Particle emissions from diesel engines

>> Research scientist Jørgen Bremnes Nielsen

While the automotive and other land-based industries have been obliged to produce solutions capable of reducing particle emissions, shipping has so far avoided such requirements. But as climate and the environment attract more attention, particle emissions from ships will come more and more into focus.

For this reason, MARINTEK has started to develop competence in measuring and understanding particle emissions from shipping. Although many of the problems are identical for ship and automobile engines, there is one major difference where particle emissions are concerned: fuel quality. Shipping's use of heavy fuel oil with a high content of sulphur and contaminants means that the challenges offered by particles are quite different.

MARINTEK has invested in instruments that are capable of measuring the distribution of particle sizes in the 5 – 10,000 nanometres (nm) (0.005 – 10 micrometres (µm)) range. We also measure particle mass emissions in accordance with the ISO 8178 standard.

The Electrical Low Pressure Impactor (ELPI) measures particles in the 7 – 10,000 nm range with a 12-channel (size classification) resolution. The instrument measures once per second, a rate that allows transient values to be studied. As well as indicating particle size distribution, the ELPI instrument is capable of collecting particles at the impactor stage, which permits changes in particle content with particle size to be analysed.

The Scanning Mobility Particle Sizer (SMPS) measure particles in the 5 – 1000 nm range. The resolution of this instrument depends on a number of factors, but is typically better than 100 channels. It normally takes around two minutes to scan the entire size range, which means that this instrument is not suitable for measuring transients.

Until now, our main objective has been to build up basic information regarding methods for measuring the particles emitted by marine engines and fuels. Little work has been

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Participation in international collaborative research is an important part of MARINTEK’s activities. It offers an important chance to do more basic research than we can do in industrial projects and it reinforces our network of scientific partners in Norway and abroad.

Flagship

Flagship is an EU-supported research project in which 47 leading European companies and institutions in the maritime sector have invested more than 120 man-years in the development of new and improved technology for use on board and ashore. In addition to being a major research partner, MARINTEK has also been responsible for technical management under the overall coordination of the European Community Shipowners’ Association (ECSA). Flagship was divided into 15 subprojects, in three of which MARINTEK plays a major role.

www.flagship.be

Technical Condition Index – TCI

MARINTEK led the further development of the Technical Condition Indexing scheme (TCI) to monitor and improve the technical condition of propulsion machinery. The method uses data collected on board during controlled tests and sent ashore for analysis and comparison with historical data as well as data from similar ships. An analysis report is returned to the vessel and the shore superintendent, in which the high-level condition of the system is indicated by means of “traffic lights”, with further details being provided if anomalies were detected. This provides a simple, efficient method for monitoring and benchmarking technical condition and engine performance.

Performance-based contracting

Another activity in which MARINTEK played a lead role was a study of the possibility of using Shipping KPI in a new type of performance-based contract for ship management. In theory, performance-based contracts will improve cooperation between owner and manager by sharing risks and profits more equally between them. However, it is not easy to implement such a scheme so that it works effectively and as intended. MARINTEK has developed a first set of principles for the design of such contracts.

www.shipping-kpi.com

International standards

MARINTEK has been project leader for the ISO 28005-2 standard on core data elements for electronic port clearance. MARINTEK also led the work on the IEC 61162-450 standard for Ethernet-based bridge data networks. The work was supported by the Flagship project.

Illustration: Photo courtesy of T eekay.

Illustration: Photo courtesy of BW Gas.
Recent investigations have revealed inability of telecommunication services to accommodate the maritime business sector’s requirements - both current and particularly in the immediate future. In coastal and sea areas currently available technologies for broadband wireless access, including mobile networks, are severely lagging behind, and thus prohibiting similar types of applications as in general use in urban areas to be provided with acceptable Quality of Service (QoS). MARINTEK has introduced the WiCAN (Wireless Coastal Area Network) concept to enable proliferation of innovative mobile network applications presently being widely in use on land-based wireless systems to be implemented at sea.

