Fuel Cells in High Seas

Author Name: K. Leites (Project Manager Fuel Cell Application, ThyssenKrupp Marine Systems / Blohm + Voss)

ThyssenKrupp Marine Systems is heading a project to develop a marine fuel cell generator plant operating on synthetic diesel oils. The aim of the project is to create a demonstrator for a 500+ kW generator set from proven technology. The result shall be the proof of functionality and a concept for commercial product.

THYSSENKRUPP MARINE SYSTEMS

ThyssenKrupp Marine Systems (TKMS) is the first privately owned shipbuilding group in Europe. The main activities are related to submarines (also with fuel cells), navy vessels and Mega-Yachts. Further activities are related to components and repair/upgrade services.

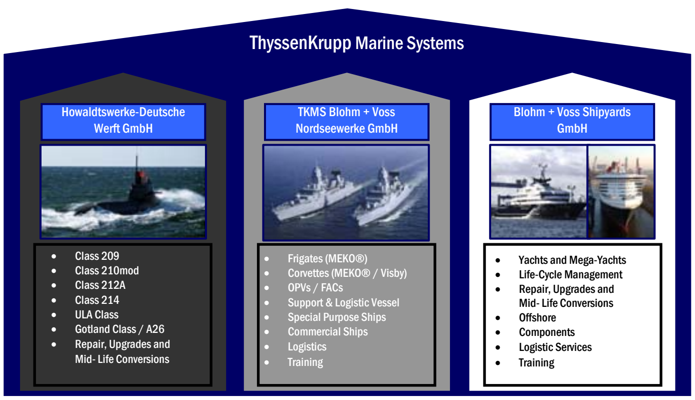

Fig. 1: Structure and business areas of TKMS

With our submarine business we have developed the first ocean going commercial fuel cell application: the submarine classes 212A and 214. Their systems are based on pure hydrogen and oxygen supply.

CHALLENGES IN SHIP POWER

The shipping industry is today facing enormous challenges. Most noticeable is the rise of the fuel prices which affects consumer prices. Although the prices are fallen dramatically since the summer last year, a target of 75 $/barrel is to be expected. Anyhow, the concurrent reduction of shipping rates puts a high pressure on fuel costs.

Probably more present in the media is the relation of ship borne emissions to the global warming.
Even if a ship is the most efficient means of transport actually available, the absolute amount of emissions from ship engines is significantly high. The overall CO_2 emissions have a share of 2.9% in the worldwide emissions. In a view from a ports perspective the share is quite higher.

Although SOx emissions are due to the coming regulations not so much in focus anymore, NOx emissions are of interest. Many ports and shipping regions have emission fees and even more will come up. The IMO has concluded the tier III limits, which can hardly be reached without secondary measures as semi-catalytic reduction. Further, particulate matter is under discussion; filtering measures like for road traffic have already become a standard for large yachts and will go into merchant vessels as well. Finally noise and vibrations should not be forgotten.

Fig. 2: Modern Mega-Yacht with current state-of-the-art technology (design by Luiz de Basto for TKMS)

In large ports the emissions are so high that they exceed allowed workplace concentrations and special breathing protection equipment could be prescribed. The authorities of several ports and favoured cruise destinations are considering prohibition of harbour generator sets and to oblige the vessels to use shore based power. This could be electrical or gaseous, depending on the concept of the harbour. Especially provision of LNG is considered by several cities at the North and Baltic seas, in the Mediterranean sea, Norway, the city of Hamburg, ports in California and some cruise lines in their home ports.

First consequences of the above are reduced transit speeds and change over from heavy fuel oil to gas oil in designated sensitive or control areas. In some ports, shore based electrical power is already offered and obligatory for the vessels.

An alternative to these shore based solutions would be to enhance the power conversion on board. Mainly two ways seem to be feasible nowadays:

1. Exhaust gas treatment
2. Higher efficiency and advanced fuels

The second option leads directly to the proposed solution in this paper:
A high temperature fuel cell with sulphur free or synthetic fuel.

