API Ballot id# 5797
SC5 TGLP

Work Item	4232 – Hydrogen-Induced Crack Testing in Mild Sour Conditions
Distribution-type [Ballot (vote and comment), Comment-only (review), Recirculation (comment resolution), Re-ballot … etc.]	Comment-only (review)
Document	TR 5HIC, 1st Edition
Other Impacts	None
Revision Key	NA—This is a 1st Ed. with no Track Changes for its initial circulation.

Work Item Charge:

After the completed work and report delivered from the approved SR3 (2014) for funding to define hydrogen induced cracking (HIC) test conditions and exposure duration needed to assess the suitability of commodity grade line pipe under mildly sour conditions, the desire now is to have the information available as an API Technical Report so the concepts – that were proposed for API 5L and subsequently passed ballot – may also be used by other standards or referenced in other applications.

Ballot Rationale:

To minimize the likelihood of HIC related cracks in sweet-service commodity grade pipes operated under mildly sour conditions by providing a quick and reliable laboratory HIC test able to separate resistant from susceptible pipes; to provide procedures consistent with upcoming NACE TM0284 & MR0175 requirements (test method, acceptance criteria); avoid premature failures of non-HIC tested line pipe steel.

NOTE See the ballot email notification for additional information regarding this ballot.

Defining Hydrogen-Induced Cracking Test Criteria for Commodity Grade Line Pipe in Mildly Sour Conditions

API TECHNICAL REPORT 5HIC
FIRST EDITION, [month] [year]

NOTE The *Contents*, *Special Notes*, and *Foreword* will be inserted by API during the page proofing process prior to publication.

Introduction

The API Subcommittee on Tubular Goods decided to have work performed to support the development of a moderate sour service commodity grade under API 5L Annex H. The project aimed at defining HIC test conditions and exposure duration needed to assess the suitability of commodity grade line pipe under mildly sour conditions. The impact of varying test durations on the extent of HIC-cracking was assessed by utilizing two sweet service SAWL pipe of Grades X65 and X70 of different susceptibility to HIC-cracking. The test program consisted of 13 HIC test batches representing mildly sour test environments containing 1–10 % H_2S with pH between 3.5–4.5. Specimen preparation, exposure, ultrasonic testing (UT) and metallographic evaluation was performed in accordance with NACE TM0284-2016.

For all mildly sour test environments and exposure durations between 4–14 days, the X70 Pipe B showed significant HIC-cracking, whereas the X65 Pipe A gave less HIC indications in terms of crack area ratios (CAR) obtained by UT and crack length ratios (CLR) obtained by metallographic evaluation.

With the clear benefit of shorter test duration in mind, the project focused on the question whether HIC-cracking can stabilize earlier in HIC tests shorter than the 14 days specified in NACE TM0284, and to what extent choice of solution pH and H_2S content could contribute to achieve this objective. Within the observed scatter, HIC tests conducted in solutions of higher acidity gave a tendency of higher levels of HIC-cracking at shorter exposure times than observed for exposure under lower acidity (higher pH) test conditions. HIC-cracking did, however, not stabilize during exposure durations shorter than 14 days in those mildly sour test environments.

API 5CT (NACE TM0177 Solution D) gave unexpectedly high cracking after 4 days exposure. Experience with this solution in HIC testing is limited. More work is needed before considering this solution, developed for SSC-DCB testing, as a standardized HIC test environment.

Considering the increase in HIC-cracking with longer test duration as important result of this project, HIC test durations shorter than 14 days in the considered range of mildly sour test environments are not recommended.

Defining Hydrogen-Induced Cracking Test Criteria for Commodity Grade Line Pipe in Mildly Sour Conditions

1 Scope

The work described herein is to support the development of a moderate sour service commodity grade under API 5L Annex H, while maintaining harmonization with ISO 15156 and NACE TM0284 as regards resistance testing to hydrogen-induced cracking (HIC).

To define the HIC test conditions and exposure duration needed for that purpose, the impact of varying test durations on the extent of cracking in mildly sour test environments was specifically assessed in solutions containing 1–10 % H_2S within pH values 3.5–4.5.

For the series of HIC tests conducted, sweet service test material from two different pipe was utilized, which did show different susceptibility to cracking in moderate sour conditions.

2 Background

Wet sour gas and H_2S containing electrolytes can be extremely corrosive to low-alloy steels. In the presence of H_2S, the anodic metal dissolution can be accelerated and hydrogen atoms originating from the corrosion reaction can diffuse into the steel, resulting in cracking, such as HIC, sulfide stress cracking (SSC) and stress-oriented hydrogen-induced cracking (SOHIC) [12, 14]. Due to the sudden, unforeseeable failure mode of cracking mechanisms, this type of damage is regarded much more dangerous than weight-loss corrosion.

The usual approach in evaluating the susceptibility of low-alloy steel to HIC is to employ laboratory test specimens without external loading, usually according to a standardized procedure (NACE TM0284-2016, EFC Publication No. 16). The test method consists of exposing test specimens to a sour solution saturated with H_2S gas at a partial pressure of 1 bar for a 96-h test duration.

HIC testing, regarding the parameters H_2S partial pressure and pH value at less severe test conditions compared to standard testing (i.e. at a lower H_2S partial pressure and/or at a higher pH), is frequently called “Fitness-For-Service” or “Fitness-For-Purpose” testing. An attempt has been made, by the European Pipeline Research Group (EPRG), to classify line pipe steels within regions of environmental severity with respect to HIC, in a similar way to the diagram given in ISO 15156-2 for the case of SSC, where SSC regions from 0–3 are defined based on pH and partial pressure of H_2S. This diagram is given in Figure 1. The HIC severity regions shown in Figure 1 are based on test results given in [10], with data from the worst performing sweet service materials from the EPRG laboratory HIC test series [9, 13] and further literature data [8, 11] included.

Figure 1 is based on various exposure times dependent on the partial pressure of H_2S. Based on the EPRG work [13] for 6-sided specimens exposed to 10 mbar or 100 mbar H_2S, the diffusible hydrogen content hardly increased when the immersion time was increased from 96 hours to 2 weeks. It was therefore assumed that the equilibrium was already reached after 96 hours. However, a remarkable increase in HIC-cracking, determined by both UT and metallographic sectioning, was observed when increasing the exposure time from 96 hours to 2 weeks. For tests at 10 mbar and pH 3.5, 1 month exposure was necessary to initiate any cracking [13].

On this basis, the EPRG decided to perform experiments comparing different materials at 10 mbar H_2S with 1 month exposure and at 100 mbar H_2S with 2 weeks exposure [9], which has been implemented in the recent revision of NACE TM0284. However, this creates scope for additional research in terms of exposure times necessary to achieve equilibrium conditions (or stabilize HIC-cracks) under mildly sour test conditions.

3 Test Conditions

To define suitable HIC test conditions and exposure duration for commodity grade line pipe, the following were used for the HIC test series in mildly sour (1–10 % H_2S) environments:

— API 5CT (NACE TM0177 Solution D), 7 % H_2S in N_2 (96 h)

— 5 % NaCl, 0.4 % NaAc, 3 % H_2S in CO_2, pH 3.5 (96 h, 7 d, 10 d, 14 d)

— 5 % NaCl, 0.4 % NaAc, 7 % H_2S in CO_2, pH 4.0 (96 h, 7d, 10 d, 14 d)

— 5 % NaCl, 0.4 % NaAc, 10 % H_2S in CO_2, pH 4.5 (96 h, 7d, 10 d, 14 d)

The test conditions have been chosen based on the reasonable assumption that they are comparable on the diagonal lines in the EPRG diagram (Figure 1), and on lines parallel, with respect to 'test severity' (Figure 2).

To ensure that the material selected shows HIC-cracking in the test conditions chosen for this work, two different sweet service pipe were selected after a preliminary study; which have shown some susceptibility to HIC in mildly sour conditions at the longest intended exposure time of 14 days. It was expected that the selected materials responded sensitive enough to distinguish between the different test conditions and exposure durations used by this work.

4 Material

The following two pipe materials were selected for testing:

— SAWL Grade X65, OD 32 in. (813 mm) x 39 mm [Designation: Pipe A]

— SAWL Grade X70, OD 56 in. (1414 mm) x 34.6 mm [Designation: Pipe B]

5 Experimental

5.1 General

The work scope needed the preparation of 156 standard specimens, testing in 13 individual test batches of 12 specimens representing the different solutions and exposure durations, and evaluation by means of ultrasonic testing (UT) and metallographic examination.

5.2 Test Plan

Testing of the two available pipe consisted of machining 2 sets of 3 HIC specimens per pipe in accordance with NACE TM0284-2016. The two sets of specimens per pipe were machined directly adjacent to each other for the different sampling positions in the pipe, to ensure that the results obtained for each material are sufficiently reproducible. Evaluation was performed by UT (CAR) according to NACE TM0284-2016 Appendix A and by equidistant metallographic sectioning according to the same NACE standard (CLR, CTR and CSR).

5.2.1 Machining

Test specimens, each specimen 100 mm ± 1 mm long by 20 mm ± 1 mm wide, full pipe wall thickness with a maximum of 1 mm removed from each of the internal and external surfaces, were machined in accordance with NACE TM0284-2016. The four cut edge surfaces were ground and finished with 320-grit paper.

5.2.2 Solutions

API 5CT (NACE TM0177 Solution D), a buffered aqueous brine solution with a chloride content, H_2S partial pressure, and pH specified by the supplemental requirements of API 5CT for DCB testing of C110 OCTG material, was used as a "reference" solution in 96 hours HIC tests. This solution consists of distilled or deionized water containing 5 % NaCl and 0.4 % sodium acetate (NaAc). 7 % H_2S in N_2 is used as the test gas at a start pH of 4.

For all other test conditions, NACE TM0284-2016 Solution C (5 % NaCl, 0.4 % NaAc) was chosen with different levels of H_2S partial pressure and pH: pH 3.5 (3 % H_2S in CO_2), 4.0 (7 % H_2S in CO_2) and 4.5 (10 % H_2S in CO_2).

