Paper 24 – LNG propulsion for push-tugs

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ABSTRACT:

Using Natural Gas (NG) for fuel in internal combustion engines has become proven technology.
The environmental benefits of using NG in these engines are obvious and are promising to fulfill the latest emission limits.
LNG (Liquefied Natural Gas) is cheaper than Diesel and available in larger quantities.
Where as the fuel cost are a major part in the OPEX of a ship owner.

It is clear that ship owners and statuary bodies are interested in this new technology.

Unfortunately NG or LNG with its flame point below $55\ ^{o}C$ was not allowed to be used as fuel for inland navigation in Europe.

1 INTRODUCTION

Shipyard Gebr. Kooiman BV is part of The Kooiman Group, a family owned group of three shipyards, a design office and an electro technical company, all based around Rotterdam in the Netherlands.

At the shipyard Gebr. Kooiman BV in close collaboration with its Design office, recently four new 5550 hp inland navigation pushers where built for ThyssenKrupp Veerhaven BV, to serve the Rhine river with push convoys for the upstream transportation of ore and coal from Rotterdam seaport to Duisburg (Germany) .

To be able to meet the coming and demanding environmental regulations for emissions on the European inland waters, The Kooiman Group developed a LNG fueled push boat that not only meets the latest emissions limits, but also will be more efficient in propulsion and power management than the existing vessels in operation.

Above the “bare” fuel costs savings, (LNG over diesel) , which will be around 20% of the diesel price, the innovative technical solutions for efficient power management together with an innovative hull, propulsion and maneuvering tools make it possible to save around 36% on total fuel costs.

As per regulations, LNG was not allowed as fuel for inland navigation in Europe . the CCNR and AND safety committee (these are European organizations of Flag states and Class societies) need to give Recommendations (permissions) on a case to case base for sailing with the LNG fueled vessels as pilot projects on European inland waters. Shipyard Gebr. Kooiman BV, in 2014 obtained all necessary Recommendations to be able to build the first LNG propelled 5750 hp push boat. Moreover the LNG pusher project was rewarded as a beneficiary in an EU Ten-T funded in the Rhine - Main -Danube LNG Master plan.

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With this paper we not only want to explain how the LNG push boat was designed, the difficulties regarding legislation and regulations faced and the technical details of layout and (LNG) installation of the pusher. We also will explain about the innovations and our design philosophy and how we believe we can realize 16 % fuel savings above the 20% bare fuel cost savings by using LNG.

Based upon thorough study of South American rivers and inland waterway operations, since 2012 Shipyard Gebr. Kooiman and its Design office made a number of designs and proposals to suit the South American market by way of low draught pushers in the range of 4500 to 6500 hp.

These design concepts obtained from the proven designs and pushers operating in European waters and from the LNG fueled concept offering ship owners the opportunities to operate these pushers in rivers of 6 ft. water depth and gain fuel savings. For low water depth rivers and delta's all over the world, this might be an advantage against traditional high draught North American designs. In this paper we will explain about the naval architectural principles and how we proved these principles to work in real life operations.

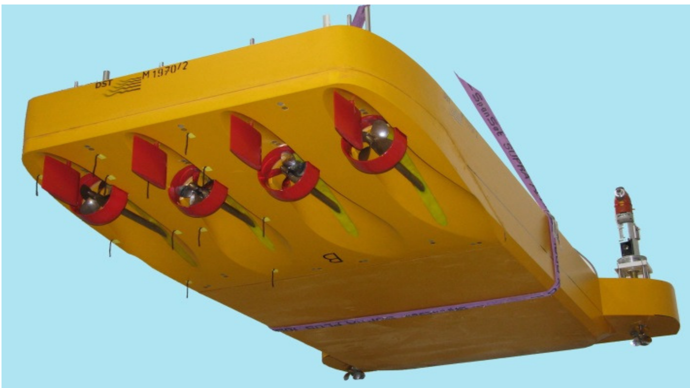
2 HOW IT ALL STARTED

2.1 *Future pusher project*

After building four new but more or less, traditional diesel driven pushers for ThyssenKrupp Veerhaven BV, the Owner facilitated a study for the development of a new generation push boats meeting the following criteria:

- In performance and functionality:
  Not to be less than existing vessels of the fleet.
- Overall fuel consumption:
  Less than existing vessels of the fleet.
- Range:
  4 round trips (=one week 24/7 sailing).
- Bunker operations:
  Within 2 hours; once a week.
- Environmental:
  Able to fulfill (at that time expected) requirements of CCNR4.
- Redundancy:
  Independent of alternative fuel supply.
- Draught:
  Less than existing vessels of the fleet.
  (Target draught: 1,60m)

In this study various alternative propulsion concepts where studied and tested (large propellers at an 30 ° angle to the waterline with intake ducts and vanes, a vertical oscillating wing and a six propeller driven concept)
Model tests were done at DST tow tank facilities in Duisburg (Germany) for a hull tunnel shape study.



And concepts for power supply systems and propulsion engines were designed to determine the most favorite configurations when projected to the sailing profile of the convoys.

The results of these studies in the future pusher project can be summarized as:

- LNG to be the favorite fuel,
- Dual fuel engines
- Propellers in nozzles as propulsion but with a load on the propellers (horse power per m^2) as low as possible.
- No bow thruster unit gondola's to be added to the hull

These findings and results became the basics for the new LNG pusher design.

2.2 *LNG pusher project*

As LNG was chosen to be the favorite fuel because of the environmental benefits the availability and the relative low fuel price we had to deal with the first regulatory obstacle:

- NG or LNG with its flame point below 55 °C was regulatory not allowed to be used as fuel for inland navigation in Europe.

At the time the concept design for the new LNG fuelled push boat started, regulatory bodies in Europe where already convinced that natural gas as propulsion fuel (like on sea going vessels) had to be seen as an realistic option for inland waterway vessel's propulsion, to be able to meet their new and demanding environmental standards.

In order to create an opportunity to sail natural gas fuelled vessels on European inland waterways the CCNR (Central Commission for the Navigation of the Rhine) facilitated a procedure to be able to allow LNG fuelled ships on pilot project basis and for a limited period to sail the Rhine.

The procedure that the CCNR created for LNG fuelled ships was:

- The vessels had to be designed and build under supervision of a Classification society (e.g. Lloyds, BV, DNV/GL)
- For each project a HAZID study had to be carried out (for the Netherlands witnessed by an authority appointed by the Dutch Administration)
- The by Class approved concepts that were judged as safe and sound by a Hazid study needed to be brought to the CCNR by the flag state's Administration.
- After appraisal by the technical comities of CCNR and ADN Safety Committee (part of United Nations Economic Commission for Europe (UNECE) that regulates transport of dangerous goods) , recommendations from both committees will be given for the LNG concepts that enables the vessels to sail the Rhine as pilot projects up to a limited period of time.
- During the pilot sailing period the vessel the owner will have to monitor all relevant operational and environmental items and report those on annual basis to the CCNR.

In autumn 2012 the Kooiman design office started with the concept design of the LNG fuelled pusher.
In December 2012 the first plans and schematics where sent to Class.
In May 2013 a 3 day's consuming the Hazid study was executed witnessed by TNO (Research Institute for Applied Natural Science) as representative of the Dutch Administration

3 THE CONCEPT DESIGN DISENTANGLED

3.1 Propulsion – ship's power concept

The propulsion and ship's power concept as indicated in Annex 2 of this paper is designed to serve a sailing profile in which the pusher is sailing upstream with six loaded barges (16800 tonnes dead weight) for approx. 240 km in 28 hr sailing time. And downstream with empty barges for approx. 12 hr.

Including coupling and decoupling the barges the vessel will make approx. 4 complete voyages each week.

These European pushers are designed, built and equipped to serve for 1,5 year in a 24/7 sailing sequence. Than they will be taken out of service for about two weeks for planned maintenance and general engine overhaul, after which they will be ready to sail for another 1,5 years.

After 30 to 40 years these pushers will be replaced by new ones and the old ones will start a second life abroad.

As diesel will be bunkered from along sailing bunker barges, LNG only is allowed to be bunkered alongside a bunker vessel while moored or at a stationary bunker station. The capacity of the LNG tank will determine the number of roundtrips that can be made on one bunkering.

The planned 145 m3 tank will allow three roundtrips to be made.

