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AVESTA CORROSION MANAGMENT

Weight Optimisation in Offshore Construction

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Introduction

Two typical features of the material selection for the offshore installations in the North Sea have been:

1. Adopting of material solutions from American Process Industry
2. Application of American design codes

Today we have to face costly maintenance of equipment, piping and structures for many installations. This arises doubts about the quality of previous material evaluations, and initiates the search for more optimal material selections.

With increased water depts for offshore installations, new and better technologies, methods and systems have to be developed. One step in this direction will be weight reductions of the topside facility systems.

Piping has an important impact to the platform weight, and this paper presents materials which allow for low weight and low maintenance costs compared with today's piping materials in the North Sea.

Line Sizing Criteria

API RP 14E has been and is extensively in use to establish flow velocities i.e. internal diameters of piping between equipments. This code is developed on the background of long experience from American Process Industry. The recommended velocities in this code are partly from experienced economical friction losses, and partly from experienced max velocity limits in order to prevent cavitation, erosion or noise problems.

However, all recommendations used today are based on data of the past, using erosion and corrosion properties, which are different from materials of today.

When looking to more resistant and more expensive materials in order to decrease maintenance costs, it is logic that higher friction losses can be accepted i.e. design velocities should be higher than those recommended for poorer and cheaper materials when looking for an optimal line sizing. This leads to the important fact that when looking for resistant piping materials to solve maintenance problems you will usually be guided into a weight reducing material selection.

API RP 14E is mostly based on onshore application where weight is of little importance. Weight has a big influence to the total investment cost of a new platform in the North Sea. Smaller pipe diameters will save piping weight but may result in increased weight of compressors and pumps etc. An adequate line sizing code for piping on offshore installations for the purpose to minimize total system weight is missing, and there is no doubt that a lot of the existing piping in the North Sea today is oversized.

Even the fact that optimal line sizing for piping on offshore installations is difficult, it is rather simple to see impacts on line sizes when changing to another material which implies a new criteria for max velocity. While most piping is sized according to a max recommended pressure drop which is independent of the pipe material, there are special sizing criteria for a number of material/fluid-combinations which may govern the line sizes. Some examples are listed below.

1. Inhibitor protected carbon steel for wet and corrosive hydrocarbon flow.

   The inhibitor, which is injected into the flow, forms a layer on the internal pipe surface, and the continuity and the quality of this layer becomes decisive for the corrosion protection. At velocities above 6 m/sec the layer may be broken by turbulence, and thus gives no protection of the pipe material.

2. Cupro alloys for seawater piping.

   Erosional properties will set low max velocity limits, 2.5-3.5 m/sec.

3. Solids in the flow and a rather soft pipe material may set a low max velocity limit in order to prevent erosion.

Velocities for the flows listed above can be increased by selecting other materials e. g. different kinds of stainless steel. Velocities may then be governed by friction losses, cavitation or noise i. e. factors not related to the material itself.

Design Codes, Pipe Wall Thickness and Pressure Ratings

For the actual pipe diameter the pipe wall thickness is calculated to withstand different loads. The most common load decisive for the wall thickness is internal pressure, and the typical formula of relevant design codes for calculation of wall thickness, t, for this load has the form of:

$$t = \frac{P \times D}{2 \times S + P}$$

where

P = Design pressure
D = External pipe diameter
S = Allowable stress of the pipe material

As can be seen from this formula, a decreased pipe diameter will automatically give a decreased wall thickness for the same pressure and the same material.

The value of design pressure, P, in the denominator will be small compared with the value of allowable stress, S, for most relevant pressures and materials, and thus making the wall thickness roughly inversely proportional to the allowable stress of the pipe material.

