The tanks can be either of the Moss spherical type, or the prismatic, membrane type which conforms to the shape of the ship's hull. Or again, in a development, they could be of a new pyramid type (see illustration) from Conoco Phillips, which has just received Approval in Principle from ABS.

The Moss type is the design emblematic of the LNG ship in that the tops of the spheres protrude above the hull making the ships instantly recognizable. Pioneered by Norway's Moss Rosenberg in the 1970's, the design is now owned by Moss Maritime a.s., Lysaker, Norway, a unit of Italy's ENI SAIPEM.

There are three types of membrane containment systems, the Gaz Transport and Technigaz systems and a self-supporting prismatic membrane design from IHI, Japan. Gaz Transport and Technigaz are now one company, whose latest containment system, CS1, incorporates features from the existing Gaztransport No 96 and Technigaz Mk III systems. CS1 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 fiber called triplex. The system has been rationalized to make assembly easier and is prefabricated allowing quick assembly on board.

2.3.2.2 The Market Where Time Stood Still :-

To marine industry veterans, today's LNG boom is deja vu all over again. There was supposed to be this sort of LNG boom some 30 years ago. But in 1979, things soured when pricing disputes between U.S. buyers and Sonatrach of Algeria eventually led to the termination of contracts, the laying up of six LNG ships (three of which were later scrapped) and the mothballing of two out of four LNG terminals.

There was still growing LNG demand in other areas, but international LNG ship construction slowed until it got a further impetus in the 1990's. What's different this time around is that the newbuilding market is dominated by South Korea, with China already entering the market. And the technology is advancing. For the first time, some ships are being specified with diesel, rather than steam turbine, propulsion, there are improvements in insulation of cargo containment systems, established containment systems are being twitched and new containment systems are being offered.

2.3.2.3 Taller Spheres:-

When is a sphere not a sphere? When it's a vertically stretched sphere. Kawasaki Kisen Kaisha, Ltd. ("K" Line), in partnership with Osaka Gas International Transport Inc.) and Nippon Yusen Kaisha (NYK), has concluded a contract for a new 153,000 m3 LNG carrier with Kawasaki Shipbuilding Corporation.

The ship will be mainly used to carry LNG for Osaka Gas from the Qalhat LNG Project in Oman from 2009. It will have four spherical LNG tanks three of which are being given a 2 m vertical stretch. This advantage enables tank capacity to be increased by about 5.5 percent but within almost the same ship dimensions and with the same fuel oil consumption.

2.3.2.4 The Shape Of Things To Come:-

A new entrant in the containment system market is Ocean LNG, Inc., Houston. It has developed a "more construction friendly LNG carrier" that can be built in "non-traditional LNG shipyards."

ABS has issued Approval In Principle (AIP) to Ocean LNG's tank containment system and carrier design.

The tank design is cylindrical with spherical dished ends. The 180,000 m3 version of Ocean LNG's ship design features five of these large 36 m diameter and 40 m high cylinder tanks each holding a volume of 36,000 m3 of LNG.

Compared to the spherical containment system, the Ocean system is expected to increase cargo capacity within the same main hull dimensions by an estimated 25 percent, while still providing full access for inspections of both the insulation and tank structure.

A key aspect of transporting LNG is the ability of the containment system to withstand dynamic sloshing loads of the LNG cargo when a tank is partially filled.

Membrane systems are particularly sensitive to sloshing loads.

The Ocean LNG tank design is fashioned according to IMO Type B independent tank design and based on the "leak before failure" principle.

The tanks are designed to minimize filling restrictions due to sloshing effects. A detailed sloshing analysis of the tank and pump tower designs was recently completed by ABS.

2.3.2.5 To Boil Off ... Or Not?

Since LNG tankers rely on insulation rather than refrigeration to keep their cargo refrigerated, a small percentage will "boil off." Traditionally, LNG tankers have utilized this boil off as fuel in steam turbine based propulsion plant.

That's changing. One way or another, the diesel is coming on board. One approach is to reliquefy the boil off gas, so that it remains as valuable cargo. Shipboard reliquefaction technology has matured considerably in recent years, making use of experience from land-based and LPG carrier installations. Among others Hamworthy KSE's patented Moss RS closed nitrogen cycle system for reliquefying boil-off gas offers a solution for pumping LNG back to the cargo tanks and hence the opportunity to deliver more cargo to the buyers.

MAN B&W Diesel has produced a paper that thoroughly examines operating costs and additional income from the transport and sale of LNG. The paper, "LNG Carrier Propulsion by ME Engines and Reliquefaction," analyzes fuel oil, lube oil and maintenance costs for both propulsion and electrical power generation under various operating conditions on a comparison basis for a diesel-based solution against a steam plant. The evaluation shows that substantial economic benefits can be gained from diesel propulsion in conjunction with gas reliquefaction over the steam turbine-powered option, simply because of the big difference in thermal efficiencies while the first cost of the various propulsion systems is virtually the same.

Overseas Shipholding Group (OSG) has ordered four 216,000 m3 LNG ships from Hyundai and Samsung. Each vessel utilizes two MAN B&W ME engines for main propulsion. Each yard will deliver two vessels for the Rasgas II project for shipping Qatari gas to the U.K.

Main propulsion will be by two 6S70ME-C engines in each vessel. The engines for the Hyundai vessels will be built by Hyundai Heavy Industries, and for the Samsung vessels by HSD. The engines will be heavy fuel burning, and the boil off gas will be returned to the tanks via onboard reliquefaction plants.

Apart from the reliquefaction solution, another means of utilizing the diesel is by using the boil off gas as fuel. MAN B&W's ME-GI engine is a gas injection, dual fuel low speed diesel engine, which can burn any ratio of fuel and gas desired.

Wärtsilä, meanwhile, has had considerable success with its DF dual-fuel engines. The first dual fuel electric LNG carrier, the 75,000 m3 Gaz de France Energy, was recently completed by Chantiers de l'Atlantique of France and is in service with Gaz de France.

Furthermore, Wärtsilä has now made a breakthrough into the Korean market with an order from Hyundai Heavy Industries Co. Ltd. to supply four sets of Wartsila 50DF dual-fuel engines to power a series of 155,000 m3 dual-fuel-electric LNG carriers, with an option on four more sets.

The ships were ordered by BP Shipping of the U.K. and each ship will be equipped with two 12-cylinder and two nine-cylinder Wärtsilä 50DF dual-fuel engines with an aggregate power of 39.9 MW, as prime movers in a dual-fuel/electric machinery arrangement. ML

CHAPTER 3

TRADITIONAL STEAM PROPULSION:-

After having been predominantly flared off or re-injected for decades, natural gas is playing an increasingly important role in global energy consumption today. Clean combustion properties and abundant reserves are the main benefactors for this evolution from unsolicited by-product of oil production to preferred energy source. With natural gas reserves often located far away from energy consumers and pipelines expensive or impractical to build, seaborne transportation of natural gas is on the rise as well. The most economic and common way to transport natural gas by sea is in liquefied form. Liquefied Natural Gas (LNG) is today transported by a fleet of some two-hundred dedicated LNG carriers. With seaborne transportation of LNG expected to double within this decade, a vast expansion of the LNG carrier fleet is imminent. At the same time, increasing cargo volumes offer the possibility to apply economies of scale, and ships are about to significantly grow in size. These circumstances create the need to verify the technical solutions that have been applied in LNG carriers so far.