5.2.3 Test Procedure

For the different test conditions of the research program, the following ratios of the volume of solution to the total surface area of the test specimens were used; which are sufficient to ensure that the pH did not exceed 4.6 when using API 5CT (NACE TM0177 Solution D), respectively, to maintain reasonable intervals of re-adjustment of pH to the target pH ± 0.2 when using NACE TM0284 Solution C:

— API 5CT (NACE TM0177 Solution D), 7 % H_2S in N_2: 12 mL/cm^2 (minimum)

— 5 % NaCl, 0.4 % NaAc, 3 % H_2S in CO_2, pH 3.5: 20 mL/cm^2 (minimum)

— 5 % NaCl, 0.4 % NaAc, 7 % H_2S in CO_2, pH 4.0: 20 mL/cm^2 (minimum)

— 5 % NaCl, 0.4 % NaAc, 10 % H_2S in CO_2, pH 4.5: 12 mL/cm^2 (minimum)

To ensure consistent and reproducible test results, the following details on the test procedure were followed:

— For the tests in API 5CT (NACE TM0177 Solution D) the initial pH before the introduction of the test gas were adjusted to 4.0 ± 0.1 by addition of hydrochloric acid (HCl) or sodium hydroxide (NaOH). During the test, pH was allowed to increase to a maximum of 4.6 without any further re-adjustment.

— For the tests in NACE TM0284 Solution C the initial pH was adjusted to the target pH ± 0.2 pH units by addition of HCl or NaOH before saturation with the H_2S/CO_2 gas mixture.

— Purging of the sealed test vessel with nitrogen for at least one hour at a rate of 100 cm^3/min per liter of solution was undertaken, until the concentration of oxygen in the solution was below 50 ppb.

The results are plotted in Figure 3 from the following steps:

— Phase I: Purging of the sealed test vessel with test specimens.

— Phase II: Solution transfer.

— Phase III: Deaeration of solution in the test vessel before test start.

— A 30 L glass test vessel was used for each test batch. In this test setup the oxygen concentration measured with an optical electrode was 34 ppb or lower after purging.

— The test gas consisting of H_2S and CO_2 (and H_2S and N_2) were commercially supplied gas mixtures with composition determined by analysis. These gas mixtures were introduced with a rate of bubbling of at least 200 cm^3/min per liter of solution for a minimum of 60 minutes. After the required H_2S concentration (i.e., 70 mg/L for 3 % H_2S, 160 mg/L for 7 % H_2S and 230 mg/L for 10 % H_2S, measured by iodometric titration) had been reached, the flow of test gas was kept constant at a minimum flow rate of 100 cm^3/min to ensure that the H_2S concentration does not fall below the required level throughout the test. During the test, the H_2S concentration was measured work-daily.

The pH was measured at the start (after saturation with the test gas mixture) and end of the test and in work-daily intervals during the test. If necessary, re-adjustment the pH to the target pH ± 0.2 pH units was undertaken by addition of HCl or NaOH.

6 Test Sequence and Evaluation

The test specimens were exposed at 25 °C in 13 individual test batches as shown in the following Table 1.

After exposure, the specimens were first examined by an automated UT system according to NACE TM0284-2016 Appendix A, with the following details:

— UT system in immersion technique,

— 10 MHz probe with a flat, unfocused transducer with 6 mm diameter,

— water path length from transducer surface to top surface of the specimen adjusted according to transducer-type to 23 mm,

— thickness of test block (i.e., minimum thickness = specimen thickness); mechanically measured,

— sensitivity adjusted to 80 % full screen height (FSH) for all the maximum amplitudes of the 5 notches of the notched test block; 80 % FSH used for threshold, too,

— printed chart of the automated UT scanning as a plot of the amplitudes above threshold over the scanning area (“C-scan”); provided for each specimen, and

— crack area ratio (CAR); provided for each specimen.

The specimens were then evaluated by metallographic inspection according to NACE TM0284-2016 and prepared for metallographic examination by employing several intermediate grinding steps to remove any prior metal deformation. The surface was finished by fine grinding with 800-grit (or finer) paper and then polished with diamond paste (grain size: 3 microns, 1 micron) and Al_2O_3 alumina paste or diamond paste (max. grain size: 0.25 micron). The surface was finally cleaned using water, alcohol, and hot air.

All cracks visible at magnification (x100) were measured and reported. In this evaluation, cracks that lie within 1.0 mm of the internal or external surface of the test specimen were disregarded. Cracks separated by less than 0.5 mm were considered a single crack. CLR, CTR and CSR were calculated and reported for each section, and the average for each test specimen, according to NACE TM0284-2016.

7 Results

The complete test results per individual HIC specimen including the single CLR, CTR and CSR evaluation of each of the 3 metallographic sections per specimen are shown in Annex A. The test results are given in Tables 2 and 3 as average results for Pipe A and B, where the evaluations considered the following:

— average CAR and CLR for all base material specimens,

— average CAR and CLR for base material specimens from 3 o’clock position,

— average CAR and CLR for base material specimens from 6 o’clock position,

— average CAR and CLR for all weld specimens, and

— average CAR and CLR for all specimens.

The color codes given in Tables 2 and 3 illustrate differences in CAR and CLR values for the different exposure conditions and durations.

In the following evaluation, CTR and CSR values were not considered because cracking perpendicular to the plate rolling direction was low in general, as expected. Occasionally, higher CTR and resulting CSR values were restricted to isolated cracks occurring in weld specimens, primarily of the more HIC susceptible Pipe B. These cracks could not be correlated to specific test conditions or exposure durations.

Compared to the other test conditions, API 5CT (NACE TM0177 Solution D) gave unexpectedly high cracking after 4 days exposure. As the balance gas used in this environment is nitrogen instead of CO_2 in Solution C to NACE TM0284, comparison of results is difficult.

Examples of typical HIC-cracks observed by metallographic examination are shown in Figure 4 for the X65 Pipe and in Figure 5 for the X70 Pipe. Cracking mostly occurred in the mid-wall region of the base material and was influenced by centerline segregation, which is more pronounced in Pipe B (see Figure 5). HIC-cracking was sometimes accompanied by near-surface blistering, especially in specimens of the X70 Pipe B as shown in Figure 6 for the base material of weld specimen B12-2.

A better overall picture of HIC-crack locations can be obtained from the ultrasonic testing (UT) after exposure and before metallographic sectioning. Typical UT plots are shown in Figure 7 for the X65 Pipe A and in Figure 8 for the X70 Pipe B.

The UT plots of the base metal specimens confirm presence of the most relevant indications in their mid-thickness. In some specimens, additional near-surface indications were found, which indicate blistering.

Hereafter, the focus is put on the results obtained from the different tests in NACE TM0284 Solution C. Cracking is generally more intense for Pipe B as expected from pre-testing.

A graphical presentation of the base material average data given in Tables 2 and 3 can be obtained by plotting the CAR and CLR values in dependence of the exposure durations for the different test conditions where NACE TM0284 Solution C was utilized. Figure 9 shows the related graph for the base metal specimen average CAR of the X65 Pipe A; in Figure 10 the same graph is given for the CLR values. Likewise, in Figures 11 and 12, the graphs for the base metal specimen average CAR and CLR values are shown for the X70 Pipe B.

The data shown in Figures 9–12 have in common that the data show scatter which is typical of HIC test data. To make trends in HIC-crack evolution with time more visible, additional trend lines were calculated for each individual exposure condition by linear regression to indicate the changes of CAR and CLR for the range of exposure durations between 4–14 days.

In principle, the three test conditions result in increased cracking for longer exposure. Due to a CAR outlier for the test in 3 % H_2S for 7 days exposure this trend is possibly not correctly reproduced in Figure 9 for Pipe A. Since the HIC-cracking response of Pipe B was much higher than observed for Pipe A, the trend lines appear to be better reproduced for this material (see Figures 11 and 12). The data indicate another overall trend of a higher increase in HIC-cracking for the higher pH test conditions (pH 4.0 and 4.5).

The weld specimens of both pipe gave lower CAR and CLR values compared to the base material specimens tested under the same conditions with the same test duration. This was caused by little to no HIC-cracking in the weld metal and reduced HIC in the base metal parts of the weld specimens. The trends observed for the base material could not be confirmed for the weld specimens, except that the highest weld specimen CAR and CLR values were found after 14 days exposure for most of the environment/material combinations tested. To account for this, trend lines were also calculated for the overall average CAR and CLR values, including base material and weld specimens. The resulting graphs are shown in Figures 13 and 14 for the X65 Pipe A and in Figures 15 and 16 for Pipe B.

The overall data confirm the trend obtained from the “base-metal-only” evaluation, but also indicate a higher increase in HIC-cracking for the higher pH test conditions because growth of HIC-cracks at a lower pH of 3.5 has further advanced at shorter exposure than at pH 4 or above. The higher acidity of the solution, despite a lower H_2S level used at pH 3.5, appears to be of some importance for this result.

8 Commentary

Both materials were found to be appropriate to serve the needs of the project, with the X70 giving higher average CAR in the range of test conditions. Within the observed scatter, typical of HIC testing, the test conditions could be confirmed to be comparable in terms of test severity only for 14 days exposure duration as required by NACE TM0284.

Increasing the test duration from 4–7 days or longer in 3 % H_2S (pH 3.5) resulted in considerably higher CAR values for both materials. No further increase in CAR values between 7–10 or 7–14 days exposure was observed. However, continuous increase in CLR with increasing test duration was found for Pipe B, which indicates that HIC-cracks that initiated early do not stabilize when the exposure time is shortened.

Tests in 7% H_2S (pH 4.0) gave no clear tendency but highest cracking (CAR & CLR) after 14 days exposure.

Increasing the test duration from 4–7 days in 10 % H_2S (pH 4.5) resulted in higher CAR/CLR values for both materials. CAR/CLR values after 10 days were in the same range as those obtained after 7 days testing, but highest after 14 days exposure.