The different design codes put slightly different correction factors related to material, fabrication etc., into the formula, and adjust differently for fabrication tolerances. However, the most significant result changes when using e.g. the TBK 6 code instead of the ANSI B 31.3 code are due to different allowable stresses for the same material. The TBK 6 will give less wall thickness and thus weight reductions for many materials compared with the ANSI code due to higher allowable stress calculated from:

- Lower safety factor for all steels related to tensile strength, 2.4 versus 3.0
- Lower safety factor for austenitic steel related to yield strength, 1.35 versus 1.5

Some examples of allowable stress according to the two codes are shown in table 1, and e. g. for the duplex steel in this table, wall thickness and weight can be reduced by about 20% when applying the allowable stress according to TBK 6 instead of the figure from the ANSI code.

Table 1:
Allowable stress of some pipe materials in N/mm^2

	According to code	
Material	ANSI B 31.3	TBK 6
C.S. ASTMA 106 GR B	138	138
S.S. UNS S 31254 (High Mo S.S.)	153	170
S.S. DIN W.-Nr. 1.4462 (Duplex S.S.)	228	274

The high allowable stress for e.g. the duplex steel in table 1 compared with the value of the carbon steel also tells that the pipe wall thickness for the same pipe diameters and thus weight can be reduced to about one half of the value for this carbon steel due to the approximately inverse proportionality between wall thickness and allowable stress. But even further reductions are gained when looking to the fact that carbon steel usually requires an additional corrosion allowance of 3-4 mm while stainless steels do not for the same application.

Pressure ratings for flanges and fittings have been selected according to ANSI B 16.5 for most offshore installations. This code gives limits for highest allowable working pressures for all classes, 150 to 2500 pounds. If applying the TBK 2 code or BS 5500 for sizing of flanges, calculations show that by using the high strength duplex steel for casting of ANSI flanges, the allowable stress will be far above actual stresses in critical sections when exposed to the max allowable pressure according to the ANSI code. In other words, flanges of high strength materials are probably oversized if applying the ANSI code. However, if calculating maximum design pressures for standard ANSI flange dimensions according to TBK 2 or BS 5500, weights of flanges can be reduced significantly by the use of high strength materials, e.g. class 300 flanges could probably be used for working pressures above 100 bar.

Examples

In order to illustrate weight and cost relationship between different material alternatives for the same application, line sizes and pipe wall thicknesses have been calculated for two piping systems, one for wet vapour lines of a hydrocarbon gas processing system and one for seawater containing systems of a gas production platform. Only materials which are expected to operate during the whole lifetime of the platform, 20 years without replacements, have been considered in the material evaluations.

Hydrocarbon gas system

Wells for oil and gas production will also produce water during the production period, and presence of chlorides, CO_2 and/or H_2S makes the wellstream more or less aggressive to carbon steel with respect to corrosion. Different means for corrosion control have been used, and commonly used are corrosion inhibitors which are injected into the wells continuously or in batches. These inhibitors are chemicals which usually form a layer on the internal surface of the production tubing and the process piping, and with a proper monitoring system for adjustments of inhibitor concentrations and injection locations, such systems have been in successful operation for many years.

However, inhibitors require low flow velocities in order to form the protective layer on the pipe surface, and an alternative will often be to use a more resistant material which needs no inhibitor, and which allows for higher flow velocities. Different stainless steels are most actual for this duty especially for the more aggressive wellstreams. The example below, however, also demonstrates that stainless steel could be an interesting alternative to inhibitor protected carbon steel even when the corrosion potential can be classified as low.

Example:
Process Piping for wet gas from separators to gas drying units:

Design data:
Design Flowrate: 6000 m^3/hr = 600,000 kg/hr
Design Pressure: 115 bar
Flow Composition: 0.3 to 1 % H_2O, 0.6 % CO_2, max 10 ppm H_2S

Material alternatives:

1. Carbon steel ASTM A 106 GR B protected by additional inhibitor to a concentration of 10 ppm, injected downstream of separation due to low concentration of inhibitor from previously injections upstream of separation in the wellstreams etc.
2. Duplex stainless steel to DIN W.-Nr. 1.4462.