Since hydrogen is for time being not a feasible fuel, we concentrate on liquid hydrocarbons as ultra-low sulphur diesel oil and synthetic fuels (XTL). With these the energy conversion process of a high temperature fuel cell (HTFC) generates a minimum amount of NOx and the CO2 emissions are reduced as consequence of the higher efficiency. SOx emissions are out of discussion, due to the absence of sulphur in the fuel.

FORMING THE LIGHTHOUSE INITIATIVE

Since this concept is interesting for different ship types, a so-called lighthouse project is initiated, which aims to bundle demonstration projects based on these issues for seagoing ships.

The lighthouse consists of a top project '*Toplaterne*' and a number of demonstration projects under this 'roof'. The whole lighthouse is government-funded from funds of the German 'national innovation programme for hydrogen and fuel cell technology' (NIP).

Partners of *Toplaterne* include, among others, a number of shipyards, classification societies, operators, equipment manufacturers and universities. These partners work together on questions like ecology and efficiency, economy and LCC, crew training and rules and standards.

Actually three demo-projects are applying for partnership in the lighthouse. The first one is the presented project called '*SchIBZ*', which is lead by TKMS.

REQUIREMENTS FOR A SHIP BORNE APPLICATION

A ship borne fuel cell system has to fulfil several requirements a land based system does not. Which are these?

a) First of all the fuel. Since LNG or similar is currently just under investigation for ships, any application in the near future of a fuel cell should operate on diesel fuel.

b) Ship equipment has to have a high level of automation. Because the crews on board are small and not very well educated all equipment has to be failsafe and electronically supervised, with a minimum amount of required operator interaction. Monitoring should be possible via a bus interface to the ship's automation system.

c) The engine spaces of ships are normally just of the size absolutely needed for the equipment and necessary maintenance. To achieve this, several aggregates are grouped by functionality and mounted into steel frames in a workshop. These frames in turn are mounted inside the vessel with respect to functionality and space economy. The same aspects should be fulfilled by the fuel cell system, compact and modular for installation.

d) A ship borne power generator must be able to operate in single mode as well as in an array of generators. Additionally it has to serve the network with sufficient power at any time. This requires a good dynamic performance.

e) The typical size of generator sets onboard Mega Yachts and midsize container vessels is 500 to 1000 kW. This defines the necessary power range of fuel cells intended for this application. A minimum of 500 kW is suitable for first applications.

CURRENT STATUS

Today the diesel generator sets are surrounded by a number of secondary measures to achieve low exhaust gas and noise emissions.

These measures take up space and have partially negative effects on the fuel oil consumption. The chain of particle filter, silencer and NOx-catalytic converter for example increases the back pressure on the engine.

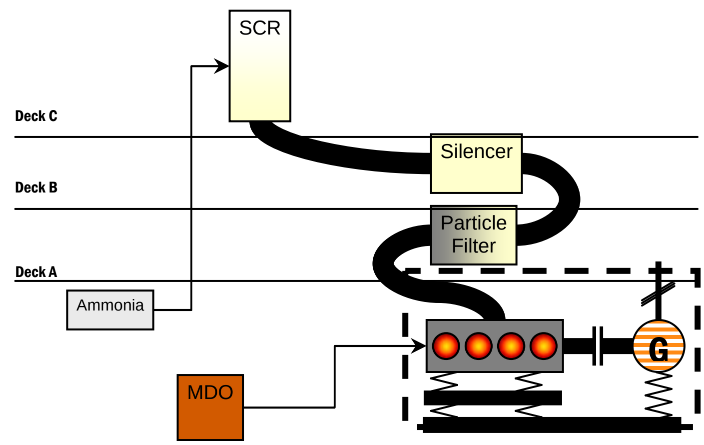

Fig. 3: schematic of a sophisticated diesel generator set

The catalytic reduction of NOx requires very low sulphur fuel oil and ammonia, which is an additional chemical on board. Filter and catalyst need certain exhaust gas temperatures which will result in reheating. Finally all these components have to be maintained.

Therefore, looking for a more easy way of achieving energy production and emission reduction is only logical.

