SELECTION OF MATERIALS FOR SOUR GAS PROCESSING

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Corrosion is a major problem in sour gas processing. Selection of materials depends on:

a) mandatory minimum provisions of codes for materials including codes covering materials to resist stress corrosion cracking (SCC)
b) compromise between carbon steel and alloys to resist attack by H_2S and/or CO_2
c) know-how accumulated through years of experience.

Some of the mandatory provisions of a) above have been addressed by C. R. Sivalls' recent paper (1). The compromise between carbon steel and alloys (a major cost decision in plant construction) will be discussed in this paper.

CO_2/H_2S CORROSION

Water-wet CO_2 in the absence of H_2S rapidly attacks carbon-steel. The corrosion rate increases with CO_2 partial pressure and also with temperature. Corrosion being a chemical reaction, the rate doubles approximately every 10°C (18°F). The corrosion only occurs in a wet system - if the gas is dry the corrosion problem disappears.

Ideka's research (2) shows the effect on CO_2 corrosion rate of increasing H_2S-content (Figure 1) - this particular work is for a chloride containing environment. Note that the highest H_2S concentration in this work (330 ppm) has the lowest corrosion rate up to about 250°F.

This very small amounts of H_2S (say less than 10 ppmv) may accelerate CO_2 - caused corrosion. However, as the H_2S-content in the sour gas increases, an ill-defined point is reached where the H_2S reduces the CO_2-induced corrosion rate (20). Even higher H_2S content can provide a sufficiently strong iron sulfide barrier to permit carbon steel's use with modest acceptable corrosion rates, and without inhibitors.

The decision between:

- use of carbon steel plus, if necessary, an inhibitor and

- use of an alloy (e.g. stainless steel)

is certainly an economic one. The relative cost of carbon steel/inhibitor should be balanced against stainless steel and the less expensive material chosen. However, the operating company's "culture" with respect to materials is a more subjective factor. Some companies are prepared to accept a higher first cost to avoid the need for the on-going costs of inhibitor; and more particularly the additional manpower required for monitoring the inhibitor program's effectiveness.

Typical corrosion allowances in sour gas processing are 1/16" in "sweet service" and 1/8" in "sour service". Sometimes first-cost can be minimized by using carbon-steel and a very large corrosion allowance (up to 1/4 inch). Often such large corrosion allowances are a mistake. The loss of this 1/4" of metal can lead to such large amounts of iron carbonate and iron sulfide corrosion products and sludge that:

- severe plugging occurs in equipment such as: trays, by-pass lines, instrument taps,

- inordinate filtration costs are incurred and filter element/cake disposal becomes a larger cost and larger problem.

Note also that such large corrosion allowances cannot be applied to heat exchanger/air cooler tubes and can affect the internal clearances and surfaces of pumps.

Erosion can dramatically accelerate corrosion in sour gas systems. This erosion can be the results of

- sand in the production stream

- excessive fluid velocities - this can be a problem downstream of flashing control valves (e.g. rich amine letdown valve)

OTHER FACTORS CONTRIBUTING TO CORROSION

The production well-stream generally contains water and usually the water contains chlorides and other salts. Inlet separators may need chloride resistant material and inhibitors. Plastic coatings are sometimes used. Also the pitting attack of chlorides on stainless steels is much worse in stagnant areas (such as level bridles) than flowing areas and therefore can be difficult to detect. When a unit is shutdown for a prolonged period the internals should be drained and conditioned to prevent corrosion such a pitting attack.

Poorly designed inlet separators can allow carryover of the chloride-containing produced water. The results of this can include:

- salt deposits/residue on compressor valves - particularly on the discharge side (3).
- salt accumulation in sour gas treating solutions which can result in severe pitting attack of stainless steel reboiler tubes - especially in certain kettle reboiler configurations.

A well-sized inlet separator will reduce these problems. However it may be worth adding a filter separator downstream of a mesh-pad fitted inlet separator to get high liquid-removal efficiency.

Chlorides can cause pitting and stress cracking of stainless steels. Oxygen in the system will accelerate such attack. Oxygen can enter the system through unblanketed tanks and, very commonly, poorly designed/operated vapor recovery systems on tank batteries or product storage tanks that allow the tank to operate at a slight vacuum. The pitting is not usually critical in flow lines with a velocity of over 4 feet/second but in any system it is almost impossible to guard against some stagnant areas.

Of course in non-chloride containing systems oxygen ingress can also accelerate corrosion. One tell-tale sign of the presence of oxygen in H_2S - containing systems is a tan colored sulfur deposit in lines and equipment.

Also it is difficult to separate the effects of one of these compounds from another, since there is often a synergistic effect much more reactive than for any one alone. For example, the stress cracking potential of H_2S is much more severe in the presence of chlorides than would be anticipated if the chlorides were absent.

