NACE
NORTHERN AREA WESTERN CONFERENCE
February 15-18, 2010 • Calgary, Alberta
Going for GOLD in Corrosion Prevention

NACE MR0175/ISO15156

INTERPRETATION AND APPLICATION

Jerry Bauman, P. Eng

Cimarron Engineering Ltd.

Requests for permission to publish this manuscript in any form, in part or in whole must be in writing to NACE International, Publications Division, 1440 South Creek Drive, Houston, Texas 77084-4906.

NACE MR0175/ISO15156

INTERPRETATION AND APPLICATION

Jerry Bauman, P. Eng.

NACE Corrosion Specialist

Cimarron Engineering Ltd.

300, 6025 – 11 Street SE

Calgary, Alberta

T2H 2Z2

ABSTRACT

In 2003, the first publication of the NACE MR0175/ISO15156 (NACE/ISO) document entitled “Petroleum and Natural Gas Industries – Materials for Use in H_2S Containing Environments in Oil and Gas Production” appeared. The document consisted of three distinct parts. This paper focuses on Part 2, entitled “Cracking-Resistant Carbon and Low-Alloy Steels, and the Use of Cast Iron”, the various nuances created in this document that did not exist in its predecessor NACE MR0175, and the confusion as to how these nuances are interpreted and used in practical applications. This paper also discusses how various industry “experts”, as well as, government regulatory bodies have chosen to interpret the document with respect to new construction and changing H_2S partial pressures within existing pipeline systems.

Background

NACE MR0175 (NACE) was first issued in 1975 and became a worldwide reference for the use of metals in H_2S containing environments with respect to sulphide stress corrosion cracking resistance. In 2003, it was merged into the ISO system and the new document was designated as NACE MR0175/ISO15156. There are significant differences between the two documents, some of which will be discussed subsequently. The biggest initial impact was the severe restrictions imposed regarding the use of austenitic stainless steels in sour service. While a lot of attention has been paid to this change, the impact on carbon/low alloy steels has largely been overlooked, especially in Western Canada. This paper examines some of these impacts, which are described in

Part 2 of the NACE/ISO document. The overwhelming consensus was that the new document was much more conservative than the last version of the original document. This is an important factor to bear in mind when considering some of the following.

Differences between the Two Documents

The definition of sour service has changed. The NACE document allowed certain exemptions, for which materials did not need to meet the requirements. Sour gas systems operating at a total pressure less than 450 kPa absolute (65 psia) were exempt, regardless of H_2S content. In oil effluent or multi-phase systems, exemption from the standard was more complicated. If the total operating pressure was below 1830 kPa absolute and the maximum gas:oil ratio is ≤ 5000 and the H_2S content is ≤ 15 mole percent and the H_2S partial pressure is ≤ 70 kPa absolute (10 psia), materials were exempt. In the NACE/ISO document, “crude oil” systems operating at a total pressure ≤ 430 kPa gauge (65 psig) are exempt. The NACE/ISO document does not provide any exemption for H_2S partial pressures below 0.3 kPa absolute (0.05 psia).

In the NACE document, since its creation in 1975, one value that has not changed with respect of suitability of carbon steel in sour service is the maximum allowable hardness being 22 on the Rockwell “C” (HRC) scale, which is equivalent to 248 on the Vickers hardness scale (HV). The NACE/ISO document changed the microhardness requirement to 250 Vickers, as did Canadian Standards Association (CSA) Z662 - 2007, however, CSA Z245.1 – 2007 still specifies 248 as the maximum allowed microhardness. While two (2) points on the hardness scale may not seem significant, when qualifying high yield strength materials weld procedures, those points may indeed mean the difference between pass or fail.

The NACE/ISO document has removed the maximum yield strength limitation, recognizing that the hardness requirements are the critical property. CSA has not removed the strength restriction, the reason for which is unknown.