The LNG trade has traditionally been based on long-term shipping contracts and dedicated fleets of ships sailing on fixed routes and schedules between the world's rather limited number of LNG terminals. The LNG supply chain does not have much buffer capacity and it is very important that the cargo is delivered on time. For the past forty years, steam turbine installations have dominated onboard LNG carriers. The ease with which steam turbine installations can burn boil-off gas and their apparent reliability have kept them in the controlling position that has been taken over by diesel engine installations a long time ago in all other segments of the shipping industry. Steam turbine installations are however not very efficient. This has a negative impact on the operating economy and exhaust gas emissions of the ship. Exactly these issues play an increasingly important role in LNG shipping these days. Encouraged by the latest developments in its gas engine technology, Engine builders started looking for a more economic and environmentally friendly way to power LNG carriers. Machinery alternatives with two- and four-stroke diesel, high pressure gas-diesel and low-pressure dual-fuel engines, in mechanical and electric propulsion arrangements, with and without boil-off reliquefaction, were studied. Dual-fuel-electric installations were found to be the most attractive alternative to steam turbine installations.

3.1 Basic Characteristics:-

Steam turbine propulsion dominates today's global LNG carrier fleet. The original reasons for this have been the availability of high power output and the possibility of using low-grade fuels as well as cargo boil-off gas. Maintenance of the turbines is relatively low-cost and infrequent and the systems are considered proven and reliable. Boil-off gas is a key issue. It must be disposed of in some way and for many years of LNG carrier construction the steam boiler was the simplest solution. This feature has long been an obstacle to other propulsion systems entering the LNG carrier market and made steam turbine the standard choice for LNG carriers. The available quantity of boil-off gas depends on the ship design and its operating conditions. Today, a natural boil-off rate of 0.15 % per day is typically considered as a design point. However, this is a nominal value and actual values as low as 0.10 % have been reported. During ballast voyages the amount of available boil-off gas can be 10-50 % of the amount prevailing during laden voyages depending on how many tanks will contain a small quantity of LNG for tank cooling. Whatever propulsion plant is chosen, there has to be some way of handling this boil-off gas either by utilising it as fuel, or reliquefying it. The composition of the boil-off and thus its energy value also varies during the voyage and is an important consideration for alternative power plants. As nitrogen has a lower boiling point than methane, the nitrogen content of the boil-off gas is high at the beginning of the laden voyage and decreases during the voyage. In ballast, boil-off gas is mainly generated from the tank cooling spray; the heavier hydrocarbons evaporate, thereby giving the boil-off a higher energy content. The same result applies to forced boil-off gas. Safety is of utmost importance in gas shipping, and LNG carriers have an excellent safety record. The reliability of steam turbine propulsion has helped to achieve this together with strict terminal regulations and procedures, and robust ship designs. For example, propulsion power has to be available at all times whilst in port

3.2. Market Requirments:-

An attractive alternative should be outperforming the steam turbine installation with respect to its apparent disadvantages, while at the same time at least matching it with respect to its advantages. It is therefore important to study these advantages and disadvantages. The main reason to remain faithful to the steam turbine installation in LNG carriers is the ease with which they can burn boil-off gas. Boil-off gas is an unavoidable by-product of the seaborne LNG transportation concept. A small amount of cargo, approximately 0.13% per day in laden condition, is left to evaporate in order to control temperature and pressure in the ship's cargo tanks. Both quantity and quality of the boil-off gas are subject to variation.

3.2.1 Operating Economy

Although steam turbine installations can utilize boil-off gas very easily, they do not use it very efficiently. **Losses in the boilers, steam turbine, high-speed reduction gear and shafting bring the efficiency of the propulsion machinery to a level below 29% at full load.** The efficiency of the electric power generation machinery is below 25% at full load. Part-load efficiencies of both the propulsion and electric power generation machinery are even lower. Such low machinery efficiencies lead to a substantial amount of HFO being required for complementing the available boil-off gas. In laden conditions, some 50% of the ship's energy requirement is covered with HFO. In ballast condition, this share grows to 80%. Also for LNG carriers, like for any other kind of ship, fuel costs are one of the most important components of the ship's operating costs.

3.2.2 Environmental-Friendliness:-

The low efficiency and the need to use large amounts of HFO have a negative impact on the ship's CO2 and Sox emissions. CO2 emissions are already the focus of attention these days, and can be expected to get even more attention in the near future.

3.2.3 Safety:-

Gas tankers attract lots of attention from safety regulators worldwide. The safety of crew, ship and environment is of utmost importance. Onboard LNG carriers, steam turbine installations have a very decent safety record. No major calamities have been reported.

3.2.4 Reliability:-

Except for some well-documented problems with high speed reduction gears, steam turbine installations have proven reliable in operation.

3.2.5 Redundancy:-

In LNG shipping, it is common practice to tie up small fleets of ships on long-term charters on fixed routes with fixed sailing schedules. As the buffer capacity of such a supply chain is limited and punctual cargo operations are important, these kinds of trades require ships with amply redundant machinery. Although steam turbine installations have proven reliable, they do not have too much redundancy incorporated.

3.2.6 'Maintanability:-

Due to the nature of the LNG trade, it is also important that maintenance of the machinery installation does not interfere with the sailing schedule of the ship or influence its performance. Steam turbine installations require a modest amount of well-schedulable maintenance. The timing can easily be made to coincide with the wet- and dry-docking intervals of the ship.

3.2.7 Crewability:-

As all other segments of the shipping industry have made the switch to diesel engine power during the last three decades, the pool of experienced and skilled steam engineers is rapidly shrinking. This poses a crewing challenge which can even reflect in manning costs.

3.2.8 Others:-

Ships with steam turbine installations have rather poor manoeuvring characteristics. When considering transits in light ice conditions and cargo operations offshore, good manoeuvring characteristics become increasingly important.

3.3 Winds of change:-

Short-term contracts and even spot cargoes are becoming more common today owing to the increasing LNG demand and supply. Some LNG carriers have even been ordered without any shipment contract or route, which was previously unheard of in the LNG business. Thus ship operators are bound to look for newbuildings with more operational flexibility and efficiency to adapt to varying contractual situations. This primarily calls for a flexible and efficient propulsion plant able to accommodate different ship speeds and alternative operating profiles. The main drawback of the traditional steam turbine plant is its inefficiency, and hence high fuel consumption. The lack of alternative usage for the boil-off gas has led to thinking that the boil-off gas is free. Alternative methods of utilizing boil-off gas have forced changes in this thinking. Furthermore the natural boil-off quantity is decreasing in modern LNG carriers owing to advances in tank insulation technology and design.