API 5CT (NACE TM0177 Solution D) gave unexpectedly high cracking after 4 days exposure. There is little experience with this solution in HIC testing. Even if its unexpected high severity might be suitable to allow for shorter exposure, the applicability of the current ISO 15156-2 acceptance criteria to this environment has not yet been established. More work would be needed to look at the effect of the balance gas (N_2 vs. CO_2) on HIC-crack initiation and evolution with time.

9 Conclusions

The introduction of non-zero acceptance criteria in the latest revision of ISO 15156-2 for HIC specimens tested in the new NACE TM0284 Solution C allows better classification of the suitability of line pipe, not designed for severe sour service, for use under mildly sour test conditions. In mildly sour HIC test evaluation the 15 % CLR acceptance level helps separate HIC resistant from HIC susceptible line pipe.

The use of ultrasonic testing to NACE TM0284 Appendix A is useful to improve confidence in the results obtained from traditional metallographic evaluation to NACE TM0284. Both methods of evaluation gave the same trends of increased HIC-cracking for longer exposure within the H_2S partial pressure (0.03–0.10 bar) and pH range (3.5–4.5) utilized for HIC exposure in NACE TM0284 Solution C. Consideration of CLR obtained by metallography appeared to be of particular importance for welded line pipe, as HIC-cracking primarily initiates in the mid-wall thickness of the pipe and extends in the plate rolling direction.

This work generally reaffirmed the previous EPRG work [9, 10, 13] that onset and development of HIC-cracking in solutions milder than NACE TM0284 Solution A requires more time at H_2S partial pressures between 0.03–0.1 bar. The test results obtained from HIC testing two sweet service pipe confirm the suitability of the 14 days exposure duration specified in NACE TM0284 for these conditions. While shorter exposure results in higher CAR and CLR values at lower pH conditions which offer higher acidity, HIC-cracking tends to be slightly higher at higher partial pressure of H_2S after 14 days testing. These trends are more obvious for the X65 Pipe A, which gave less overall HIC-cracking than the X70 Pipe B.

Considering the observation that HIC-cracking did not stabilize during shorter exposure, bearing the risk of too low HIC-cracking response, HIC test durations shorter than 14 days in those mildly sour test environments are not recommended. The results from this work support the changes to ISO 15156-2 regarding the non-zero cracking criteria for solutions milder than NACE TM0284 Solution A. Further, these results are consistent with EPRG's basis for changes to API 5L Annex H for a commodity grade mild sour pipe product.

Table 1—Pipe A+B: Overview of Individual HIC Test Batches and Exposure Conditions

No.	1 Batch	2 Gas Mix	3 Days Exposure	4 pH Test Solution	5 pH at Start	6 pH at End	7 $c(H_2S)$ at Start [mg/l]	8 $c(H_2S)$ at End [mg/l]
1	1-79	7 % H_2S/N_2	4	API 5CT	4.2	4.3	204	204
2	2-80	3 % H_2S	4	3.5	3.5	3.5	79	86
3	2-81		7		3.4	3.5	71	83
4	2-82		10		3.5	3.6	87	102
5	2-83		14		3.6	3.5	90	85
6	2-84	7 % H_2S	4	4	4.1	4.1	163	194
7	2-85		7				170	179
8	2-86		10				187	170
9	2-87		14				190	187
10	2-88	10 % H_2S	4	4.5	4.5	4.6	240	286
11	2-89		7				261	254
12	2-90		10				237	274
13	2-91		14				247	259

Table 2—X65 Pipe A: Overview of Average HIC Test Results via CAR and CLR

No.	1 Duration	2 H_2S (%)	3 pH	4 CAR BM	5 CAR 3	6 CAR 6	7 CAR W	8 CAR All	9 CLR BM	10 CLR 3	11 CLR 6	12 CLR W	13 CLR All
1	4	7	API	11.5	9.3	13.6	0	7.7	0.4	0	0.7	0	0.3
2	4	3	3.5	0	0	0	0	0	0	0	0	0	0
3	7			3.4	1.7	5.1	0.3	2.4	1.3	0.3	2.2	0.1	0.9
4	10			0.6	0.9	0.2	0	0.4	0	0	0	0	0
5	14			0.9	0.3	1.5	0	0.6	0.8	1	0.7	0	0.5
6	4	7	4	1.7	0.9	2.5	0	1.1	0.2	0.1	0.4	0	0.1
7	7			1.5	2.1	0.9	0.3	1.1	0.9	1.8	0	0	0.6
8	10			0.4	0.6	0.1	0.1	0.3	0	0	0	0.2	0.1
9	14			3.7	0.5	6.9	0	2.5	3.2	1.5	5	0	2.1
10	4	10	4.5	0	0	0	0	0	0	0	0	0	0
11	7			0.5	0.7	0.2	0	0.3	0	0	0	0	0
12	10			0.3	0.2	0.3	0	0.2	0	0	0	0	0
13	14			1.8	3	0.5	21.5	8.4	5	9.6	0.3	19.4	9.8
	Key	CAR/CLR (%)		0–1	1–3	3–5	5–10	10–15	15–20	20–25	25–30	> 30	

Table 3—X70 Pipe B: Overview of Average HIC Test Results via CAR and CLR

No.	1 Duration	2 H_2S (%)	3 pH	4 CAR BM	5 CAR 3	6 CAR 6	7 CAR W	8 CAR All	9 CLR BM	10 CLR 3	11 CLR 6	12 CLR W	13 CLR All
1	4	7	API	43.8	56.4	31.15	15.5	34.4	13.7	13.8	13.6	4.7	10.7
2	4	3	3.5	10.6	17.1	4	7.7	9.6	1.7	1.4	2	5.6	3.0
3	7			26.4	36.9	15.8	10.8	21.2	6	7.2	4.8	5.1	5.7
4	10			20	29	11	5.8	15.3	17.5	26	9.1	8.1	14.4
5	14			20.9	25.5	16.2	3.2	15	32.1	38	26.1	2.4	22.2
6	4	7	4	21.1	24.1	18.1	5.8	16	8.8	9.2	8.3	0.4	6.0
7	7			28.4	32	24.7	6	20.9	8.9	6	11.7	2.4	6.7
8	10			35.1	48.2	21.9	6.6	25.6	46	58.5	33.4	9.4	33.8
9	14			24.7	36.2	13.2	6.5	18.6	29.9	37.1	22.7	16.1	25.3
10	4	10	4.5	3.2	3.3	3	2	2.8	0.5	0.2	0.8	0.4	0.5
11	7			8.9	8.8	9.1	2.3	6.7	3	2	4	3.2	3.1
12	10			4.7	4.2	5.1	3.8	4.4	2.9	1	4.9	0.1	2.0
13	14			28.8	44.9	12.6	7.9	21.8	20.7	27.9	13.5	7	16.1
	Key	CAR/CLR (%)		0–1	1–3	3–5	5–10	10–15	15–20	20–25	25–30	> 30	

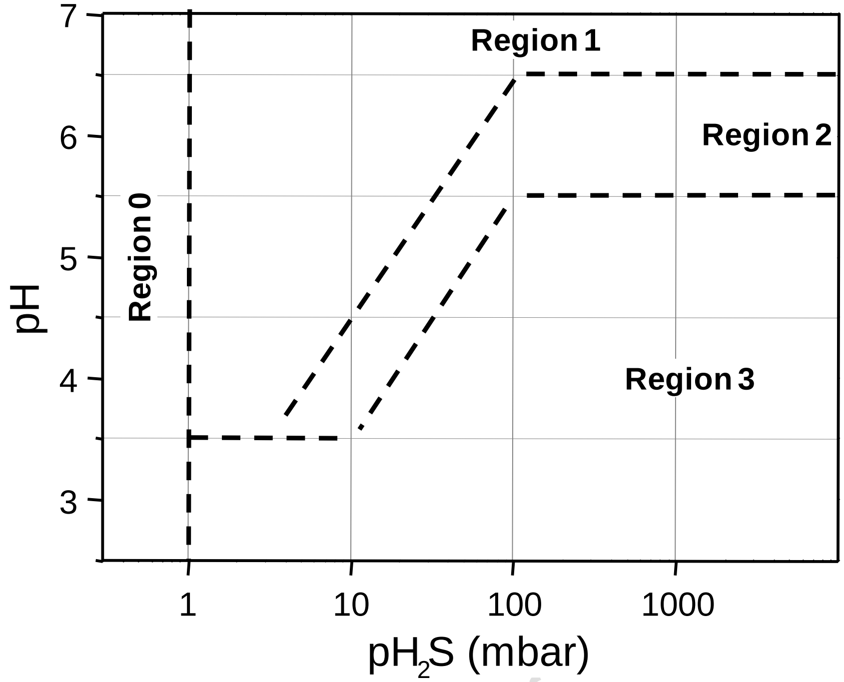

Figure 1—Proposal of HIC Severity Regions Suggested by EPRG

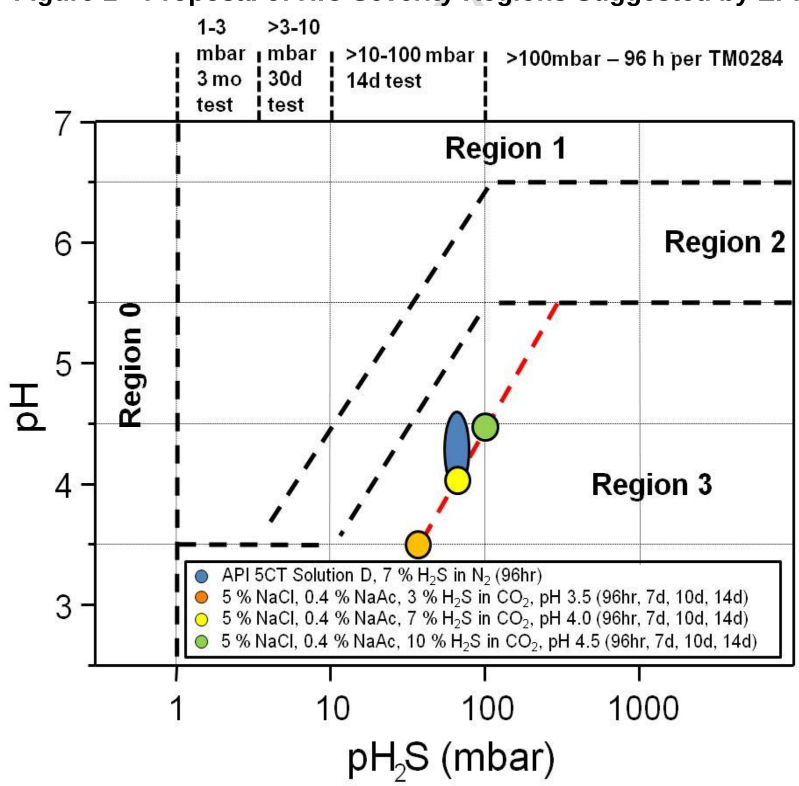

Figure 2—Mildly Sour Test Conditions to Define Test Criteria for Commodity Grade Line Pipe

