This is a summary of Wärtsilä’s approach to design and technology in the Wärtsilä 46 engine.

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Due to its excellent combustion performance and reliability level the Wärtsilä 46 has become the most popular engine for power generation onboard new cruise vessels. Liberty of the Seas is equipped with six 12-cylinder Wärtsilä 46 V-engines with a total output of 75,600 kW.

### DESIGN PHILOSOPHY

Wärtsilä engine designs are based on generations of know-how combined with innovations in response to customer needs. The WÄRTSILÄ® 46 engine offers customers the following core values:

- Real reliability
- Low operating costs
- Low exhaust gas emissions
- Easy and cost-effective installation
- Proven flexible mounting technology
- Easy maintenance

### DEVELOPMENT POLICY

The Wärtsilä 46 is a medium-speed engine for which reliability and total economy have been the guiding principles.

Extensive testing in our modern diesel laboratory backed up by several thousand running hours have made the Wärtsilä 46 a really reliable diesel engine. Laboratory testing is full-scale engine testing: it covers various types of endurance testing, and also combustion measurements and system optimizations. All these confirm theoretical calculations, simulations as well as performance mapping of such factors as heat balance, fuel and lube oil consumption, exhaust emission, noise and vibration level.

Wärtsilä works in close co-operation with the customer in conducting field tests and follow-ups of selected test components. Data on wear rates, maintenance intervals and consumption rates are collected regularly. This activity is part of a long-term customer relationship creating an even better product.

The Rio Negro Power Master plant in Manaus, Brazil. The plant has a total capacity of 158 MW and is equipped with ten 18-cylinder Wärtsilä 46 engines as prime movers.
EXHAUST EMISSIONS

The emphasis on environmental issues has steadily grown and it is expected to grow further in the future. The main focus has been on nitrogen oxides (NOX) emissions, sulphur oxides (SOX) and particulate emissions. Lately much attention has been paid to CO2 due to the Kyoto Protocol and in the marine sector smokeless operation has become important especially for cruise ships.

- CO2 and SOX emissions are practically directly proportional to the carbon and sulphur content of the fuel and the fuel consumption. The superior fuel efficiency of diesel engines therefore gives lower CO2 and SOX emissions than most other power sources, when comparing operation on the same fuel.
- Generally diesel engines have very low CO and THC (Total HydroCarbon) emissions compared to other power sources thanks to the efficient combustion.
- Smoke is by definition visible. In the exhaust from a diesel engine smoke consists of soot particles that are large and concentrated enough to become visible. Smokeless operation at any load is achieved with common rail fuel injection, which maintains an optimum fuel injection pressure also at low load and reduced speed. The ash content of the fuel strongly affects both smoke and particulates.
- The factor that has the most significant influence on NOX formation is the temperature. Therefore the most successful approach to lower NOX emissions is to reduce the peak temperatures during the combustion. The available means to achieve stable and low combustion temperatures can be divided into dry methods and wet methods.
- Dry methods involve optimum shape of the combustion chamber, high compression ratio, sophisticated fuel injection equipment and adapted cam profile, optimised turbocharging system for correct air to fuel ratio and internal cooling of the cylinder by earlier closing of the air intake valves (Miller concept).
- The principle of wet methods is to introduce water into the combustion chamber. Wärtsilä has developed a new technology for addition of water named Wetpac humidification, which briefly described means that pressurized water is injected directly after the compressor of the turbocharger. Less water is required if it is injected directly into the cylinder. The Wärtsilä 46 is available also with Direct Water Injection (DWI) (only for marine applications). Direct water injection is an option for low sulphur fuel. Wetpac humidification and DWI can be applied in addition to the dry methods already utilised to achieve further NOX reduction.
- Selective catalytic reduction (SCR), which is external from the engine, offers the highest possible NOX reduction. The standard engine meets the NOX level set by IMO (International Maritime Organisation) in Annex VI to MARPOL 73/78, and the World Bank Group specified in “Thermal Power: Guidelines for New Plants, 1998” for engine driven power plants in “non-degraded air sheds”. All marine engines are delivered with an EIAPP (Engine International Air Pollution Prevention) certificate, technical file and marked engine components as required by the NOX Technical Code in MARPOL 73/78 Annex VI.
The NO\textsubscript{X} reduction technology developed by Wärtsilä is named Wetpac humidification. The principle of Wetpac humidification is to introduce water with the intake air to reduce the combustion temperature and thereby the formation of NO\textsubscript{X}. Pressurized water is injected directly after the compressor of the turbocharger. The high temperature of the compressed air evaporates the water, which enters the cylinders as steam. A water mist catcher prevents water in liquid state from entering the cylinders. The maximum NO\textsubscript{X} reduction is typically 30-50\% depending on application specific limitations, and the water consumption is normally up to two times the fuel oil consumption.

