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A Study on Technical Development on LNG Vessel

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***Abstract*—This article through a literature review of LNG vessel from the earliest stage through to the present-day industry, examine the technical developments on LNG fleet, cargo containment systems, main propulsion systems and other new possible technique approach for LNG transportation.**

***Keywords*—LNG transportation, technical development, containment systems, main propulsion systems**

I. INTRODUCTION

Liquefied Natural Gas (LNG) is clean and readily available in quantity and in a number of locations all over the world such as Qatar, Australia, and Russia etc. The booming in the LNG industry that has been ongoing since the turn of the century had moved to new heights in 2006. Nowadays LNG industry has becomes one of the vital sector of the energy industry, it was predicted by some experts that during the next two decades, LNG will be the world's fastest-growing major energy source, supplying one-quarter of the world's energy needs by 2030 [1].

With the increasing demands of LNG, the LNG fleet has significantly increased in the number of vessels required worldwide. The total LNG fleet in service as at the beginning of June 2006 is about 206 vessels of approximately 24.7 m m^3 capacity [2]. By the end of 2009, the fleet will be extended to number over 300 vessels [3] [4], an equivalent to at least a doubling of the existing LNG fleet. Since 2000s, competition, economies of scale have played an important role in the development of the LNG fleet, it made vessel capacity growing rapidly and designers and ship-owners are going to looking for technical innovations on new building. During the design, construction and operation of LNG vessels, there are several technical factors to be considered, primarily impacting cargo containment systems and propulsion systems.

II. HISTORICAL REVIEWS OF TECHNICAL DEVELOPMENT ON LNG FLEET

A. *Developments of LNG ship and motivation on technical innovation in past years*

The world's first LNG vessel, the Methane Pioneer, a converted World War II liberty freighter containing five, 7000 Bbl aluminum prismatic tanks with balsa wood supports and insulation of plywood and urethane, was funded by the British Gas Council and the American design consultants Constock in the 1959 and carried an LNG cargo from Lake Charles, Louisiana to Canvey Island United Kingdom on 25th Jan 1959. This event demonstrated that large quantities of LNG could be transported safely across the ocean. Following the successful performance of the Methane Pioneer, the British Gas Council proceeded with plans to implement a commercial project to import LNG and started commercial LNG transport from Algeria to UK by Methane Princess of 27400m^3 capacities in 1964. Other designers and companies were also retained at this time to advice on various specialized aspects of work, these included Shell Group, Burness, Corlett in London, Norway shipowners-the Lorentzens and some shipyards and ship-owners in Germany, France and Italy [5]. The classic LNG vessels are fitted with membrane or independent cargo tanks, and dual fuel steam turbine propulsion. The standard size was established in a range of 125000 – 130000m^3 and 125000m^3 and 138000 m^3 capacities later became standard; until recently that 153500 m^3 vessel is just due for completion at the end of 2004[6].

With forecasts of a doubling in demand for LNG vessels over the next decade, building LNG vessels of the same type at the same rate is definitely not a good option. As the effects of economic scale and demands for larger tonnage, the next generation of LNG vessels must be bigger, faster, higher operational flexibility and efficiency, consequently even more sophisticated, than the present breeds of LNG vessels are [6]. It has rewarded years of new building marketing efforts by designer of LNG cargo containment system, low and medium speed diesel engine designers. The largest LNG vessels on order today are 265000 m^3 Q-Max designs and costs about US $300mn. [7].

B. *Cargo containment systems*

In the early years, designers toyed with a number of containment systems, but by the middle 1970s and after, the choice of containment system had narrowed to three mainly designs from Moss spherical tank, Gaz Transport and Technigaz (GTT) Membrane tank –GTT Mark III, GTT No96, GTT CS1[6] and a self-supporting prismatic membrane system (IHI-SPB) from IHI, Japan [1]. The Moss Maritime of Norway and G.T.T. of France play a major role in the LNG containment systems market and the IHI of Japan has a small share too [8].