As a result, the natural boil-off is far from sufficient to fuel the propulsion power needed for the relatively high ship operating speeds. Therefore forced boil-off gas or heavy fuel oil is needed to top up the fuel demand of the boilers, both of which increase operating costs. On a laden voyage typically around 50 % of the energy requirement comes from heavy fuel, and up to 80 % during ballast voyage. Environmental aspects also need to be considered. The high fuel consumption of a steam turbine plant leads directly to high CO2 emissions which will become an increasing liability in the future. Although NOX emissions of traditional LNG carriers are very low owing to the combustion characteristics of boilers, their SOX emissions are considerable because of the heavy fuel used to top up the energy requirement. Among the other arguments often heard against steam plant are an increasing lack of competent steam engineers, poor manoeuvring characteristics, and limited propulsion redundancy.

3.4 Alternative Propulsion Concept:-

Alternative machinery installations for LNG carriers could potentially be built around **diesel engines, gasdiesel engine, dual-fuel engines and gas turbines.** An attractive machinery alternative has to at least match the performance of the steam turbine installation with respect to the following aspects:

- Reliability
- Safety

Additionally, an attractive alternative has to outperform the steam turbine installation with respect to the following aspects:

- Efficiency
- Environment
- Redundancy

In relation to the boil-off gas, a choice has to be made between:

- Using boil-off gas as fuel
- Returning boil-off gas to the cargo tanks

After Reliquefaction The machinery alternatives have sorted by the technology applied for basic power generation.

CHAPTER 4

SLOW SPEED DIESEL ENGINE

4.1 Slow Speed Diesel with BOG reliquefaction:-

Since the nineteen-seventies, diesel engine installations have become dominant in all shipping segments, except LNG shipping. Experience gained from thousands of diesel engine installations in service has resulted in the development of highly-efficient, reliable and safe diesel engines. The latest developments, like the application of common rail fuel injection on both four- and two-stroke diesel engines, are taking diesel engine technology yet one step further. As diesel engines can only burn liquid fuels like marine diesel oil MDO) and HFO, the boil-off gas on LNG carriers has to be reliquefied in an onboard Reliquefaction plant and fed back into the ship's cargo tanks. These reliquefaction plants require a substantial amount of electric power to operate and are costly, heavy and have only been applied in the marine environment on a very limited scale. The most simple and straightforward diesel engine installation for a ship the size of a conventional LNG carrier or larger would be a single two-stroke engine in direct-drive to a single fixed-pitch propeller. As the LNG trade sets high standards with respect to 'maintainability' and redundancy, the most simple and straightforward diesel engine installation onboard an LNG carrier will likely feature twin two-stroke engines, each in direct drive to a fixed-pitch propeller. In order to keep the complexity low and the operational flexibility high, electric power will likely be generated by a group of four-stroke diesel generating sets. Devices for locking or disconnecting the propeller shafts will be necessary to enable maintenance activities on one engine while sailing. Having one engine out of operation for maintenance will however still have a substantial impact on the ship's service speed. This impact can be reduced by selecting controllable-pitch propellers, or by using the tuning possibilities of electronically-controlled, two-stroke engines. The exhaust emissions of two-stroke engine installations are reasonable, but certainly not excellent. Without additional equipment like SCR units or direct water injection, NOx emissions are substantial. As an inevitable consequence of using HFO as a fuel, SOx emissions are
high too. More propulsion redundancy and operational flexibility can be offered by applying multiple four-stroke diesel engines driving controllable-pitch propellers through reduction gears. A further enhancement can be realized by applying electric propulsion. The application of electric propulsion will at the same time result in a higher part-load efficiency.

Major advantages of the diesel system are the high overall fuel efficiency - which is about 60% higher than for steam plants, the reduced engine room space required and considerable lower initial costs. Diesel propulsion is perceived as offering less redundancy than existing steam systems, which we do not completely accept. In any case, redundancy could be achieved by installing a combined power take off, power take in (PTO / PTI). In the case of a main engine failure, the e-motor on the shaft line would be driven by the diesel gensets which would allow the ship to sail at a safe manoeuvring speed. This is a proven design which has been installed on several chemical tankers. Another consideration with diesel propulsion is that amount of LNG delivered is higher because the BOG is being reliquefied. One negative point is the potential increase in NOx, and SOx emissions as the engines burn HFO, however the amount of CO2 released into the atmosphere could be reduced.

For our analysis, the system shown in fig. 1 was adopted. The reliquefaction plant is a closed Brayton cycle. The BOG is removed from the tanks, compressed and cooled and condensed to LNG in a cryogenic heat exchanger. Non-condensibles, mainly nitrogen, are removed in a separator and exited to the vent. The LNG is returned to the tanks. The cryogenic temperature in the heat exchanger is produced by means of a nitrogen compression – expansion cycle. The plant requires about 3.5 MW electrical power.