The NACE/ISO document allows the end user to waive hardness qualification in welding procedures, providing that the specified maximum yield strength (SMYS) of the material does not exceed 360 MPa. The vast majority of pipelines are constructed from low alloy steels whose SMYS is either 290 MPa or 359 MPa. As such, the conservative NACE/ISO document implies that it is virtually impossible to exceed acceptable hardnesses in either the weld metal or the heat affected zones where the base material is relatively soft. CSA once again does not agree, as evidenced in Z-662 (2007), as well as, Z245. 1 (2007) and Z245.11/12/15 (2005), where hardness restrictions on such materials require measurement to confirm adherence to hardness specifications.

The NACE/ISO document addresses other forms of Hydrogen Embrittlement, e.g., Hydrogen Induced Cracking, Stress Oriented Hydrogen Induced Cracking, etc., that the NACE document did not consider.

The NACE/ISO document introduced the concept of field experience as an alternative for in-situ materials that were not originally intended for sour service or where the service has become more severe than the original design. A minimum period of two (2) years experience was selected as the time criteria. If the end user could demonstrate that the material has operated within a given environment for the time criteria, it became acceptable for continued service. This may sound logical and applicable, but there was an added stipulation stating that the material could not be exposed to more severe conditions than the documented experience. This is also true for autoclave testing results, which essentially shortens the exposure period from two (2) years to 500 hours.

Interpretation and Application

Regardless of which route is chosen, the question then becomes “How is severity defined?” Figure 1 in Section 7.2.1.2 of Part 2 of the NACE/ISO document depicts four (4) regions of severity, as defined by H_2S partial pressure and pH (See Figure 1). It is important to note that chlorides have no virtually no impact on cracking susceptibility. Nowhere in the document is there any explanation of how to use these regions. Section 7.2.1.1 discusses “Option 2” which describes how to select materials for a specific service, or for a range of sour services. There following statement is at the end of the discussion: “Option 2 can also facilitate fitness-for-purpose evaluations of existing carbon or low alloy steel equipment exposed to sour service conditions more severe than assumed in the current design.” This is immediately followed by the plot of H_2S versus pH in Figure 7.2.1.2. This infers that somehow field experience can be extrapolated, without any discussion as to how. To illustrate how these sections have led to various interpretations a specific autoclave test conditions point, which could also be a filed experience point is selected to use to justify the design/continued use of a carbon/low alloy steel in a given environment. That point selected is at an H_2S partial pressure of 100 kPa and an in-situ pH of 2.6 (see Figure 2).

One interpretation of severity, which is shared by the Energy Resources Conservation Board of Alberta (ERCB), is that the material cannot be exposed to conditions where the H_2S partial pressure exceeds 100 kPa or the pH is less than 2.6. The shaded area in Figure 3 depicts the area of exposure that this interpretation allows. This essentially precludes using materials based on field experience. The operating conditions will define a certain H_2S partial pressure, but the pipeline would likely have a significantly higher maximum allowable operating pressure (MAOP), which would result in a higher

H_2S partial pressure. To illustrate, assume that the 100 kPa H_2S partial pressure is based on a historical operating pressure of 1000 kPa with 10 mole percent H_2S in the gas phase. If the MAOP of the pipeline is 5000 kPa, the H_2S partial pressure could then theoretically reach 500 kPa, which falls outside of the approved area depicted on Figure 3. This approach also allows a material to be used in a large area within Region 3, but will not allow the material to be used in any area of Region 2 where the H_2S partial pressure exceeds 100 kPa. This appears contrary to the document's definition of regions of severity, i.e., the material is suitable in Region 3, but not in certain areas of Region 2.

A second interpretation of severity uses the same starting point, but instead of lines that parallel the x and y axes from that point, a line is drawn at a 45 degree angle, with the range of allowable H_2S partial pressures and corresponding pH levels being "northwest" of this line (see Figure 4). This approach seems to be more sensible in that it recognizes that while the H_2S partial pressure might exceed the defined point, if the pH also increases, i.e., due to lower CO_2 content, the risk of SSCC is reduced. Realistically however, it is extremely unlikely that the pH would increase, i.e., CO_2 and H_2S mole percentages would remain constant, thus higher operating pressures would result in lower pH's. Again, the autoclave/field experience approach becomes unusable. As with the first interpretation, a material could qualify within Region 3, but could be disqualified for use in part of Region 2.