CHOOSING THE FUEL

The marine industry is used to using oil as fuel. It is an easy to handle liquid with
- a high energy density,
- low fire risk,
- well proven system components,
- high efficiency when used in modern diesel engines.

Natural gas is today used mainly in gas carrier vessels. They have to treat the boil off gas, which can be burned in boilers for steam turbines or newly in dual-fuel engines.
Since the ecological influence of LNG is lower than that of higher hydro-carbons like diesel, many studies to use it are carried out. One big hurdle for the introduction onto ships is the storage with a high volumetric energy content: this means either compressed or deep cooled in a liquid state. Both ways cause a significant change in the design of vessels to incorporate the tanks. For the time being there is no technology to bunker LNG in either form in double-bottom tanks like diesel fuel.

From the above follows, that it is preferable to stay with diesel for the near future to fuel the fuel cell. Luckily, the legislation and the market tend towards sulphur free fuel, which is a prerequisite to apply it to fuel cells.

Even better is synthetic fuel. This fuel is produced using the Fischer-Tropsch-process. In this process, an energy source, which can be **c**oal, **g**as or **b**iomass, is gasified to CH_4 and then synthesised to longer C_xH_y chains – petrol gas, diesel or also grease. The fuels are called XTL, where X stands for C, G or B, for example CTL (coal-to-liquid). One big advantage of XTL is the absence of arenes. This improves the thermal treatment a lot and reduces smell to a not noticeable level.

Today available are BTL and GTL. GTL is easy to produce, since the gasification is not necessary. Its use in engines reduces already emissions and noise. It is commercial in small amounts and related to the by-gas of oil fields.
The United States are developing a program to use the homeland coal to produce CTL for the army.
BTL (biomass-to-liquid) offers additionally a 'green' fuel production. By gasifying organic waste, vegetable oil or animal fat a nearly CO2-neutral fuel can be gained. This is also commercially available in growing amounts worldwide.
The products of this process are not distinguishable from each other and show the same results when burned.

The above mentioned fuels have the advantage of fitting in existing logistics, do not need new or special safety measures and the personnel are used to handle such liquids.
The only additional effort needed is the installation of a completely separated piping system, to protect the sulphur free fuel from contamination by other fuel, if onboard.

CHOOSING THE FUEL CELL

The aforementioned is important for the selection of the suitable fuel cell type.

Fuel cells have in common, that they operate on gaseous fuels. The difference is, that low temperature fuel cells like PEM only use and tolerate hydrogen, which has to be supplied in a very high purity.
High temperature fuel cells tolerate CO2 (a MCFC in fact needs it) and generate electrical current from CH4 and CO.

Fig. 4: New HM320 from MTU Onsite Energy

To utilize liquid fuels they have to be transformed into a gaseous state, this is called reforming. In this process the liquid is catalytic broken down to a so-called hydrogen rich gas under high temperature, which also contains CH4, CO and CO2.
The H2 can be split off from this gas mixture. This requires a large number of very expensive noble metal membranes to gain a sufficient hydrogen supply for 500 kWe. This was investigated by our colleagues from our former sister company HFCS.

Although the PEM fuel cells are smaller in size, according to the above mentioned high temperature fuel cells are the logical choice for a ship borne application, to avoid the large, expensive gas cleaning stage.

On vessels from around 80 m upwards weight is of course an issue, but additional single items of 30 ton are not significant. The point is the size. Especially engine spaces in yachts are very tight, so the integration of such a fuel cell including the auxiliary components requires a major redesign. An intelligent partitioning of the components can ease the integration. The fuel cell from MTU Onsite Energy itself stays in the limits of typical deck heights, making it unnecessary to move deck levels.

This type can be combined with a relatively easy to build pre-reformer, which generates methane from the liquid fuel. With respect to a high overall efficiency of the system the thermal energy for the reforming is taken from the exhaust gas of the fuel cell.