Requirements

The communications requirements of shipping have greatly changed in recent years. In addition to vast amounts of operational data such as navigational information, weather data, and data for performance monitoring, crew now demand opportunities to read electronic newspapers and surf the Internet, send emails, perform bank transactions and hold web chats with their family before the children’s bedtime. Ever-increasing amounts of information also require an Internet connection to obtain input from other on-line sources needed to perform essential applications. All this needs ever more bandwidth, which in turn requires an adequate communications infrastructure to support these needs for communication.

Propagation of electromagnetic waves at sea

In the projects ‘MarCom – Broadband at sea’ and ‘MarSafe High North’ we carried out a wide range of studies and experiments on wireless signal propagation at sea, and produced new results that demonstrate the potential of terrestrial solutions such as WiMAX and LTE technologies to support high bandwidth services to vessels operating along the coast. An example of our measurements is illustrated in Figure 1. The theoretical line of sight above the horizon is about 35 km, and the figure shows that signals can be transmitted slightly further than that distance, although with somewhat higher attenuation. These results will be utilized to recommend technologies and solutions capable of providing vessels with adequate bandwidth, in addition to establishing guidelines for on-board antenna arrangements that can provide reliable connections and consistent QoS performance for mobile services.

The figure shows that there is a “noise-like” RSL (Received Signal Level) for the inbound trip for distances beyond 35 km, which is due to changes in the vessel’s heading and antenna turning.

These measurements were made at 2 GHz – a relevant frequency for the new terrestrial systems referred to above. However, MARINTEK and other partners have advocated the 800 MHz band (from the ‘Digital Dividend’) as being far more advantageous for maritime applications, since, as well as having attractive propagation characteristics, this frequency range requires a relatively undemanding development process and low-cost manufacturing of radio equipment of reasonable size and weight.

Figure 1.
A new multi-purpose carriage in the MARINTEK towing tank

Research scientist Kjetil Berget

To meet the demands of increasingly demanding test configurations, a new multi-purpose carriage has been developed for MARINTEK’s towing tank. A wide range of test applications were taken into account in the design phase and the carriage can be used for both typical seakeeping tests and less conventional tests such as forced heave oscillations and lifeboat drop tests. New features such as motion actuators have also been adapted to efficiently perform series of test configurations with a minimum of delay.

The seakeeping carriage

The seakeeping carriage has been custom-designed for seakeeping tests and other tests of free or fixed/towed models. The test space, which is surrounded by the carriage structure, provides both excellent control of the model and a good viewing area for observations and video from all directions. Two fully movable work platforms provide excellent access to the models at the test location. For easy operation a crane that spans the entire test space allows most models to be lifted out of the water for inspection or repair without disconnecting the test set-up.

The multi-purpose carriage includes a 6 degrees-of-freedom hexapod motion platform, allowing forced oscillation tests, including large-amplitude PMM tests for manoeuvring studies to be performed. The hexapod is mounted on transverse rails and a pivot axis, making it capable of large sway and yaw motions. This also enables the hexapod to change rapidly between heading configurations. The hexapod can be operated in calm water and in incoming waves. This enables the engineer to isolate excitation loads from added mass, damping and restoring forces by performing tests with a clamped model in forced excitation waves in calm water.

A clamped model in waves and forced motions in calm water from: (c) 2003 Odd M Faltinsen, Sea Loads of On Ships and Offshore Structures (Cambridge University Press) used with permission.
MARIITEK seakeeping carriage in the towing tank. The hexapod is a 6 degrees-of-freedom motion actuator that is very suitable for manipulating objects with scaled vessel motions. For these tests the model was excited by forced heave motions in order to provoke ventilation of the tunnel as if it was experiencing rough seas. Both forces on the entire model and the propeller were measured.

Comparisons of local forces on the propeller and global forces on the clamped model revealed that the model may experience up to 20% higher thrust loads than the propeller. The added thrust comes from the distribution of pressure on the hull, which can be compared with the added thrust from a duct. Ventilation occurs when the top of the tunnel is close to the surface and air is sucked into the tunnel causing a sudden loss of thrust. A large number of ventilation events of various durations and local draughts were tested to provide a basis for a simplified model capable of predicting thrust loss in a time-domain simulator. The results demonstrated that thrust loss from ventilation can be modeled in a simplified manner by finding maximum thrust loss for different local draughts and the ratio of how rapidly thrust may be lost and gained when the local draught oscillates as in a seaway. These parameters were found to depend on both thrust level (power) and tunnel length.