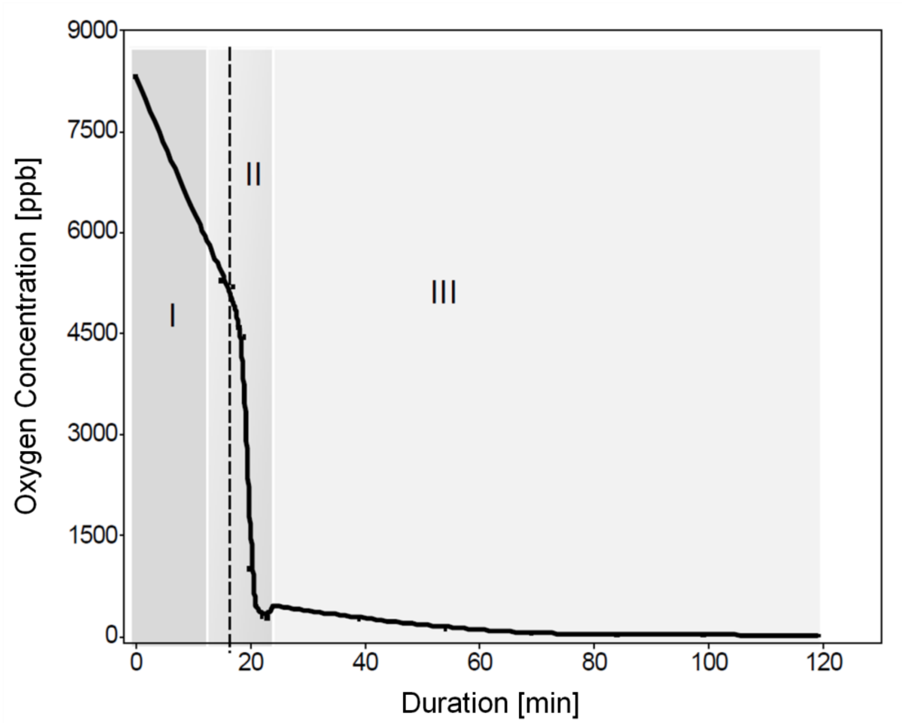

Figure 3—Oxygen Concentration Range during HIC Test Preparation in 30 L Test Vessel

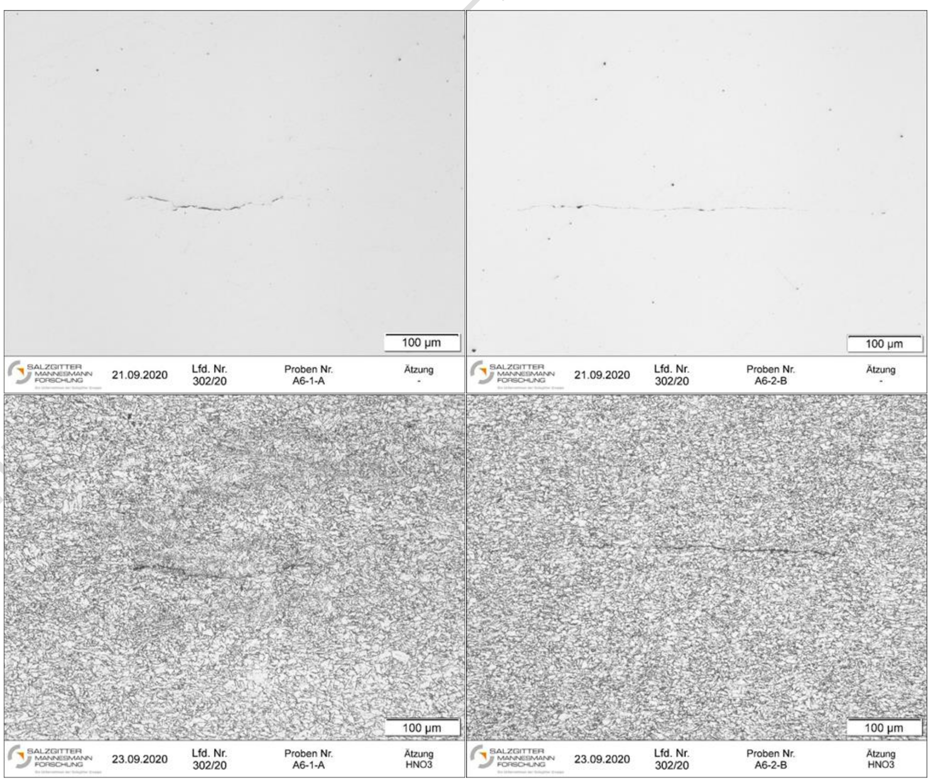

Figure 4—HIC-Cracks, Unetched (top) and Etched (bottom), Specimens: A6-1 Section A (left) and A6-2 Section B (right)

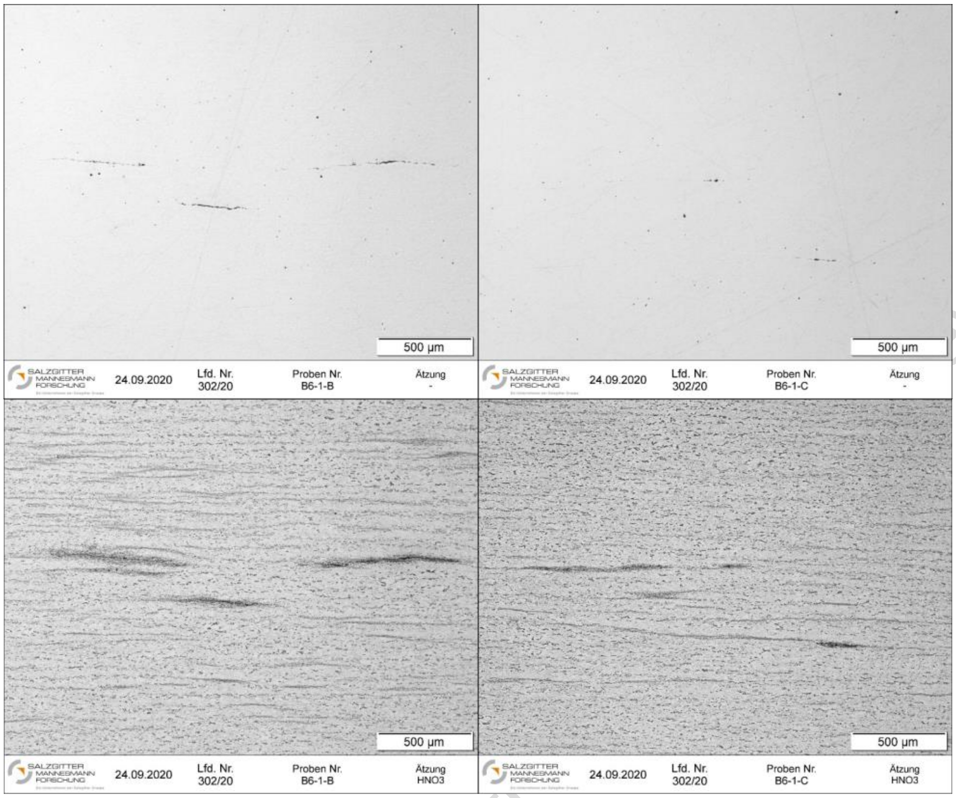

Figure 5—HIC-Cracks, Unetched (top) and Etched (bottom), Specimens: B6-1 Section B (left) and B6-1 Section C (right)

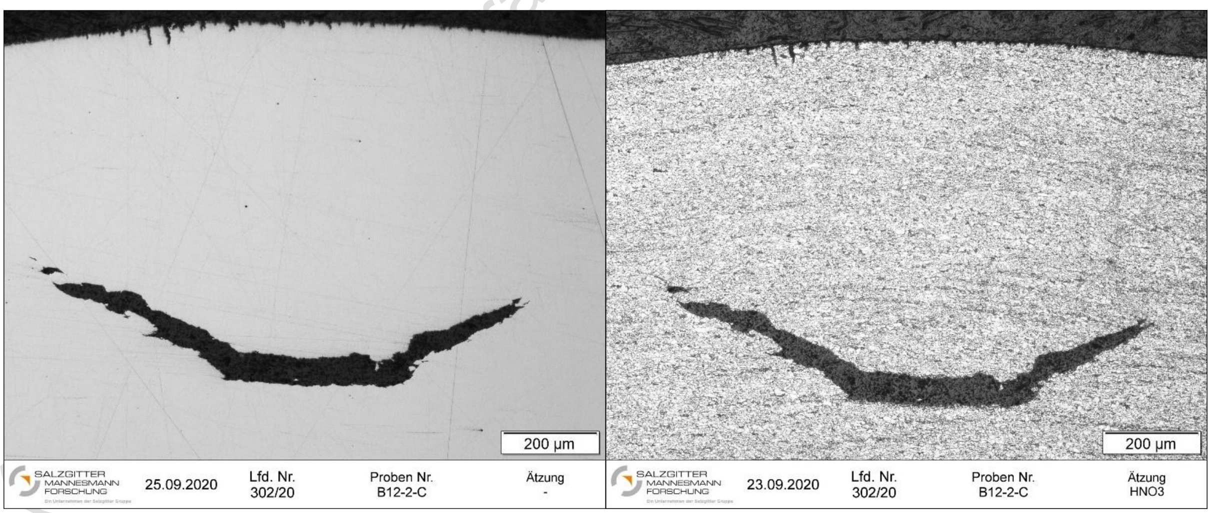

Figure 6—Base Material Blistering, Unetched (left) and Etched (right), Specimen: B12-2 Section C