Because these pushers are operating in cycles with eight or more convoys, the time allowed for bunkering LNG is only three hours once in every three roundtrips.

Sailing upstream, the four 1060 kW Wärtsilä Dual Fuel main engines will be preforming at about 65% - 85% of their MCR.

Through a shaft generator on each propeller shaft, power can be taken from the propulsion line to feed ship's electrical systems. The surplus of power generated can be stored in two batteries.

Sailing downstream (with empty barges) only two Wärtsilä diesels are needed for ship's propulsion and manoeuvrability. Than there might be a possible shortage of power for ship's electrical systems because only two shaft generators are in operation.

If so, there are two options to generate extra power supply: firstly; the two "wind milling" propellers can drive the shaft generators lines or secondly the surplus of power needed can be subtracted from the batteries that have been charged whilst sailing upstream.

For emergency power supply, a dual fuel (LNG and diesel) driven generator is installed to deliver power when no main engines are running.

3.2 Dual fuel engines.

Since one of the design criteria was to be independent of the alternative fuel supply (LNG) a choice was made for Duel Fuel engines.

The four 1060 kW Wärtsilä type 6L20 DF main engines are designed to operate on a mixture of 95% to 99% NG (natural gas at approx. 5 bar pressure) while ignition in the cylinders is ensured by 1-5% pilot diesel.

When NG is not available the engine can run on diesel only.

Where for the internal combustion in the Wärtsilä main engines, gas is injected into the cylinder like diesel is injected into the cylinder via the nozzles. The emergency diesel can operate on a 80% NG -20% diesel mixture by sucking gas into the cylinder, together with the combustion air at the air intake of the engine.

As such, actually each engine on board can run on diesel only when no LNG is available.

3.3 LNG tank

In the centre of the pusher a vertical LNG tank is situated.

As LNG is bunkered at very low temperatures (-160 °C), a double shelled vacuum insulated LNG tank is to be installed to keep the gas in liquid state for extended periods, even without any gas consumption, (gas consumption will cool down the content of the tank), the tank is made in a double wall construction in which the space in between outer and inner tank (approx. 300 mm) is brought to a vacuum condition.

Moreover the space between outer and inner tank is filled with Perlite to gain even more insulation capabilities.

Besides the possibilities of Perlite insulation, there is an option for the even better "super insulation" (a multilayer system of thin aluminium sheets and paper). However, such system may cause problems facing ships vibrations in combination with the vertical position of the tank.

Both the inner and outer tank are made of stainless steel, a material that can withstand the low temperature of the LNG.

Using stainless steel for the outer tank also makes this tank a second barrier in a case of a rupture in the piping or the piping connections to the inner tank.

Although the tank is situated in the vessel at a location as indicated by Class and other regulatory bodies, energy absorbing calculations for the surrounding hull constructions are made to predict the forces on the tank and its supports in case of a collision.

Liquefied Natural Gas (LNG) is formed when Natural Gas NG is cooled down to minus 162°C under atmospheric conditions. In this liquefied conditions the volume is 600 times smaller than the Natural Gas in gas condition.

Because of this physical property all pipelines and tanks in which LNG can be blocked need to be equipped with pressure safety valves for the situation that the LNG will be warmed up and expand.

All the ventilation pipes, together with the ventilation pipe for the main LNG tank safety valve need to be lead to a safe location above top deck level.

3.4 LNG – NG process unit

The LNGPac design philosophy is based on safety and simplicity.

The gas storage system consists of a vacuum insulated tank, equipped with a set of Safety Relief Valves placed on top.

The LNG is processed inside the Tank Room or valve box, an enclosure with dedicated ventilation system made of stainless steel and therefore functioning as a secondary barrier to avoid LNG spill to the vessel's hull structure in case of a LNG leakage.

The process control of the LNGPac includes a PLC cabinet, a separate pneumatic valves control cabinet and junction box for all electrical equipment & sensors inside the Tank Room and several peripheral interfacing connections.

Human Machine Interfacing of the Fuel Gas Process control is realized by two redundant panel computers, designed for full remote control of all primary process & safety control functions.

The system includes all classification required alarms and indications, to be connected, either hard-wired or via serial interfacing, to the vessel alarm & monitoring system.

A serial interfacing can be provided for visualization & limited process control at secondary level to the Vessel Automation System.