**Typical applications:**

- Seakeeping – motions
- Seakeeping – sea loads
- Seakeeping – slamming, whipping
- Seakeeping – active control
- Directional stability tests
- Maneuvering – zig-zag tests
- Maneuvering – PMM tests
- Crabbing tests
- Dynamic positioning
- Ship-ship interaction
- Forced motion tests
- Lifeboat drop tests
- Measurement of current forces on offshore structures
- Moonpool response comparison tests for moonpool internal damping structure
- Thruster ventilation tests

**Tunnel thruster ventilation tests**

The effects of seakeeping and ventilation and hull-propeller interaction effects on tunnel thrusters are significant. These factors are critical for the available thrust and moment in dynamic positioning (DP) and other operating situations with offshore vessels. Knowledge of various loss mechanisms is essential in order to ensure correct dimensions and hull locations for tunnel thrusters. Making better design choices will ensure reliable thrust-allocation and DP systems.

In cooperation with Brunvoll AS and STX DSV AS, MARIITEK has performed model tests of ventilation and thrust loss in tunnel thrusters. The tests were performed by clamping a bow section model to a hexapod actuator mounted on the tunnel thruster.
Various devices aimed at improving the efficiency of conventionally propelled vessels have been around for at least half a century, such as the vane wheel, contra-rotating propellers and various swirl fin solutions. These devices have been employed only occasionally and with various degrees of success. However, rising fuel costs and increased environmental awareness have spurred the shipping industry to look to new and innovative energy-saving solutions. The Becker Mewis Duct® is a recently developed device for increasing the propulsion efficiency of full-form slower ships.

In the course of the past year, MARINTEK has performed extensive tests on models of three different vessels equipped with the Becker Mewis Duct®, two of which were tanker designs in the fleet of the Norwegian company Odfjell Management.

The Device consists of three to five stator fins installed inside an eccentric duct that is positioned ahead of the propeller. The function of the stator fins is to generate a pre-swirl in the propeller inflow, thus reducing rotational losses. The duct reduces axial losses by improving the wake and reducing vortex shedding. The duct also actually generates thrust because it consists of wing-profile cross-sections that take advantage of the oblique flow around the aft-body of full-form ships. Both stator fins and wake-improvement ducts are well-known concepts, but the combination of the two into one fairly simple unit is what makes the new duct a suitable product for both newbuilds and retrofits.

The model tests were carried out in MARINTEK’s towing tank, both with and without the Becker Mewis Duct® installed, in order to determine the efficiency of the device. Each of the stator fin angles was also optimized by extensive testing for each individual vessel to obtain maximum power saving. The duct models were produced in MARINTEK Ship Technology’s new 3D-printer, which has proven to be a cost-effective prototype manufacturing method that meets our requirements for high accuracy.

The model tests indicate that power savings of 6% or better could be made with the duct installed, depending on speed and loading condition. Given the good results obtained in the model tests, Odfjell Management are currently installing Becker Mewis Ducts® on several sister ships with the same specifications as the 37,500 DWT and 40,000 DWT vessels tested at MARINTEK.
Composition of the fleet is a major strategic decision that most shipping companies are making based on qualitative evaluations and the gut-feeling of experienced analysts. The MARFLIX project will establish also quantitative methods for analyzing such decisions, and hence improve the overall decision support for the investors.

Fleet size and mix - a fundamental decision

What a fleet should be composed of in terms of size and mix is a core decision for all shipping companies. In any given market situation, the number of vessels (fleet size) and the variety of vessel types (fleet mix) will determine the profit potential for the company. Operational optimization in terms of capacity utilization can only be done within the bounds imposed by the available fleet resources. History has shown that being positioned with the right fleet is even more important for profit than operational excellence, and that the most successful companies are those who are able to manage both.

