

How to define drillstring specification maximizing safety, performance in sour service environments

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THE EVOLUTION OF drilling programs has driven the industry to develop more suitable solutions adapted to extreme and aggressive environments such as sour service. High-strength drill pipe is necessary to achieve deeper drilling objectives, even if the sulfide stress cracking susceptibility is an acknowledged concern starting with minimal partial pressure of H_2S .

Due to the astringency of the sour environment, particular attention must be paid to the drillstring design, which includes the sour service steel grade.

This article summarizes current knowledge about the sulfide stress cracking phenomenon, recommended practices and material trends for drill stem components.

INTRODUCTION

“Sour service” refers to a well environment containing hydrogen sulfide (H_2S), which is naturally associated with acid conditions. H_2S comes from the decomposition of organic material, so it is often found in oil and gas environments. Even if not sour at the onset, some wells become sour over time as H_2S -bearing formation water flows together with oil.

It is well known that H_2S is hazardous to humans and other living organisms, and more generally to the environment. Historically, this is the reason wells found with sour gas were carefully plugged and abandoned. Depending on H_2S concentration, it can cause symptoms such as coughing, eye irritation, loss of the sense of smell, respiratory disturbances, unconsciousness and even death – within two minutes to two days.

The physical phenomenon associated with the sour service environment and affecting steel-based products under applied or residual stress is known as H_2S embrittlement, or, more specifically, sulfide stress cracking (SSC). H_2S , in combination with water and low pH, releases free hydrogen, which can be absorbed through the steel surface. Then hydrogen particles diffuse further into the steel matrix and interact with the steel itself, which becomes brittle.



NACE Testing Method A evaluates the suitability of service through a testing of the material resistance to axial stresses (pure tension), which can be close to the maximum operational stresses that will actually be applied onto drilling tubulars.

The key activating factors are high H_2S content, a low temperature environment, low pH, and high stress state of the material (tensile stress). Through the unfavorable combination of all these factors, a crack can initiate in the material and propagate until a catastrophic failure, even with stresses largely below the yield limit of the material. There is a need to cope more systematically with this hazardous environment.

INDUSTRY RECOMMENDED PRACTICES

Material selection for drill pipe in a sour environment is significantly complex. Even though nothing is specified in API 5D specification, the sour service market is largely influenced by its normalized environment. Industry standards were created to insist on people's security.

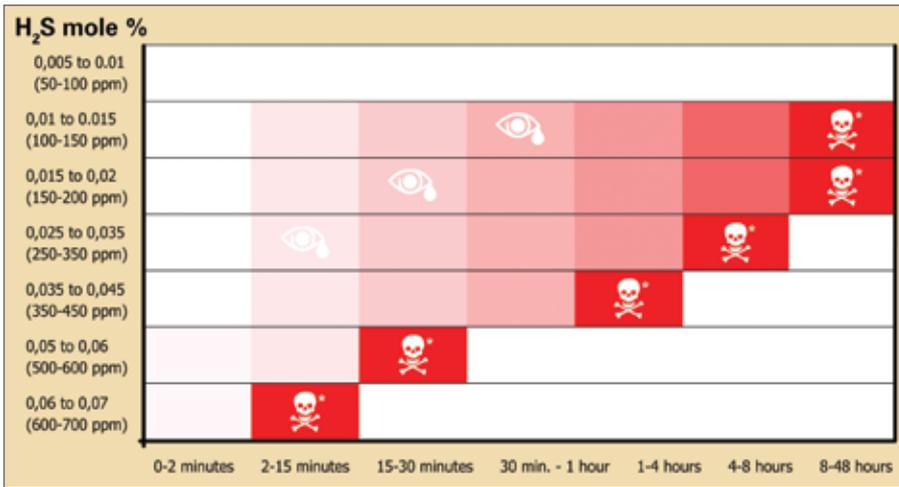
Steel manufacturers have developed proprietary grades addressing the SSC requirements and referring to industry testing standards and material recommendations.

