The smokeless Sulzer ZA40S

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'Smokeless' operation is rapidly becoming a requirement for marine vessels, especially for cruise and RoRo ships. Newbuildings can of course be fitted with the latest technology. But what about existing ships? Here we review two retrofit packages, 'dry' and 'wet', developed by Wärtsilä for its popular Sulzer ZA40 and ZA40S four-stroke engines.

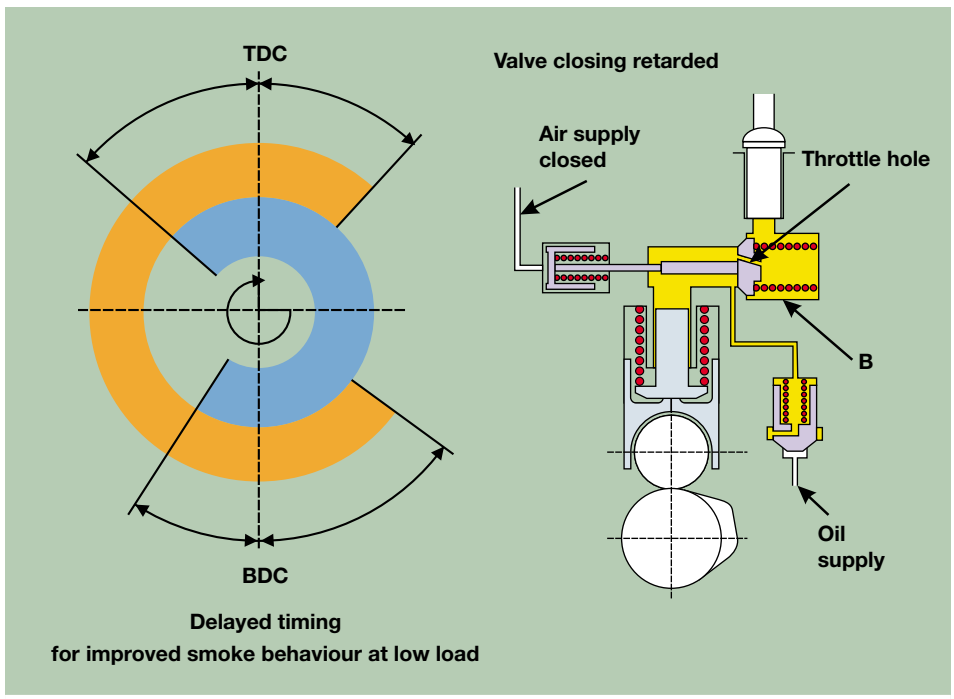

Fig. 1 - Variable inlet valve closing.