CODES

Codes are written as minimum requirements and are based on the best data available at the time. This data is being further studied and reviewed by such organizations as the Materials Properties Council. Failure analysis of accidents also plays a big part in code revisions. The point is that codes are revised periodically, as are the ASTM specifications.

When referencing a specification, therefore, it should not be done by a statement "the latest edition". Instead the specific edition should be noted in the specification or purchase order to avoid a dispute over a specification change after the order has been placed. Remember that a specification, by definition is intended to be specific.

An example of such a change was noted in the 1-1/4% Cr, 1/2% Mo pipe involved in a recent major Power Plant accident (19). The allowable stress at the time the plant was built was higher than it is today. As a result, the pipe met code allowable stress at the time but did not meet present day allowable stress for this material.

The selection of material for resistance to sulfide stress cracking (SCC) caused by H_2S (sour service) is well covered by the NACE standard MR-01-75 (Figure 3). In several states this is now a mandatory requirement to obtain a permit for operating such a facility. MR-01-75 has also been revised since its first introduction (15). This particular standard has limitations that may not be obvious to the occasional user (16). A word of caution here: the MR-01-75 is a standard addressing H_2S SCC alone. It does not provide general corrosion protection, nor recognize other sources such as chlorides or CO_2 and H_2O. Nor does it address the corrosion of carbon steel by H_2S and H_2O with oxygen in the system.

A recent serious accident was caused by cracking of the weld area of a vessel in amine service at a Lemont, Illinois Plant (17). From this and other cases, it has become apparent that both rich and lean amine service piping should have carbon steel welds stress relieved. Some of the plants are revising their installations by stress relieving in place, while new installations are adding stress relieving for this service as a requirement.

MATERIALS IN COMMON USE

Material selection for sour gas processing is dependent upon stream compositions, operating temperatures and pressures. As previously stated, carbon steels are acceptable for most piping and equipment in sour gas service. Of course, this must be qualified based on sour components and water concentrations and temperature. Typical grades of carbon steel in sour services for piping, vessels, columns and heat exchangers are shown below. These carbon steels are typically low carbon steel and fully killed. Specific applications require some of the following:

Seamless Tubes (Heat Exchangers) - SA-179
Tubes - SA-214
Pipe - SA-106 Grade B
Vessels - SA-516 Grade 70, SA-285
Forgings - SA-105

In general, seamless piping and tubing is used in sour service and threaded connections should be avoided. Sour service piping and equipment is, in most cases, fully stress relieved and welds are 100% x-rayed. Hardness of welds and heat affected zones should be checked after stress relieving.

Common stainless steels used in sour service are:

Tubes (Heat Exchangers) - SA-249 Grades 304, 316, 410
Pipe - SA-312 Grades 304, 410
Vessels - SA-240 Grades 304, 410
Forgings - SA-182 Grades 304, 410

Typically, valves and bubble caps on contactor trays and mist eliminators are specified as 304 or 410 stainless steel in sour service. In rich amine sweetening units and wet sour systems, some piping and tubing is specified as stainless steel. In sour service all austenetic stainless steel are usually in the solution annealed condition.

Miscellaneous material in sour service environments commonly are used:

Instrument Tubing: Polyethylene or 316 stainless steel
Bolting: SA-193-B7 (B7M is used if the bolt is exposed to H_2S)
Nuts: SA-193 Grade 7

Note: If temperature falls below -20°F then carbon steel SA-320 bolts should be used with nuts to match instead of SA-193.

Allowable stresses for some common piping material are presented in Figure 6 (4, 18). Notice the extensive and complex set of notes that accompany this figure. A similar set of information is available for vessel plate and fittings in the ASME Pressure Vessel Code (6).

ALLOYS

A partial listing of alloys found in sour gas processing plants is presented in Figure 5. These are drawn from ANSI/ASME B31.3a (1985) (4), ANSI/ASME B16.5 (5) and ASME Boiler and Pressure Vessel Code Section VIII (6).

Austenetic stainless steels (18 Cr, 8 Ni) are often used in sour gas processing plants where carbon steel alone, or carbon steel with an inhibitor, is unsatisfactory. However, stainless steel in the presence of 100 ppm chlorides at temperatures above 150°F may stress crack in service. The stainless steel should be low-carbon ($\leq$ 0.03 wt. %C) to minimize risks of sensitization and intergranular cracking in the weld's HAZ. In non-low carbon stainless steels the carbon can precipitate out of solid solution migrate to the grain boundary location and draw chromium to form chromium carbide which is a brittle constituent. The matrix in the immediate vicinity becomes depleted in chromium which renders it susceptible to intergranular corrosion. The alloying materials can only be redistributed by solution annealing of the entire component - this is sometimes impractical (7).

