Welding LNG tanks and vessels in 5% and 9% nickel steels

There is growing interest in the use of natural gas as a source of energy. Every year new reserves are found and globally far more gas is being discovered at present than is being consumed. The world has been finding roughly four times as much gas as it uses each year. Much of the world's gas resources are, however, generally located far from the main consumption areas. This leads to the need for the transportation and storage of gas. Liquifying the gas at cryogenic temperatures decreases its volume by a factor of more than 600 which thus simplifies storage and transportation.

The liquefaction temperature for some types of gas can be seen in Table 1.

In the case of Liquefied Natural Gas, LNG, the temperature needs to be as low as below -163°C, but ethylene liquifies already at -103.8°C.

It is obvious that the cost of liquefaction and of storage and transportation at cryogenic temperatures by LNG carriers is much higher than that of other energy products. However, due to the increased demand for energy combined with greater emphasis on the environmental effects, there is enormous market potential for LNG. Several large projects have been completed in recent years and many new projects are in progress. This includes the exploration of reserves in the Middle East, Nigeria, Indonesia and Australia among others.

Materials for LNG tank construction

The materials used in the vessels which keep the gas at liquefaction temperatures need to remain ductile and crack resistant with a high level of safety. The material also needs to have high strength in order to reduce the wall thickness of the container and it must permit welding without any risk of brittle fracture. The materials used for the various working temperatures are listed in Table 1. In the case of LEG/LNG, large landbased tanks, at temperatures of below -105°C only 5-9%

Table 1

Liquefaction temperatures of gases and used types of parent materials

Gas	Liquefaction temperature (°C)	Type of parent material used
Ammonia	-33.4	Carbon steel
Propane (LPG)	-42.1 - 45.5	Fine grain Al-killed steel
Propylene	-47.7	2.25% Ni steel
Carbon disulphide	-50.2	
Hydrogene sulphide	-59.5	3.5% Ni steel
Carbon dioxide	-78.5	
Acetylene	-84	
Ethane	-88.4	
Ethylene (LEG)	-103.8	5-9% Ni steel
Krypton	-151	
Methane (LNG)	-163	
Oxygen	-182.9	
Argon	-185.9	
Fluorine	-188.1	
Nitrogen	-195.8	Austenitic stainless steel
Neon	-246.1	
Heavy Hydrogen	-249.6	Aluminium alloys
Hydrogen	-252.8	
Helium	-268.9	
Absolute zero	-273.18	

nickel steels have the optimum properties.

Large LNG carriers are using aluminium for the spherical tanks to reduce weight.

When the temperatures are even lower it is necessary to use austenitic stainless steels or aluminium alloys.

5-9 % nickel steels

The 9% nickel steels provide a combination of properties at a reasonable price. The excellent low temperature impact properties are the result of a fine grained structure of tough nickel-ferrite. Small amounts of stable austenite formed by tempering improve impact resistance after heat treatment.

The cryogenic nickel steels are usually quenched and tempered in a very narrow temperature range to optimize the microstructure and thereby its properties.

Welding of 5 %, 9 % nickel steels and austenitic CrNi steels

The 5 % nickel steels were developed since they are less expensive than the 9% ones but still have good impact resistance at low temperatures. The tensile strength is lower than that of the 9% nickel steels.
Both 5% and 9% nickel steels have very good weldability and are welded with Shielded Metal Arc Welding (SMAW) with covered electrodes and with Submerged Arc Welding (SAW)

Gas Metal Arc Welding (GMAW) has been used occasionally at least on components in the workshop.

Examples of typical analyses and mechanical properties for 9% nickel steel and nickel-based weld metal can be found in Table 2 A and B.

