Application Report

Explosion protection on the high seas

Transporting explosive substances on ships

by Thorsten Arnhold

Figure 1: LNG tanker according to the Kvaerner-Moos S sphere-system

The rapid development of the enormous Asian economic countries of India and China as well as the Asian ›Tiger‹ states, and the constant cyclical development in western world countries and the break up of many East European countries has caused an extreme growth in energy requirements. This development will continue in the decades to come. If the current daily global energy requirement is at 30 million tons of oil per day, this number will probably rise to 50 million tons by the year 2030.

Currently nearly 90 % of the energy requirement worldwide is covered using fossil fuels. Crude oil and natural gas nearly constitute 60 % of that. According to most expert opinions, fossil fuels will continue to make up a large portion of the worldwide energy consumption through the year 2030, since by implementing the most economical measures their exploitation can be managed until then.

Apart from nuclear energy, hydro energy and other energy forms are currently only used at low levels for generating energy, and thus it is easy to see that nearly all the currently used energy sources involve explosive substances. When you take a closer look into the future, you will see that hydrogen also constitutes a highly explosive medium for energy transport.

By looking at the distribution of the currently known oil and gas reserves in the world, as shown in Figures 2, 3 and 4, you will notice an interesting discrepancy.

The countries of Europe, America and Asia, which are responsible for 80 % of the gross social product worldwide and thus also have the largest energy requirements, lie more or less outside of the strategic ellipse that comprises the deposits containing approximately 70 % of the world's oil reserves, and also 65 % of the world's gas reserves. When considering hydrogen as the future source of energy, there still remains one, perhaps less conspicuous, dilemma: hydrogen is only available in a chemically bonded form. Hydrogen is bound in molecules such as hydrocarbons and naturally, in larger quantities, as the prime element of water. Releasing hydrogen by electrolysis in turn requires large quantities of energy. According to today's standpoint, such ample quantities of energy can only be found in solar energy near the equator. And, in order to secure a hydrogen-based energy economy, the transport problem must be solved!

Essentially, there are two methods for transporting crude oil and natural gas over longer distances: conveying them through pipelines or transporting them on ships. Figure 5 illustrates the superiority of using pipelines for transporting natural gas in liquefied form on LNG ships (LNG = liquefied natural gas) from a distance of 2,200 miles (= 3,540 km). There are similar surveys for transporting crude oil.

In 2004, 1,800 million tons of crude oil and 465 million tons of oil products were transported by ship worldwide.

The world's leading shipbuilding nations are South Korea which produces 32.8 % of the ships, Japan with 31.4 % and China with 12.5 %. With a large gap distance in between, Germany is ranked fourth with a share of 3.4 %.

In 2003, crude oil tankers were produced with a total transport capacity of 4.8 million gross register tons (GRT). As a result of numerous tanker disasters along with their associated natural disasters, for example, the Exxon Valdez incident in 1989, a ban, which takes effect in 2010, was imposed on single-hulled tankers within the EU. As of 2015, this ban will extend to the entire international maritime traffic. This will in turn create another increase in demand for doubled-hulled tankers for transporting crude oil.

Chemical tankers, which also include the LNG tankers, were produced with a total transport capacity of 3.8 GRT. This number rose to 4.7 GRT in 2004.

Safety characteristics of LNG

Liquefied natural gas (LNG) is obtained from natural gas with the typical components of methane (over 90 %), ethane, propane and heavy hydrocarbons as well as a small quantity of other substances. During the liquefaction process, the gas is cooled down to more than –162 °C (evaporation temperature). In cooling down the gas, it condenses and the volume is reduced by one-sixth-hundredth. This means that 600 cubic meters of natural gas is reduced to 1 cubic meter of LNG. LNG weighs a little less than half as much as water. Following the liquefaction process, the LNG is filled into the ship tanks. These tanks are made of flat, doubled-walled constructions. There is a relatively low pressure of less than 35 kPa inside the tanks.