**DIRECT WATER INJECTION (DWI)**

Direct Water Injection reduces NO\textsubscript{X} emissions typically by 50-60\% without adversely affecting the power output. Built-in safety features enable immediate water shut-off in the event of excessive water flow or water leakage. The water system is completely separate from the fuel system: if water shut-off should prove necessary, engine operation is not affected. The water-to-fuel ratio is typically within the range 0.4-0.7. Direct water injections is an option for low sulphur fuel (below 1.5\%).
**FUEL SYSTEM**

The Wärtsilä 46 is available with conventional fuel injection, or optionally with common rail fuel injection for smokeless operation also at low load.

The entire fuel system is enclosed in a fully covered compartment for maximum safety. All leakages from injection valves, pumps and pipes are collected in closed system.

**CONVENTIONAL FUEL INJECTION**

- The monoelement injection pump design is a rigid, distortion-free solution for high injection pressures.
- A constant pressure relief valve in the injection pump eliminates the risk of cavitation erosion by maintaining a residual pressure, which is on a safe level over the whole operating field.
- A drained and sealed-off compartment between the pump and the tappet prevents leakage fuel from mixing with lubricating oil.
- Precalibrated pumps are interchangeable.
- The injection valve is designed to have a small heat absorbing surface facing the combustion space. Together with efficient heat transfer to the cooling water this eliminates the need for a separate nozzle temperature control system.

**COMMON RAIL FUEL INJECTION**

The common rail system comprises pressurizing fuel pumps, fuel accumulators and electronically controlled fuel injectors. The fuel pumps are driven by the camshaft and each pump and accumulator serve two cylinders. Adjacent accumulators are connected with small bore piping in order to reduce the risk of pulsation in the rail. The engine can operate with one or two fuel pumps disconnected, should this ever be necessary. A safety feature of the system is that there is no pressure on the injection nozzles between injections. All functions are controlled by the embedded control system on the engine.

The main advantage of the common rail system is that the injection pressure can be kept at a sufficiently high level over the whole load range, which gives smokeless operation also at low load.

**FUELS**

The Wärtsilä 46 engine is designed and developed for continuous operation on fuels with the following properties:

**DIESEL OIL & HFO**

Diesel oils (distillate oils) have traditionally been the fuels for diesel engines. Heavy fuel oils (HFO) have been used in Wärtsilä engines since the 1970’s. During the recent years, oil refineries have developed processes to increase the yield of high-revenue products resulting in poorer quality residues. This means higher sulphur content, higher ash content and worse combustion properties.

**HIGH VISCOITY Hfos**

Among the recently approved fuels, there are varieties of high-viscosity mineral oils that can be found either naturally in e.g. oil-sand or as heavy residues from oil refineries.

**CRUDE OILS**

Crude oils are especially suitable for pumping stations along crude oil pipelines and for electricity production at oil fields. Crude oils have been in frequent use as fuels for Wärtsilä engines at power plants and oil pumping stations since mid 1990-ties.

**EMULSIFIED FUELS**

Emulsification offers means of utilising fuels with even higher viscosity. Among the emulsified fuels, the Venezuelan Orimulsion® is already in commercial use and other qualities are being evaluated. The high water contents in these fuels facilitate the handling of these fuels almost in the same way as conventional fuel oils and they have advantageous effects on the exhaust gas emissions. These fuels will be of importance in the future.

**LIQUID BIO FUEL**

Vegetable based bio oils have been accepted for Wärtsilä engines since 1996 and they have found commercial use for diesel power plants. Olive oil, palm oil, soy bean oil and rape seed oil are some of the main qualities among the bio oils, all usable as diesel fuel. Biodiesel, transesterified bio oil, can also be used.
Wärtsilä 46 is provided with Spex (Single pipe exhaust) system and with high efficiency turbocharger.

