Dual-Fuel Upgrade
As the availability of natural gas increases worldwide, gas powered engines are becoming more and more attractive for power generation in land-based and marine applications. Operators are looking for solutions that make use of gas in their existing diesel engines wherever possible.

Dual-fuel engines provide the ability to run on either gas or liquid fuels. Upgrade solutions for upgrading existing diesel engines to dual-fuel capability are a suitable way to benefit from the economical and environmental advantages of gas operation.

MAN Diesel & Turbo provides dual-fuel upgrade solutions based on the latest state-of-the-art technology, enabling engine operation with higher efficiency and lower emissions in combination with a lifetime extension.
MAN Diesel & Turbo currently offers two dual-fuel engine types in its four stroke large bore program: 32/40DF for stationary application and 51/60DF for marine or stationary application. Both types are based on the existing and well-proven 32/40 and 48/60 engines with heavy fuel oil (HFO) capability. In addition, MAN Diesel & Turbo offers suitable dual-fuel retrofit solutions for both HFO diesel engines 32/40 and 48/60. They are designed and working according to the same principles, however show differences in their technical details. In the near future more dual-fuel retrofit solutions for other engine types will be designed and introduced to the market.

Fuel flexibility
Dual-fuel engines combine the ability to run on either liquid or gaseous fuels. A variety of fuels can be used, such as natural gas in broad qualities and all kinds of liquid fuels incl. HFO. The 32/40DF is designed to run on DMB qualities (MDO) in liquid mode. The wide variety of applicable gaseous and liquid fuels generally secures a high level of plant availability. In a scenario of fluctuating fuel prices, operators can choose the most economic fuel depending on the current price differences.

Dual-fuel operation
Generally, the air-gas mixture in MAN dual-fuel engines is ignited by pilot injection of distillate fuel. For the combustion process at full load, about 1% of the required energy is represented by pilot fuel and 99% is gas or liquid fuel. The pilot injection is always activated: in gas mode for ignition purposes and in liquid mode to prevent clogging at the of the pilot injectors nozzle holes. The 51/60DF engine features an electronically controlled pilot injection system based on common rail technology with one pilot injector in each cylinder head. The common rail pump is electrically driven and provides up to 1,600 bars of injection pressure. The pilot fuel system of the 32/40DF consists of a mechanically cam-driven pump for each cylinder which feeds two pilot injectors in each cylinder head. Dual-fuel engines, which are derived from diesel engines, have an adapted compression ratio and thus, in comparison to their pure diesel equivalent, a reduced mean effective pressure. This is necessary for gas combustion in order to prevent knocking. One of the major advantages of MAN Diesel & Turbo dual-fuel technology is the low pressure gas application, which does not require a high pressure gas compressor for gas injection. Its absence is advantageous, resulting in a lower investment and no additional electrical losses for the operation of such plant equipment.

In liquid fuel mode, uninterrupted heavy fuel oil operation of the 51/60DF is possible in a power range from 100% to 20% and even, for limited periods, below 20%. The so-called “low-load” capability even enables the customer to operate the 51/60DF on loads below 15% MCR in gas mode for a noticeable duration. This technical ability can be realized by newest MAN Diesel & Turbo technology.

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Engine data for 32/40DF
- Application: Stationary
- Bore: 320 mm
- Stroke: 400 mm
- Swept volume per cylinder: 32.2 dm³

Engine data for 51/60DF
- Application: Marine (Genset, CPP) or Stationary
- Bore: 510 mm
- Stroke: 600 mm
- Swept volume per cylinder: 122.6 dm³

Gas quality:
- Natural gas with methane number ≥ 80,
- min. LCV = 28,000 kJ/Nm³*, deviating gas qualities require engine derating

*Values in m³/N at 0°C and 1,013 bar

The fuel consumption is based on a lower calorific value (LHV) of the fuel of 42,700 kJ/kg without engine driven pumps. Tolerance 5%. Lubricating oil consumption value is given with a tolerance of +20%. MCR = maximum continuous rating.
Fuel Flexibility

Switching between fuels
One of the major advantages of modern MAN Diesel & Turbo dual-fuel engines is the ability to switch over from gaseous fuel to liquid fuel at almost all load points during normal operation. The 51/80DF engine can seamlessly switch from gas to diesel at any time and load. Even at full load no loss of engine output or speed is measurable and the engine will not trip. Therefore, operation on diesel is a back-up mode for those operators who cannot rely on their gas supply. Switching over from liquid fuel to gas is a normal procedure during every engine start-up. Generally, a dual-fuel engine is started on liquid fuel and is switched to gas after a few minutes. The switch over is normally executed at loads higher than 15% and takes about two minutes. During the normal switch over the combustion residuals from the liquid start-up are burnt and do not result in hot spots which, in gas mode, would lead to knocking events. If the engine is scheduled to stop, it is switched to liquid fuel again and stopped in liquid mode.