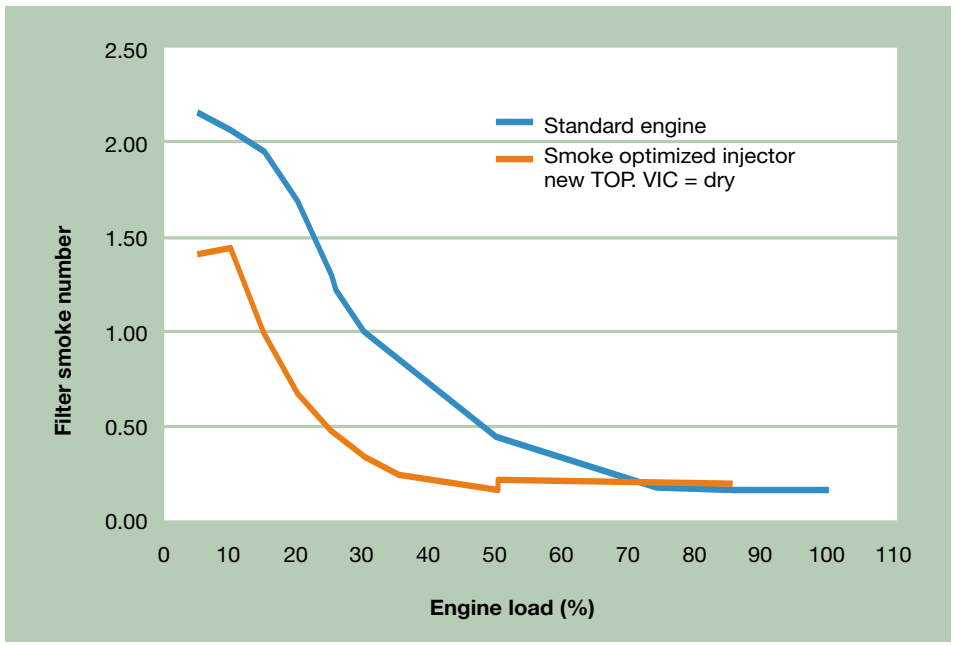

Fig. 2 - Smoke emissions, standard engine vs. dry package.

Eagle-eyed smoke observers are crowding coasts on the some of the main waters for cruise liners. Environmental issues are becoming more and more important as we should pass on Planet Earth in good shape to future generations. The implications for the marine industry are clear: we have to achieve lower emissions and better efficiency.

New engines benefit from the latest technology. We can reach quick environmental gains, however, if we make the existing engine population more environmental sound while ensuring that shipowners benefit economically as well. This can be done, for example by lowering fuel and lubrication oil consumption, and by having lower harbour fees and preventing smoke-related fines in smokeless zones like the waters of Alaska.

The Sulzer ZA40 (400 mm bore x 480 mm stroke) and Sulzer ZA40S (400 mm bore x 560 mm stroke) have been popular 4-stroke engines especially on cruise and RoRo vessels. Based on market signals a smoke reduction programme was started for the Sulzer ZA40S in which two different approaches were verified: a 'dry package' and a 'wet package'. Both packages reduce smoke considerably, but the dry package also offers reductions in fuel consumption and the wet package reductions in NO_X emissions.

The dry package consists of optimized piston, injection nozzle and anti-polishing ring combined with variable inlet valve closing (VIC). The wet package is based on emulsified fuel, called microemulsion.

The target for the programme was to reduce smoke emissions without a penalty in other engine performance parameters and to validate the functionality of the injection equipment and combustion chamber components. An additional target for microemulsion was to validate the external module for mixing microemulsion.

Final acceptance has been received from the main classification societies for Marpol Annex VI.

Smoke reduction: the dry package

Dry package optimization concentrated on optimizing the combustion space and fuel injection as well as maximizing the amount of available combustion air at low loads without reducing the high load performance.

The shape of the piston crown and the fuel injection were optimized according to experiences from other Wärtsilä engines. The amount of combustion air was maximized using variable inlet valve closing (VIC). Retarded inlet valve closing at low loads

results in increased combustion air in Miller cycle engines. At high loads the inlet valve closes before the bottom dead centre, as is normal in the Miller cycle. The operating principle of VIC is shown in Figure 1.

The space between the valve tappet and push rod is filled with oil. In normal high-load operation the throttle valve B is open, oil can flow freely and the push rod moves according to the cam lobe.

At low loads the throttle valve is closed, which results in delayed closing of the inlet valve as the return oil flow between the tappet and push rod is throttled. The inlet valve is opened in the normal way by the tappet as the tappet pushes the throttle valve open hydraulically. VIC is built on the engine and no external mechanical system is necessary. A simple automation system is used for control air.

Smoke reduction with the dry package compared to a standard engine in constant speed operation is shown in Figure 2. At 25% load the smoke is reduced from FSN 1.3 with a standard engine down to FSN 0.5 when using the dry package.

In addition to smoke reduction, the specific fuel consumption was also reduced at all loads: 2-5 g/kWh depending on the load. The reduction is shown in Figure 3.

The benefits when using the dry package include significantly reduced smoke emission, lower fuel consumption, lower lubrication oil consumption and reduced liner wear. Lower lubrication oil consumption and reduced liner wear are achieved by using the anti-polishing ring.

Dry package technology is proven and as most of its components are replaced during overhauls, the only additional investment is the variable inlet valve closing and the anti-polishing ring. Economic calculations have shown that a payback time of less than two years can be achieved.