- The Spex turbocharging system is an exhaust gas system that combines the advantages of both pulse and constant pressure charging.
- Compared with a constant pressure system, the ejector effect of the gas pulses will provide better turbine efficiency at partial loads.
- The Spex system is practically free from interference. This means very small deviations in the scavenging between the cylinders and consequently an even exhaust gas temperature.
- The modular-built exhaust gas systems are durable enough to handle high pressure ratios and pulse levels, but at the same time elastic enough to cope with thermal expansion in the system.
- The turbocharger has the highest available efficiency.
- The turbocharger is equipped with plain bearings and there is no cooling water.
- The turbocharger is fitted with cleaning devices for both the compressor and the turbine side.
- Exhaust waste-gate and air by-pass are used to obtain specific requirements on the operating range, load response or partial load.
PISTON
- A composite low-friction piston with a nodular cast iron skirt and a steel top.
- The special cooling gallery design assures efficient cooling and high rigidity for the piston top. The design can handle combustion pressures beyond 200 bar.
- Hardened top ring grooves assure a long lifetime.
- Low friction is ensured by the skirt lubrication system featuring:
  - A well distributed clean oil film that eliminates the risk of piston ring scuffing and reduces the wear rate.
  - Cleaner rings and grooves free from corrosive combustion products.
  - Hydraulically damped tilting movements provided by an oil pad between the liner and the piston, resulting in less noise and wear.

PISTON RING SET
- Low friction three-ring set
- Special wear resistant coating for the compression rings
- Dimensioned and profiled for maximum sealing and pressure balance

CYLINDER LINER AND ANTI-POLISHING RING
Cylinder liner deformations are normally caused by cylinder head clamping, thermal and mechanical load. Thanks to a special design with a high collar-to-stroke ratio, the deformations in this liner are very small. A round liner bore in combination with excellent lubrication improves conditions for the piston rings and reduces wear.

To eliminate the risk of bore polishing, the liner is provided with an anti-polishing ring in the upper part. The purpose of this ring is to “calibrate” the carbon deposits on the piston top land to a thickness small enough to prevent contact between the liner inner wall and the deposits on the piston top land. “Bore-polishing” can lead to local liner wear and increased lube oil consumption.

The temperature distribution in the cylinder liner is important not only in terms of stress and deformation but also decisive for the cylinder liner wear rate. The temperature must remain above the sulphuric acid dew point to avoid corrosion, but at the same time remain sufficiently low to avoid lubricating oil breakdown.

The material composition is based on long experience with the special grey cast iron alloy developed for excellent wear resistance and high strength.
**CONNECTING ROD**

The connecting rod is a three-piece marine design, where combustion forces are distributed over a maximum bearing area and where the relative movements between mating surfaces are minimized.

- Piston overhauling is possible without touching the big end bearing and the bearing can be inspected without removing the piston.
- The three-piece design also reduces the piston overhauling height.
- All nuts are tightened with hydraulic tool.

**CRANKSHAFT**

The crankshaft design allows for use of high combustion pressure and still maintains a conservative bearing load.

The crankshaft is:

- Forged in one piece and fully machined.
- Rigid due to moderate bore/stroke ratio and large pin and journal diameters.
- Fitted with counterweights on every crankweb.
- Designed for full power take-off, also from the free end.

**CYLINDER HEAD**

The cylinder head design is based on reliability and easy maintenance.

- A rigid box like design for even circumferential contact pressure between the cylinder head and the cylinder liner.
- Four cylinder head fixing bolts are used, which simplifies maintenance.
- No valve cages are used; this improves reliability and provides greater scope for optimization of the exhaust port flow characteristics.
- Efficient water-cooled exhaust valve seat rings.
- Valve rotators on both exhaust as well as inlet valves guarantee an even thermal and mechanical load on the valves.
CAMSHAFT AND VALVE GEAR
The camshaft is built of single cylinder sections with integrated cams.
• The camshaft sections are connected through separate bearing journals, which makes it possible to remove the shaft sections sideways from the camshaft compartment.
• The valve follower is of the roller tappet type, where the roller profile is slightly convex for good load distribution.
• The valve mechanism includes rocker arms working on yokes guided by pins.
• Both exhaust and inlet valves receive a forced rotation from Rotocaps during every opening cycle. This forced rotation provides for even temperature distribution and wear of the valves, and keeps the sealing surface free from deposits. Good heat conduction is the result.