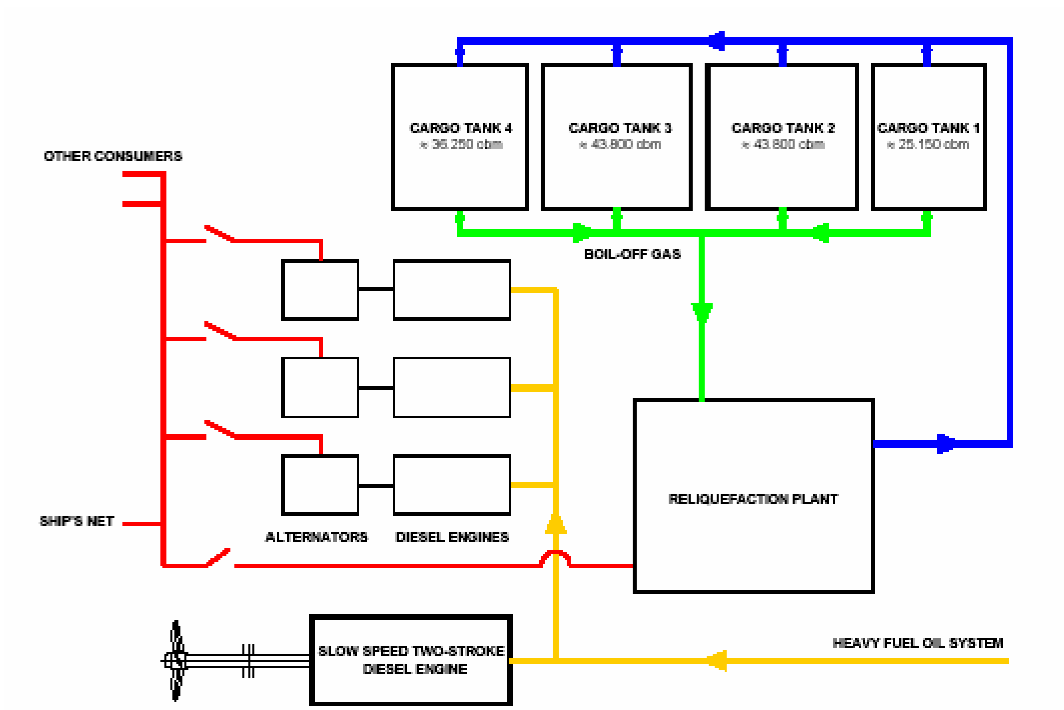


Figure 1: Diagram of Diesel engine with Reliquefaction

4.2 GAS-DIESEL ENGINE ALTERNATIVES:-

Gas-diesel engines act according to the Diesel principle and can virtually burn any possible mixture of gas and liquid fuel, with only a few restrictions to the quality of the gas. As the mixture of gas and liquid fuel is injected into the combustion chamber during air compression (Fig. 2), the required injection pressure is high. For four-stroke gas diesel engines, a gas pressure of around 350 bar is required, while for two-stroke gas-diesel engines some 250 bar is deemed sufficient.

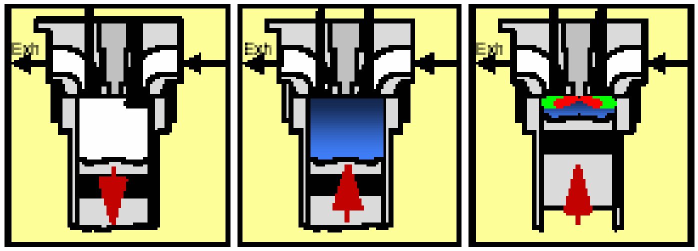


Fig. 2 - Gas-diesel engine working principle

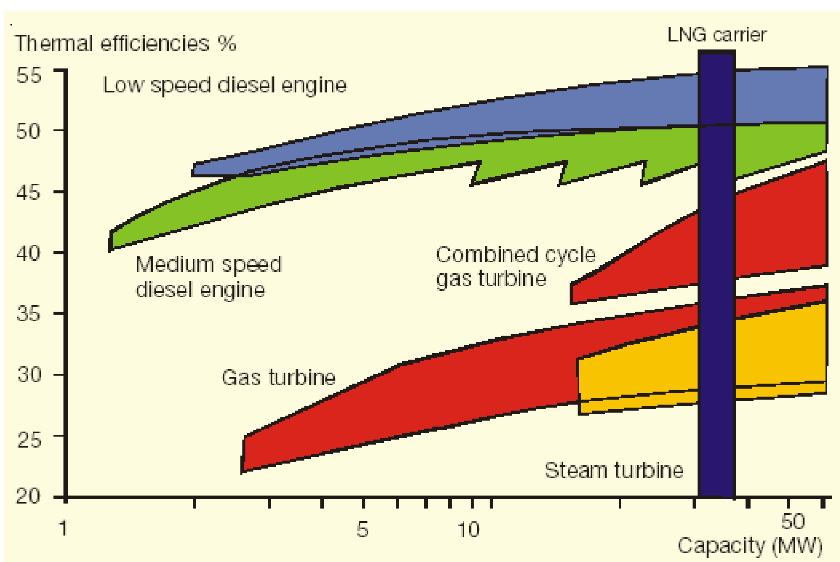
Except for the reliquefaction plant, LNG machinery installations based on gas-diesel engines look fairly similar to concepts based on conventional diesel engines. As boil-off gas is generated at atmospheric pressure, large gas compressors are required to boost the gas pressure to the appropriate level. These compressors require a substantial amount of electric power to operate and are costly and heavy. Additionally, the presence of high-pressure gas in the engine room is a major safety concern, especially on LNG carriers. **Emissions of gas-diesel engine installations are generally lower than those of steam turbine and diesel engine installations** as a result of higher efficiency and cleaner fuel, respectively.

M/V Excalibur LNG Carriers

LNG carriers represent the last stand for the – in all other markets – practically extinct marine steam turbines. With efficiencies of only about 30%, versus the diesel engines' more than 50%, and in combined systems even higher, diesel engines are the propulsion system of choice in the marine industry.

Diesel Driven with reliquefaction plant

This reason for the dominance of the diesel engines is clearly demonstrated in Fig showing the thermal efficiency of the various prime movers.

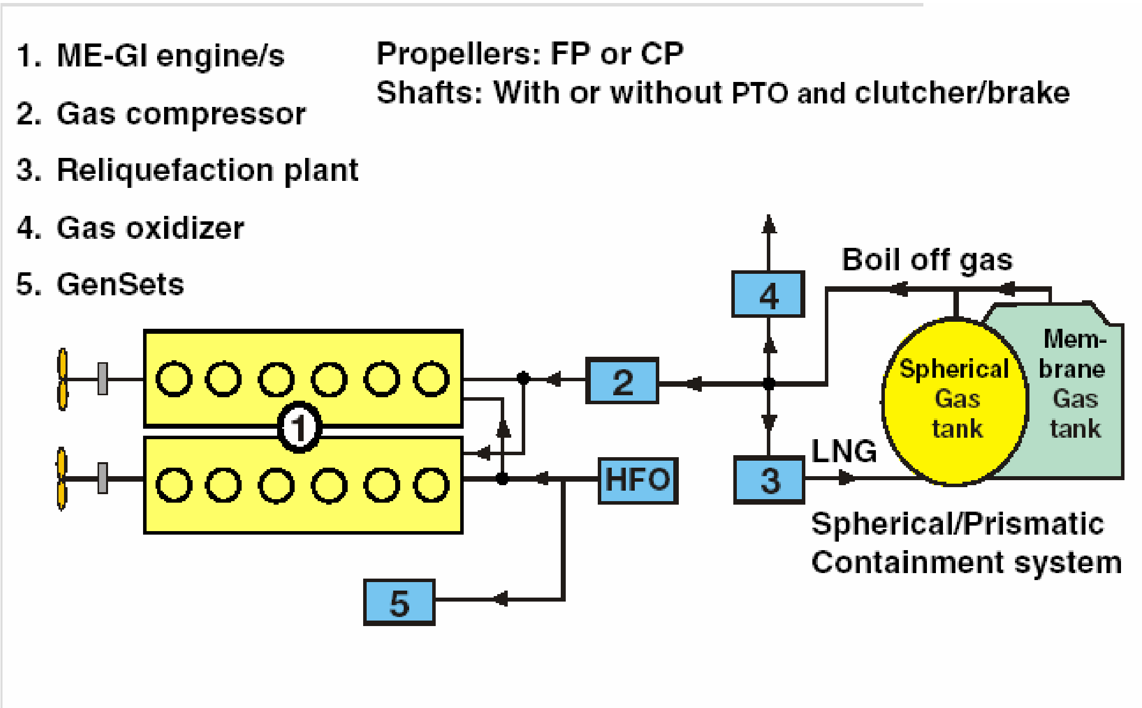


Typical thermal efficiencies of prime movers

As shown, steam turbine propulsion plants generally have a lower efficiency and therefore need far more input energy than modern, fuel efficient diesel engines. With efficiency and CO2 emission being largely inversely

proportional, MAN B&W is proposing alternative propulsion concepts based on low speed diesel engines with electronic control for modern LNG tankers.
Two different concepts are offered:

- **ME HFO burning engines**
- **ME-GI dual fuel burning engines**.