One realization in using either of the above two interpretations is that it totally negates the need for identifying regions. Instead, all that would be required is the blank graph and the ability to draw one or two straight lines through that point. Being in one region or another is irrelevant. This begs the question of why regions were created. The question was put in several different ways to ISO for clarification in July of 2009. At that point, ISO reverted that the answer would likely be forthcoming within eight (8) weeks. At the time of writing this paper, over 23 weeks have passed with no response as yet. This indicates that ISO is as confused as everyone else that has tried to use this portion of the document.

CSA Z245.11/12/.15 all require that components manufactured to these three documents "shall meet Region 3" of the NACE/ISO document, with no delineation of where in the Region the qualification must meet. As previously discussed, one could easily qualify a material for Region 3, yet either or the interpretations would preclude service in numerous environments. Figures 5 and 6 show how qualifying to Region 3 could leave significant areas deemed unsuitable by the previously described interpretations of severity. CSA Z245.1 requires only that the material qualify to the region where its service conditions would place it. In this case, one could perform testing at conditions that the operating conditions would never reach and thus be qualified appropriately.

It seems that the “safe” approach is to either ensure that the hardness does not exceed 22 HRC/248 HV or to follow the NACE/ISO document where it states that to qualify a carbon/low alloy steel for any range of conditions, perform autoclave testing according to NACE TM0177 – 2006 (TM0177). In reality, the latest revision of TM0177 is 2005. For the sake of argument, assume that if a 2006 version had been issued, it would not have substantially changed from the 2005 version. To qualify for any environment, TM0177 specifies that “Solution A” be used, which is at an H_2S partial pressure of 100 kPa and a solution pH between 2.6 and 2.8. Note that these are the same values that were used for the previously described example. The ERCB accepts that passing this test will qualify a carbon/low alloy steel for any environment, yet, by their own interpretation, exceeding 100 kPa would not be permissible. The second interpretation previously mentioned would also preclude application at much higher H_2S partial pressures, despite the reality that in-situ pH values within normal operating parameters rarely decrease below 4.0. As part of the earlier questions submitted to ISO for clarification, questions surrounding this aspect of material qualification were also raised. Again, to date, there has been no response to these queries.

In defence of the ERCB, if ISO cannot seem to explain how to use these figures and test conditions, how can the ERCB be expected to apply the document? The author fully appreciates that the ERCB has a need to define an interpretation, otherwise entertaining sour conversions or increases in H_2S partial pressures within any given pipeline could not be done.

This paper would like to offer a third approach. SCC, regardless of type, behaves like a set of parameters cliff. Carbon/low alloy steel will not SSCC at any hardness below HRC 22, but could at HRC 23. These materials will not suffer SSCC at 71 ^{0}C, but could at 69 ^{0}C. Austenitic stainless steel are susceptible to chloride SCC at 61 ^{0}C but not at 59 ^{0}C. Considering such cliff-like behaviour, it seems reasonable to re-look at the four regions in the NACE/ISO document as different plateaus of severity. As long as the material passes either the two-year field experience criteria or an autoclave testing criteria on any given plateau, it should be suitable for use anywhere on that plateau, or any lower plateau, i.e., a material that qualifies within Region 2, is also suitable in Regions 0 and 1. As such, as long as a material does not “fall of off the cliff”, it will not be subject to SSCC. There does not appear to be any other reason for establishing regions.

Summary

Part 2 of the NACE/ISO document introduced several significant changes in the manner of determining the suitability of materials for sour service. The document is some ways is much more conservative than its NACE predecessor and in some ways has removed some restrictions that previously existed. The majority of these changes are straightforward in their intent and how they are to be applied. One area that is anything but straightforward is the definition of severity and how carbon/low alloy steels can be qualified for service should either their hardnesses be unknown or higher than HRC 22/250 HV. Facing continuous applications for conversion of pipeline systems to sour service or increasing the H_2S partial pressure within systems that already have some level of H_2S has forced regulatory bodies to enforce their own interpretation, which has been shown to be incorrect. However, with no direction from those that wrote/approved the document, there is little other choice.