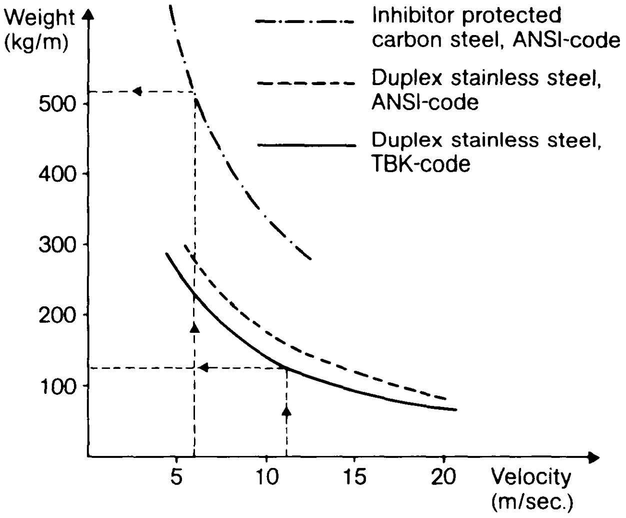
Line sizing criteria:
Max velocity for inhibitor protected carbon steel:
6 m/sec.

Max allowable pressure drop: 0.2 bar/100 m
(This corresponds to a velocity of about 11 m/sec).

Results:
The results of the evaluation are presented in table 2. The tabulated weight figures are excerpted from figure 1.

Table 2: A weight and cost comparison of pipe materials for a 6000 m^3/hr wet hydrocarbon vapour line.

	Duplex steel TBK 6	Carbon steel ANSI B 31.3
Size	18", 11.1 mm	26", 33.5 mm
Velocity	11.2 m/sec	6 m/sec
Unit weight	122 kg/m	518 kg/m
Weight of 100 m of straight pipe	12200 kg	51800 kg
Material price	40 NOK/kg	5 NOK/kg
Cost of pipe material	NOK 488,000	NOK 259,000
Inhibitor price		30 NOK/kg
Annual cost of inhibitor injection to an average of 10 ppm into the gas flow		NOK 1.55 mill.



Volumetric flow: 6000 m^3/hr
Design pressure: 115 bar
Max pressure drop: 0.2 bar/100 m corresponding to a velocity of abt. 11 m/sec.
Max velocity for inhibitor protected carbon steel:
6 m/sec