Table 2 A

Typical properties for cryogenic steels

	ASTM 304L EN 10088-1 1.4305	ASTM A553Gr1 EN 10028-4 X8Ni9	EN10028-4 12Ni19	ASTM A203GrE EN10028-4 12Ni14
C max. %	0.03	0.13	0.12	0.15
Mn max. %	2.0	0.9	0.8	0.8
Cr %	16.5			
Ni %	9.5	9	5	3.5
Rp MPa min	190	585	390	345
Rm MPa min	490	690	530-710	490-640
Charpy V Joule	>60 -196°C	>70 -196°C	> 34 -120°C	> 27 - 100°C

Table 2 B

Typical all weld metal properties of consumables for welding cryogenic steel

	SMAW OK 92.55 Basic AC/DC AWS ENiCrMo-6	SMAW OK 92.45 Basic DC+ AWS ENiCrMo-3	SAW OK Autrod 19.82/ OK Flux 10.90 AWS ERNiCrMo-3
C %	<0.08	<0.03	0.01
Mn %	3	0.4	1.5
Cr %	13	21	21
Ni %	70	64	60
Mo %	6.5	9.5	9
W %	1.5		
Nb %	1.3	3.3	3.5
Rm MPa	710	780	720
Charpy V Joule	85 J -196°C	50 J -196°C	90 J -196°C
Lat. Exp mm	1.0-1.5	0.9	1.0-1.5

Austenitic or nickel-based consumables are used to guarantee weld metal ductility and to reduce possibilities for hydrogen induced cracking.

Unless the constructions are heavily restrained there is no need for pre-heating or post heat treatment when welding 5-9% nickel steels. Interpass temperature should be kept below 150°C. The peak hardness in HAZ will reach 250-320 HV10 at normal heat input bet-ween 1-3 KJ/mm. SAW is