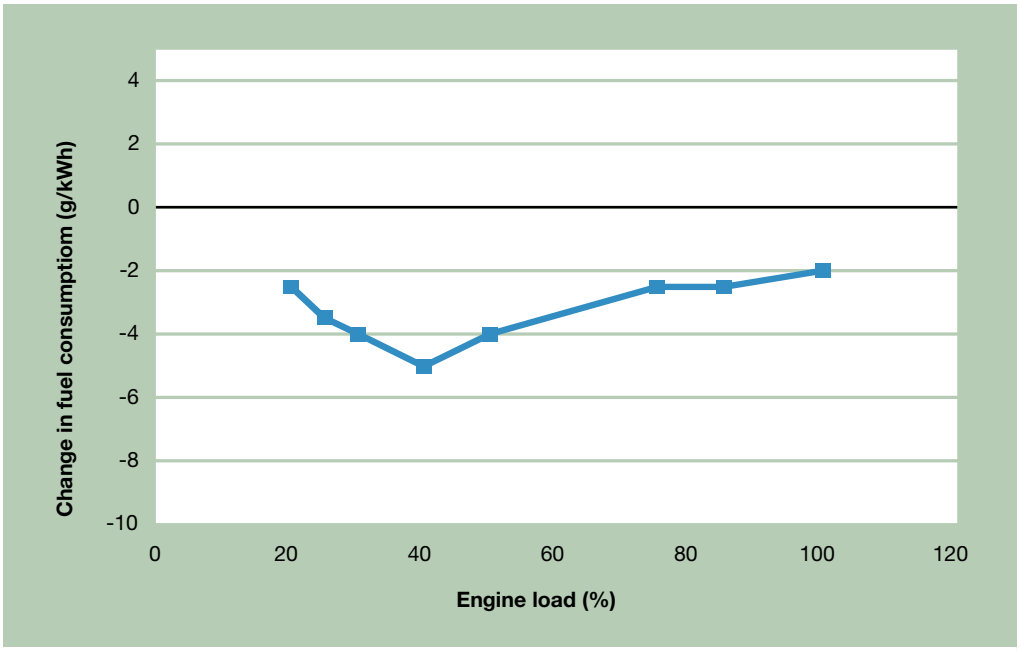

Fig. 3 - Reduction of specific fuel oil consumption using the dry package.

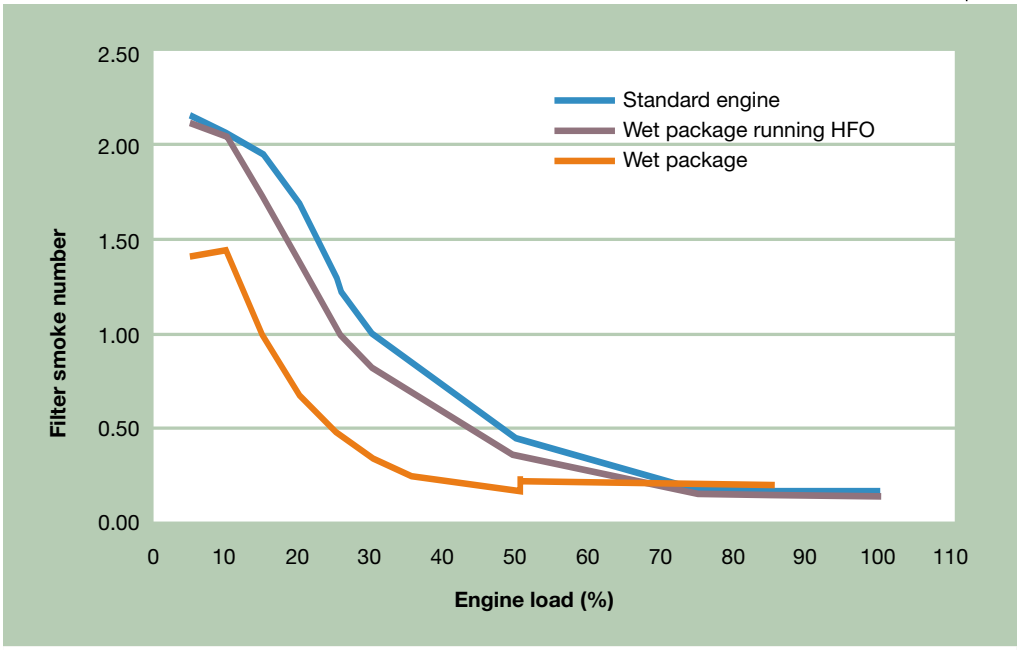

Fig. 4 - Evidence of smoke when using microemulsion on a conventional engine vs. engine with the dry package, Sulzer 6LZA40S.