Building Blocks for an LNG Carrier

HFO burning fuel efficient Low Speed two-stroke diesel engines in single or twin propeller configuration, in combination with reliquefaction of the Boil Off Gas (BOG), offer economic benefits for those trades where loss, i.e. consumption of cargo, is not accepted and the supply of the full amount of cargo is honoured. Where this is not the case, and gas fuel is preferred, the ME-GI dual fuel engine is the proper answer.

Recent technical development has made it possible for MAN B&W to offer the option of dual fuel operation on ME-powered LNG carriers. The system focuses around a high pressure reciprocating compressor supplying the engine with the main gas injection, while ignition is ensured by pilot oil injection.

Ten years of operational experience have been logged with this concept. However, LNG carriers are expensive ships, and the contractual supply of cargo is usually tied by strict charterparty conditions. Therefore, the market has been hesitant to look at and accept other than the traditional steam propulsion system.

Now this has changed. With the market launch of electronically controlled low speed diesels and reliable independent reliquefaction technology, all the traditional reasons not to leave the steam turbine have become invalid. It must also be realised that manning of steam driven commercial vessels will be increasingly difficult because of the phasing out of marine steam turbines.

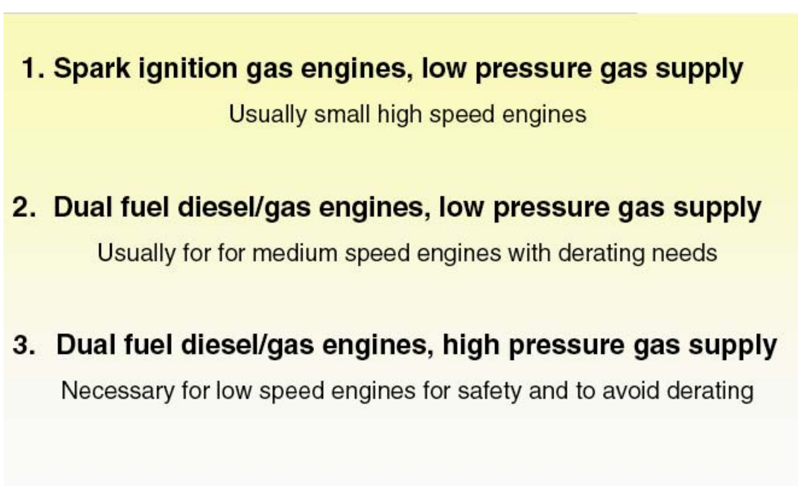
The purpose of this paper is to demonstrate by comparison that the LNG transport industry can benefit greatly in terms of US$ savings by changing to electronically controlled low speed diesels while, at the same time, contributing to a better environment by significantly reducing CO2 emission. The OVERALL conclusion is that more than US$ 3 million is lost every year through the funnel of every steam driven LNG carrier.

MAN B&W offers a full programme of marine diesel engines for every conceivable application. The low speed engine programme is developed in Denmark and manufactured by a family of licensees at major shipbuilding centres of the world. Single unit powers range from 2,000 hp to well over 100,000 hp, all for direct coupled installation at propeller speeds from 250 rpm down to 60 rpm for the largest propellers. The power requirement for an LNG carrier calls for some 40,000 hp, typically two off 60 or 70 cm bore units.

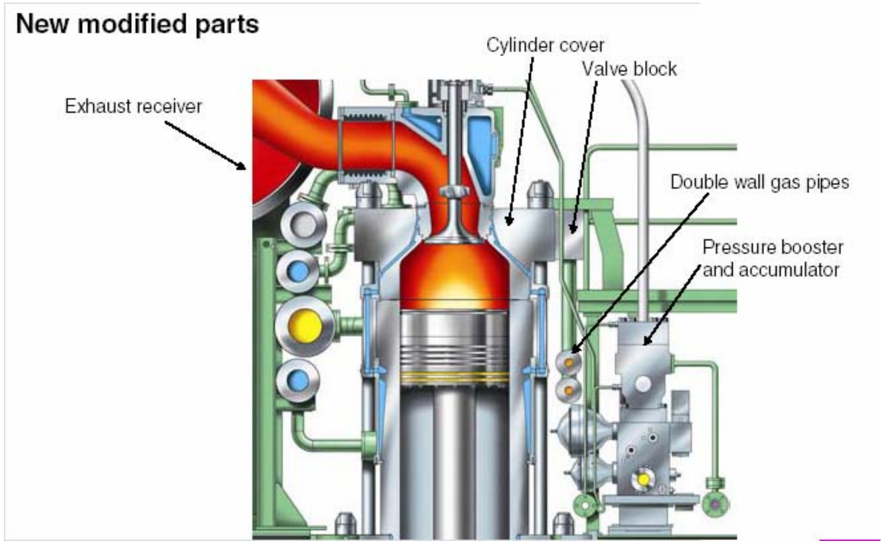
MAN B&W low speed engines hold a worldwide market share of about 65 % in their segment.. Another recent demonstration took place with the delivery of a 6S70ME-C engine at HSD in Korea in July 2003.

4.2.1 ME-GI -- The Dual Fuel Engine:-

MAN B&W Diesel A/S launches the ME-GI engine. This range of engines is designed for the highly specialised LNG carrier market. The design builds on experience gained from the earlier MC-GI engines combined with the developments in the latest electronically controlled ME engines.