NACE MR0175/ISO 15156-2:2003

Section 7.2.1.2 SSC Regions of Environmental Severity

X axis – H_2S Partial Pressure, kPa

Y axis – in situ pH

0 – Region 0

1 – SSC Region 1

2 – SSC Region 2

3 – SSC Region 3

Figure 1: As seen in NACE MR0175/ISO 15156

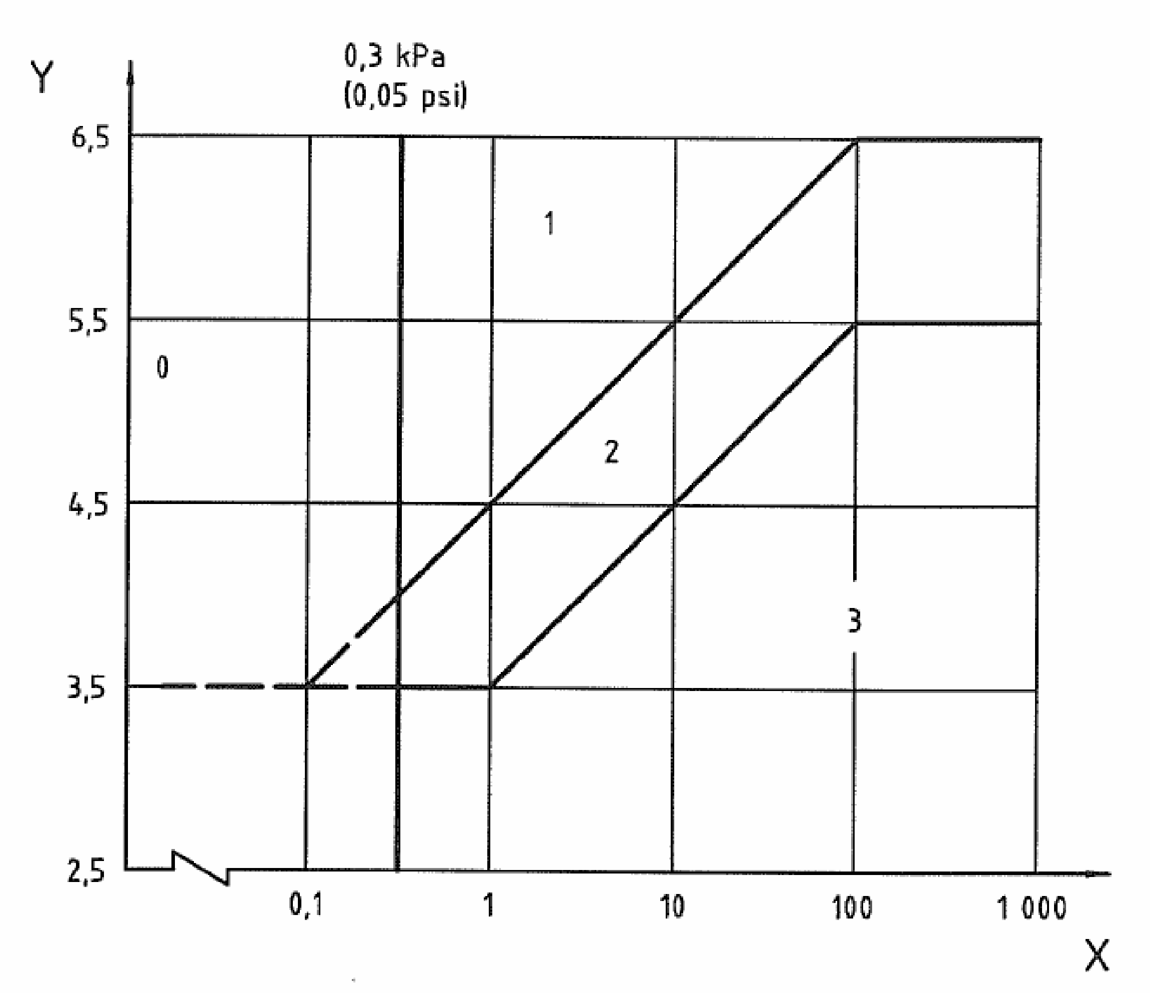