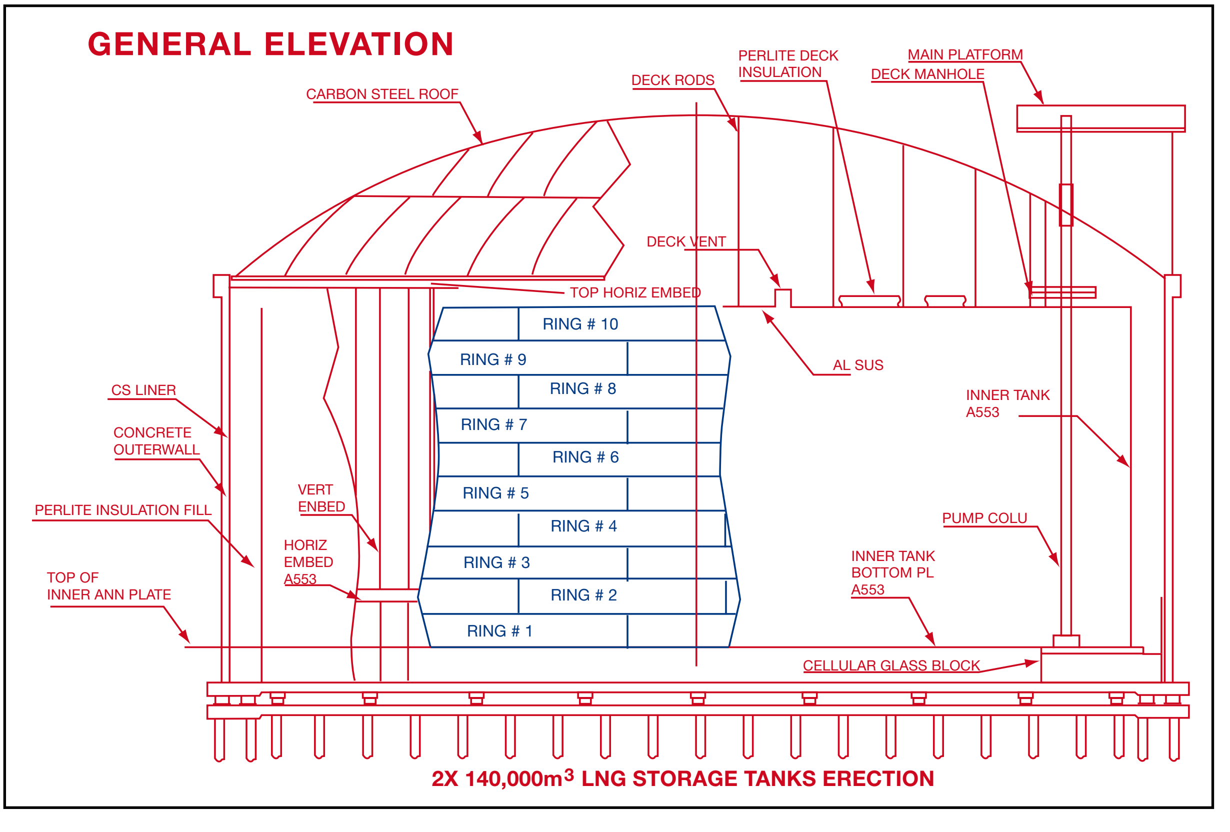

Table 3

Recommended welding consumables for cryogenic applications						
Steel	Temp. °C	SMAW	AWS	MIG/TIG	SAW	AWS
5% Ni	-105°C	OK 69.25 OK 92.45 OK 92.55	(E316LM) ENiCrMo-3 ENiCrMo-6	OK Autrod 16.38 OK Autrod/Tigrod 19.82	OK Autrod 16.38/OK Flux 10.93 OK Autrod 19.82/OK Flux 10.90	(ER316LM) ERNiCrMo-3
9% Ni	-196°C	OK 61.35 Cryo OK 92.55	ENiCrMo-3 ENiCrMo-6	OK Autrod/Tigrod 19.82	OK Autrod 19.82/OK Flux 10.90	ERNiCrMo-3
304L	-196°C	OK 61.35 Cryo	E308L	OK Autrod/Tigrod 308L	OK Autrod 308L/OK Flux 10.93	ER308L
316L	-196°C	OK 63.35	E316L	OK Autrod/Tigrod 316L	OK Autrod 316L/OK Flux 10.93	ER316L

Table 4

Austenitic welding consumables. All weld metal composition and mechanical properties.				
	SMAW OK 61.35 Cryo Basic DC + E 308 L-15	SMAW OK 63.35 Basic DC + E 316 L-15	SMAW OK 69.25 Basic DC + (E 316 LM)	SAW OK Autrod16.38/ OK Flux 10.93 (ER316LM)
C %	< 0.03	< 0.03	< 0.04	<0.03
Mn %	1.7	1.7	6.5	6.5
Cr %	19.5	18.5	19	19
Ni %	10.5	12	16	15
Mo %		2.8	3	3
W %				
Others			N=0.15	N=0.15
Rp MPa	450	430	450	420
Rm MPa	590	560	650	615
Charpy V J	>35	>35	50	65
-196°C				
FN WRC	2-4	3-8	0	0
Lat. Exp.	>0.38	>0.38	>0.38	>0.38

Table 5

Test results from WPQR LNG Tank in 9% nickel steel					
Filler metal	Plate Thickness mm	Heat Input KJ/mm	Position -196°C	Rm MPa WM	Charpy V J
OK 92.55	23.8	1.3-2.0	3G	718 BM	97w
OK 92.55	16.3	0.6-1.6	2G	727 BM	102 102
OK Autrod 19.82/ OK Flux 10.90	25	0.9-1.6	2G	742 WM	100
OK Autrod 19.83/ OK Flux 10.90	15	0.8-1.6	2G	746 WM	81

Transverse tensile test performed. BM-Fracture in plate.
WM-Fracture in weld metal.

a high productivity welding method and is used for all the circumferential welds. The welding equipment hangs in a platform from the plates top rim.

SMAW is used manually for all the vertical welding of the shell plates together. The requirement on the toughness of the welded joints are extremely high to prevent initiation of a brittle fracture. The consumables in Table 3 have been used in welding of over twenty LNG storage tanks during a 10 year period including those being built recently in South Korea, Trinidad and Puerto Rico. The weld metal provides a combination of high strength and excellent ductility. Extensive investigations of weld metal properties have confirmed their high toughness at -196°C.

All weld metal composition and properties for austenitic weld metals are given in Table 4.

Stainless steels

Stainless steels for cryogenic applications down to liquid helium temperatures are well established and play an important role in LNG ships and in piping systems and associated equipment.

The standard grade of wrought stainless steel for general cryogenic applications is type 304L, but various additional grades have been specified, including 304LN and 316LN. An important feature of the austenitic stainless steels is their very good weldability and corrosion resistance.