Fleet size and mix - a complex decision

The basic inputs for a fleet size and mix problem (also referred to as the fleet composition problem), are the potential vessels for inclusion in the fleet and the future transport volume demand as perceived by the shipping company. If this were known, the task of finding the optimal fleet to fit the demand would still be challenging, but manageable. Unfortunately, there is a lot of uncertainty that needs to be taken into account. When building expensive vessels that need to operate for 25-30 years, future demand, prices, rates and ship technology are all uncertain factors that can have important negative impacts on future profit if fleet decisions are based on incorrect forecasts. It is therefore important that the risks involved are addressed and that the fleet composition decision-making is robust. One way of dealing with this problem is by looking at the flexibility of the fleet in coping with unforeseen events. A good mix of wholly-owned, long-term and short-term chartered vessels may provide the necessary flexibility.

The MARFLIX project

In January 2010, a four-year research project called MARFLIX (MARitime FLeet size and mix) was launched by MARINTEK, NTNU and DNV, with financial support from the Research Council of Norway. The project aims to develop and test methods for improved support for fleet size and mix decision-making. This will be done by combining analytical techniques and methods from various disciplines that are relevant for such analyses.

The project includes two PhD and two Post-doc scholarships at NTNU in addition to a significant industry case-related research activity at MARINTEK. A world-leading Ro-Ro shipping company, Wallenius Wilhelmsen Logistics (WWL), joined MARFLIX as an industry partner in 2010, and has supplied the project with excellent industry cases and experience.

The project consortiums expect that the MARFLIX project will advance the state of the art of strategic fleet planning and provide innovative methods and solutions from which the shipping industry will benefit in the future.
Particle emissions ... cont. from page 1

done in this area, so our point of departure had to be based on equipment and methods designed with the measurement of car and heavy duty engines in mind. Heavy fuel oil with its high sulphur content and two-stroke engines produce particle emissions with characteristics that mean that existing methods are not capable of producing good results.

Our aim has been to develop a measurement method that distinguishes between volatile and solid particles. Volatile particles are a result of the measurement method employed, the sulphur content of the fuel and the engine’s emissions of hydrocarbons, while the solid particles remain unchanged once they have been created during combustion. Measuring only the solid particles gives us a measurement method that allows comparisons to be made between different fuel qualities and different engines.

Measuring particle emissions from different qualities of fuel is interesting as a way of studying the effects of future requirements regarding reducing the sulphur content of heavy fuel oil. MARINTEK is also focusing on measuring the effects of exhaust scrubbing systems on particle emissions.

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WiCAN – Wireless Coastal Area Network

MARINTEK’s WiCAN concept is illustrated in the figure to the right, and comprises:

- Extended-coverage terrestrial systems that ‘illuminate’ coastal waters
- Base stations on fixed and floating offshore installations to further extend the area of coverage
- Mesh networking; utilizing other vessels, lighthouses and similar installations for Mobile Multi-hop Relay (MMR), primarily to service shadowed areas
- SatCom solutions to complement and supplement terrestrial systems, mainly beyond their coverage

Broadband at sea ... cont. from page 3

WiMAX (Worldwide Interoperability for Microwave Access) is a wireless communications standard designed for creating Metropolitan Area Networks (MANs). In its simplest form it is similar to the Wi-Fi (WLAN) standard, but supports a far greater range of coverage and an extended number of users and services with robust QoS (Quality-of-Service) capabilities. While a Wi-Fi signal can cover a radius of up to about 100 m, a fixed WiMAX station can cover a range of up to about 50 km, while mobile WiMAX stations can broadcast up to 20 km at a data rate of about 10 Mbps.

LTE (Long Term Evolution) is a 4G (4th generation) wireless broadband technology developed by 3GPP (Third Generation Partnership Project), an industry trade group. 3GPP engineers named the technology “Long Term Evolution” because it represents the next step (4G) in a progression from GSM (a 2G standard) to UMTS (the 3G technologies based on GSM). LTE provides significantly increased peak data rates, with the potential for 100 Mbps downstream and 30 Mbps upstream, reduced latency, scalable bandwidth capacity, and backwards compatibility with existing GSM and UMTS technology.