Figure 2: Single point at 100 kPa H_2S and pH = 2.6

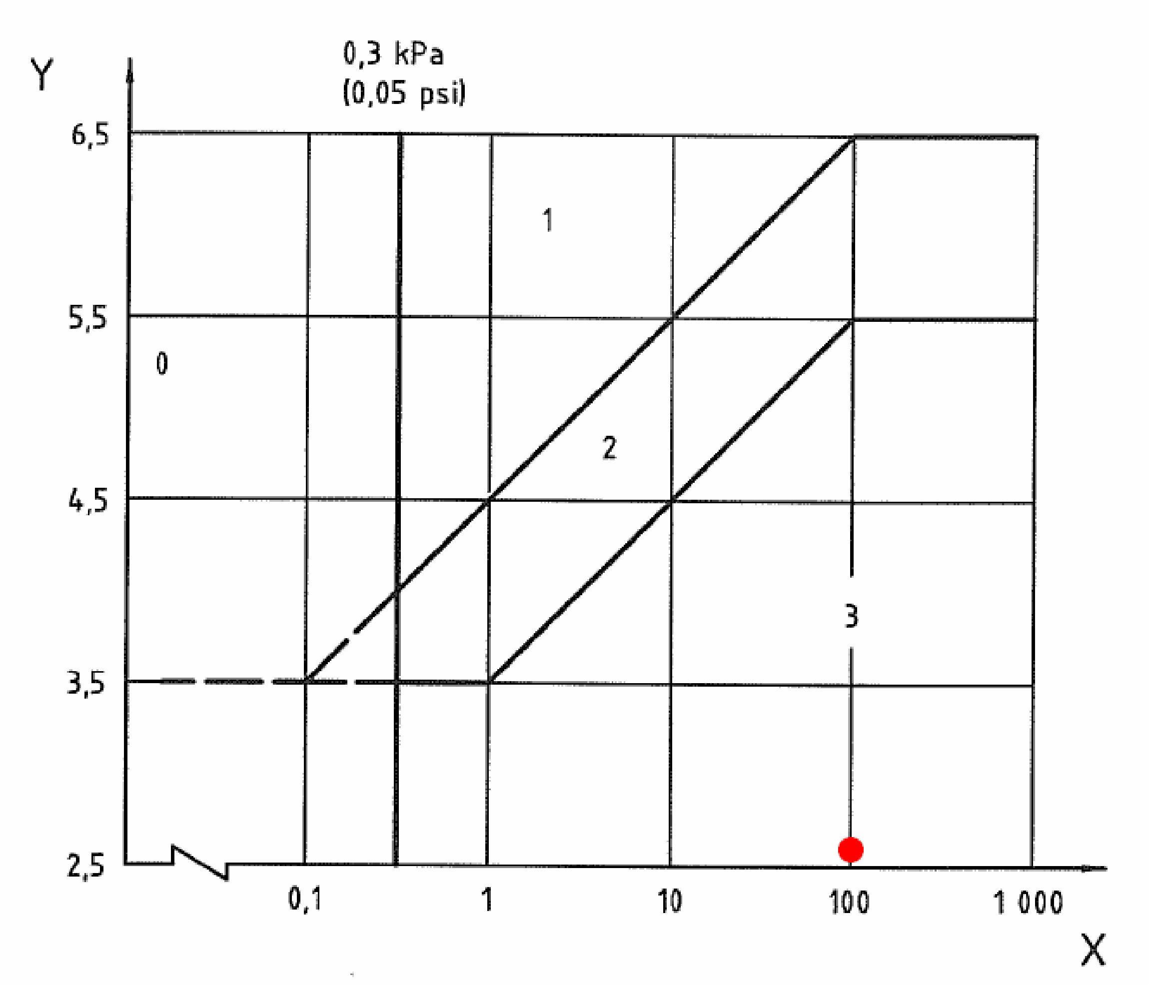

Figure 3: 100 kPa H_2S and pH = 2.6, Shaded North and West