The important task is maintaining the storage temperature of at least –162 °C during the entire transport time. In addition

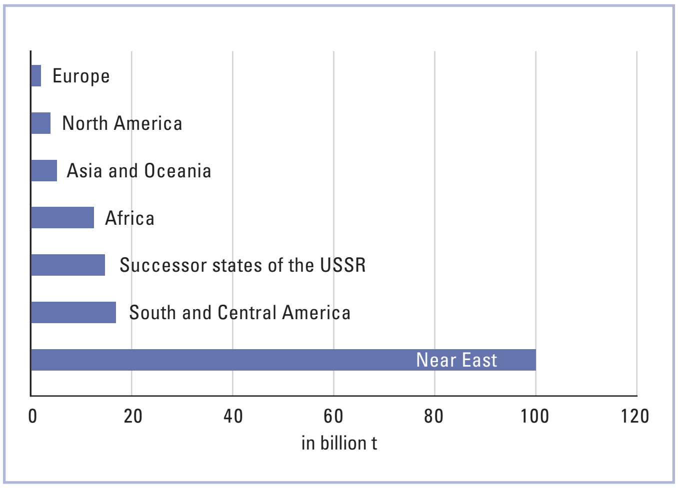

Figure 2: Distribution of the world's crude oil reserves in the crude oil production countries

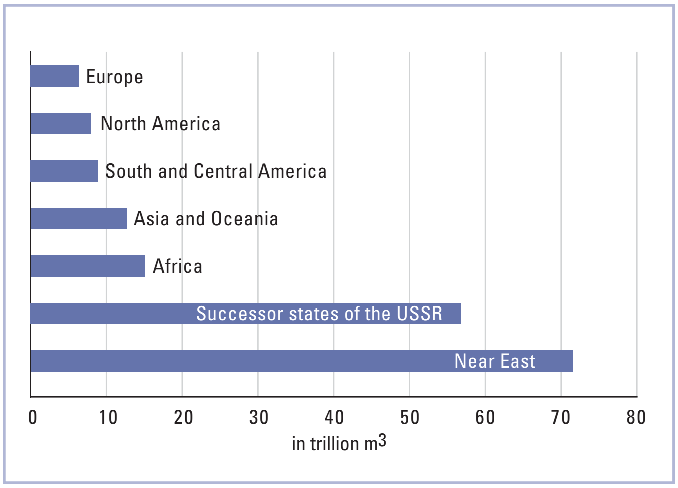

Figure 3: Distribution of the world's natural gas reserves in the natural gas production countries