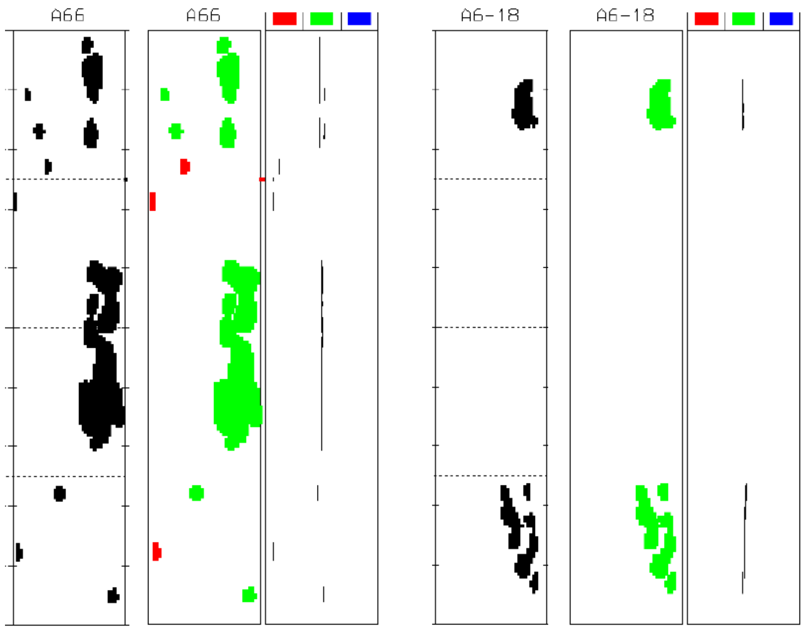

Figure 7—UT Plot Indications of HIC-Cracking, Specimens: A6-6 (left) and A6-18 (right)

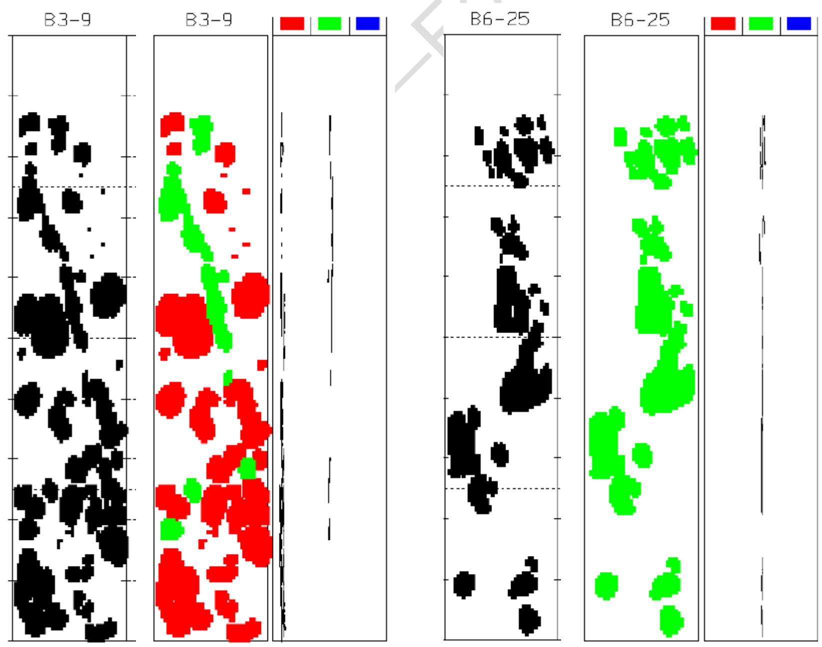

Figure 8—UT Plot Indications of HIC-Cracking, Specimens: B3-9 (left) and B6-25 (right)