Where required by classification or local authorities, the necessary alarms, controls & signals shall be provided for the Vessel / Engine Room Safety System.

The Tank Room ventilation is directly connected to a dedicated ventilation system, all designed according to classification requirements.

LNG will be bunkered through a Bunkering Station via a single walled piping. Interface to shore bunkering facilities is carried out with a flexible hose connection or fixed loading arm.

The pressure in the LNG tank will be brought to an approx. 5 bar level by an Evaporator Pressure Build up Unit which is heated by the cooling water of the main engines.

The LNG liquid than is pressed out of the tank and being vaporised in another evaporator. The Natural Gas than will be regulated to the pressure required by the engines by a Gas Valve Unit for each main engine. This GVU is incorporated in but not part of the Tank Room.

From the GVU, gas will be lead to the main engines in the engine room through double walled ventilated piping. This piping, like all piping and ducts on the main engines, is double walled and ventilated. The complete engine room can be considered as Non Hazardous area.

3.5 Ventilation

To meet the regulations for proper ventilation, finding safe locations for intake and exhausts and to meet the required amounts of fresh air to be pumped into the hazardous enclosures was a mayor challenge on this relative small vessel.

By using all extends of ship's superstructures and by constructing ducts in different corners between bulkheads and decks we managed to create a sound and safe ventilation arrangement.

The generator room with the dual fuel generator and the Tank Room needed to be ventilated with over 30 air changes per hour. Intakes and exhaust where not allowed to be in a sphere of 10 m radius around the vent stack. The accommodation required overpressure with air taken from a safe area.

And off course a dedicated gas detection system should be installed.

3.6 Hull

One of ship owner's criteria was a shallow draught. The target was 1,60 m at 50% consumables (Existing vessels of the fleet measure 1,70 m at 50% consumables)

Where the ships length is limited to 40 m because of the total maximised convoy length not to be more than 269,5 m upstream in the operational area Rhine Rotterdam – Duisburg and 193 m sailing downstream, extra displacement only could be generated by extra beam and in the shape of the hull.

Considering a double walled LNG fuel tank of approx. 22 and 18 mm stainless steel plating, the stainless steel tank room and all extra equipment, the target for shallow draught was a challenge.

Besides the 145 m3 LNG, 100 m3 diesel can be bunkered, to be able to sail the 3 round trips when LNG is not available.

The four 1950 mm diameter propeller configuration was chosen to get appropriate propeller surface to convert all available horsepower into the required thrust.

3.7 Accommodation

For comfort reasons the complete accommodation block is placed onto air filled flexible mountings and rubber springs and shock dampers will keep the accommodation in position.

This design is a proven concept already installed on al modern pushers of the fleet. The comfort level gained by this system is qualified by the owner to be more than essential not only for the actual sailing crew but even more for the recruitment of new members for the sailing team.

4 HOW 16% EFFICIENCY IS GENERATED

4.1 Ship's power management

Stipulated in item 3.1 is the sailing profile and the way in which can be sailed with four engines upstream and two engines downstream with this four propeller push boat.

The traditional pushers are propelled with three propellers dividing the same total power like the new 4 propeller design. They use three engines upstream and two engines downstream.

The traditional pushers generate ship's power by using a generator.

After thorough study of the load on each propeller and the energy generated for ship systems we came to the conclusion that sailing upstream and downstream all engines (including the generator) where used at only 65 to 70 % of their capacity.

In the new configuration with four main engines that also are used to produce power for ship's electrical system the more economic level of 85% load was reached, resulting in a roughly estimated 5% fuel savings.

4.2 Propulsion

For all pushers and tugs built at the Kooiman shipyard extended pollard pull tests were executed before delivery.

In these tests the power was measured at the propeller shafts, thus exact figures are known for the load on the propellers.

Bollard pull test always exist of measurements of power and thrust on individual shafts and also the thrust was measured in astern conditions.