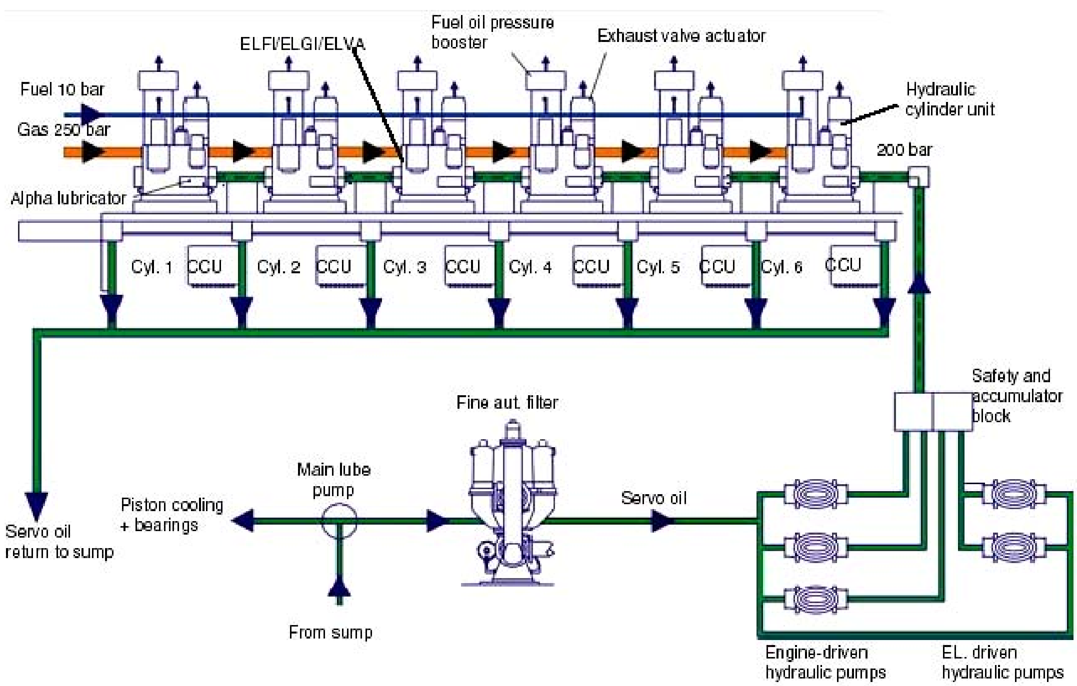


The ME-GI Engine



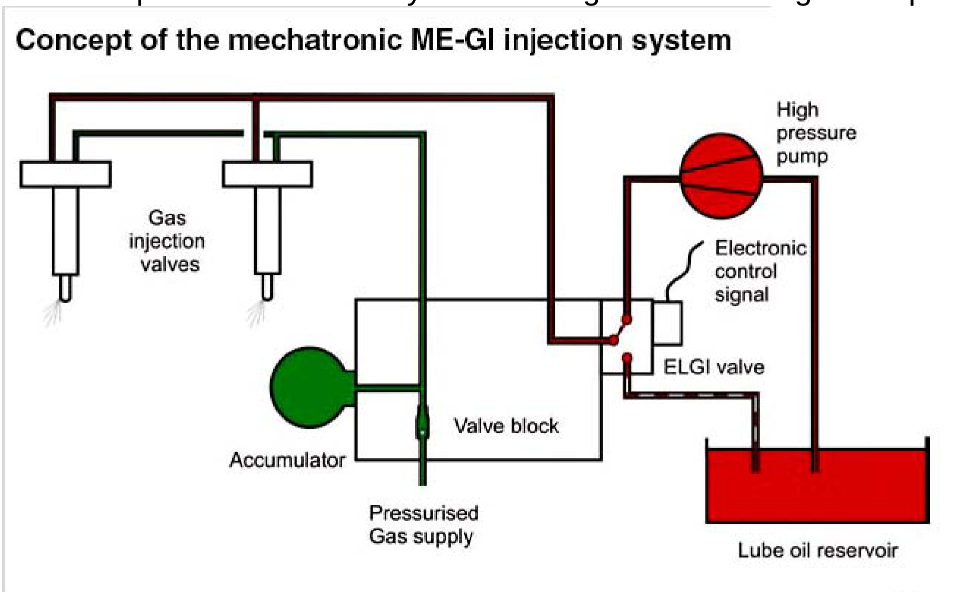
The ME-GI Engines

After careful consideration of the various alternatives for LNG carrier propulsion, the conclusion from MAN B&W is that a two-stroke engine solution is the best system for powering LNG carriers.



The ME-GI Engine Hydraulic Oil Loop

The combination of low installation and running costs for this highly specialized type of vessel makes the adoption of the dual fuel ME-GI engine from MAN B&W very attractive for any ship owner and operator who needs to keep their costs to a minimum. An additional Reliquefaction plant allows sale of more gas when the gas price is higher than the fuel oil price. Traditionally, LNG carriers have been driven by steam turbines that are fed from boilers fired by the boil off gas, supported by heavy fuel oil. Responding to a market demand for more efficient engines, while retaining the option to burn the boil off gas, MAN B&W is now reintroducing its high pressure gas injection low speed diesels now in electronically controlled execution. Designated ME-GI, this gas burning option is being offered in parallel to the heavy fuel-burning solution with gas reliquefaction.



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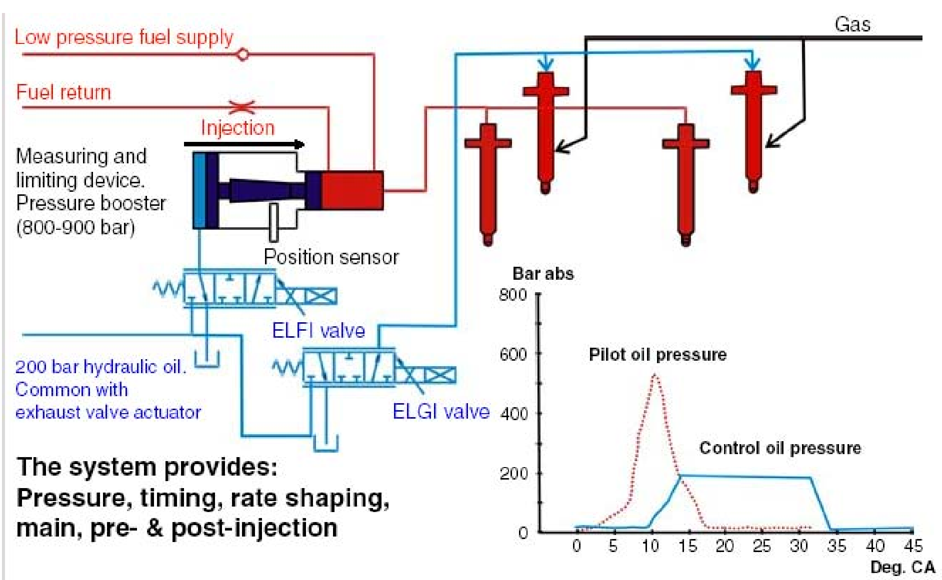
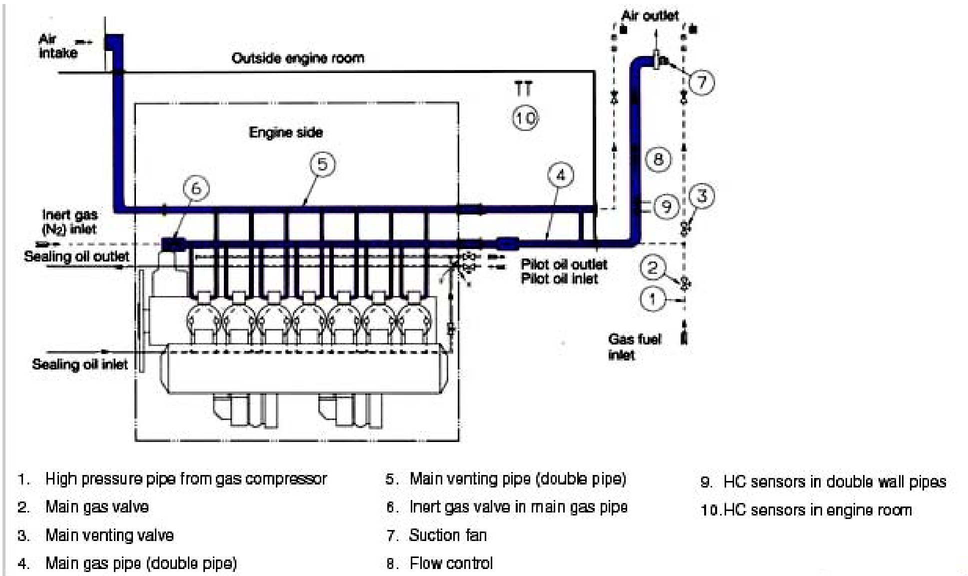
The combination of the ME-GI engine, installed with a reliquefaction plant, allows the owners and operators the choice to either use the boil off gas in the engine or to reliquefy the gas and use HFO instead. The choice being dependent on their relative prices and availability, as well as environmental considerations