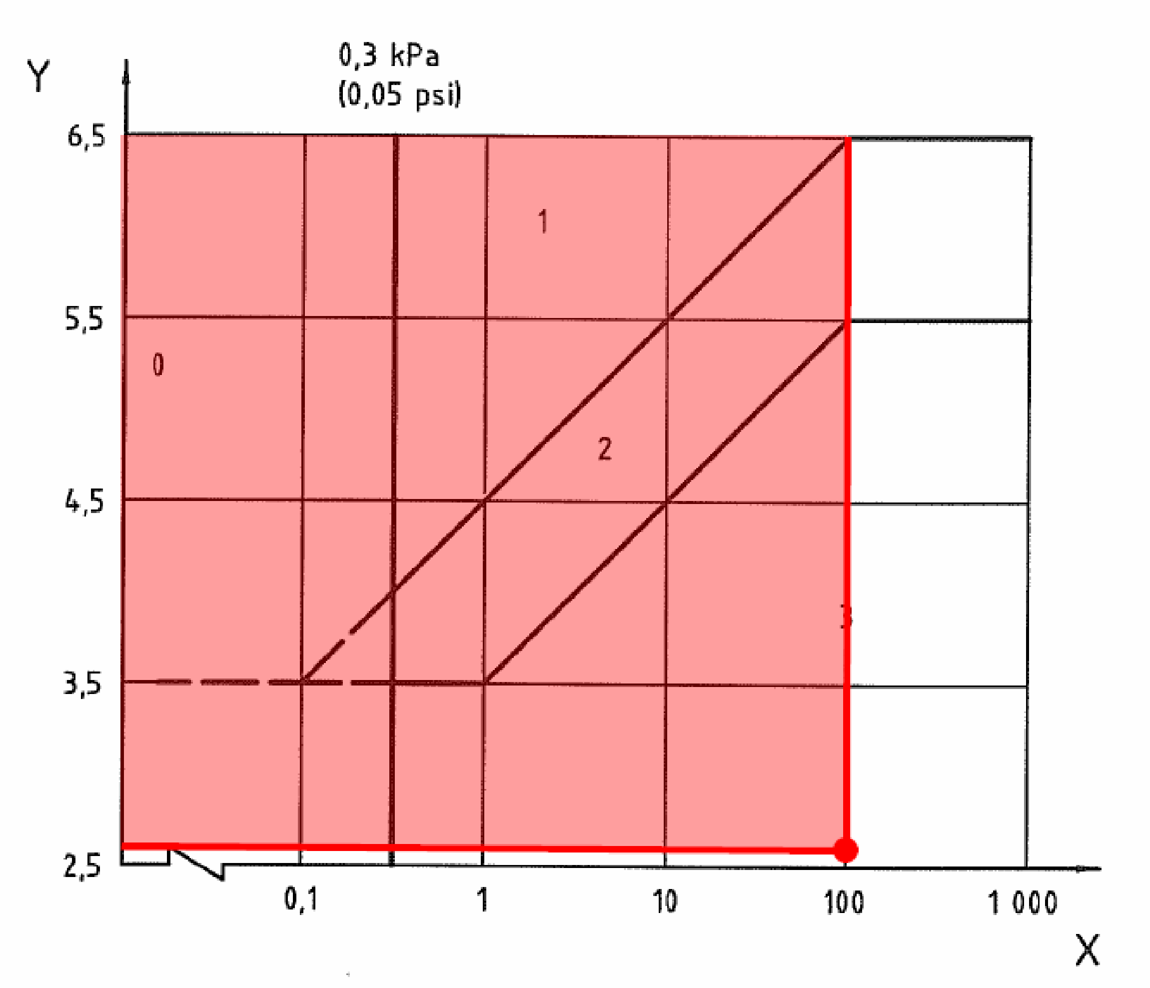

Figure 4: 100 kPa H_2S and pH = 2.6, 45° angle

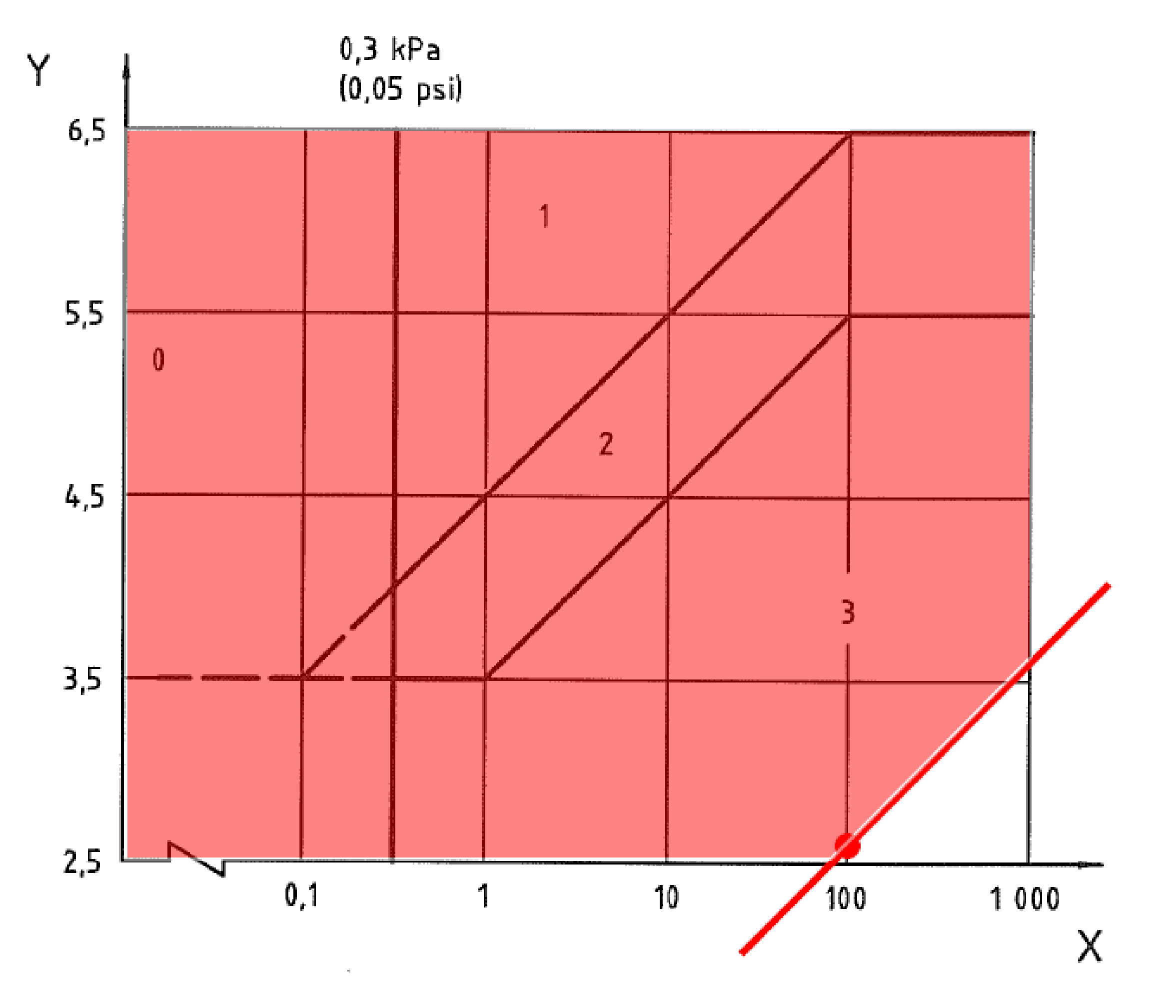

