. Figure 1a illustrates the entire test system and figure 1b shows the test cage.

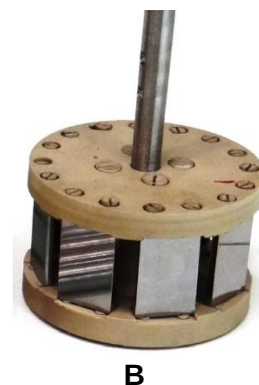
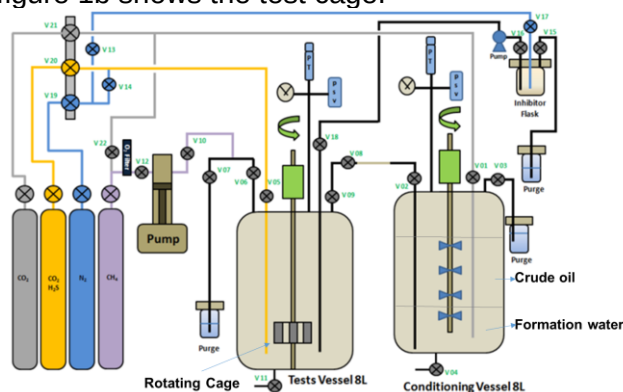


Figure 1: A - Schematic drawing of test system. B - Rotating Cage with coupons

Table 2 shows the test conditions of the results presented in this paper. To simulate the shear stress in the production column, for each test, the corresponding rotation speed calculation followed the equation described in ASTM G170¹⁹ and the density and viscosity data of each oil/brine mixture obtained from fluid dynamics computational simulation¹⁶. The influence of each experimental condition on fluid dynamics represents field environment.

1. OLI systems, inc. software version 9.0

Table 1 – Crude oil data

	Crude oil		
Properties/chemical composition	A	B	C
Density (°API)	31.0	28.4	30.2
Total Acid Number (TAN), mg KOH/g	0.11	0.36	0.32
Saturated hydrocarbons (SARA) %m/m	61.5	52.6	63.1
Aromatic hydrocarbons (SARA) %m/m	23.1	27.2	18.2
Resins (SARA) %m/m	15.4	19.9	18.6
Asphaltenes (SARA) %m/m	< 0,5	< 0,5	< 0,5

Table 2 – Test conditions to evaluate corrosiveness of Carbon steel on three different wells

Crude	BSW, (%brine)	Time (days)	T (°C)	P _{CO2} (MPa)	P _{CH4} (MPa)	τ(Pa)/RPM*	Cl ⁻ (ppm)	HCO ₃ ⁻ (ppm)	HAC (ppm)	%CO ₂	P _{Total} (MPa)
A	10	7	60	0.5	19.5	88/897	140,000	500	200	2.5	20
A	30	7	60	0.5	19.5	88/863	140,000	500	200	2.5	20
A	40	7	60	0.5	19.5	88/780	140,000	500	200	2.5	20
A	40	28	60	0.5	19.5	88/781	140,000	500	200	2.5	20
A	40	7	60	0.85	33.15	88/920	140,000	600	200	2.5	34
A	60	7	60	0.5	19.5	88/798	140,000	500	200	2.5	20
A	60	28	60	0.5	19.5	88/781	140,000	500	279	2.5	20
A	80	7	60	0.5	19.5	88/777	140,000	500	200	2.5	20
	100	7	60	0.5	19.5	88/761	140,000	500	200	2.5	20
B	5	7	65	8	12	130/1094	140,000	1,000	270	40	20
B	10	7	65	8	12	130/1086	140,000	1,000	270	40	20
B	20	7	65	8	12	130/1074	140,000	1,000	270	40	20
B	50	7	65	8	12	130/970	140,000	1,000	270	40	20
C	10	28	65	6	14	88/1,187	140,000	1,070	279	30	20
C	20	28	65	6	14	88/1,090	140,000	1,070	279	30	20
C	20	7	65	6	14	88/1,090	140,000	1,070	279	30	20
C	40	28	65	6	14	88/910	140,000	1,070	279	30	20
C	40	7	65	6	14	88/910	140,000	1,070	279	30	20
C	60	28	65	6	14	88/795	140,000	1,070	279	30	20
C	80	28	65	6	14	88/712	140,000	1,070	279	30	20

- To convert the shear stress into RPM it was considered the fluid kinematic viscosity and density at specific experimental conditions using the equation: $\tau = 0.0791 \times Re^{-0.3} \times \rho \times r^2 \times \omega^{2.3}$

All tests were performed only with 3 coupons despite the cage hold 8, to minimize pH variations due to corrosion products. However, it is worth to mention that all cage positions were filled coupons (carbon steel or inert material coupons) to keep the cage geometry close to a cylinder, enabling the use of the