The Moss type containment system, Fig 1, is the design emblematic of the LNG carrier in that the tops of the spheres protrude above the hull making the ships instantly recognizable. Moss Maritime of Norway-Kvaerner, now a unit of Italy's ENI SAIPEM, develops 88000 m^3 Moss spherical containment system in 1971 [9]. The hull and tanks are

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independent; the structural transition joint equatorial ring acts as the gradient to allow use of normal vessel building steel in hull. Largest dome built with Aluminum alloy and self-supporting tanks are arranged inside the hull. Insulation is of Sipro or Kawasaki type and annular space between sphere and insulation is fed with nitrogen. As a result, the liquid cargo acts on the self-supporting tanks and not directly on the insulation material. The spherical shape means that the sloshing forces on the tank wall will be much smaller for the Moss system. Now almost half the LNG vessels in the world are of the spherical independent tank type, Fig 2.

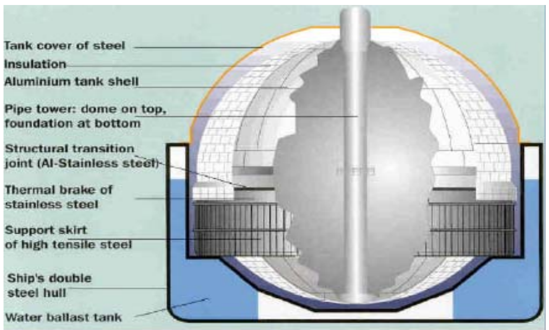

Fig 1: Kvaerner-Moss (Source: Lloyd's Register Fairplay)

Fig 2: Existing Worldwide Fleet Cargo Containment System Market Share (Source: Lloyd's Register Fairplay)

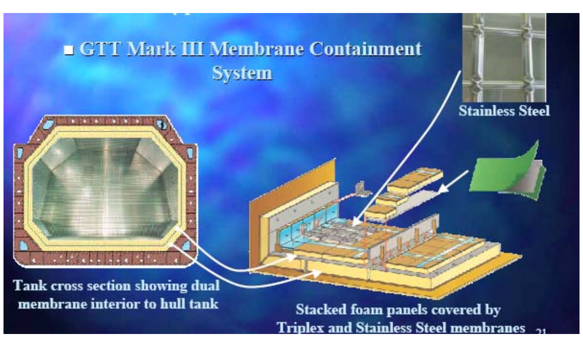

Fig 3: GTT Mark III Membrane Containment System (Source: Lloyd's Register Fairplay)

The GTT Mark III containment system, Fig 3, is not connected to the hull hence no fatigue strength required for the membranes. The tank built with corrugated stainless steel and it uses reinforced polyurethane foam inside plywood boxes as the insulation material; 1.2 mm thick primary membrane and secondary membrane made of glass cloth with Aluminum foil in-between. The corrugation absorbs the thermal expansion and contraction. There is over 120 kilometers of weld inside the tanks to ensure safety.

The GTT No96 containment system has a liner that includes two complete identical and independent metallic membranes, which made of Invar (36% Nickel Iron alloy). The one in contact with the cargo is called "primary membrane"; the second is "secondary membrane". These membranes act as dual barriers protecting the hull from exposure to the low-temperature cargo. The insulation, filled with expanded silicone-treated perlite, is internally strengthened to withstand high-impact pressures and to absorb the energy from the liquid motions and pressure head. The insulation spaces are inserted with nitrogen and equipped with detectors for a permanent monitoring of the said spaces in order to detect eventual leaks. The tanks are independently and mechanically secured to the double hull by means of studs and couplers specially designed for thermal insulation.

The GTT CS1 containment system, a new membrane containment system developed by GTT, combines the best features of the Mark III and No96 membrane systems. It uses reinforced polyurethane foam insulation and two membranes, the first one 0.7 mm thick made of Invar (low thermal contraction coefficient metal and high nickel content), the second made of a composite aluminum-glass fibre called triplex. The system has been rationalized to make assembly easier and is prefabricated allowing quick assembly on board. It offers increased strength, faster fabrication, and a cost reduction of 15 per cent compared to existing systems [10].

IHI prismatic containment system, Fig 4, is unlike the Moss type spherical tank, the prismatic tanks of a membrane LNG vessel are fully integrated into the hull, which serves as the supporting structure. The cargo containment system is fitted inside the tanks, between the inner hull and the liquid cargo.