Duplex stainless steels (22-25 Cr, 5 Ni) have superior resistance to chloride attack. They have been used for example in one Canadian application at up to 550°F in 3000 ppmw chloride (no oxygen present). Other applications include gas/oil gathering systems in sea water (8). They have higher strength than the 300 series stainless steels and can be designed with as little as half the corresponding wall thickness. They are more resistant to chloride stress cracking, pitting, crevice and general corrosion than type 304 or 316 SS. They are also more resistant to abrasion type wear.

Titanium is also being used in some high CO_2/high H_2S applications - particularly water-wet and chloride containing (9) (10). An example is heat exchanger tubes where a large corrosion allowance cannot be applied.

Titanium tubing is indeed expensive and thinner tube walls are used than comparable carbon/stainless steel. The thinner titanium tubes are less stiff leading to greater risk of tube vibration and baffle cutting. Dampening devices can be retrofitted to exchangers experiencing flow-induced vibration. Titanium is the base metal and is available in commercially pure grade. For better strength alloyed titanium is available, but as in steels, each alloy has its peculiarities and should be evaluated by an experienced metallurgist before being selected.

Methods of cladding titanium to carbon steel have been developed but have yet to see significant use in severe service sour gas application (11). One reason for this is the difficulty in welding such a combination. The general rule is do not weld titanium to anything but itself.

Aluminum alloys have recently been used in high CO_2 gathering systems (12), but only in the absence of chlorides (aluminum alloys will pit severely in a chloride environment).

If conditions are encountered which are more aggressive than the limit of endurance of the above materials, then nickel base materials (e.g. INCONEL or a HASTELLOY) should be considered. Due to the high cost of these materials their use should be carefully scrutinized.

FABRICATION CONTROLS TO MINIMIZE CORROSION

In selection material for the aggressive conditions of conaminant of H_2S greater care should be exercised, than for less hazardous products. H_2S is toxic even in small doses, therefore while leaks in systems containing non-toxic products may be tolerated until repair can be scheduled, such a condition must be avoided with H_2S gas.

Carbon steel can be used for such an H_2S system, providing the temperature does not exceed 550°F although applications approaching 650°F have been reported. Up to this temperature limit, a generous corrosion allowance can be used to compensate for the sulfidation which increases with temperature.

Once a suitable specification has been written, it is often regarded as the ultimate control. There have been many cases in which the material actually produced did not meet the specification and this was never detected by inspection. The emphasis on inspection is even more important in the present era, in which competitive bidding is so intense. There is a greater pressure for certain suppliers to take steps to reduce cost, even to the point of providing questionable documentation.

In fabrication we shall briefly discuss three main categories of in-shop fabrication and then draw attention to the importance of field fabrication. The three categories are vessels, heat exchangers, and piping.

Vessels

The vessel fabrication specification usually requires that the material to be used in fabrication, and the welding procedures are acceptable to the buyers, inspectors before the fabrication can begin. The quality control is therefore much easier to follow than for fabrication such as piping. It is recommended that this procedure must continue in order to provide the ultimate of safety in operation.

Heat Exchangers

While a significant corrosion allowance can be used in a vessel and in exchanger tube sheets and shells, it is not so applicable in the heat exchanger tubing. But the tubing is the heart of the function by conducting heat through the tube walls. It is therefore a functional requirement that the tube walls be reasonably thin and a corrosion resistant alloy be used. If stainless steel is used in hairpin bends, the low-carbon (L) grades should be specified. These tubes may be bent cold, but they should be re-solution annealed after bending.

One supplier has an acceptable system of doing this, since it is impractical to re-solution anneal 50 or 60 foot long hairpins, only to accommodate the reverse bend in a furnace with full containment. This source contacts the tube electrically about 3 feet from the bend on each side, and applies resistance heat which brings the tube between the contacts to solution anneal temperature. The current is then turned off and water is circulated through the tubes. The tubes are then drained by hydraulically pushing oversized plastic plugs through the tubes. By this method, it has been shown that the material is in a solution annealed condition without sensitization.

Carbon steel tubes can be handled differently. After bending, the reverse bend only can be inserted into a furnace, where stress relieving is applied without affecting the condition of the unbent tube. However, the temperature of stress relieving must not exceed the manufacturing tube-producing temperature on which the mechanical properties were based.

Piping

A more precarious category is piping. Here there is a myriad of parts and pieces coming together from various sources. Often the pipe components are supplied "off the shelf" with an untraceable history of source. At times the supplier can only provide a certificate of compliance that the material meets an ASTM specification number.

Hot bends are sometimes used instead of using elbows. When this is done, the more recent induction pushing hot bend is much more reliable than the old furnace overheat and pull bends. The induction hot bend provides bends with minimum wall thinning and actually enhances the properties over the older method.

Specifications should be written to accommodate the limits of hot bending, instead of adapting the bends to conventional elbow layouts. There are cost savings to be made in fabricating with bends instead of fittings.

All welds on pipe for H_2S service, like vessel fabrication, should be stress relieved.