BEARINGS
The Thick-Pad bearing design emphasizes one key concept: Reliability.
The bearing loads have been reduced by increasing crankshaft journal and pin diameters as well as length.
• Low bearing loads allow for softer bearing materials with greater conformability and adaptability. This makes the bearing virtually seizure-free.
Engine Block

- The engine block is manufactured of nodular cast iron in order to achieve the rigid and durable construction needed for resilient mounting.
- The main bearings are of the underslung type, with hydraulically tightened bolts.
- Side bolts add further rigidity to the main bearing housing.
- In-line engines are equipped with an integrated air receiver featuring increased rigidity, simplicity and cleanliness.
RESILIENT MOUNTING

RESILIENT MOUNTING – POWER PLANT APPLICATIONS
A Wärtsilä 46 engine mounted on a common base frame with steel springs under the generating set. This kind of installation can be used both for land-based and floating power plants.

RESILIENT MOUNTING – MARINE APPLICATIONS
In marine applications resilient mounting is used for preventing structure borne vibrations.
COOLING SYSTEMS

- The fresh water cooling system is divided into high temperature and low temperature cooling systems.
- The high temperature cooling water system operates constantly at a high temperature level to make the temperature fluctuations in the cylinder components as small as possible and preventing from corrosion due to undercooling.
- For obtaining maximum heat recovery the charge air cooler is split into a high and low temperature section.
- Engine driven pumps can be provided as an option for marine application. In power plant application, these are standard.

LUBRICATING OIL SYSTEM

- Marine engines have dry sump and power plant engines wet sump. The lube oil is treated outside the engine by continuous separating.
- On the way to the engine, the oil passes through a lube oil cooler, a full flow automatic filter unit and a safety filter for final protection.
- For the purpose of running-in, provision has been made for mounting special running-in filters in the crankcase in front of each main bearing.
- Engine driven lube oil pump can be provided as an option for marine application. In power plant application this is standard.
AUTOMATION SYSTEM

The Wärtsilä 46 is equipped with a modular embedded automation system, Wärtsilä unified controls - UNIC, which is available in three different versions. The basic functionality is the same in all versions, but the functionality can be easily expanded to cover different applications.

UNIC C1 and UNIC C2 are versions applicable for engines with conventional fuel injection, whereas UNIC C3 additionally includes fuel injection control for engines with common-rail fuel injection.

UNIC C1

In the UNIC C1 engine automation system, the fundamental aspects of the engine control and safety are handled by the embedded control and management system. This includes engine speed and load control as well as overspeed protection, lube oil pressure and cooling water temperature protection. For the other parts, the design requires the majority of the sensors to be hardwired to an external alarm and monitoring system.

The following functionality is provided:
- Fundamental safety (overspeed, LO pressure, cooling water temp.)
- Basic local monitoring
- Hardwired interface to external alarm and monitoring systems
- Speed and load control

The engine control system is designed to:
- Achieve the highest possible reliability, with components, e.g. sensors, designed specifically for the on-engine environment,
- Reduce cabling on and around the engine, with a clear point of interconnection and a standardized interface, and
- Provide high performance with optimized and pre-tested controls.
UNIC C2/C3
The UNIC C2 and C3 engine automation system provides a completely embedded engine management system, which in case of common rail fuel injection has integrated electronic control of the fuel injection. This is a distributed and bus-based system in which the monitoring and control function is placed close to the point of measurement and control. This significantly simplifies both the on- and off-engine wiring. Additionally, the advanced functions in the system, e.g. for diagnostics and control, provide outstanding performance and reliability,
and the need for off-engine systems is considerably reduced.

The system meets the highest requirements for reliability, with selective redundancy and fault-tolerant designs, and can be applied to single main engine operation.