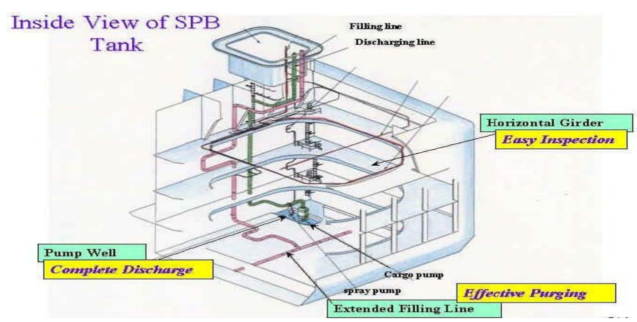

Fig 4: IHI Self Supporting Type B Prismatic Tank (Source: Lloyd's Register Fairplay)

C. *Main propulsion systems*

Steam turbines have dominated LNG vessel propulsion for the last four decades and proved extremely reliable in LNG industry. But steam turbine is low efficiency and hence high fuel consumption. It is probably fair to say that if the development of LNG fleet had continued at the levels of five years ago, very little interest would been shown by the designers and others, especially two big players in Engine manufacture market – MAN B&W, and Wartsils. But with the prospect of an expected demand equivalent to at least a doubling of the existing LNG fleet, the whole issue for new LNG propulsion system was opened up. Now MAN B&W, Wartsils and Rolls Royce have all adopted different technical solution of alternative to the steam turbine, and the concept of gas turbine, dual-fuel diesel-electric engine and slow speed diesel electric propulsion with gas reliquefying plant propulsion all offers significant benefits on the operating costs, saving space and the low engine's emission levels. These kinds of engines have broken the dominance of steam turbine installations in LNG carriers. [6][11].

Steam turbines propulsion: The steam turbine propulsion has dominated LNG industry since the first purpose built gas vessel in 1960s [12]. There are number of factors contributed towards the steam turbine as the main power source, mainly due to the steady supply of 'free' fuel available in the shape of boil off gas from the cargo tanks [6]. The others include high-power output, proven reliability, relatively modest turbine maintenance in cost and no vibrations problem [12]. The one of the drawbacks is low efficient, about 30%, Fig 6 shown the thermal efficiency of the various prime movers, and hence high fuel consumption, which translates directly to high carbon dioxide emissions [13].

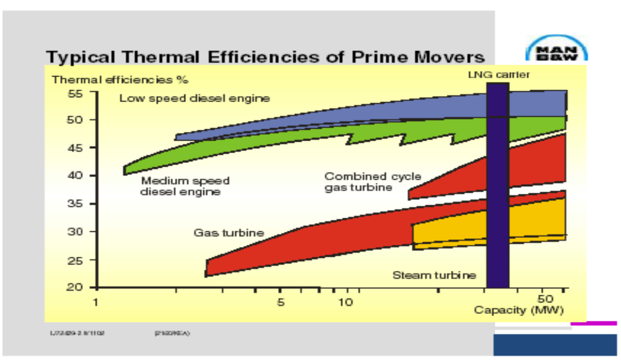

Fig 6: Thermal Efficiencies (Source: MAN B&W Diesel)

Another is declining population of competent seagoing steam engineers. But in coping with new generation of large and fast LNG vessel, it should be required to provide significantly large unite, Fig 7 shown propulsion power requirement. So the use of steam turbine propulsion will be limited.

Dual-fuel gas turbine-electric propulsion system: LNG vessels offer an excellent opportunity to exploit the power density of aero-derived gas turbines – particularly in conjunction with electric delivery cost and raise the revenue potential, acknowledging the significant improvements in both fuel efficiency and reliability of aero-derived designs. An alternative to the steam turbine was proposal by Rolls Royce for gas turbine powered COGES (combined gas electric system) in 2002, such as MT30 dual-fuel gas turbine-electric propulsion system meets the requirements of large LNG vessels, particularly those of 200000m^3-plus capacity. Primary fuel for the gas turbines will be cargo boil-off gas, marine diesel oil (MDO) would be carried as a secondary emergency fuel source along with fuel for voyages to and from dry dock when gas is not available[14]. Gas turbines are relative newcomers to the world of commercial maritime propulsion although they have some background in naval service. Dual-fuel gas turbine-electric propulsion systems have excellent emissions characteristics and have cited by low weight and volume, reduced installation cost, freely located plant, low noise and vibration. That delivers increasing cargo carrying capacity, operational flexibility and life cost savings. But the scarcity of in service commercial engines has added to the perception that the gas turbine is a highly sophisticated device with too few engineers available on board [6] [13].