Improvement of Emissions
Like pure gas engines, dual-fuel engines running in gas mode have a favorable emission profile in regard to nitrogen oxides and carbon dioxide. The NOx emissions of a 51/80DF engine in gas mode are up to 90% lower in comparison to diesel operation. Emissions of the greenhouse gas CO2 are likewise reduced by approximately 20%. Emissions of SOx are almost zero and mainly depend on the quality of the pilot fuel oil used. Thus, dual-fuel engines provide a considerably better emission footprint than diesel engines. The emission values of the 51/80DF engine are significantly below the current limits for land based and marine applications. In fact, in gas mode it already fulfills the strict IMO Tier III NOx limitations prescribed for maritime Emission Control Areas (ECAs).

Emission reduction in gas mode

<table>
<thead>
<tr>
<th>Emission</th>
<th>Diesel operation</th>
<th>Gas operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>100 %</td>
<td>90 %</td>
</tr>
<tr>
<td>SOx</td>
<td>50 %</td>
<td>40 %</td>
</tr>
<tr>
<td>CO2</td>
<td>100 %</td>
<td>80 %</td>
</tr>
</tbody>
</table>

Comparison of emission in diesel and gas mode of 51/80DF engine.
Dual-Fuel Retrofit

Gas and pilot fuel injection technology

The 51/60DF pilot fuel system, which uses the latest common rail technology, is fed by an electrically driven high pressure pump and is mounted on-engine. The fuel injection technology with electronically controlled solenoid valves for gas and pilot fuel allows for a flexible setting of injection timing and duration for each cylinder. This flexibility is key to promoting the optimization of fuel consumption and emissions of the 51/60DF at any point in its operating profile, even down to very low engine loads.

Likewise, the common rail technology, in combination with modern engine controls, offers the opportunity to rapidly respond to potentially occurring combustion knocking or misfiring on a cylinder-by-cylinder basis.

SaCoS\textsubscript{one} control system

The 51/60DF engine is controlled by a special SaCoS\textsubscript{one} electronic system. SaCoS\textsubscript{one} is MAN Diesel & Turbo’s advanced engine safety and control system houses the engine speed control, an microelectronic controllers safety functions and alarm pre-processing (processing and transmission of all relevant data to the machinery alarm system). Furthermore, the system integrates the individual cylinder signals from the knocking sensors, the control of the lambda control flap for adjusting the air-fuel ratio, and the off-engine placed gas valve unit (GVU), which adjusts the overall gas supply pressure upstream of the engine’s gas supply pipe. All controls communicate with SaCoS\textsubscript{one} via a CAN-bus connection. Since all cylinders are individually regulated in gas mode, SaCoS\textsubscript{one} ensures reliable engine operation with optimum fuel efficiency and, at the same time, low emissions.

Cylinder head

The cylinder head arrangement, one of the core components of a modern 51/60DF engine, features the most relevant dual-fuel components, such as the gas valve and pilot fuel injector. The on-engine gas pipe on top of the rocker arm casing has a double wall design to provide the possibility of continuous ventilation of the outer pipe in order to detect potential gas leaks. The gas flows from the gas valve integrated in the air manifold via a gas flow control pipe to the inlet valve port, where it is mixed and swirled with the intake air. The geometry of the cylinder head and piston crown assures the optimum combustion of gaseous and diesel fuels. Atomization of the pilot fuel spray in both operating modes is unimpeded, resulting in very good air fuel mixture formation and an optimum combustion process, i.e., a reduction in fuel consumption in both operating modes.

Engine design features

The 51/60DF engine is based on the design of the well-proven 48/60 engine - therefore the major engine components are the same. This is also a precondition for a retrofit solution. The main differences in engine design are the components of the combustion chamber, such as the cylinder liner, piston, cylinder head of the fuel supply systems for gas and pilot fuel, and special electronic control modules (including knocking detection). The following paragraphs explain engine details.

Details of 51/60DF cylinder head arrangement

1. Double wall gas pipe
2. Gas valve arrangement
3. Rocker arms
4. Charge air manifold
5. Gas flow control pipe
6. Main fuel injection nozzle
7. Pilot fuel injection nozzle

Design Features 51/60DF
Dual-Fuel Upgrade

51/60DF engine upgrade

Because MAN Diesel & Turbo supports customers during the entire life cycle of their engines, upgrade solutions for engines in service in general and conversion packages from purely liquid fuel operated to dual-fuel engines are possible. Even engines that have logged more than 100,000 operating hours can benefit from such conversion packages. Economically, the best approach for the operator is a combination of major overhaul work and DF retrofit at the respective interval.

A dual-fuel retrofit involves a limited number of components and assemblies necessary for gas operation to be added or replaced at the engine. Since the 51/60DF engine is derived from the 48/60 platform, the following major components remain after retrofit: the engine frame, crankshaft, bearings, connecting rods, and main diesel injection equipment.

The retrofit centers on exchanging the original 48 cm bore cylinder liners and pistons for new 51 cm bore components. This replacement is the key to maintain the level of power output. Together with the redesigned cylinder liner new support rings are installed. The larger liners fit into the existing bores of the 48/60 engine frame, thus no major machining of the engine frame is necessary. The dual-fuel piston crowns are specially designed to form an optimized combustion chamber for gas operation.