Figure 1
Dry pipe weight as a function of flow velocity

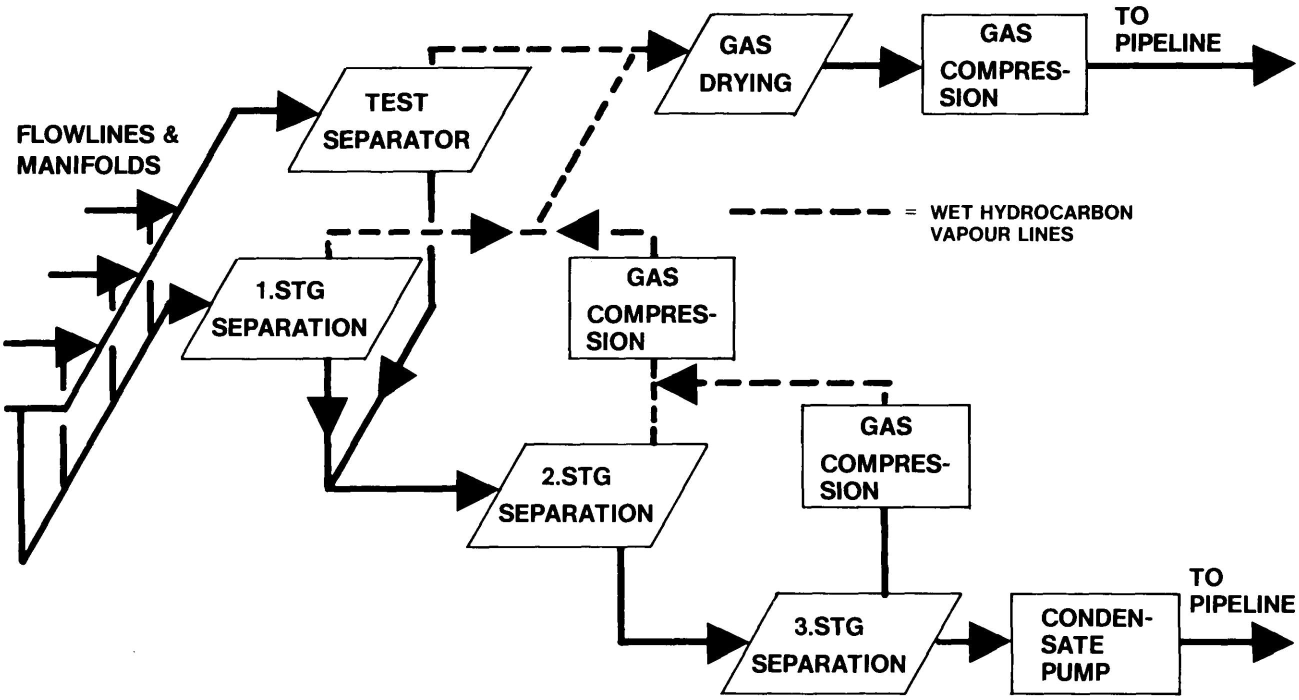


Figure 2. Typical gas processing (very simplified)

The annual cost of inhibitor, NOK 30 per kg, is calculated from 10 ppm per mass flow unit as shown below:

360 x 24 h x 600,000 kg/h x 10 x 10^{-6} x 30 NOK/kg = **NOK 1.55 mill**

For the wet vapour piping of a 16 mill std. cu. m. gas production platform, see figure 2, a weight comparison resulted in 107 tonnes of carbon steel piping sized for a velocity of 6 m/sec while the use of duplex steel sized to max recommended pressure drops resulted in 32 tonnes of piping.

Seawater containing systems

Seawater containing systems for oil and gas production platforms comprise seawater cooling systems, ballast water systems, firewater systems and water injection systems. Total weight of such piping systems for one platform may be several thousand tonnes, and weight differences between different material alternatives may exceed 1000 tonnes of dry weight. This is illustrated in the example to follow.

Seawater is known as an aggressive fluid to many materials like carbon steel and many of the stainless steels.

Some previously applied materials for seawater systems for oil and gas production in the North Sea have suffered from severe corrosion, and due to this experience only 3 alternatives were found interesting for an evaluation for the Sleipner project. These are:

1. High molybdenum stainless steels like the UNS S 31254 or similar
2. Cupro-Nickel-Iron Alloys like the Kunifer 10 or similar
3. Rubber lined carbon steel

A fourth alternative like glassfibre reinforced epoxy or polyester could be of interest for future projects, but today's lack of standardisation and lack of consistent design criteria mainly related to aging and temperature effects are major factors to consider other materials where safety and reliability are of great importance.

When calculating weight for the 3 material alternatives above, it will mainly be the flow velocity which governs the results. This is because of the relative low design pressure compared with lots of the process piping, and the pressure alone will not be decisive for the pipe wall thickness. Criteria like resistance against buckling or distortion will more often be decisive for the wall thickness together with a minimum thickness for proper welding etc. This results in similar wall thickness for materials of different strength properties.

Example:

For one of the Sleipner platform concepts parts of the seawater containing systems have been analysed for a material evaluation, and the results of this evaluation are shown in table 3 and 4.

As previously described some materials like the copper alloys need low flow velocities in order to be resistant against erosion, and as can be seen from table 3 this has a great impact on the weight: 3.5 m/sec is used as an upper limit for the 90/10 cupro-nickel piping while 7 m/sec is assumed to correspond to max. acceptable pressure drop, and is therefore used for the stainless steel alternative. However, only low velocities about 2-4 m/sec will give acceptable pressure losses for the smaller dimensions below 8 inches.