Further efficiency can be gained by using the excess heat for shipboard heating purposes. Today a lot of heat onboard non-commercial vessels is electrically generated. By changing this to heat recovery, which a high temperature fuel cell provides at around 400° C, a large amount of electric power can be saved.

ENERGY BUFFERING

A MCFC has a kind of “steady state dynamic”, which is in the range of 50 % in 3 h. This can be regarded as steady state when compared to the load changes in the board network.

For this reason a fuel cell needs a supporting device, which compensates the load changes in the network until the fuel cell has followed. Depending on the power supply system set up, this may be an accompanying diesel generator set or an energy storage module like a battery.

The system suggested here shall be capable of operating in isle mode, without the aid of other combustion engines. For storing of electrical energy several options are available, e.g.:

- batteries
- super caps
- rotating mass energy storage system (fly wheel)

The necessary features are large storage capacity and high current rates.

Although the fly wheel systems can store and release large quantities of power, the total amount of energy is moderate. The upsizing capabilities are under research. If satisfying values can be achieved, this module could be interesting. Due to a simple mechanical working principle they have a very long lifetime.

Similar is valid for super caps, which work on a physical principle. They can switch even faster from load to unload but are limited in storage capacity, what would result in a big number of caps to be bundled.

Very promising are the current improvements at the Li-Ion-technology. Depending on the material combination and sizing of active layers, a trade off between current and capacity can be made. With certain configurations a combined behaviour between battery and super cap can be gained. An important feature of Li-Ion batteries is that the lifetime increases over proportionally with a reduced depth of discharge (DOD).

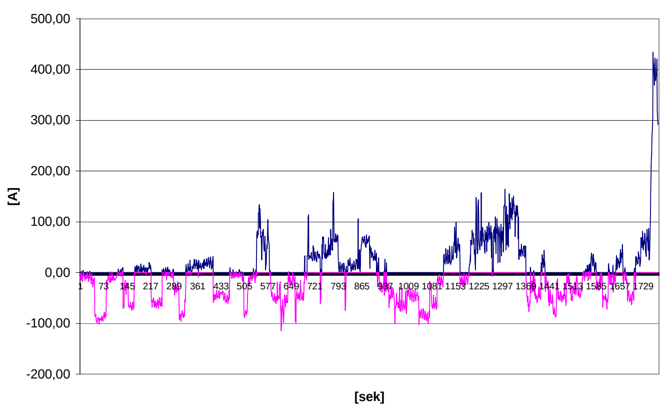

Fig. 5: typical power curve as deviation from the average

This circumstance is fortunate because the battery cells must be sized to take several 100 kWh surplus energy, while the fuel cell is transferred to a different output level. In a steady state operation the battery cell has only to compensate smaller load changes. This results in a low (DOD) and prolongs the lifetime drastically.

DC/AC CONVERSION

The board network of a ship without electrical propulsion is normally a 440 or 690 V at 50 or 60 Hz system. The fuel cell voltage varies between around 370 and 450 V direct current, depending on the operating point.

To match this with the board network a specialised inverter will be used, which incorporates frequency control, voltage regulation and back-voltage prevention. Special attention has to be put on the handling of those large currents, which requires suitable switches and breakers. Here we use the experience from our submarine colleagues.

A topic for the time being not decided is whether to connect the energy buffer in parallel with the fuel cell to one inverter or to fit both with own inverters and connect that to the network.

SYSTEM CONCEPT *SCHIBZ*

The project *SchIBZ* is a development undertaking for the above indicated fuel cell system. The system is intended to be a marine demonstrator plant, as close to a commercial application as possible. Since it is a demonstrator, which will be only temporary installed on board a ship, compromises will be made.

For example, the plant has to be completely containerised for a positioning on deck, while an integrated plant in a new building will be placed inside the machinery spaces. Also the main parts of the electronic will be integrated in the container although it could belong to the main switchboard. The heat recovery can not be shown at all – which is acceptable, because this is normal power plant engineering.

Centre of the system is the MCFC from MTU Onsite Energy. The fuel cell is a revised and upgraded version from the well known Hot Module.