NACE Material Recommendation MR0175 was written in 1975. BP's and

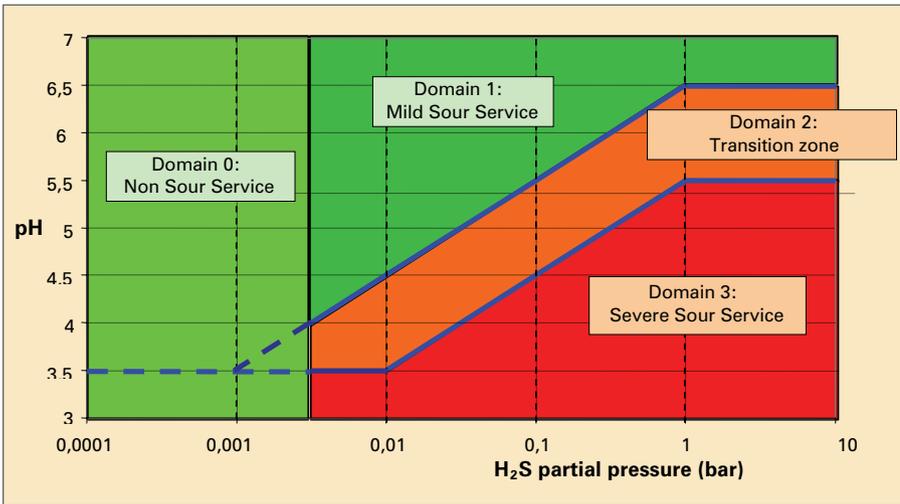
Elf's works in the early 1990s helped to fine-tune knowledge about sour service domains. This document, reviewed in 2004, clearly defines four application domains providing a range of susceptibility to H_2S related to well conditions. NACE MR 0175-2004 is considered a confident selection guide for casing and tubing materials.

NACE MR0175 also introduces pH and temperature as major parameters. Temperature influences the SSC mechanism: The higher the energy is, the more mobile the hydrogen particles are, leading to fewer “blockages” in the steel matrix and to lower risks of failure. pH while drilling can be controlled through fluid chemistry, neutralizing H_2S coming from the formation. Practically maintaining a mud pH of 10 or higher and utilizing sulfide chemical scavengers and/or corrosion inhibitors will minimize the risk of drillstring failures.

This guideline doesn't take into account extreme sour drilling conditions or recent advanced drilling technology such as underbalanced drilling (UBD), where H_2S gas can be permanently in direct contact with the drillstring.



This graph shows H₂S toxicity to human health depending on H₂S concentration.



This graph illustrates sour domains for NACE MR 0175-2004.

The NACE specification also defines normalized test methods gathered in the NACE Testing Methods TM 0177, created in 1977 and reviewed in 2005. Four testing methods are specified by NACE for oil and gas tubular: A, B, C and D.

Hydrogen embrittlement of high-strength low-alloyed (HSLA) steels can lead to pipe failures at a stress level below the yield strength of the steel. Testing methods are used to evaluate the resistance of the steel to hydrogen in solutions saturated with H₂S.

Testing conditions are defined as below and correspond to one of the most severe environments (Domain 3).

- $P[H_2S] = 1$ bar
- $pH = 3$
- $NaCl = 5wt. \%$
- $CH_3COOH = 0.5wt. \%$
- $Temperature = 75^\circ F \pm 5^\circ F (24^\circ C \pm 3^\circ C)$

The testing methods are not equivalent, and each can have a specific role. Method A evaluates the suitability for service through a testing of the material resistance to axial stresses (pure tension), which can be close to the maximum operational stresses that will actually be applied onto drilling tubulars. Method C is principally used to check the resistance of similar materials of circumferential stresses. Method D is designed to check the steel resistance to fracture propagation.

In the majority of applications for tubulars such as tubing, casing and drill pipe, axial and circumferential stresses are the most relevant: Methods A and C are therefore the testing methods most commonly used. Method D is interesting in order to evaluate the impact of surface defects on pipes when immersed in a sour environment, such as slip marks on drill pipe.

The NACE B Method, or "NACE Bent Beam Test," has been replaced by the "Four Points Beam Test." It gives a

constant stress inside the two medium points of the holder. This test has been developed to study SSC resistance of line pipes, particularly for welded areas.

The IRP (Industry Recommended Practices) section 1.8 "Drilling String Design and Metallurgy" has been developed recognizing the need for drill pipe integrity during drilling operations in sour environments. It originated in Canada but is now used all over the world.

IRP 1 section 1.8 specifies metallurgy and design requirements in a severe environment for the drill pipe body and tool-joints, heavy-weight drill pipe, pup joints and safety valves. Drill collars are not included in this specification.