A hardness check of the weld metal and the heat affected zone (HAZ) showing that the hardness is below $22R_C$ (the most common MR-01-75 hardness limit for H_2S service) is sometimes used to avoid the necessity to stress relieve the weld. Note that the residual stress, not the hardness, causes the steel to crack. The hardness is used as a rough but convenient means of checking the stress. Since it is impractical to check the hardness on every inch of weld, there is always the chance that the weld may be above $22R_2$ at an untested location. The H_2S environment, however, will find the weakness, and the fact that a different location checked is below $22R_2$, will not prevent the unchecked zone from the risk of cracking.

The preferable procedure is to stress relieve, which assures that the local residual stress has been reduced.

If stainless steel is being used, it should not be stress relieved, it should be solution annealed. If the piping system or part is to be welded, then after welding it should be solution annealed. If subsequent welding is required after solution anneal, there is always danger of sensitization. For that reason, either low carbon stainless steel (the L grades) or the stabilized grades 347 or 321 should be used. Remember that the allowable stress on the L grades is lower than the regular grades, and as such, it may be necessary to look critically at the design strength and wall thickness. Generally, stainless steel is received in the solution annealed condition, but check that it is not in the cold worked condition.

Field fabrication is performed under less controlled environments, often with less structured supervision and often in inclement weather. Good quality shop fabricated components can be rendered useless if field welding is not adequately controlled.

There is always the risk of accelerated corrosion by galvanic reaction when dissimilar metals are in contact with each other. Consider the metals in relation to their galvanic potential in the presence of an electrolyte. Insulating gaskets should be used where such potential for corrosion exists.

NON-METALLIC MATERIALS

This paper has concentrated on metallurgical issues. However, materials selection also encompasses many other metallic and non-metallic materials such as:

Block valve trim (seats, seals)
Control valve trim including springs
Gaskets, bolting
Elastomers (used in many valves and instruments)

Materials have to resist attack by solvent (glycols, amines, hot carbonate) as well as wet H_2S/CO_2.

SOME TYPICAL MATERIALS IN USE FOR SPECIFIC UNITS

Sour Gas Plant Inlet Area

Knockout Vessels - SA-516-70
Piping - SA-106-B, 316 stainless steel
Exchangers -
- Tubes - SA-214, SA-106-B, SA-213-304
- Tubesheets - SA-516-70
- Shell - SA-516-70

Condensate Stabilizer Area

Vessels/Columns - SA-516-70
Trays - SA-516-70
Valves, Caps - 410, 304, 304L stainless steel
Mist Eliminators - 304, 410 stainless steel
Exchangers -
- Tubes - SA-214, SA-106-B
- Shell - SA-516-70

Piping - SA-106-B, 316 stainless steel

Amine Units

Vessels/Columns - SA-516-70, SA-240-304L
Trays - SA-516-70, SA-240-304L
Valves, Caps - 410, 304, 304L stainless steel
Mist Eliminators - 304, 410 stainless steel
Exchangers -
- Tubes - SA-249-304, 304L, SA-214, SA-179
- Shell - SA-516-70

Piping - SA-106-B, 304, 304L stainless steel

Glycol Dehydration Units

Vessels/Columns - SA-516-70, SA-53-B
Exchangers -
- Tubes - SA-214
- Shell - SA-516-70, SA-53-B

SUMMARY

Selection of materials for sour gas processing is heavily influenced by a compromise between inexpensive carbon steels and a progressively more expensive range of alloys. Experience on past units is the key ingredient to satisfactory selection and service. Meeting mandatory provisions of the applicable codes and standards is important for a safe installation. Also very important is diligent inspection during fabrication and any field modifications.

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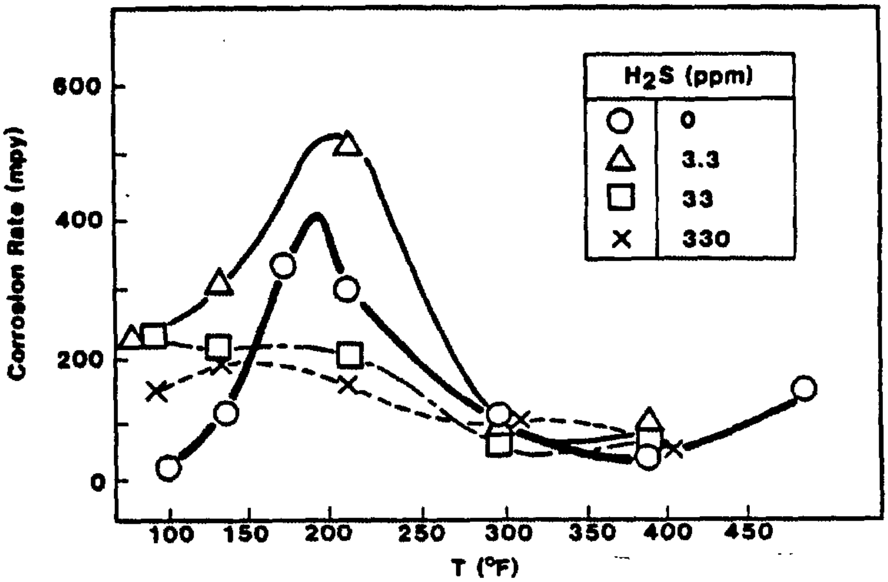
FIGURE 1
EFFECT OF A LITTLE AMOUNT OF H_2S AND TEMPERATURE ON CORROSION RATE (PURE IRON)[2]