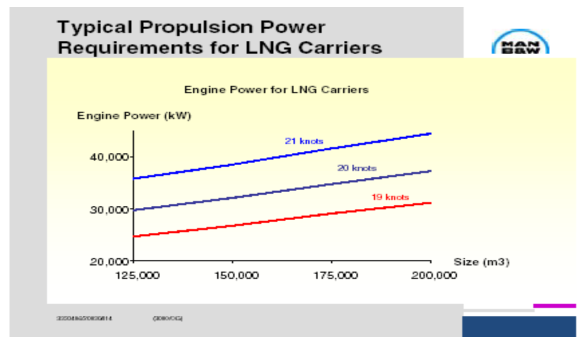

Fig 7: Propulsion Power Requirement (Source: MAN B&W Diesel)

Dual-fuel diesel-electric propulsion system: Other alternatives to steam turbine propulsion are dual fuel diesel-electric engines. Wärtsilä favors using dual fuel engines that operate partly on oil fuels much as steam driven vessels do. However, burning the fuel in a diesel engine rather than a steam turbine, the efficiency of dual fuel engines is almost half to between 40% and 45%, Fig.6. But dual fuel engines do not run well on very heavy oil so MDO is the second choice of fuel after boil off gas [13]. Dual-fuel medium speed diesel – electric propulsion has staked a strong claim in LNG vessel market through the successful R&D and marketing efforts of engine designer/builder Wärtsilä. Its 50DF stand a minimum 34 LNG vessels, FPSO vessel and offshore supply vessel. [15] [11] [1].

MAN B&W have also opted for a different approach-using a dual-fuel engine as one alternative-and reliquifaction plant to increase the quantity and value of cargo actually delivered [13]. The dual-fuel ME-GI (gas injection) engines are designed to burn any radio of fuel oil and gas desired, depending on the amount of natural or forced boil-off gas available from the cargo tanks. The electronically controlled design, applying fuel oil pressure boosters, is particularly suitable for high-pressure dual-fuel gas operation. Specifying a GI engine avoids the need for a shipboard reliquefaction plant but installing both allows the operator to exploit fluctuating LNG/fuel oil price differences over the extensive lifetime of LNG carriers [16][17].

Diesel-electric propulsion system: A number of economic, environmental and technical factors thus favor selection of low speed engine-base solutions [18]. And built-in redundancy in the electrical propulsion system also ensures the availability and reliability required by shipowner and charterer [19].

The Wartsils method uses the diesel engine in diesel-electric set-up that it considers as the most flexible of several alternatives. It employed the Sulzer Common Rail System-RT-flex low speed engine to get smokeless operation and reduce fuel consumptions. This also involves a fair amount of extra power management equipment to be installed [6].

MAN B&W also uses electronically-controlled ME low speed two-stroke engines with the cargo boil-off gas returned to the containment tanks via onboard reliquefaction systems. These new generations are particularly attractive for LNG vessel propulsion. Because ME low speed diesel engines exploit hydraulic-mechanical systems supported by electronic hardware and software to deliver fuel and have a considerably higher thermal efficiency than steam turbine plant, the associated lower fuel consumption, lower NOx and smokeless operation, and reduced operating costs enabled them to oust steam propulsion from every other commercial shipping sector.

2.4 New possible technique approach for LNG transportation

In recent years, a group of experts has proposed a new possible technique –called pressurised LNG (PNG) or Compressed Natural Gas (CNG). PNG could be especially useful for remote or stranded gas. Cargoes are carried at a higher temperature and pressure than conventional LNG. Since less cooling is required to liquefy the gas, refrigeration and processing systems are reduced; making PNG facilities less expensive than those for LNG and this transport system requires very limited investment in infrastructure dedicated to a specific field. The elevated pressure of PNG requires a new vessel and a pressurised cargo containment system consisting of multiple pressure vessels contained in an insulated 'coldbox' [20][21].