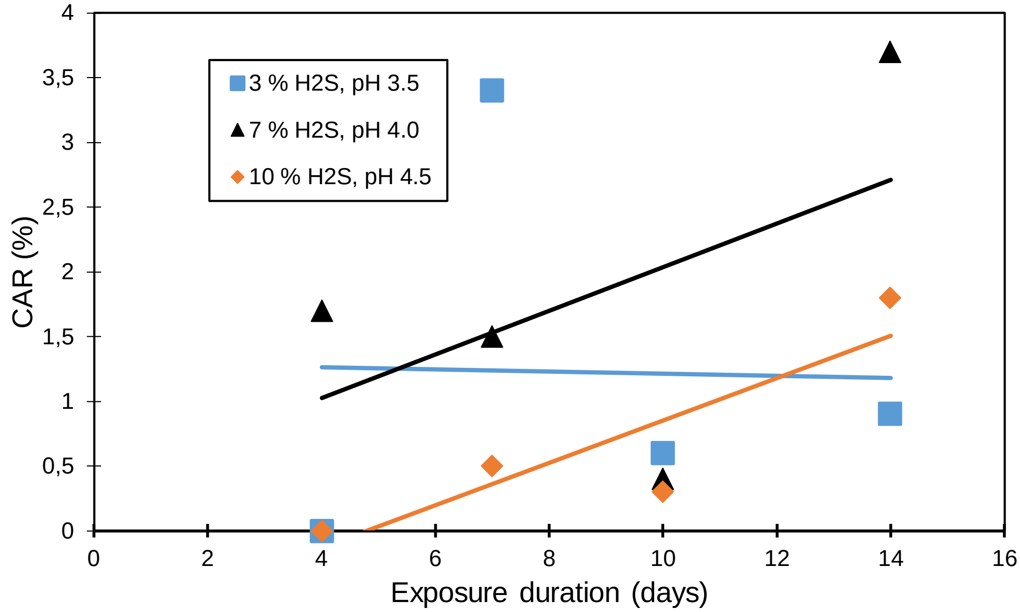

Figure 9—X65 Pipe A: Base Material Average CAR Dependent on Exposure Duration

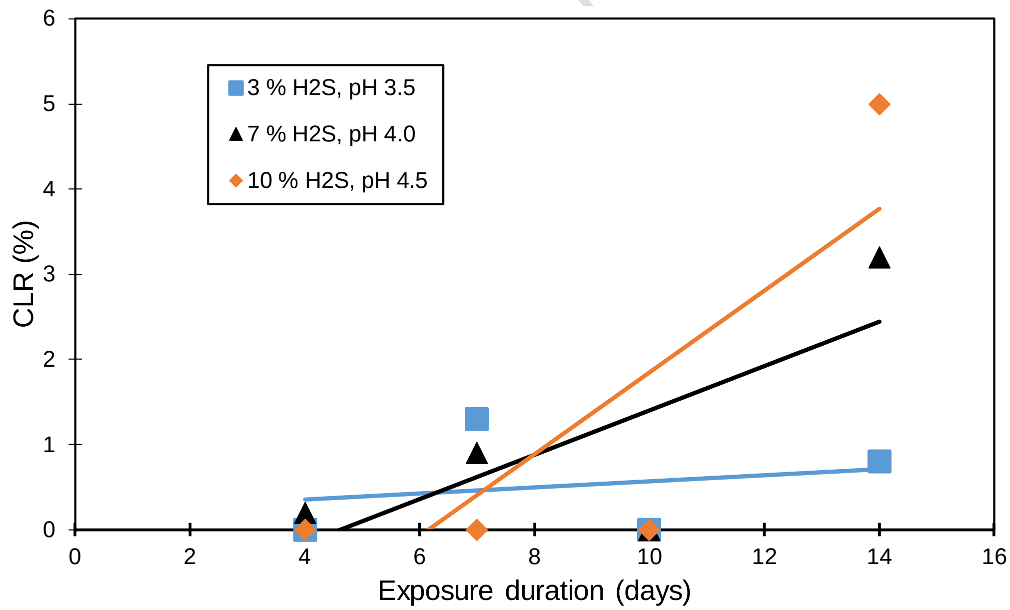

Figure 10—X65 Pipe A: Base Material Average CLR Dependent on Exposure Duration

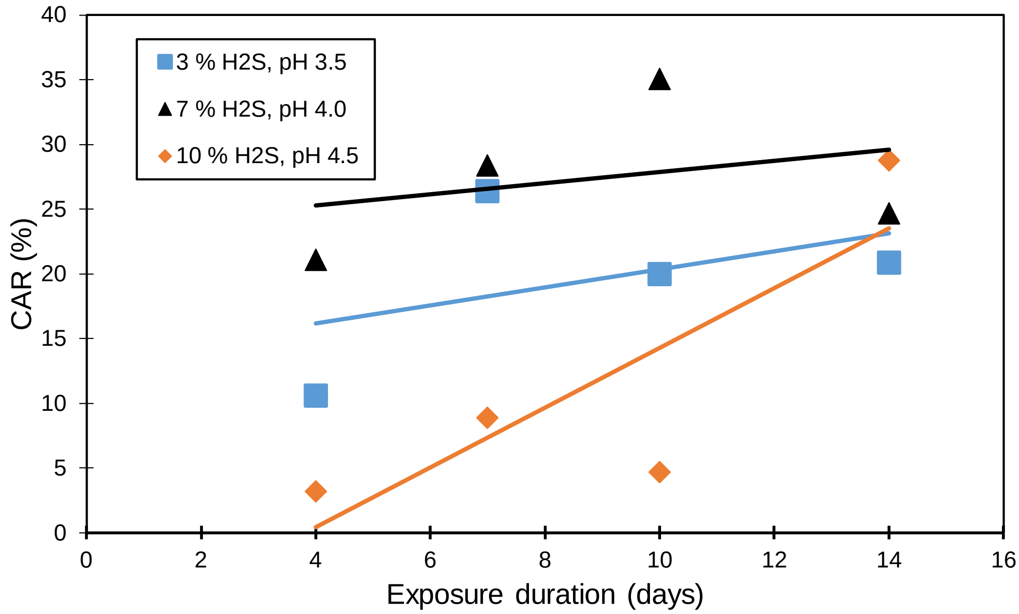

Figure 11—X70 Pipe B: Base Material Average CAR Dependent on Exposure Duration

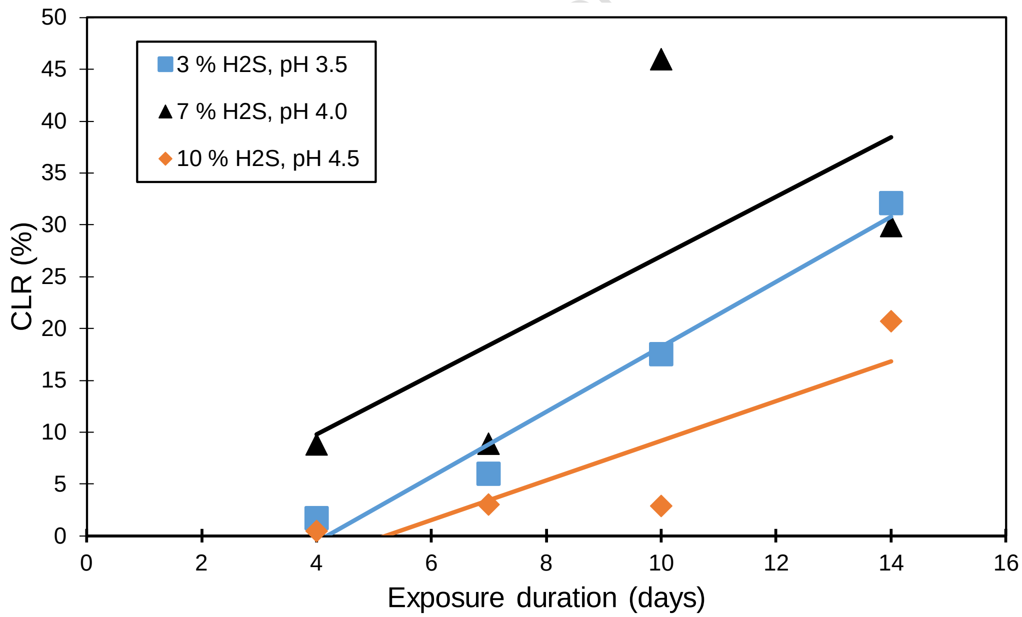

Figure 12—X70 Pipe B: Base Material Average CLR Dependent on Exposure Duration

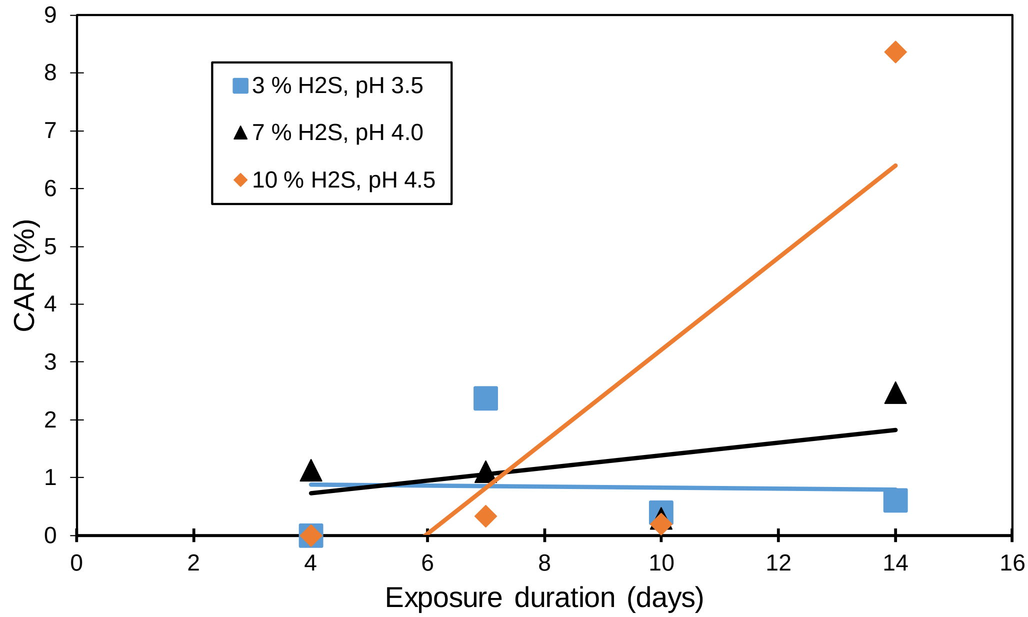

Figure 13—X65 Pipe A: Overall Average CAR Dependent on Exposure Duration

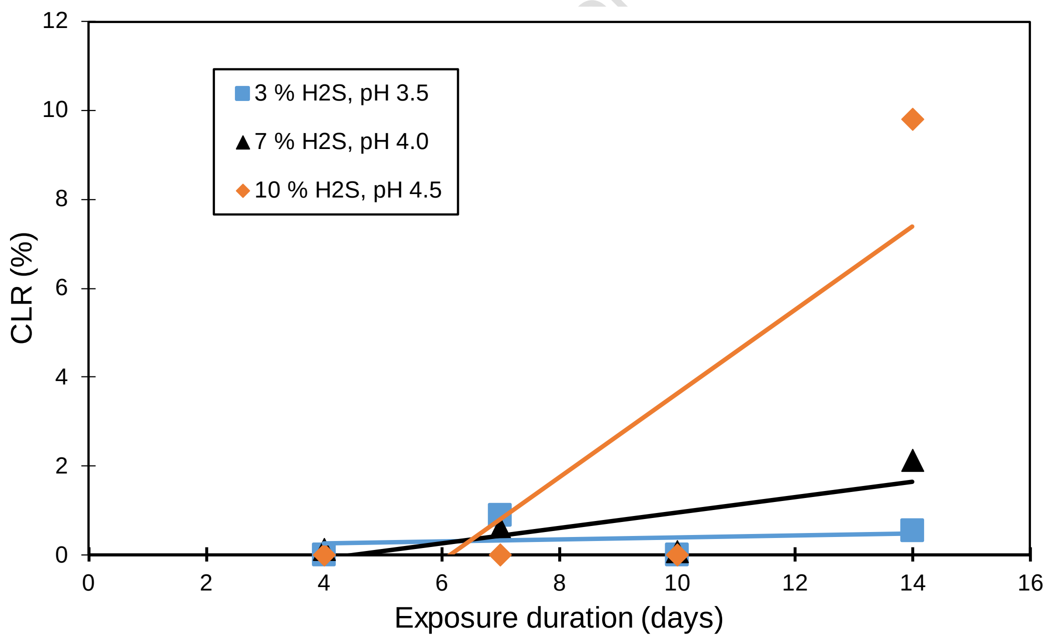

Figure 14—X65 Pipe A: Overall Average CLR Dependent on Exposure Duration

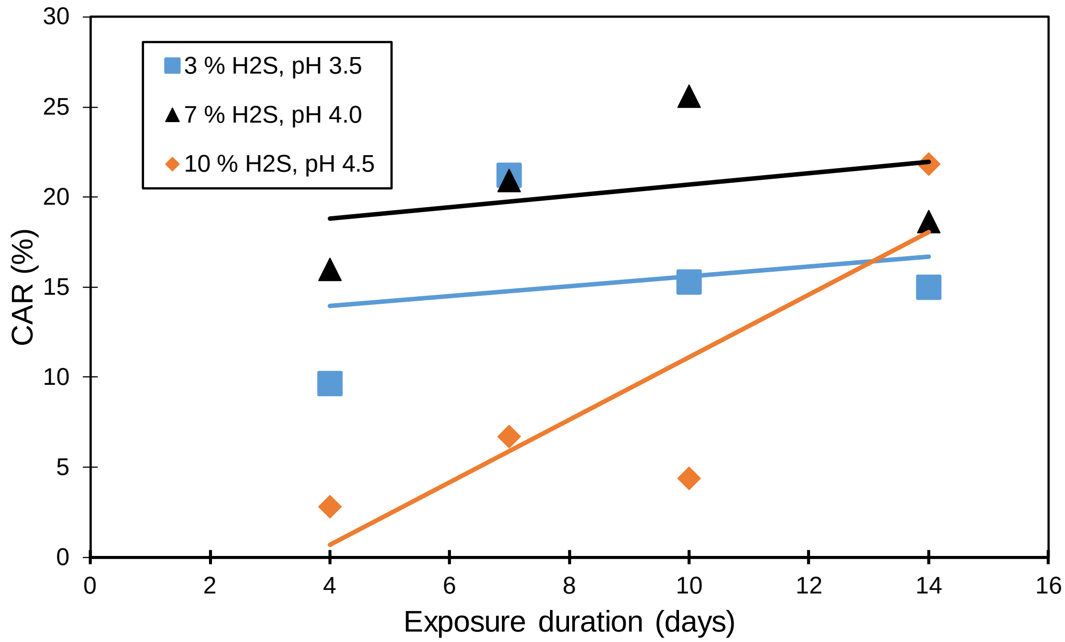

Figure 15—X70 Pipe B: Overall Average CAR Dependent on Exposure Duration

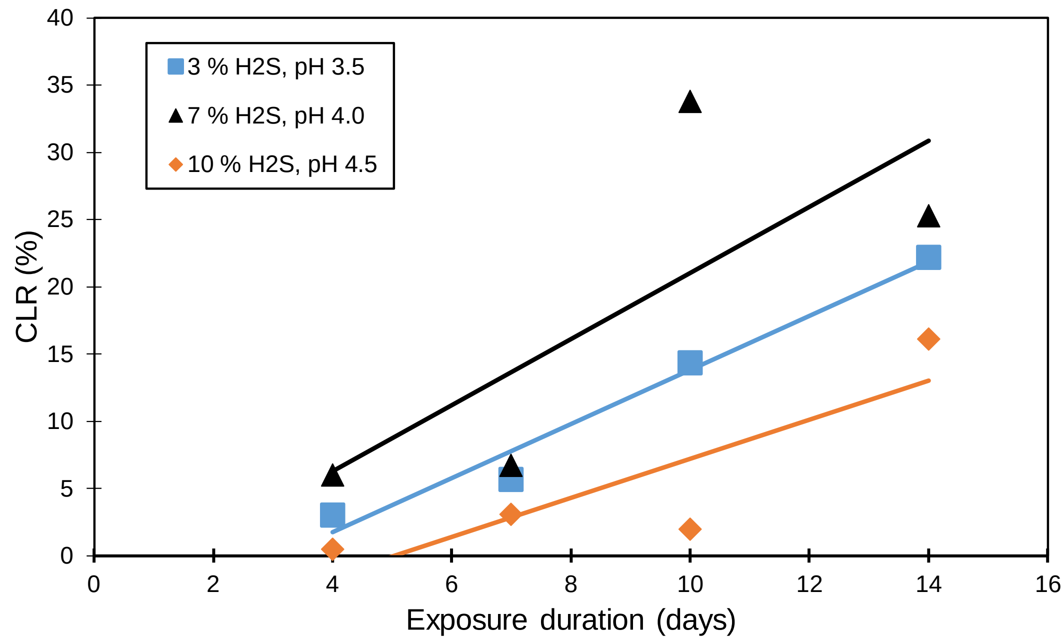

Figure 16—X70 Pipe B: Overall Average CLR Dependent on Exposure Duration

Annex A
(informative)

Individual Specimen Test Results for Pipe A and B

Table A.1—Individual Specimen Test Results for Pipe A and B

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Batch	**Pipe**	**Pos.**	**No.**	**Gas Mix**	**pH**	**Expo-sure** (days)	**CAR** (%)	**Average per Specimen** (%)			**Sub-section A** (%)			**Sub-section B** (%)			**Sub-section C** (%)		
									CLR	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**
1	1-79	A	3	1	7 % H_2S / N_2	API 5CT	4	10.1	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
2			6	1				18	0.5	0.02	0	1.5	0.1	0.00	0.0	0.0	0.00	0.0	0.0	0.00
3			12	1				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
4			3	2				8.5	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
5			6	2				9.1	0.83	0.01	0	0.0	0.0	0.00	2.5	0.0	0.00	0.0	0.0	0.00
6			12	2				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
7		B	3	1				53.1	19.38	0.59	0.05	8.5	0.2	0.02	38.1	1.2	0.11	11.6	0.4	0.02
8			6	1				28.5	10.37	0.93	0.08	5.8	0.2	0.01	17.2	1.2	0.12	8.2	1.4	0.11
9			12	1				17	5.2	0.66	0.06	0.0	0.0	0.00	5.3	0.7	0.04	10.3	1.3	0.14
10			3	2				59.7	8.05	0.4	0.03	0.0	0.0	0.00	13.2	0.6	0.03	11.0	0.6	0.05
11			6	2				33.8	16.72	0.94	0.19	27.8	1.6	0.44	5.5	0.4	0.01	16.9	0.8	0.11
12			12	2				13.9	4.16	0.8	0.07	2.7	0.2	0.00	0.0	0.0	0.00	9.8	2.2	0.22
13	2-80	A	3	3	3 % H_2S	3.5	4	0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
14			6	3				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
15			12	3				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
16			3	4				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
17			6	4				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
18			12	4				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
19		B	3	3				16.1	1.98	0.23	0	1.7	0.1	0.00	1.9	0.4	0.00	2.4	0.2	0.00
20			6	3				5	2.6	0.12	0	1.7	0.1	0.00	5.4	0.1	0.00	0.8	0.2	0.00
21			12	3				7.7	3.7	2.48	0.09	7.0	3.7	0.26	0.0	0.0	0.00	0.2	3.7	0.01
22			3	4				18.1	0.65	0.06	0	0.4	0.1	0.00	0.8	0.1	0.00	0.9	0.1	0.00
23			6	4				3	1.37	0.11	0	1.0	0.1	0.00	2.8	0.2	0.00	0.4	0.1	0.00
24			12	4				7.6	8.71	1.81	0.05	0.1	0.0	0.00	0.0	0.0	0.00	26.0	5.4	0.79

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Batch	**Pipe**	**Pos.**	**No.**	**Gas Mix**	**pH**	**Expo-sure** (days)	**CAR** (%)	**Average per Specimen** (%)			**Sub-section A** (%)			**Sub-section B** (%)			**Sub-section C** (%)		
									CLR	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**
25	2-81	A	3	5	3 % H_2S	3.5	7	0.6	0.35	0.04	0	1.1	0.1	0.00	0.0	0.0	0.00	0.0	0.0	0.00
26			6	5				0.2	0.33	0.03	0	0.0	0.0	0.00	0.0	0.0	0.00	1.0	0.1	0.00