Note: (5% NaCl), 3.0 MPa CO_2 + H_2S at 25°C(77°F), Test Duration; 96h, Flow Velocity; 2.5 m/s, Specific Volume; 25 cc/cm²)

FIGURE 2
CO_2/H_2S RATIO

EXAMPLE GUIDELINE FOR MATERIAL SELECTION IN WATER-WET SERVICE

CO_2 : H_2S >100:1 PROBABLY REQUIRE ALLOY OR CORROSION INHIBITION PROGRAM

CO_2 : H_2S < 10:1 PROBABLY USE CS

NOTE THE "GRAY AREA" BETWEEN CO_2 : H_2S OF 100:1 AND 10:1 WHERE THE MATERIAL SELECTION IS NOT CLEAR - PAST EXPERIENCE WITH SIMILAR MATERIALS AND GAS ANALYSIS SHOULD BE RELIED UPON.

SELECTION COULD BE AFFECTED BY EROSION DUE TO LINE VELOCITY OR SAND; ALSO BY CORROSION DUE TO CHLORIDES AND OTHER TRACE CONTAMINANTS.

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FIGURE 3
TYPICAL GAS ANALYSES AND POSSIBLE MATERIAL SELECTIONS

	GAS COMPOSITION MOLE %		MATERIAL SELECTION
A.	70	C_1 WATER WET	
	20	CO_2	C.S
	10	H_2S	
B.	80	C_1	C.S
	19.5	CO_2 Note 1	
	0.5	H_2S	
C.	80	C_1	SS OR
	20	CO_2	CS w/inhibitor
	10 gr/100 scf	H_2S (160 ppmv)	
D.	25	C_1	SS OR
	65	CO_2	CS w/inhibitor
	10	H_2S	

Notes: 1. Pressure 900 psia, therefore CO_2 partial pressure is 900 x 0.195 = 175.5 psia.

Extracted Figures for "Sour Service Designation" from NACE MR-01-75.