Figure 5: 1.1 kPa H_2S and pH = 3.5, shaded North and West

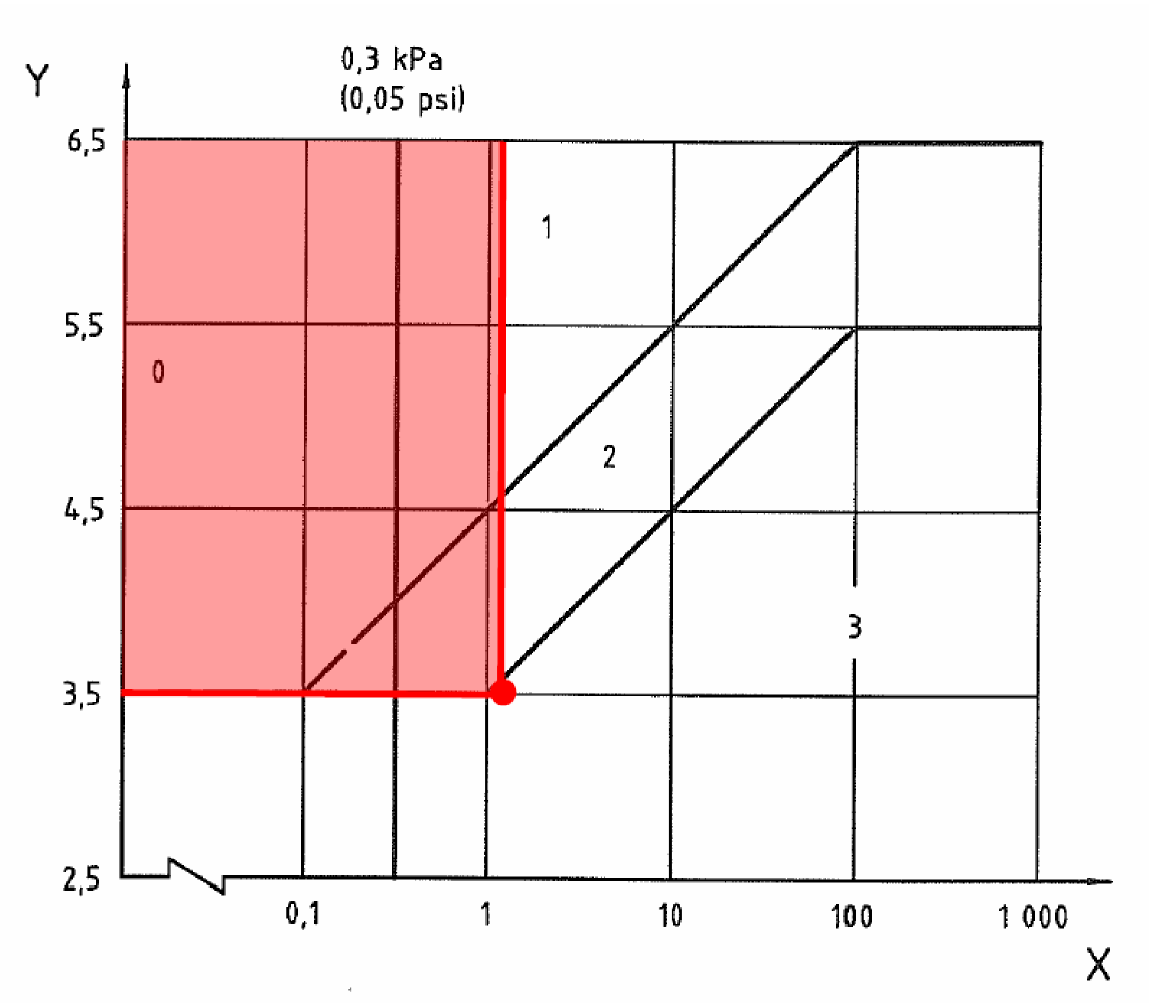

Figure 6: 1.1 kPa H_2S and pH = 3.5, 45° angle