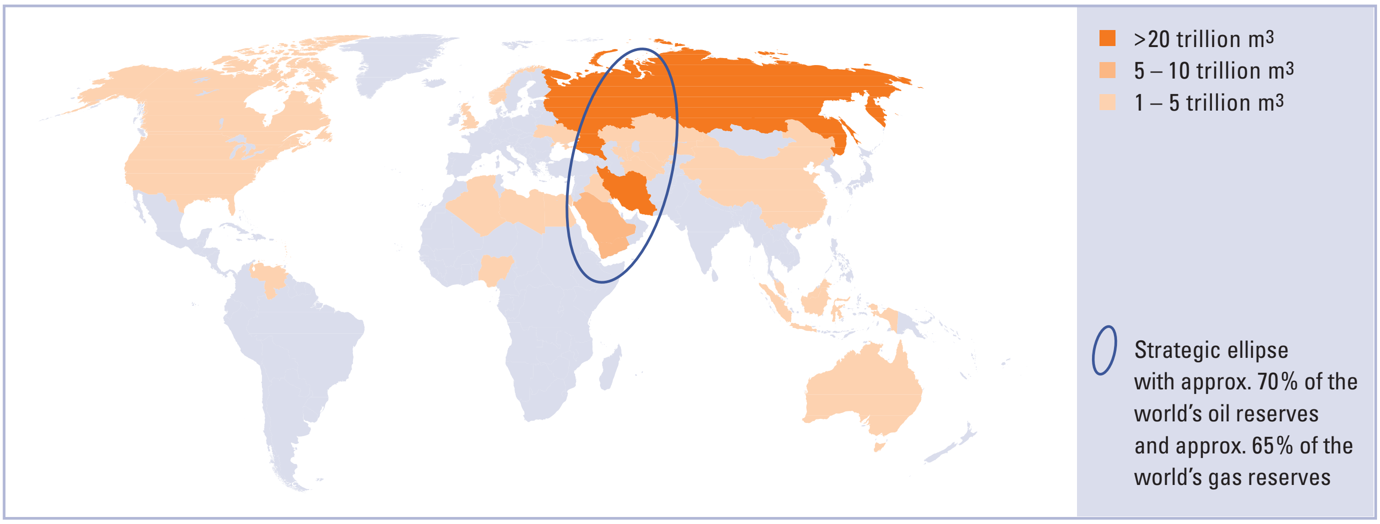

Figure 4: Strategic ellipse of the oil and gas reserves

to the extremely effective tank isolation, the ›auto cooling‹ principle is also used to achieve this. This principle entails maintaining the LNG at the evaporating temperature during transport.

Similar to steam, the evaporating temperature for LNG is also constant, even if the heat volume conveyed from the outside is continually increased. The temperature is held constant by the corresponding quantity of vapour generation. As long as the pressure in the tank remains constant, the temperature does not rise above the evaporating point. The LNG tanker's constant release of vapour (gas) through funnels is also an important aspect.

If the LNG absorbs heat from the environment, it evaporates very quickly and the resulting gas-air mixture lies within the explosion limits of 5 – 15 percent by volume. The relevant characteristics regarding fire and explosion protection can be compared with the other hydrocarbons (see Table 1). The only considerable difference is that LNG has a significantly lower molecular weight than air, and if its temperature is increased to above –108 °C, it has a lower density than air and thus spreads very quickly once released.

However, the density of LNG at evaporation temperature –162 °C is 1.5 times higher than the density of air at 25 °C. If in practice LNG is released in the course of ›auto cooling‹, first the generated vapour will fall down to ground, and than as it warms up it very quickly will volatilise. The range between the explosion limits is surpassed relatively quickly. If there are any ignition sources during this brief time, the gas-air mixture can ignite. If methane ignites in an open area, it normally cannot produce dangerous levels of excessive pressure. However, excessive pressure can build up if the LNG is released in a closed or partitive rooms, from which the gas cannot volatilise quickly enough. Even complex system components with machines, pipelines, protective roofs and similar objects can thus become hazardous areas.

If there are large quantities of heavy hydrocarbons within the LNG, the required ignition energy and the dispersion velocity is reduced. This increases the risk of a dangerous explosion.

Regulations for explosion protection on sea going vessels

There are no superordinate regulations for handling hazardous areas stipulated in shipbuilding. The scope of the ATEX Directives 94/9/EC and 1999/92/EC does not include sea going vessels.

Up until now at IEC level the standard IIEC 52 Part 502 was relevant for sea going vessels. This standard did not provide classification into zones or divisions as it is required for other hazardous areas. Only the safe areas and hazardous areas are distinguished. The requirements for Zone 0 stipulated that only intrinsically safe equipment with the protection level (category) ›ia‹ could be used.

Now, in accordance with a decision made by the Marine Safety Committee (MSC) in December 2004, the new edition of the Standard IEC 60092-502 is valid. This standard provides a zone classification comparable to onshore areas.

On a LNG tanker built in accordance with the new standard for example, the area that is located directly at and up to 2.5 m away from the tank as well as a 10 m perimeter surrounding the funnel outlet openings are classified as Zone 1. The interior of the tanks is still classified as Zone 0.