Smoke reduction: the wet package

Wärtsilä has tested water-fuel emulsion several times. The focus has been on NO_X reduction and no other positive effects were recorded at those times. Making and handling the emulsion in the fuel system was not that easy and the stability of the emulsion was not good.

However, when a new method of making the emulsion was introduced, it deserved a closer look. Microemulsion is created in a device called a turbotransducer, which is basically a cavitation chamber. Heavy fuel oil and water are mixed at a pressure of 20 bar and high-flow velocities cause a vortex, which creates an emulsion with small water droplets in the fuel grid.

The module supplier claims that the droplet size is 3-6 microns, which would be much less than competing technologies can offer. The droplet size is important in two respects: it helps the emulsion to stay stable, and it improves the combustion behaviour as the fuel and water in the fuel jet are less likely to separate than with big droplets. Test results have shown that microemulsion is more stable than previously tested emulsions and the engine performs better as well.

Using microemulsion as the fuel increases the total amount of injected liquid. This also raises the injection pressure, which improves atomization in an engine with conventional fuel injection. However, the mechanical load on the pump drive and camshaft also increases. The nozzle size was optimized to keep stresses below the set limits.

The fuel pump capacity, likewise, sets limits on the amount of water that can be used. The ignition delay was generally slightly increased. This becomes more obvious at low loads when running with high amounts of water. The duration of combustion was not increased.

During the optimization stage seven different injection nozzle configurations were tested in combination with three different water-to-fuel ratios. The optimum combination for the Sulzer ZA40S is a 5% larger nozzle size and water-to-fuel ratio of

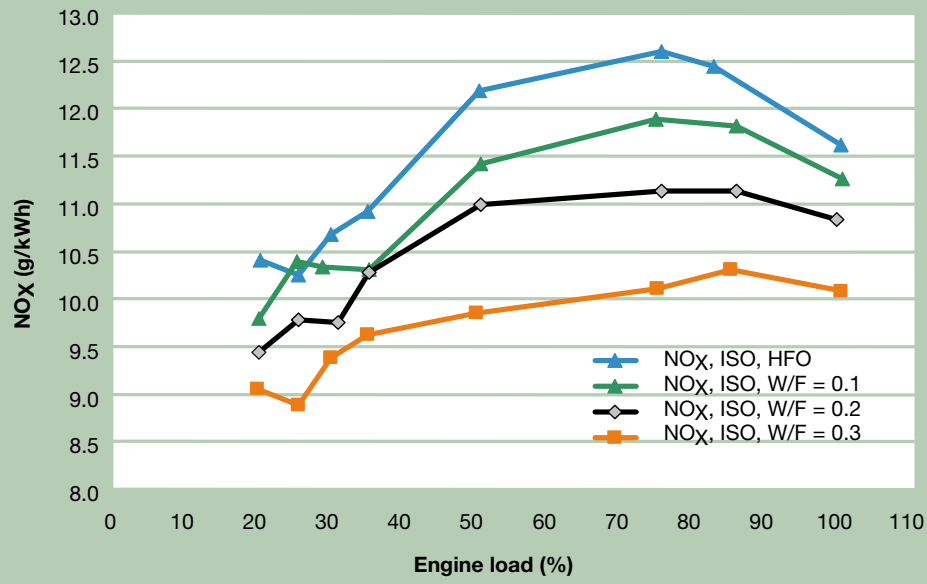

Fig. 5. - NO_X reduction with the wet package.