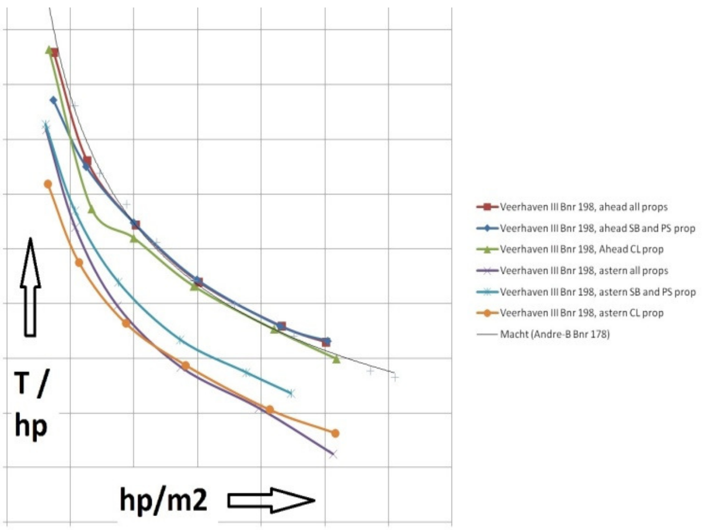
From all these test Kooiman generated graphs that showed the relation between horsepower and propeller square meters against thrust gained per horse power.

From these graphs we learned that the efficiency of power strongly grows when the ratio horsepower per m2 decreases. To gain more thrust out of each horse power you should decrease the load on the propeller. In practise: increase the propeller diameter as much as possible!

For example the inland waterway pushers Kooiman built for European waters have propeller diameters of 2.05 m while the sailing draught is only 1,70 m, special tunnel shapes in the aft ship region make it possible to do so.

In the new four propeller pusher design the propeller diameter is 1,95 m which means an increase in propeller diameter surface of 20 % resulting in 6 % more thrust out of each horse power. (In this 4 propeller 4x 1060kW propulsion concept compared to the 3x 1360 kW propulsion concept of the traditional pushers at 80% MCR.)

As horse power and fuel consumption have a 1:1 relationship this results in 6 % fuel reduction gaining the same thrust. (See HP-T-m2 diagram below)



4.3 Manoeuvring

For manoeuvring in and around the harbours at both ends of the trip, the traditional diesel driven pushers where equipped with bow thruster units.

Although manoeuvrability of these vessels is excellent. The bow thruster units itself needed to be mounted in domes added to the hull at the front end of the pusher.

These bow thruster domes by their configuration, unfortunately caused extra drag and resistance to the vessel which can be seen as loss in thrust expensively generated by the propulsion line.

For the new LNG pusher, a traditional steering tool called Flanking rudder was reintroduced in a new execution.

Flanking Rudders are rudders placed in front of the propeller and can be operated when sailing ahead with the propellers rotating in opposite direction.

In the traditional execution the Flanking rudders are always inposition also when sailing ahead where they cause extra resistance and have a bad influence on the flow of water to the propeller.

Kooiman changed the traditional design into retractable wings of which we placed four in front of each propeller. Two for steering to PS and two for steering to SB when sailing astern.

During sailing ahead these wings are retracted totally inboard the hull.

CFD (computerised dynamic fluid) calculations and simulations showed that these retractable wing generate the same transverse thrust than the original flanking rudders did which is even more than two bow thruster units could produce.

Again this innovation results in 5 % fuel savings by not adding bow thruster units or traditional Flanking rudders for manoeuvring.

5 CONCLUSION

Unfortunately after the design was finalized and all Recommendations were signed by CCNR and ADN safety committee, the Owner was not able to sign a building contract for this well designed pusher, due to the poor economic forecast for Europe's steel production industry.

Though the staff and designers of the Kooiman Group are proud to have been able to gain the knowledge in LNG installations, and that we played an important role in developing legislation and regulations to make LNG a possible solution as fuel for inland ships.

With our design and knowledge we have opened doors for future owners to safely and environmental friendly adopt alternatives for diesel and heavy fuel oil.

An alternative that can deal with demanding emission standards, but also an alternative that will show payback times between 5 to 6 years by lower OPEX costs (in sailing profiles like those for ships of ThyssenKrupp Veerhaven). In particular when combined with the other design features.
Perhaps, tit will take time before LNG will become as accepted and available as diesel oil nowadays. By having the experience in designing LNG powered push boats, The Kooiman group is prepared for the future.

Appendices:

Enclosure 1 : 3D General Impression
Enclosure 2 : Propulsion Concept

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