To reduce SSC risks, IRP 1.8 also recommends accomplishing an exposure control by:

- Maintaining the drilling fluid density to minimize formation fluid influx (mud pressure > pore pressure).
- Neutralizing H₂S in the formation by maintaining mud pH above 10 to dissolve sulfides.
- Using sulfide chemical scavengers and corrosion inhibitors.

Standard API grades of drill pipe should not be used for critical sour wells because they are highly susceptible to both H₂S- and chloride-induced failure.

Moving to a stronger grade or weight of drill pipe will usually be required based on insufficient over-pull margin at surface, as opposed to insufficient torsion capacity, which may be the limiting factor in certain deep and deviated wells.

PRODUCT SELECTION

As a general rule, the final user shall consider all drillstring components that might be concerned by sulfide stress cracking risks: drill pipe, heavy-weight drill pipe, and drill stem accessories such as pup joints, subs safety valves. Consistency in material properties among these products is mandatory to assure safety and performance from surface equipment to bottomhole assembly.

From VAM Drilling, three base levels of sour service products matching NACE MR 0175 sour domains are commercially available. Fit-for-purpose specifications can be supplied on demand based on anticipated drilling conditions.

The mild sour domain defined in NACE MR 0175 is covered by the drill pipe

grade VM-105 DP MS and the heavy weight drill pipe VM-65 HW MS for welded construction, and VM-110 HW MS for high-strength integral construction. These product chemistries have been adapted for low levels of H₂S concentrations.

Due to the testing conditions associated with NACE TM 0177, NACE A Method is not the most appropriate to test mild sour service grades. It is better to use specific testing solutions linked to operational downhole conditions and following recommended testing practices of ISO 15156.

Domain 2, or "the transition zone," is a domain requiring more resistance than the mild sour domain. VAM proposes the VM-95 DP S and VM-105 DP S drill pipe, VM-80 HW S heavy-weight drill pipe, VM-110 PUP S pup joints.

Regarding severe sour service, or Domain 3, VAM offers VM-95 DP SS and VM-105 DP SS grades, which are fully compliant with IRP 1.8. The H₂S corrosion resistance for the VM-95 DP SS and VM-105 DP SS grades is checked according to NACE TM 0177 standard with a frequency of one test (a triplicate) per heat. Acceptance criterion is no more than one failure for three samples. Samples for tools joints are taken in the threading cone.

NACE tests are mandatory, and the stress level applied on the test sample is equivalent to 85% specified minimum yield strength (SMYS) of the drill pipe base material.

From a manufacturing process control stand point, pipe are required to be 100% hardness tested.

Finally, VAM manufactures engineered products responding to fit-for-purpose needs. The most adequate drillstring design depends on:

- Downhole environment (H₂S partial pressure, total pressure at the bottom of the well, well temperature and pH).
- Drilling fluid properties.
- Well profile (total depth, true vertical depth of the well).
- Drillstring mechanic evaluation (torque and drag, POOH, RIH forces).

PRODUCT TRENDS

The evolution of drilling programs has driven the industry to develop more suitable solutions adapted to extreme and aggressive conditions. These drilling trends drive today's developments and predict the evolution of products requirements for tomorrow.

Ultra-high strength drill pipe is necessary to achieve deeper drilling objectives. Because higher strength is generally detrimental, more resistance to sulfide stress cracking, innovative chemistries and new heat treatment processes are pushing material limits even further. **Vallourec & Mannesmann** has developed the VM-110 S and VM-125 MS for casing and tubing and drill pipe with similar properties. They are expected to become available soon.

CONCLUSION

Today, sour service environments are associated with deeper and more deviated wells and higher pressures and temperatures downhole. Drilling these wells requires highly engineered tubulars in

order to secure operations, to control risks and to preserve the environment and human health.

Materials selected also must make the drilling operation economically profitable, enabling efficient ROP (rate of penetration), coping with considerable tension and torsional loads and resisting rotary bending fatigue.

To reach these objectives, no gambling is permitted. All parties are involved – operator, drilling contractor and tubulars supplier – should select the drillstring based on operational parameters, manufacturing expertise and qualified manufacturing routes.

For today's and tomorrow's drilling challenges, user requirements combined with key industry players will contribute to the right technology for future breakthroughs.

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