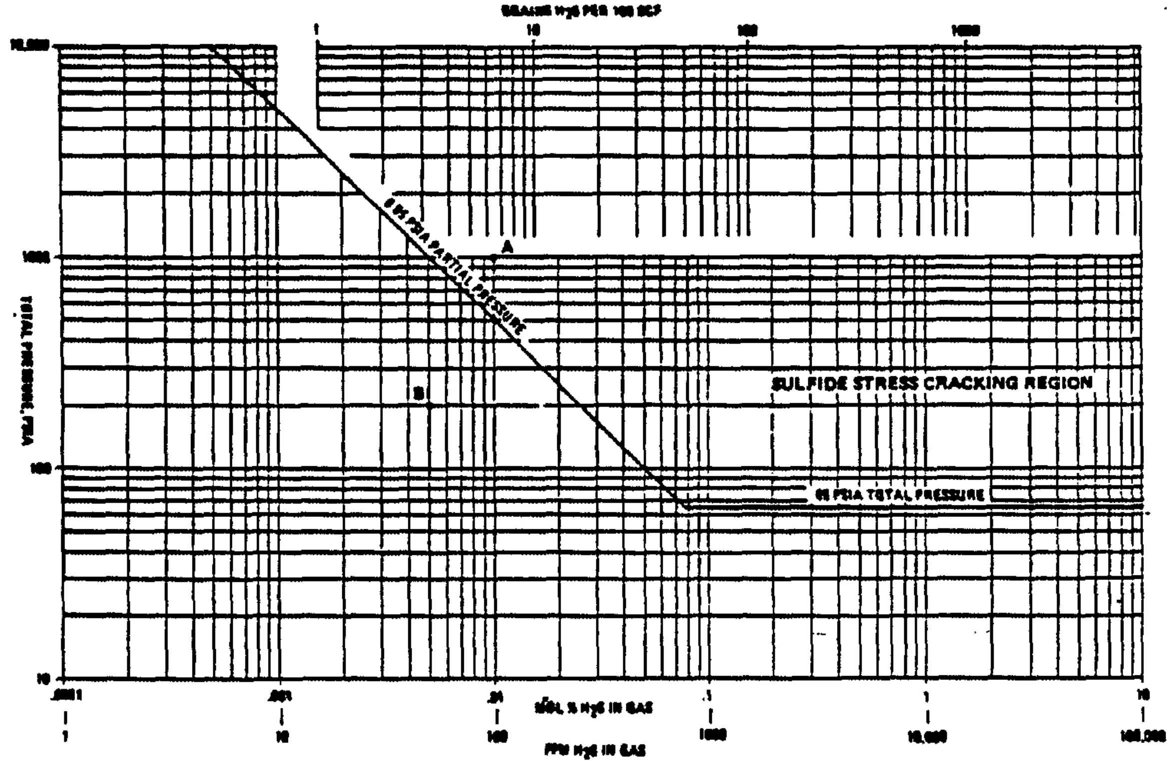

FIGURE 4a - Sour gas systems (see Paragraph 1.3.1 of NACE MR-01-75).

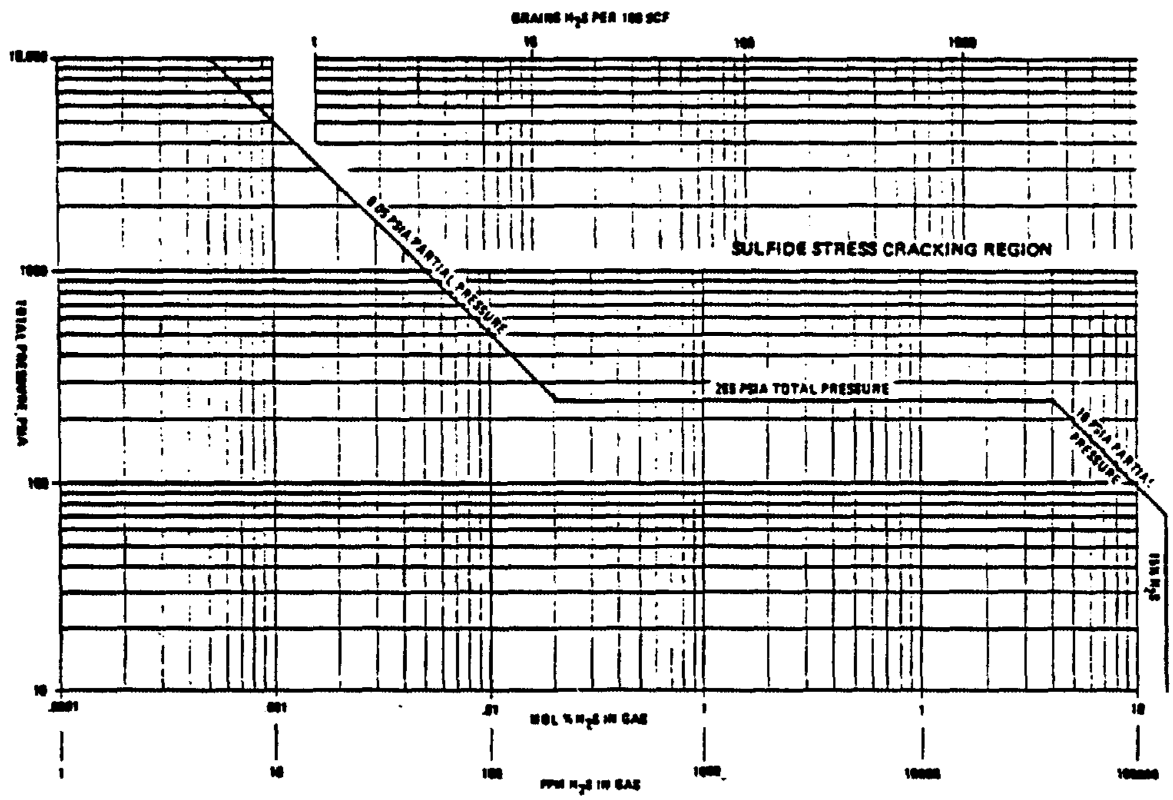

FIGURE 4b - Sour multiphase systems (see Paragraph 1.3.2 of NACE MR-01-75).