The exchange of 48/60 cylinder heads for 51/60DF cylinder heads incorporates the fuel injection components for gas, pilot fuel, and diesel. The pilot fuel supply system consists of an electrically driven high pressure fuel pump and common rail pilot fuel injectors connected to high pressure piping. A pressure accumulator, small filter, and solenoid valve are integrated in each injector. New cam elements adjust the engine timing to Miller Cycle for emission reduction and optimized gas operation.

Depending on the gas quality and ambient running conditions of the engine, the turbocharger needs to be either “rematched” by fitting a new nozzle ring or modified by a different turbine or compressor geometry in order to be optimized for gas operation.

Besides converting the engine, the adaption of plant equipment is also necessary. Engine auxiliary modules for gas and pilot fuel supply, and safety devices in the engine environment (i.e., gas sensors, alarm equipment, and sufficient ventilation) need to be installed. Ventilation units and rupture discs in the exhaust stack are essential for safety reasons. The new SaCoSone engine control system is connected to the engine and plant control. After engine conversion and plant equipment adaptation, the recommissioning of the engine to gas operation is then conducted.
12 Dual-Fuel Retrofit

51/60DF retrofit, TMG
In 2008, MAN Diesel & Turbo’s after-sales organization MAN PrimeServ carried out the first conversion of an existing 12V48/60 diesel engine to a 12V51/60DF dual-fuel at an industrial cogeneration plant in Portugal. After logging approximately 88,000 operating hours in almost 12 years the owner, Têxtil Manuel Gonçalves, Sociedade de Produção de Electricidade e Calor S.A. (TMG SPE), decided to convert the 12V48/60 to 12V51/60DF. The fuel price advantage of gas and the reduced environmental impact of dual-fuel technology were key for this decision. Since the retrofit was combined with major overhaul work, the most economical approach was taken.

32/40 DF retrofit, Sanko power plant
The first dual-fuel conversion of an 18V32/40 to 18V32/40DF was at the SANKO Power Plant in Turkey. This genset, originally commissioned for HFO operation in 2001, was upgraded to dual-fuel capability in 2007. The major reason for this conversion was the availability and price advantage of gas in comparison to HFO.

Study: Gas-fuelled container feeder with integrated LNG-tanks in cargo holds
As a result of emission legislation and rising fuel prices, the market interest in converting marine engines to dual-fuel capability is strongly increasing. Vessel operators are looking for alternatives to HFO fuel. Together with leading partners from a classification society, a supplier of gas storage and supply systems, and a ship designer, MAN Diesel & Turbo conducted a feasibility study for a gas fueled 1200 TEU container feeder. The study showed that the LNG tanks and gas supply equipment could be accommodated on board without a significant loss of cargo space. A dual-fuel retrofit in marine application could therefore be carried out in the following steps:

- Conversion of existing main engine to dual-fuel operation
- Adaptation of engine room systems
- Safety installations
- Installation of bunkering equipment
- Installation of Fuel Gas Preparation Unit
- Adaptation of HFO und MGO tanks
- Installation of LNG-tanks in cargo holds

The study found that exchanging LNG containers is advantageous because it is much faster than a bunkering procedure and does not interfere with the normal handling operations of a commercial load. A standardized and containerized LNG supply would bring a high grade of flexibility to the entire shipping industry, especially in short distance traffic. In addition, the investment cost would be considerably lower than a fixed mounted bunker system.

Study: Gas-fuelled RoRo ferry with exchangeable LNG-storage containers
A further study recently carried out by MAN Diesel & Turbo, Flensburger Schiffbau-Gesellschaft (FSG), and TGE Marine Gas Engineering investigated the possibilities for incorporating LNG storage and handling systems on RoPax ferry. This study was based on LNG storage in standardized gas containers. The study used exchangeable LNG containers mounted on trailers. The study posited that instead of carrying out a normal bunkering procedure to fill integrated tanks, a tractor vehicle could be used to carry the trailers on board to a designated place on the upper car deck close to the engines. The containers, filled before the port call with LNG at a land based terminal, would be waiting in stand-by at the wharf.

- Gas as realistic option to fulfill future emission requirements (IMO TIER III, EU ships on berth)
- Feasibility study: Gas-fuelled container feeder for ECA operation
- Partners: Germanischer Lloyd, TGE, Neptun Stahlkonstruktion / WIG
- Realised between 05-11/2009

References

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32/40 DF retrofit, Sanko Power Plant
CV Neptun 1200 DF, study

Study: Gas-fuelled container feeder with integrated LNG-tanks in cargo holds

Study: Gas-fuelled RoRo ferry with exchangeable LNG-storage containers
Characteristics

- Dual-Fuel upgrades offer the opportunity to use gaseous fuels in existing Diesel engines
- Retrofit solutions available for several MAN Diesel & Turbo medium speed engine types
- Fuel flexibility and switch over at almost all engine loads
- High reduction of fuel cost by use of natural gas
- Environmental advantages by reduction of NOₓ, SOₓ and CO₂ emissions
- Available for power plant and marine applications
- Attractive pay-back time
- Life time extension of engine and plant
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