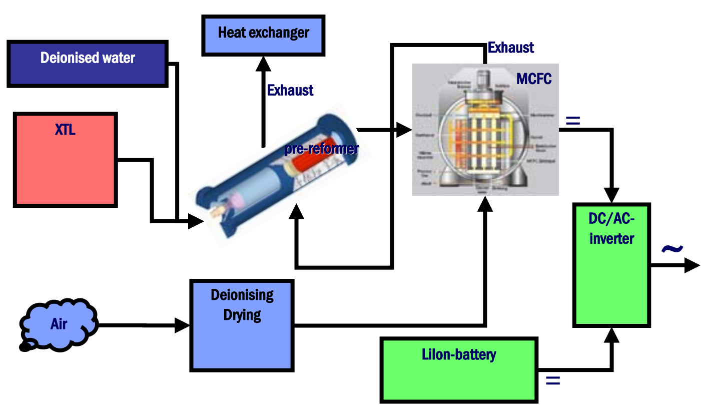

Fig. 6: system concept of the fuel cell plant *SchIBZ*

Main characteristics are the now container-like housing and an increased power of 500 kW. The most significant change is the new design of the stack, which is now self containing. This is important, since a ship makes motions and is affected by forces in all three axes.
Due to the electrical demand of the test vessel, the fuel cell will operate in the demonstrator system on maximum 350 kW.

The fuel processing will be done by a pre-refomer from EVT Aachen. This unit cracks the supplied fuel and provides the fuel cell with CH_4, CO, CO_2 and H_2. This is a high temperature endothermic process, which can be heated internally or externally.

Essentially for a high system efficiency is a low energy demand for the reformer process. With the high temperature of the fuel cell exhaust gas it is natural to use this for the heating of the reformer. Therefore a so-called steam reformer is chosen which does not need additional energy and can be integrated with the fuel cell, which includes exhaust gas heat recovery and automation.

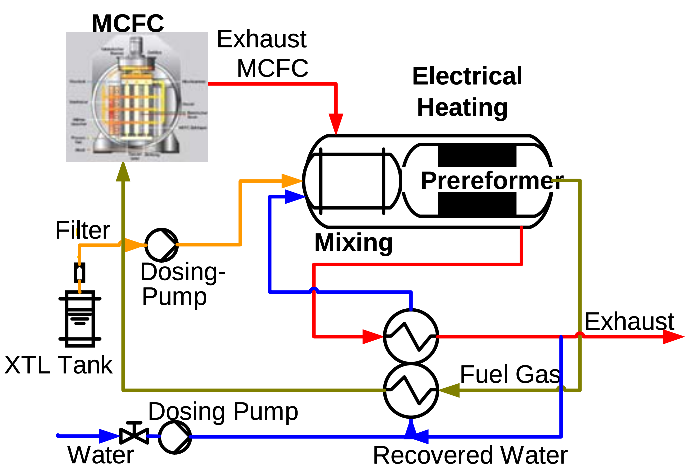

Fig. 4: Schematic of the thermal integration of Fuel Cell and Reformer (courtesy of EVT GmbH)

A sophisticated automation task is the handling of load shedding. Since the fuel cell is stressed by an emergency shut off and a restart needs a long time, our concept is to use the reformer as electrical load sink. The reformer needs an external start up heating until the exhaust gas temperature is sufficient. In the demonstrator this will be an electric one for above mentioned reason.
This irregular operation helps to keep the cell running over a certain time, in order to connect it with the net again, after the failure is rectified.

PARTNERS

The project is carried out by a consortium of 8 partners.
Leader of the consortium is ThyssenKrupp Marine Systems (TKMS). The work package of TKMS is the ship integration, practically for the test installation as well as the theoretical investigation for yachts and container vessels.
They also do the manufacturing of the system and provide the facilities for the shore test on their premises.

Supplier of the fuel cell is the aforementioned MTU Onsite Energy GmbH Fuel Cell Systems. For this project they do not deliver the gas supply, since this is substituted by the diesel reformer. This is part of the work package of EVT Gesellschaft für Energieverfahrenstechnik. They do also additional reforming tests with different fuels.