FIGURE 5

NOMINAL CHEMICAL COMPOSITION OF SOME ALLOYS

ASME/ASTM GRADE DESIGNATION		PERCENT COMPOSITION					
P-1		C / 1/2 Mo					
		Cr	Mo				
P-11		1-1/4	1/2				
P-22		2-1/4	1				
P-6		9					
P-9		9	1				
STAINLESS							
		Cr					
410		13					
		Cr	Ni				
304	304L (0.03% C max)	18	8				
		Cr	Ni	Mo			
316	316L (0.03% C max)	17	12	2.5			
		Cr	Ni	Mo	Cb		
317		19	13	3.5			
321		Ti Stabilized, 5 x % C min					
347		Cb Stabilized, 10 x % C min					
		Cr	Ni	Mo	N		
Duplex 2205		22	5.0	3	0.10 min		
		Cr	Ni	Mo	Cu	Cb	N
ALLOY 20		20	37.5	2.5	3.5	0.3	
254 SMO		20	18	6.1	0.7		0.20
		Cr	Ni	Mo	Cu	Al	Ti
INCOLLOY 800		21	42.0	3	2.5		
INCOLLOY 825		22.5	42.0	3	2.0	0.2	1.0
		Cr	Ni	Mo	Cu	Cb/Ta	W
HASTELLOY 276		15	60	16			4.0
HASTELLOY G		22	44	6.5	2		
		Cr	Ni	Mo	Cb	Al	Ti
INCONEL 625		21.5	60	9	4.0	0.4	0.4
		Cu	Sn	Zn			
ADMIRALTY BRASS		71	1	28			

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FIG. 6.
Allowable Stresses in Tension for Materials (1)
(Excerpted from ANSI B31.3a-1985, Appendix A, Tables A-1, A-1B)

Material	Specification	Grade	Class	Factor (E)	Tensile Strength Min. PSI	Yield Strength Min. PSI	Notes	(6) Min. Temp.	BASIC ALLOWABLE STRESSES IN TENSION (PSI)(4) Metal Temperature Degrees F (7): Min. Temp. To 100	200	300	400	500	600	650	700	750	800	850	900	950	1000	1050	1100
CARBON STEEL																								
Seamless Pipe	ASTM A53	A	Type S		48000	30000	57, 59	20	16000	16000	16000	16000	16000	14800	14500	14400	10700	9300	7900	6500	4500	2500	1600	1000
	ASTM A53	B	Type S		60000	35000	57, 59	20	20000	20000	20000	20000	18900	17300	17000	16500	13000	10800	8700	6500	4500	2500	1600	1000
	ASTM A106	A			48000	30000	57	20	16000	16000	16000	16000	16000	14800	14500	14400	10700	9300	7900	6500	4500	2500	1600	1000
	ASTM A106	B			60000	35000	57	20	20000	20000	20000	20000	18900	17300	17000	16500	13000	10800	8700	6500	4500	2500	1600	1000
	ASTM A106	C			70000	40000	57	20	23300	23300	23300	22900	21600	19700	19400	19200	14800	12000						
	ASTM A120						8	20	‖12000	11400														
	ASTM A333	1			55000	30000	57, 59	50	18300	18300	17700	17200	16200	14800	14500	14400	12000	10200	8300	6500	4500	2500	1600	1000
	ASTM A334	1			55000	30000	57, 59	50	18300	18300	17700	17200	16200	14800	14500	14400	12000	10200	8300	6500	4500	2500	1600	1000
	ASTM A333	6			60000	35000	57	50	20000	20000	20000	20000	18900	17300	17000	16500	13000	10800	8700	6500	4500	2500	1600	1000
	ASTM A334	6			60000	35000	57	50	20000	20000	20000	20000	18900	17300	17000	16500	13000	10800	8700	6500	4500	2500	1600	1000
	API 5L	A			48000	30000	57, 59	20	16000	16000	16000	16000	16000	14800	14500	14400	10700	9300	7900	6500	4500	2500	1600	1000
	API 5L	B			60000	35000	57, 59	20	20000	20000	20000	20000‖	18900	17300	17000	16500	13000	10800	8700	6500	4500	2500	1600	1000
	API 5LX	X42			60000	42000	51, 55	20	20000	20000	20000	20000‖												
	API 5LX	X46			63000	46000	51, 55	20	21000	21000	21000	21000‖												
	API 5LX	X52			66000	52000	51, 55	20	22000	22000	22000	22000‖												
	API 5LX	X52			72000	52000	51, 55	20	24000	24000	24000	24000‖												
Electric Resistance Welded Pipe																								
	ASTM A53	A	Type E	0.85	48000	30000	57, 59	20	13600	13600	13600	13600	13600	12600	12300	12250	9100	7900	6700	5500	3800	2150	1350	850
	ASTM A53	B	Type E	0.85	60000	35000	57, 59	20	17000	17000	17000	17000	16100	14700	14500	14000	11000	9200	7350	5500	3800	2150	1350	850
	ASTM A120			0.85			8	20	10200	9800														
LOW AND INTERMEDIATE ALLOY STEEL & STAINLESS STEEL (4.40)																								
Seamless Pipe																								
3½ Ni	ASTM A333	3			65000	35000		150	21700	19600	19600	18700	17800	16800	16300	15500	13900	11400	9000	6500	4500	2500	1600	1000
3½ Ni	ASTM A334	3			65000	35000		150	21700	19600	19600	18700	17800	16800	16300	15500	13900	11400	9000	6500	4500	2500	1600	1000
Ni-Cr-Cu-Al	ASTM A333	4			60000	35000		150	20000	19100	18200	17300	16400	15500	15000									
2¼ Ni	ASTM A333	7			65000	35000		100	21700	19600	19600	18700	17600	16800	16300	15500	13900	11400	9000	6500	4500	2500	1600	1000
2¼ Ni	ASTM A334	7			65000	35000		100	21700	19600	19600	18700	17600	16800	16300	15500	13900	11400	9000	6500	4500	2500	1600	1000
9 Ni	ASTM A333	8			100000	75000	47	320	31700	31700														
9 Ni	ASTM A334	8			100000	75000		320	31700	31700														
18Cr-8Ni Pipe	ASTM A376	TP304			75000	30000	20, 26, 28, 31, 36	425	20000	20000	20000	18700	17500	16400	16200	16000	15600	15200	14900	14600	14400	13800	12200	9700
18Cr-8Ni Pipe	ASTM A376	TP304H			75000	30000	26, 31, 36	325	20000	20000	20000	18700	17500	16400	16200	16000	15600	15200	14900	14600	14400	*13800*	*12200*	9700