27			12	5				0.1	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
28			3	6				2.8	0.13	0.02	0	0.0	0.0	0.00	0.0	0.0	0.00	0.4	0.1	0.00
29			6	6				10	4	0.04	0	6.7	0.1	0.00	5.3	0.1	0.00	0.0	0.0	0.00
30			12	6				0.5	0.06	0.01	0	0.0	0.0	0.00	0.0	0.0	0.00	0.2	0.0	0.00
31		B	3	5				36.2	6.38	0.31	0.03	0.6	0.2	0.00	1.6	0.3	0.00	17.0	0.5	0.08
32			6	5				19.8	1.97	0.44	0	1.3	0.5	0.00	4.0	0.7	0.01	0.7	0.1	0.00
33			12	5				9.8	6.47	0.86	0.05	5.3	1.0	0.02	0.0	0.0	0.00	14.1	1.6	0.15
34			3	6				37.5	7.95	0.34	0.02	0.5	0.1	0.00	18.7	0.4	0.06	4.7	0.6	0.01
35			6	6				11.8	7.63	0.88	0.02	0.4	0.1	0.00	3.0	2.5	0.03	19.6	0.1	0.01
36			12	6				11.7	3.62	0.47	0.04	0.8	0.1	0.00	0.0	0.0	0.00	10.1	1.3	0.12
37	2-82	A	3	7	3 % H_2S	3.5	10	0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
38			6	7				0.1	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
39			12	7				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
40			3	8				1.7	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
41			6	8				0.3	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
42			12	8				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
43		B	3	7				33.2	43.45	1.19	0.31	24.1	0.6	0.15	58.8	1.7	0.39	47.5	1.2	0.40
44			6	7				11.2	11.38	1.41	0.22	17.0	0.5	0.03	16.8	3.7	0.62	0.4	0.1	0.00
45			12	7				4.2	9.42	2.6	0.31	22.7	4.2	0.75	0.0	0.0	0.00	5.6	3.6	0.18
46			3	8				24.7	8.43	0.29	0.01	5.0	0.2	0.01	11.0	0.3	0.02	9.4	0.3	0.02
47			6	8				10.8	6.65	0.56	0.08	15.2	1.5	0.22	0.8	0.1	0.00	4.0	0.2	0.00
48			12	8				7.4	6.74	5.07	0.23	0.2	0.1	0.00	0.0	0.0	0.00	20.1	15.1	0.70

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
No.	**Batch**	**Pipe**	**Pos.**	**No.**	**Gas Mix**	**pH**	**Expo-sure** (days)	**CAR** (%)	**Average per Specimen** (%)			**Sub-section A** (%)			**Sub-section B** (%)			**Sub-section C** (%)		
									CLR	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**
49	2-83	A	3	9	3 % H_2S	3.5	14	0.5	1.92	0.08	0	0.0	0.0	0.00	5.8	0.2	0.1	0.0	0.0	0.00
50			6	9				2.9	1.22	0.04	0	1.9	0.1	0.00	1.8	0.1	0.00	0.0	0.0	0.00
51			12	9				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
52			3	10				0.1	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
53			6	10				0.1	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
54			12	10				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
55		B	3	9				30.6	47.13	2.37	0.77	16.5	0.6	0.10	10.4	0.2	0.01	114.6	6.2	2.20
56			6	9				14.1	28.68	2.45	0.6	5.9	0.5	0.02	63.6	4.1	1.31	16.6	2.8	0.46
57			12	9				2.3	4.27	0.23	0.02	10.1	0.6	0.05	0.0	0.0	0.00	2.7	0.1	0.00
58			3	10				20.3	28.77	2.88	0.72	16.2	0.5	0.08	26.7	5.4	1.44	43.5	2.7	0.64
59			6	10				18.3	23.5	0.74	0.17	3.1	0.2	0.00	32.4	1.0	0.32	35.1	1.0	0.19
60			12	10				4.1	0.41	0.09	0	0.0	0.0	0.00	0.0	0.0	0.00	1.2	0.3	0.00
61	2-84	A	3	11	7 % H_2S	4	4	1.2	0	0	0	0.0	0.0	0.00	5.8	0.2	0.01	0.0	0.0	0.00
62			6	11				2.5	0.3	0.04	0	0.7	0.0	0.00	0.0	0.0	0.00	0.3	0.1	0.00
63			12	11				0	0	0	0	0.0	0.0	0.00	5.8	0.2	0.01	0.0	0.0	0.00
64			3	12				0.6	0.05	0.01	0	0.0	0.0	0.00	0.2	0.0	0.00	0.0	0.0	0.00
65			6	12				2.4	0.45	0.04	0	0.0	0.0	0.00	1.3	0.1	0.00	0.1	0.0	0.00
66			12	12				0	0	0	0	0.0	0.0	0.00	5.8	0.2	0.01	0.0	0.0	0.00
67		B	3	11				24.5	8.27	1.44	0.04	8.1	1.5	0.04	3.7	2.6	0.08	13.1	0.2	0.01
68			6	11				13.8	6.87	1.82	0.04	9.0	3.9	0.09	8.6	1.3	0.04	3.1	0.2	0.00
69			12	11				3.9	0.29	0.06	0	0.0	0.0	0.00	0.0	0.0	0.00	0.9	0.2	0.00
70			3	12				23.7	10	0.48	0.02	1.5	0.2	0.00	24.7	0.6	0.03	3.8	0.7	0.02
71			6	12				22.3	9.7	0.86	0.04	17.9	0.8	0.10	4.9	1.0	0.01	6.4	0.8	0.02
72			12	12				7.7	0.49	0.05	0	0.0	0.0	0.00	0.0	0.0	0.00	1.5	0.1	0.00