Out of all the options for the prime mover, the low speed twostroke diesel engine gives the best thermal efficiency for any conventional propulsion system. This is especially the case for LNG carriers, where the power requirement is around 30 to 40 MW. Thermal efficiencies of around 50% for diesel engines far exceed the 30% offered by steam turbines and any other combination alternatives.



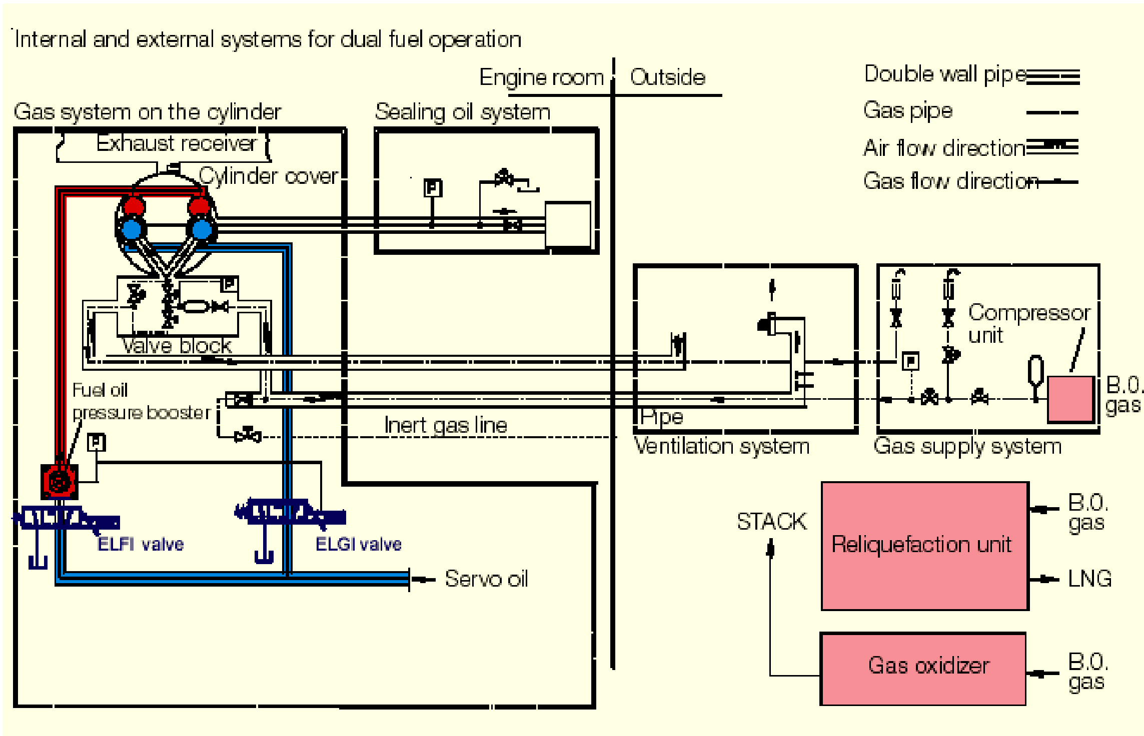
General arrangement of double wall piping system for gas

The ME-GI dual fuel enhanced engine control and monitoring systems enable the latest ME technical developments to be applied to the LNG carriers. The precise timing and combustion rate shaping gained through the use of the electronic control of injection and exhaust valves produce greater control at any load.
In order to make it possible to use the Boil Off Gas from an LNG Carrier as fuel in low speed diesels as well, MAN B&W has readdressed this technology based on our ME engine concept.

The benefits of the greater control given by the ME engine range further enhance the operational reasons for introducing this option. Some years ago, MAN B&W developed the MC range of engines for dual fuel. These were designated MC-GI (Gas Injection). The combustion cycle was initiated by the injection of pilot fuel oil, followed by the main gas injection. The technology was widely published as, for instance, in Ref. [2]. The fuel injection timing on these dual fuel engines was mechanically controlled, but in the electronically controlled version, like all ME engines, it can be user-defined and is subject to greater control and flexibility, thereby allowing the dual fuel concept to be further optimized.

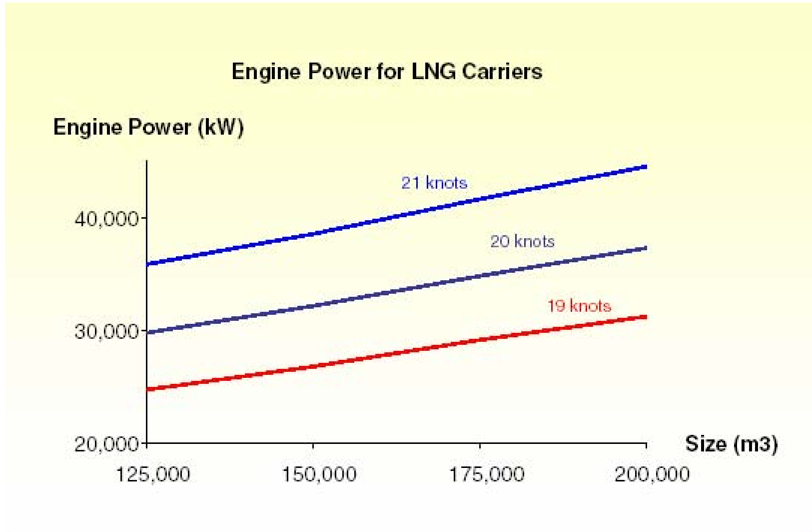
The efficiency of the ME-GI duel fuel engines is the same as an ordinary ME engine, due the diesel cycle. The system efficiency will be higher than that of other gas consuming propulsion system, incl. dual fuel diesel electric even considering the compressor power. Full redundancy as required by International

Association of Classification Societies' (IACS) can be met with one compressor, one reliquefaction unit or one oxidizer as also discussed later. The system configuration is shown in Fig. 5.