Moreover, among the few designer/manufacturers of large steam turbines and boilers still active in the marine market. Such as Kawasaki Heavy Industries (KHI), one major manufacture of steam turbines, had installed its UC400 and UC450 turbine for 125000 m^3 and 128000 m^3 since 1980s, and now promote that UA series marine steam turbines with the special double- reduction gearing for LNG vessel [22].

III. Conclusions

LNG was not particularly valued as a fuel compared to oil. The environmental benefits of LNG have now been recognized and its value increased proportionately along with skyrocketing demand. That fact, together with increasing efficiency of diesel engine has led to a complete rethink on LNG vessel propulsion and another factor in the equation is the improvements of cargo containment systems. The improvements have achieved that whereas the natural rate of boil was from initially 0.25% of cargo volume to a maximum of 0.15% or even as 0.10%, and natural boil off gas is only about 20% of the fuel available to it 'free' as an early LNG vessel [13].

The dynamic LNG market has dramatic grown in capital expenditure and fleet on global LNG business, it certain that more changes will occur in the design of LNG vessels and tanks in the recent than has happened over the previous 40 years, optimums design of the cargo containment and propulsion technology will ensure higher service speed and environment friendly, reduced main engine output and savings in fuel costs [23]. Furthermore, LNG vessels will fully meet future market needs for higher economic efficiency, safety and reliability.

References

[1] Cusdin, D.R. (1997). President's Day Address - The development of liquefied natural gas carriers - a marine engineering success. Retrieved July 26, 2005 from the World Wide Wed: http://www.imarest.org/publications/content/default.asp

[2] LNG Trade and Transport 2006 - Market Research Reports (R). London: Clarkson Research Services Limited, 2006.

[3] Going off the boil? [J]. Lloyd's Shipping Economist, 2005, July, 17-21.

[4] Gas boom opens door to alternative propulsion systems [J]. Marine Propulsion, 2005, April/May, 19

[5] Ffook, R. Natural gas by sea (2nd Edition) [M]. London, 1993: Witherby & Co.Ltd.

[6] Gas ship evolutions accelerates-New generation bring big changes [J]. Fairplay Solution, 2005, May.12-13.

[7] Samsung records LNG order. (2006). Retrieved January 10, 2007 from the World Wide Wed: http://www.marinelink.com/Story/Samsung-Records-LNG-Order-204995.html.

[8] Rao H.M. (2005). COOL CUSTOMER. Retrieved July 26, 2005 from the World Wide Wed: http://www.etshipping.com/dec2001/lng1.html

[9] Nick B. LNG boom continues. (2005). Retrieved July 26, 2005 from the World Wide Wed: http://www.marinelog.com/DOCS/PRINTMMV/MMVFebLNG2.html

[10] BV approves new LNG containment concept (2002). Retrieved January 10, 2007 from the World Wide Wed:http://www.marinelog.com/DOCS/NEWSMMII/MMIIJan11.html.

[11] New strides in ship size and technology [J]. Naval Architect: Gas Ship: Trend and technology, 2006, Oct, 1-4.

[12] LNG carriers running out of steam [J]. The Motor Ship, 2005, January/February, 14-16.

[13] Steam runs out for gas carriers [J]. Fairplay Solution, 2005, May, 13-16.

[14] Gas turbines keen to take their turn [J]. Marine Propulsion, 2005, April/May, 31-34.

[15] Dual-fuel electric drives surge into market [J]. Marine Propulsion, 2005, April/May, 22-23.

[16] GI low speed engines offer dual-fuel capability [J]. Marine Propulsion, 2005, April/May, 25-26.

[17] Anticipating the first order for a G-I engine [J]. Naval Architect: Gas Ship: Trend and technology, 2006,30-32.

[18] ME engines + reliquefaction plant make breakthroughs [J]. Marine Propulsion,2005, April/May,28-29.

[19] The future is LNG, the future is electric [J]. Lloyd's Ship Manager, 2005, June, 39.

[20] Pressurised LNG: an alternative way to transport gas [J]. The Naval Architect, 2005, June, 20.

[21] CNG ship plans are taking shape [J]. Fairplay Solutions, 2005, May, 20-21.

[22] KHI geared up for higher steam turbine output [J]. Marine Propulsion, 2005, April/May, 21.

[23] Dyck,P.V.LNG carriers go larger [J]. The Motor Ship, 2005, March, 47-49.