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
No.	**Batch**	**Pipe**	**Pos.**	**No.**	**Gas Mix**	**pH**	**Expo-sure** (days)	**CAR** (%)	**Average per Specimen** (%)			**Sub-section A** (%)			**Sub-section B** (%)			**Sub-section C** (%)		
									CLR	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**
73	2-85	A	3	13	7 % H_2S	4	7	4	3.27	0.32	0	0.9	0.4	0.00	9.0	0.6	0.01	0.0	0.0	0.00
74			6	13				0.1	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
75			12	13				0.3	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
76			3	14				0.1	0.17	0.03	0	0.0	0.0	0.00	0.2	0.0	0.00	0.4	0.1	0.00
77			6	14				1.6	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
78			12	14				0.2	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
79		B	3	13				34.7	6.38	1.59	0.03	3.6	1.6	0.02	9.6	2.2	0.04	6.0	0.9	0.03
80			6	13				26.5	14.9	0.37	0.06	15.0	0.4	0.04	29.7	0.7	0.14	0.0	0.0	0.00
81			12	13				5.5	2.62	0.59	0.01	3.8	0.6	0.01	0.2	0.0	0.00	3.9	1.2	0.03
82			3	14				29.2	5.62	0.45	0.04	1.6	0.5	0.00	0.3	0.1	0.00	15.0	0.8	0.11
83			6	14				22.9	8.45	0.28	0.02	1.1	0.1	0.00	2.6	0.5	0.00	21.7	0.3	0.05
84			12	14				6.5	2.03	0.63	0.01	0.2	0.0	0.00	0.0	0.0	0.00	5.9	1.8	0.04
85	2-86	A	3	15	7 % H_2S	4	10	0.5	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
86			6	15				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
87			12	15				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
88			3	16				0.7	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
89			6	16				0.1	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
90			12	16				0.1	0.25	0.05	0	0.6	0.1	0.00	0.0	0.0	0.00	0.2	0.0	0.00
91		B	3	15				49.7	48.62	4.5	0	42.4	4.6	1.69	54.5	6.4	2.22	49.0	2.6	1.05
92			6	15				19.1	36.52	2.71	1.65	36.9	3.1	0.96	27.1	1.2	0.12	45.7	3.8	0.72
93			12	15				6.0	8.37	1.53	0.6	0.0	0.0	0.00	0.0	0.0	0.00	25.1	4.6	0.82
94			3	16				46.7	68.37	3.73	0.27	78.5	1.5	0.69	77.4	6.1	1.84	49.3	3.6	1.02
95			6	16				24.6	30.25	1.19	1.18	39.7	2.0	0.78	4.7	0.5	0.02	46.4	1.1	0.50
96			12	16				7.2	10.27	1.96	0.44	14.5	1.6	0.14	0.0	0.0	0.00	16.3	4.3	0.70

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
No.	**Batch**	**Pipe**	**Pos.**	**No.**	**Gas Mix**	**pH**	**Expo-sure** (days)	**CAR** (%)	**Average per Specimen** (%)			**Sub-section A** (%)			**Sub-section B** (%)			**Sub-section C** (%)		
									CLR	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**
97	2-87	A	3	17	7 % H_2S	4	14	0	0	0	00.28	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
98			6	17				10.4	9.83	0.42	0.05	4.3	0.2	0.00	25.3	1.0	0.14	0.0	0.0	0.00
99			12	17				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
100			3	18				1.0	2.88	0.2	0.02	0.0	0.0	0.00	0.0	0.0	0.00	8.7	0.6	0.05
101			6	18				3.4	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
102			12	18				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
103		B	3	17				39.3	32.9	1.7	0.56	9.8	0.1	0.01	9.6	0.3	0.03	79.4	4.6	1.63
104			6	17				15.5	41	1.97	0.75	63.1	4.1	1.35	57.4	1.8	0.91	2.6	0.0	0.00
105			12	17				6.9	21.36	4.47	0.7	43.9	10.3	1.76	0.0	0.0	0.00	20.2	3.2	0.33
106			3	18				33.1	41.27	1.73	0.55	44.8	3.0	0.91	24.4	0.3	0.05	54.7	1.9	0.69
107			6	18				10.9	4.33	0.42	0.02	4.8	0.8	0.04	6.1	0.4	0.02	2.2	0.0	0.00
108			12	18				6.1	10.78	3.79	0.38	32.3	11.4	1.15	0.0	0.0	0.00	0.0	0.0	0.00
109	2-88	A	3	19	10 % H_2S	4.5	4	0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
110			6	19				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
111			12	19				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
102			3	20				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
113			6	20				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
114			12	20				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
115		B	3	19				2.3	0.07	0.01	0	0.0	0.0	0.00	0.0	0.0	0.00	0.2	0.0	0.00
116			6	19				4.2	1.1	0.11	0	2.2	0.1	0.00	0.9	0.2	0.00	0.3	0.1	0.00
117			12	19				4.4	0.08	0.02	0	0.0	0.0	0.00	0.0	0.0	0.00	0.2	0.1	0.00
118			3	20				4.3	0.22	0.02	0	0.0	0.0	0.00	0.7	0.1	0.00	0.0	0.0	0.00
119			6	20				1.7	0.4	0.1	0	0.0	0.0	0.00	1.2	0.3	0.00	0.0	0.0	0.00
120			12	20				2	0.41	0.32	0	0.6	0.8	0.00	0.0	0.0	0.00	0.7	0.1	0.00

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
No.	**Batch**	**Pipe**	**Pos.**	**No.**	**Gas Mix**	**pH**	**Expo-sure** (days)	**CAR** (%)	**Average per Specimen** (%)			**Sub-section A** (%)			**Sub-section B** (%)			**Sub-section C** (%)		
									CLR	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**
121	2-89	A	3	21	10 % H_2S	4.5	7	0.6	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
122			6	21				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
123			12	21				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
124			3	22				0.8	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
125			6	22				0.3	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
126			12	22				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
127		B	3	21				10.4	0.17	0.03	0	0.0	0.0	0.00	0.5	0.1	0.00	0.0	0.0	0.00
128			6	21				7.8	2.75	0.34	0.01	1.1	0.2	0.00	5.7	0.8	0.02	1.5	0.0	0.00
129			12	21				1.3	5.17	0.06	0.01	15.2	0.1	0.02	0.3	0.0	0.00	0.0	0.0	0.00
130			3	22				7.1	3.78	0.26	0.01	4.8	0.5	0.02	5.9	0.2	0.01	0.08	0.1	0.00
131			6	22				10.2	5.1	1.53	0.03	5.9	2.0	0.04	3.8	1.3	0.01	5.6	1.3	0.04
132			12	22				3.2	1.17	0.21	0.01	0.3	0.1	0.00	0.0	0.0	0.00	3.2	0.5	0.01
133	2-90	A	3	23	10 % H_2S	4.5	10	0.4	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
134			6	23				0.5	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
135			12	23				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
136			3	24				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
137			6	24				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
138			12	24				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
139		B	3	23				2.1	0.2	0.01	0	0.0	0.0	0.00	0.0	0.0	0.00	0.6	0.0	0.00
140			6	23				3.3	9.67	0.33	0.09	0.0	0.0	0.00	27.8	1.0	0.27	1.2	0.0	0.00
141			12	23				3.3	0.12	0.05	0	0.2	0.1	0.00	0.0	0.0	0.00	0.2	0.1	0.00
142			3	24				6.3	1.63	0.1	0	0.8	0.1	0.00	2.9	0.2	0.00	1.3	0.1	0.00
143			6	24				6.9	0.1	0.01	0	0.0	0.0	0.00	0.0	0.0	0.00	0.3	0.0	0.00
144			12	24				4.2	0.06	0.02	0	0.0	0.0	0.00	0.0	0.0	0.00	0.2	0.1	0.00

No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	Batch	**Pipe**	**Pos.**	**No.**	**Gas Mix**	**pH**	**Expo-sure** (days)	**CAR** (%)	**Average per Specimen** (%)			**Sub-section A** (%)			**Sub-section B** (%)			**Sub-section C** (%)		
									CLR	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**	**CLR**	**CTR**	**CSR**
145	2-91	A	3	25	10 % H_2S	4.5	14	4.8	19.15	1.07	0.6	0.0	0.0	0.00	57.5	3.2	1.80	0.0	0.0	0.00
146			6	25				0.8	0.47	0.17	0	0.0	0.0	0.00	1.4	0.5	0.01	0.0	0.0	0.00
147			12	25				0	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
148			3	26				1.2	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
149			6	26				0.1	0.02	0.02	0	0.0	0.0	0.00	0.0	0.0	0.00	0.7	0.1	0.00
150			12	26				0.2	0	0	0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
151		B	3	25				42.9	38.75	3.81	1.11	21.7	1.6	0.34	34.9	2.8	0.88	59.8	7.0	2.12
152			6	25				17.2	15.87	0.81	0.16	3.0	0.4	0.01	5.1	0.5	0.02	39.6	1.5	0.45
153			12	25				8.9	2.17	0.09	0.01	0.0	0.0	0.00	0.0	0.0	0.00	6.5	0.3	0.02
154			3	26				46.9	16.95	0.9	0.18	29.9	1.6	0.49	13.2	0.6	0.04	7.8	0.4	0.01
155			6	26				8	10.97	0.5	0.04	0.7	0.1	0.00	27.4	0.9	0.12	4.9	0.5	0.01
156			12	26				6.8	11.83	1.72	0.24	12.4	1.3	0.16	0.0	0.0	0.00	23.1	3.9	0.56

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