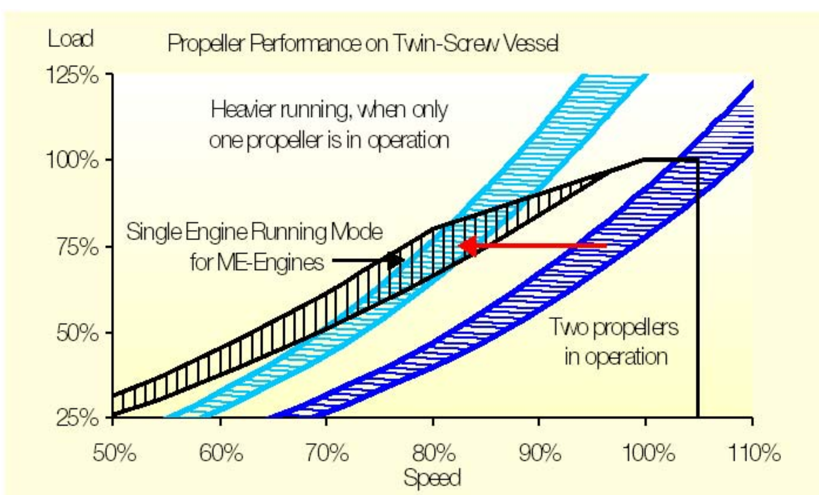
ME-GI engine and gas handling units

The average lifetime of commercial vessels is 25 years, by which time the vessels are usually scrapped for reasons of economy. Diesel engines could operate for decades beyond, as all wear parts are replaceable. Long living diesels are seen mainly in power plants. The low speed diesel engine has a long lifetime which also makes it relevant for LNG carriers with a lifetime of up to 40 years. The latest series of electronically controlled engines, the ME series, are particularly suitable for the trade discussed, as the control system software can be updated routinely. Maintenance requirements for diesels are predictable, and parts supplies over the engine lifetime are guaranteed by the manufacturer and designer. Vibration levels are fully predictable and controllable, both for vessels with spherical tanks and membrane tank systems. Furthermore, the segregation of the gas cargo and heavy fuel for propulsion ensured with reliquefaction means that handling of gas in the engine room and surrounding areas is avoided. Based on the technology described in the foregoing, the machinery to replace the steam turbine and boilers in a typical 145,000 m3 LNG carrier is therefore *2 x* approx. 20,000 hp low speed fuel burning ME or ME-GI type diesel engines. Typical propulsion power requirements for LNG carriers of different sizes are shown in Fig



Typical Propulsion Power Requirements for LNG Carriers

The bridge and engine room control system shall be able to handle operation with both one (emergency) and two engines. The bridge and engine room control system shall, in the case of operation on two engines, be able to handle both individual control and simultaneous control of the engines. Simultaneous control consists of equality in power distribution, order for reversing, start of engines and stop of engines. The control system shall, in case of failure on one of the engines, be able to ensure continuous operation with only one engine without jeopardizing manoeuvrability or safety of the ship or engines. In the case of FP propellers, it is presumed that, the shaft is declutched from the engines and the propeller wind- milling, alternatively that a shaft brake is applied. In the case of CP propellers, it is presumed that the propeller is at zero pitch and the shaft brake is active. If engine overhaul is to take place during sailing, declutching is necessary.



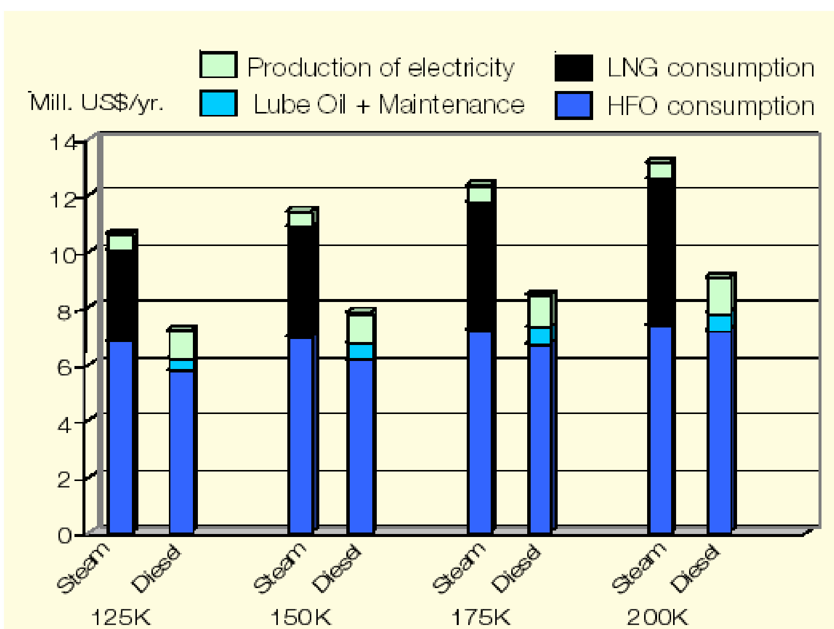
Propeller curves in load diagram with one vs. two propellers working

In the case of a FP propeller the working engine will have to accept a 'heavy propeller', i. e. higher torque, as shown in Fig, which basically calls for a changed engine timing.

With the ME engine concept, this can be done by push button only, activating "single engine running mode". This can be pre-programmed into the software just as the so-called "economy mode" and "low Ox mode". Hence, the operating engine of will be readily optimised for the purpose, and full mobility of the vessel ensured. As per calculation, a speed of 75% of the design speed of the vessel can be obtained with a single engine in operation.

4.2.2 Economical Evaluation:-

The operating costs and the additional income from sale of the reliquefied LNG for a 150,000 m3 LNG carrier is analysed in the following. The analysis includes fuel oil, lubricating oil and maintenance costs for both propulsion and electricity production under various operating conditions. The analysis is based on state-of-the-art insulation of tanks, and thus BOG rate, and a traditional service speed of the vessel. An evaluation of the operating costs and the additional income from selling reliquefied LNG shows that substantial economic benefits can be obtained. The actual outcome of the evaluation will depend on the project in question. i.e. voyage profile, service speed, size of the vessel economic factors, price of HFO and LNG, as well as of the Boil-Off rate. In any case, diesel engine propulsion offers significant economic savings for the operator. The operating costs are indicated in the tables in the Appendix and based on the Basic Data and a typical voyage profile as shown in Fig.



Operating costs for LNG carriers