The following functionality is provided:

- Complete engine safety system
- Complete local monitoring, including all readings, events and diagnostics
- Speed and load control
- Complete engine control, including start/stop, load reduction request, etc.
- Alarm signal provision
- Full system diagnostics
- Fieldbus interface
- Combustion control, EFIC, for diesel or gas applications
- Redundant control strategies, and fault-tolerant operation

The engine control system is designed to:

- Provide a compact embedded engine control and management system for space-saving applications,
- Reduce installation and commissioning time by providing a very simple fieldbus-based interface that is delivered pre-tested and fully operational from the factory,
- Achieve the highest possible reliability with components, e.g. sensors, designed specifically for the on-engine environment,
• Considerably reduce cabling on and around the engine through a bus-based architecture, with a clear point of interconnection and with a standardized hardwire and fieldbus interface,
• Provide high performance with optimized and pre-tested controls, and
• Act as an easy and convenient calibration and service tool for on-line tuning and system diagnostics.

MAINTENANCE

During design and development the engine manufacturer emphasizes the necessity of easy maintenance by including tooling and easy access in the basic design and by providing easy-to-understand instructions.

• The Wärtsilä 46 maintenance principle is substantiated by the following:
  • A cylinder head with four fixing studs and simultaneous hydraulic tightening of all four studs.
  • A hydraulic jack for the main bearing overhaul.
  • Uniform one-cylinder camshaft pieces.
  • Slip-on fittings are used wherever possible.
  • Exhaust gas system insulation by using easy-to-remove panels on a frame that is mounted flexibly on the engine.
  • The three-piece connecting rod allows inspection of the big end bearing without removal of the piston, and piston overhaul without dismantling the big end bearing.

WÄRTSILÄ 46 MAIN TECHNICAL DATA

<table>
<thead>
<tr>
<th></th>
<th>Ship Power and</th>
<th>Ship Power</th>
<th>Cylinder bore</th>
<th>460 mm</th>
<th>460 mm</th>
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<tbody>
<tr>
<td>Piston stroke</td>
<td>580 mm</td>
<td>580 mm</td>
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<tr>
<td>Cylinder output</td>
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<tr>
<td>Engine speed</td>
<td>500, 514 rpm</td>
<td>500, 514 rpm</td>
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<tr>
<td>Mean effective</td>
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<td>28.0, 28.8 bar</td>
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<td>Pressure</td>
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<td>Piston speed</td>
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<td>Fuel specification:</td>
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<td>Fuel oil 730 cSt/50°C</td>
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Data for Ship Power engines

<table>
<thead>
<tr>
<th>Engine type</th>
<th>Rated power</th>
<th>Dimensions (mm) and weights (tonnes)</th>
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<tr>
<td></td>
<td>500, 514 rpm</td>
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<tr>
<td></td>
<td>kW</td>
<td>bhp</td>
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<td></td>
<td>975 kW/cyl</td>
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Data for Power Plant engines

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<tr>
<th>Technical data 50 Hz/500 rpm</th>
<th>Unit</th>
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<th>18V46</th>
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<tr>
<td>Power, electrical kW</td>
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<td>17076</td>
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<td>Heat rate, kJ/kWh</td>
<td>7692</td>
<td>7669</td>
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<tr>
<td>Electrical efficiency %</td>
<td>46.8</td>
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</table>

Technical data 60 Hz/514 rpm

| Power, electrical kW         | 11349| 17076 |
| Heat rate, kJ/kWh            | 7692 | 7669  |
| Electrical efficiency %      | 46.8 | 46.8  |

Dimensions and dry weight with generating set

| Length (mm) | 15400 | 18260 |
| Width (mm)  | 5090  | 5090  |
| Height (mm) | 5700  | 5885  |
| Weight (tonne) | 265 | 358   |

Heat rate and electrical efficiency at generator terminals, including engine-driven pumps. ISO 3046 conditions and LHR. Tolerance 5%. Power factor 0.8.
Wärtsilä enhances the business of its customers by providing them with complete lifecycle power solutions. When creating better and environmentally compatible technologies, Wärtsilä focuses on the marine and energy markets with products and solutions as well as services. Through innovative products and services, Wärtsilä sets out to be the most valued business partner of all its customers. This is achieved by the dedication of more than 17,000 professionals manning 160 Wärtsilä locations in 70 countries around the world. Wärtsilä is listed on The Nordic Exchange in Helsinki, Finland.

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