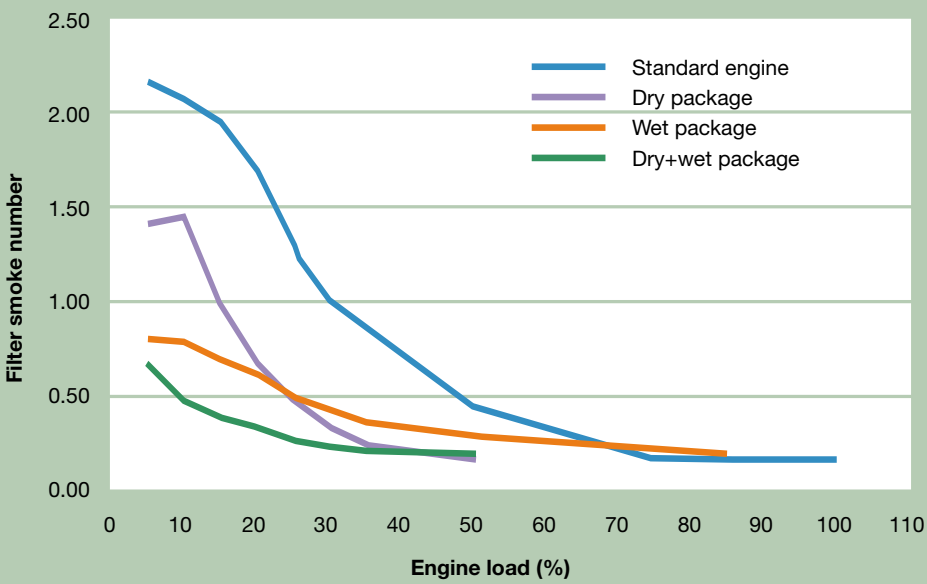

Fig. 6 - Summary of smoke reduction packages.

0.2 when taking into account engine performance and the above considerations. Smoke reduction with 0.2 water-to-fuel ratio is equal when compared to higher water-to-fuel ratios.

Smoke reduction using the wet package is shown in Figure 4. At 25% load smoke has been reduced from FSN 1.3 with a standard engine down to FSN 0.5 using microemulsion. This is the same FSN value as with the dry package.

One important target for the optimization was that the performance of the microemulsion-optimized engine should not be worse than the standard engine also when running on normal heavy fuel oil. Figure 4 shows that smoke emission is equal or even better also in this respect.

It is well known that introducing water into the combustion chamber decreases NO_X emissions. When water is introduced during compression or combustion there is general rule of thumb that a one percent addition of water results in a one percent NO_X reduction. However, in this case the reduction was slightly lower. NO_X reduction is shown in Figure 5.

It was also expected that fuel consumption would deteriorate due to lost compression work by water evaporation, but no negative effect could be measured. In fact, in tests with some other engines a small improvement has been noted when running with microemulsion. When adding all the results together – lower smoke and NO_X as well as no penalty in fuel consumption and same duration of combustion – it is believed that any negative effect arising from the evaporation of water in the cylinder is counteracted by improved combustion.

Tests performed so far confirm that microemulsion is a feasible method of improving engine performance. Long-term endurance testing will show whether component lifetimes are on the expected level.

The benefits of the wet package for engine operators include:

- Significant smoke reduction, and
- A NO_X reduction of roughly 1% NO_X to 1% water with no change in mechanical load or other operating parameters like fuel consumption, turbocharger speed, firing pressure and component temperatures.

The best results can be achieved by combining both methods. At 25% load smoke is reduced to below FSN 0.3 and at 10% load the filter smoke number is less than 0.5. The results are shown in Figure 6. At the same time fuel consumption is reduced by 2 – 5 g/kWh depending on the load.

Field testing of smoke reduction packages

The development programme will continue with a field test with extended running hours. The behaviour of the engine components with microemulsion will be evaluated. Special attention will be paid to the combustion chamber components in relation to corrosion, and the injection equipment in relation to cavitation.

The first step of the validation has been completed at the Trieste Engine Laboratory in Italy now that all the necessary temperature, stress and pressure measurements have been performed. In addition an endurance test was run and test results have been promising as no corrosion or cavitation was observed.

A field test is planned during 2005 depending on the maintenance schedule of the selected installation.

The dry package is a technically proven solution. Also measurements on the laboratory engine show that all critical parameters are well within limits. The dry package will be installed in four vessels starting in June 2005 and they will of course be monitored very closely. ■