Table 4 presents cost figures for 3 different alternatives in addition to weight figures. The amount of small piping, 1-6 inches, is in proportion to the amounts of such piping in the Gullfaks A project, when related to the larger dimensions in order to give a representative picture by the summary of table 4.

Material costs for rubber lined piping is based on the use of stainless steel valves and lots of pipe couplings. Pipe couplings will reduce fabrication and installation costs and is selected due to lack of experience from welding methods which do not damage the rubber. The designation "Fab. cost" in the table means both fabrication and installation costs, and this is not calculated for rubber lined piping due to lack of experience data.

As can be seen from table 4, total piping weights of seawater systems are probably doubled when using copper alloys and their corresponding recommended velocities instead of stainless steel pipes designed for velocities corresponding to max. acceptable friction losses.

Table 3: Dry weights of piping for seawater

		High Molybden stainless steels			90/10 Cu Ni alloys		
Syst. no.	Description of seawater piping	Size inches	Wall thickness mm	Weight tonnes	Size inches	Wall thickness mm	Weight tonnes
1	Seawater lift discharge from pumps 6 m pipe + 3 flanges + 1 Butterfly valve per pump	14	4.78	2.7	20	7.5	5.8
2	Seawater lift header 180 m straight pipe	26	6.35	18.7	36	8	37.7
3	Firewater discharge from pumps. 6 m pipe + 3 flanges + 1 Butterfly valve per pump	10	4.19	1.3	16	9	3.8
4	Firewater discharge headers	16	3.96	5.6	20	11	24.6

Table 4: Weight & material cost

Syst. no.	Description of seawater piping	S.S. Cr Ni Mo			Cu Ni Fe			C.S. 6.4 mm rubber		
		Size inch	Weight tons	Mat.cost+ Fab.cost NOK	Size inch	Weight tons	Mat.cost+ Fab.cost NOK	Size inch	Weight tons	Mat.cost NOK
1	Seawater lift discharge from pumps. 6 m pipe + 3 flanges + 1B.fl. valve per pump	14	2.7 (2.8)	325.000 182.000	20	5.8 (5.7)	297.000 391.500	14	3.0 (2.6)	243.000
2	Seawater lift header 180 m straight pipe	26	18.7 (59.2)	1.217.000 1.262.000	36	37.7 (114.0)	1.800.000 2.545.000	26	22.3 (56.9)	733.000
3	Firewater discharge from pumps. 6 m pipe + 3 flanges + 1B.fl. valve per pump	10	1.3 (1.3)	146.000 88.000	16	3.8 (2.8)	199.000 256.500	10	1.6 (1.2)	121.000
4	Firewater discharge headers to ringmain 160 m straight pipe	16	5.6 (20.0)	528.000 378.000	20	24.6 (30.0)	1.207.000 1.661.000	18	12.1 (23.6)	428.000
5	1-6" pipe materials, typical amounts		16 (14)	1.600.000 1.080.000		18 (14)	900.000 1.215.000		16 (14)	
	Summary		44.3 (97.3)	6.806.000		89.9 (166.5)	10.472.000		55.0 (98.3)	

Notes: - Small sizes 1-6" are assumed to be stainless steel when combined with rubber lined C.S. in the summary.
- Weights are dry weights, water weights in parantheses.

Conclusion

Evaluation of optimal material selections together with optimal line sizes for piping systems is difficult to obtain from existing guidelines today. A research programme within this subject including two-phase flow and the latest materials which proves superior corrosion resistant properties, would be fruitful to all operators within oil and gas production.

However, in spite of these missing guidelines, there should be no doubt that new materials of poor availability are economic for the use on offshore installations.

The importance to minimize weight for new installations is a strong push for the consideration of piping materials which allow for high flow velocities.

Thus the important advice to pipe manufacturers and the users must be to prevent that the material selection becomes a question of availability at the stage of purchasing.

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