The general automation except the safety systems of fuel cell and reformer and the connection to the board network is done by HDW Hagenuk Schiffstechnik. This package includes remote control and monitoring and power management between fuel cell and battery.

The conformity with rules and regulations is supervised by Germanischer Lloyd. Their task is to control and consult design and manufacturing phase. Additionally they provide measuring equipment for evaluation purposes. The overall evaluation and analysis of the plant is carried out by the Helmut-Schmidt-University of the German Forces in Hamburg. They also develop a simulation system for automation purposes.

Fig. 5: Demonstrator test vessel MS Cellus

Finally, the vessel for the ship test belongs to the Reederei Braren. In line with their environmental efforts they are interested in advanced technologies and therefore provide a very valuable platform for the sea test phase. During the envisaged 10 months at sea the plant should experience every season and obtain many results for the development of a commercial version.

CHALLENGES FOR SHIP BOURNE APPLICATIONS

Even if we do see a ship not as a moving application like trucks or trains, it is a power plant in motion. This means, the equipment has to stand ongoing inclinations around two axes, accelerations and shocks along three axes and constant vibrations affecting all components.

This requires equipment which is designed accordingly. Especially the design of High Temperature Fuel Cells has to respect this, since the stack suffers large thermal expansions but has to be leak proof at every time. MTU is working on the new marine design for the stack which will be tested in different applications.

Furthermore, the environment at sea and inside ships is challenging. The effects of temperature range, moisture and especially the salt-content of sea-air on the membranes are unknown. While no bad influence on the reformer is expected a concept for the conditioning of the process air for the fuel cell is under investigation.

POSSIBLE APPLICATION IN YACHTS, CRUISE LINERS AND CONTAINER VESSELS

The described system is best suitable for seagoing vessels. Due to weight and size it is not very suitable for inland shipping, but for vessels operating a lot in coastal waters and with many harbour calls. Due to its characteristics it shall operate continuously. The advantages in efficiency compensate for the higher fuel costs compared with HFO used on open sea. But even this will change in favour for the fuel cells with the upcoming IMO regulations on emissions.

With the benefits of a fuel cell system (invisible smoke, no noise, lower consumption) but the higher investment we see Mega-Yachts as the first application for the introduction to commercial ship building.

These vessels must not fulfil economic requirements, although the fuel cell has advantages in running and maintenance costs.

According to first calculations is more than half of the additional investment – compared with a state-of-the-art diesel generator – compensated by the savings in fuel consumption. Including savings in maintenance and harbour emission fees the system is nearly cost neutral.

Next market is seen at the cruise liners. These ships are often operating in sensitive areas, where today emissions are regulated by taxes. The application of fuel cells for such ships can also be beneficial for harbours. Due to the lower emissions efforts for harbour side power supply are probably unnecessary.

The commercial shipping will most likely be the last market to be entered by fuel cells. The owners are traditionally very anxious to get equipment which has proved the reliability, durability and economy. Therefore it will need some successful installations to convince an owner of this technology. Anyhow, depending on the upcoming regulations worldwide these applications will be realised.

TIME FRAME

The project is planned to start in February 2009 and to run for about 4 years. The superordinated *Toplaterne* runs 5 years, to have a phase for assessing the results of the demonstration projects.

The project is structured in 4 main phases:

1. Design and development
2. Manufacturing
3. Start up and land based test in Hamburg
4. Sea test North and Baltic Sea

Each of these phases will last approximately one year.

Table 1: Basic Project Plan

	2009	2010	2011	2012
Design and development				
Assembly				
Shore test				
Ship test				

CONCLUSIONS

The presented application of the fuel cell technology onboard sea-going ships shows a solution for the near term realisation of fuel cell based power generation.

The technologies and modules are today available, just the combination has to be developed. This is no basic research but advanced engineering.

Even the economies are in the range of a black "0", so that it is the right time to start using fuel cells.

We expect the availability of commercial systems in short time after finishing the project.

ThyssenKrupp Marine Systems

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