Welding consumables and weldability

The recommended welding consumables for LNG applications are to be found in Table 3.

For cryogenic temperature applications only nickel-based and austenitic weld metals are to be used in order to comply with the ductility and strength requirements. These weld metals are covered by AWS. 9% nickel steel is not susceptible to under-bead cracking or to excessive hardening in the HAZ.

The portion of austenite in the steel may absorb hydrogen. It can be welded at a thickness of at least 60 mm without pre-heating and no post weld treatment is required by the ASME pressure vessel code up to this thickness. The thermal expansion coefficient of nickel-based weld metals closely matches the 9% nickel steel itself. Some real test results from WPQR for an LNG Tank in 9% nickel steel are given in Table 5.

The magnetic properties of 9% nickel steels make that arc blow might be encountered during welding.

AC welding will reduce the magnetic forces acting on the arc and is therefore the recommended current type to use. OK 92.55 has a coating designed for use on AC.

OK 92.45 is used when emphasize is put on maximum tensile strength and when lower impact strength is acceptable.

If the magnetic field in the joint is below 2 mT (20 gauss) problems with arc blow is normally not encountered. Within the range 2-4 mT (20-40 gauss) arc instability should be expected.

Mechanized welding

When it comes to the assembly of large storage tanks sub-arc welding is generally used for the circumferential welds and SMAW for the vertical welds. Nickel-based wires are used in combination with basic flux as listed in Table 3.

In order to obtain high impact resistance in the weld metal and to facilitate these welds, the use of small diameter 1.6 mm wire is recommended.

Special sub-arc machines, including a backing rubber belt to support the welding flux, have been developed.

Stainless steels

When welding austenitic stainless steels no weldability problems are generally encountered. The low carbon steels and weld metals are not sensitive to intergranular corrosion and do not undergo any complete phase transformations during welding.

However, in order to provide satisfactory resistance to hot-cracking a minimum level of delta ferrite is required. Higher levels of ferrite reduce the low temperature impact properties and this calls for an optimized weld metal composition.

The sub-arc flux and the covered electrode coatings are basic in order to obtain a weld metal with a low level of micro-slag and subsequently high ductility.

Procedures and applications

Large storage tanks for LNG are designed to eliminate any possible risk of failure since the consequences could be catastrophic.

Tank sizes can vary between 50,000 and 160,000 cubic meter volume, i.e. from 50-80 m diameter and 40 m height and more. They are built as double walled tanks; in other words the 9% nickel tank is surrounded by a leakproof steel shell capable of absorbing the liquid release and an outer heavy concrete containment, bottom and roof protect the construction from damage from earthquakes. The inner roof can be designed as a free-floating aluminium roof which will give way if the gas expands through failure.

The only pressure on the vessel is the hydrostatic pressure of the liquid.

Reference list
OK 92.55 and OK Flux 10.90 /OK Autrod 19.82

For welding of 9 % nickel steel LNG storage tanks.

Tank location		Year	Customer	Tank size, m^3
Cartagena	Spain	2000	Whessoe	160,000
Bilbao	Spain	2000	Technigaz	135,000
Tongyoung	Korea	2001	Daewoo	140,000
Huelva	Spain	2002	Technigaz	160,000
Hazira	India	2002	Technigaz	160,000
Damiette	Egypt	2002	Technigaz	150,000
Damiette	Egypt	2003	Technigaz	150,000
Cartagena	Spain	2003	Technigaz	160,000
Huelva 4	Spain	2004	Technigaz	135,000
Sagunto	Spain	2004	Monesa	150,000
Guangdong	China	2004	Technigaz	160,000
Sagunto	Spain	2004	Monesa	150,000
Adriatic	Italy	2005	Hyundai Heavy Industry	250,000
Freeport	US	2005	Technip-Zanchry-Saipem	154,000 x 2
Fos-Cavaou	France	2005	Sofregaz-Saipem- Technigaz	110,000 x 3
Zeebrugge	Belgium	2005	Technigaz-Fontech-MBG,	140,000
Darwin	Australia	2005	TKK	188,000
Costa Azul	Mexico	2005	Mitsubishi	160,000

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