NOTE: These Notes are requirements of the Code. Those marked with an asterisk (*) restate requirements found in the text of the Code. The other Notes are limitations or special requirements applicable to particular materials. Full interpretation of these notes will require reference to ANSI/ASME B31.3a — 1984 Edition.

(1)* The stress values in Table A-1 and the design stress values in Table A-2 are basic allowable stresses in tension in accordance with 302.3.1(a). For pressure design, the stress values from Table A-1 are multiplied by the appropriate quality factor *E* (*E*, from Table A-1A, or *E*, from Table A-1B). Stress values in shear and bearing are stated in 302.3.1(b); those in compression in 302.3.1(c).

(3)* This casting quality factor can be enhanced by supplementary examination in accordance with 302.3.3(c) and Table 302.3.3C. The higher factor from Table 302.3.3C may be substituted for this factor in pressure design equations.

(4)* In shaded areas, stress values printed in *italics* exceed two-thirds of the expected yield strength at temperature. All other stress values in shaded areas are equal to 90% of expected yield strength at temperature. See 302.3.2(d)(4) and 302.3.2(d) [Note (3)].

(6)* The minimum temperature shown is that design minimum temperature for which the material is normally suitable without impact testing other than that required by the material specification. However, the use of a material at a design minimum temperature below −20°F (−29°C) is established by rules elsewhere in this Code, including any necessary impact test requirements.

(7)* A single bar (|) in these Stress Tables indicates there are conditions other than stress which affect usage above or below the temperature, as described in other referenced Notes. A double bar (‖) after a tabled stress indicates that use of the material is prohibited above that temperature. A double bar (‖) before the stress value for "Min. Temp. to 100°F" indicates that the use of the material is prohibited below the listed minimum temperature. At temperatures where there are no stress values, the material may be used in accordance with 323.2 unless prohibited by a double bar (‖).

(8)* There are restrictions on the use of this material in the text of the Code.

(20) For pipe sizes NPS 8 and larger and for wall thicknesses of Schedule 140 or heavier, the minimum specified tensile strength is 70.0 ksi (483 MPa).

(26) These unstabilized grades of stainless steel have increasing tendency to intergranular carbide precipitation as the carbon content increases above 0.03%.

(28) For temperatures above 1000°F (538°C), these stress values apply only when the carbon content is 0.04% or higher.

(30) For temperatures above 1000°F (538°C), these stress values may be used only if the material has been heat treated at a temperature of 2000°F (1090°C) minimum.

(31) For temperatures above 1000°F (538°C), these stress values may be used only if the material has been heat treated by heating to a minimum temperature of 1900°F (1040°C) and quenching in water or rapidly cooling by other means.

(36) The specification permits this material to be furnished without solution heat treatment or with other than a solution heat treatment. When the material has not been solution heat treated, the minimum temperature shall be −20°F (−29°C) unless the material is impact tested per 323.3.

(40) The stress values for austenitic stainless steels in these Tables may not be applicable if the material has been given a final heat treatment other than that required by the material specification and any overriding requirements of this Code called for by Note (30) or (31).

(47) If no welding is employed in fabrication of piping from these materials, the stress values may be increased to 33.3 ksi (230 MPa).

(51) Special P-Numbers SP-1, SP-2, and SP-3 of carbon steels are not included in P-No. 1 because of possible high carbon, high manganese combination which would require special consideration in qualification. Qualification of any high carbon, high manganese grade may be extended to other grades in its group.

(55) Pipe produced to this specification is not intended for high temperature service. The stress values apply to either nonexpanded or cold expanded material in the as-rolled, normalized, or normalized and tempered condition.

(57)* Conversion of carbides to graphite may occur after prolonged exposure to temperatures over 800°F (425°C) (see Appendix F).

(59)* For temperatures above 900°F (480°C), consider the advantages of killed steel (see Appendix F).