In addition to the requirements for the electrical explosion protection, the equipment used on a sea going vessel must also fulfil a relevant marine standard and have a related certificate. The leading global organisations for this are:

- Det Norske Veritas (DNV)
- Lloyds Register (LR)
- Germanischer Lloyd (GL)
- Bureau Veritas (BV)
- Korean Register of Shipping (Korea KR)

and the ABS (American Bureau of Shipping) for the USA.

The standards implemented by these certification authorities are diverse and equipment-specific. At this point, only examples for measuring and control equipment standards are mentioned:

- Standard for certification no. 2.4: Environmental test specification for instrumentation and automation equipment (April 2001) (DNV)
- LR Type Approval System No. 1: Performance and environmental test specification for control and electrical products to be used in marine and offshore applications (2002) (LR)
- Rules for classification and construction: Guidelines for the performance of type tests, pt. 1 – test requirements for electrical/ electronic equipment, computers and peripherals (2001) (GL)

The standards for the respective equipment correspond to their essential requirements.

The requirements defined in the test standards depend on the on-board locations. Among other things, this creates differences between the usage on the open deck, in the command bridge, in the engine room and in the common rooms.

The defined tests affect the following parameters: temperature resistance, vibration resistance, moisture resistance, electromagnetic compatibility and the properties of the enclosure.

The test and inspection reports issued by an independently accredited laboratory are generally accepted by all certification authorities. Some of the certificates issued by the aforementioned certification authorities however, are not accepted by the others. The validity period of a certificate is limited and normally only lasts for one or two years!

In summary, it is apparent that the approval method for shipbuilders, their suppliers, the ship user, and the responsible public authorities is by far not as clearly organised as, for example, the scope of the EC-ATEX-Directives. In view of the increased significance of maritime traffic for the global transport of energy and materials mentioned at the beginning, it would be exceedingly advantageous to implement clear noticeable revisions in the near future.

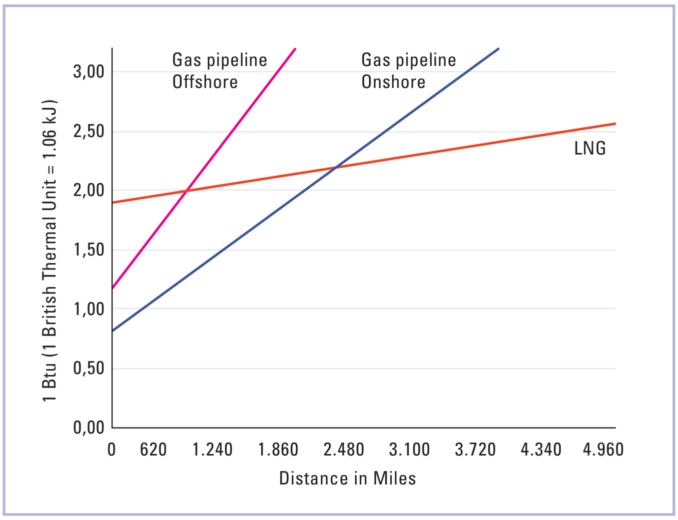

Figure 5: Comparison of the transport costs for natural gas
(Data sources: Institute of Gas Technology)

Substance		Ethylene[1,2]	Petrol[1,3]	LNG/ Methane[1,2]	Propane (LPG)[1,2]
Flash point (°C)		–186	–40 bis –49	< –259	< –155
Explosion limits (volumes %)	UEG	2.7	1.3	5	2.1
	OEG	36	7.1	15	9.5
Auto-ignition temperature (°C)		910	820	1.000	840
Minimum ignition energy (kJ)		7×10^{-8}	unknown	2.6×10^{-7}	2.5×10^{-7}
Flame propagation velocity[4] (m/s)		0.8	0.4	0.4	0.45
Relative density		0.97	<2	0.55	1.55

Table 1: Safety characteristics of hydrocarbons
Data sources: 1. NFPA (National Fire Protection Association 1995); 2. Lees (1980); 3. NFPA (2001); 4. NFPA (2002)