## Contents

Abstract.................................................................................................................. 5  
Business concept..................................................................................................... 5  
Definition of alternative fuels.................................................................................. 5  
Experience with alternative fuels.............................................................................. 6  
Fuel supply system.................................................................................................... 8  
Other auxiliary systems............................................................................................. 8  
Selection of cylinder lube oil..................................................................................... 8  
Emission control......................................................................................................... 9  
Status in 2015............................................................................................................. 9  
Evaluation of alternative fuels.................................................................................. 10  
Outlook....................................................................................................................... 10
MAN B&W Stationary Engines
Alternative Fuels

Abstract
The demand for energy and technological development is increasing worldwide.

Ideas, proven by operational experience on reciprocating engines with the highest possible efficiency level, are subject to renewed interest.

This paper deals with the use of alternative fuels in MAN B&W two-stroke low speed engines for stationary application.

Business concept
The MAN B&W two-stroke engines for marine and stationary application, see Fig. 1, are developed and designed by MAN Diesel & Turbo. The actual sale and production takes place via licensees placed worldwide, see Fig. 2.

The MAN B&W two-stroke stationary engines are applied for base-load operation, peak-load operation, power barges, direct drive of machines with low rpm, or as part of energy storage solutions. Both MAN Diesel & Turbo and the licensees are available for technical clarification in connection with the application of MAN B&W two-stroke engines.

Definition of alternative fuels
Alternative fuels cover a wide range of liquid fuels created by the processing of different types of feedstock into liquid fuels that can be applied to the energy supply to electrical grids.

This technical paper focuses on alternative fuels that can be injected into reciprocating internal combustion engines of the MAN B&W engine design.

Liquid fuels may originate from the processing of vegetables and plants, animal fats, used cooking oils and waste products, resulting in pyrolysis oil.

In 1995, the general perception that conventional fossil fuels were unlimited was challenged by estimations predicting that fossil fuel in liquid form was limited. Consequently, new ideas have emerged in the search for alternative utilisation of liquid substances which, potentially, can be fired into reciprocating internal combustion engines to

![Fig. 1: MAN B&W two-stroke low speed engine programme](image1)

![Fig. 2: Licensees for MAN B&W engines](image2)
Alternative fuels provide the highest possible efficiency and secure the power supply in a world with scarce resources. This is why we choose to apply the designation alternative fuels.

Alternative fuels from vegetables cover crude rapeseed oil, crude sunflower oil and crude soya oil.

Alternative fuels from plants cover crude palm oil and crude jatropha oil.

Alternative fuels with the designation animal fats covers fats produced by the processing of any type of meat in the meat processing industry.

Alternative fuels with the designation used cooking oil covers both vegetable and animal-based products that have already been applied in cooking processes either in private homes or, more likely, at restaurants.

Alternative fuels with the designation “pyrolysis oil” are derived from the processing of waste products according to the pyrolysis process. Feedstock for this fuel type may vary from used tires to wasted or unconsumed food.

Common for these fuels are that the lower calorific value is low compared with those of fossil fuels. Average is approximately 36 MJ/kg.

**Experience with alternative fuels**

In 2001, the first experience with the combustion of alternative fuel was

---

**Biofuel Composition**

<table>
<thead>
<tr>
<th>Test</th>
<th>Unit</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid number (TAN)</td>
<td>mg KOH/g</td>
<td>0.57</td>
<td>4.15</td>
<td>4.72</td>
<td>6.40</td>
<td>6.70</td>
<td>7.20</td>
<td>7.60</td>
<td>7.85</td>
<td>9.40</td>
</tr>
<tr>
<td>Carbon residue</td>
<td>% wt</td>
<td>0.14</td>
<td>0.34</td>
<td>0.36</td>
<td>0.56</td>
<td>0.19</td>
<td>0.42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water by distillation</td>
<td>% vol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flash point</td>
<td>°C</td>
<td>190</td>
<td>99</td>
<td>214</td>
<td>206</td>
<td>200</td>
<td>182</td>
<td>192</td>
<td>196</td>
<td>198</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>mg/kg</td>
<td>32</td>
<td>8</td>
<td>3</td>
<td>26</td>
<td>30</td>
<td>5</td>
<td>22</td>
<td>4</td>
<td>196</td>
</tr>
<tr>
<td>Lower calorific value</td>
<td>MJ/kg</td>
<td>37.17</td>
<td>37.02</td>
<td>37.14</td>
<td>36.88</td>
<td>36.84</td>
<td>36.84</td>
<td>36.78</td>
<td>36.92</td>
<td>36.91</td>
</tr>
<tr>
<td>Density at 15°C</td>
<td>g/ml</td>
<td>0.9217</td>
<td>0.9138</td>
<td>0.9235</td>
<td>0.9194</td>
<td>0.9184</td>
<td>0.9140</td>
<td>0.9198</td>
<td>0.9209</td>
<td>0.9192</td>
</tr>
<tr>
<td>Viscosity at 50°C</td>
<td>cSt</td>
<td>24.89</td>
<td>29.15</td>
<td>27.47</td>
<td>25.42</td>
<td>26.47</td>
<td>29.55</td>
<td>27.14</td>
<td>25.84</td>
<td>24.95</td>
</tr>
<tr>
<td>Sulphur</td>
<td>ppm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.3</td>
</tr>
<tr>
<td>Ash</td>
<td>% wt</td>
<td>0.027</td>
<td>0.006</td>
<td>0.006</td>
<td>0.015</td>
<td>0.016</td>
<td>0.017</td>
<td>0.014</td>
<td>0.005</td>
<td>0.001</td>
</tr>
</tbody>
</table>

*Table 1: Biofuel comparison sorted by TAN value*
made with medium speed engines, and MAN Diesel & Turbo’s office in Copenhagen, responsible for research, development and design of MAN B&W two-stroke low speed engines, was first approached in 2005. It was acknowledged that challenges for handling alternative fuels with high total acid number (TAN) were to be expected in the fuel supply system and in the fuel-injection equipment on the engine proper.

Table 1 shows that fuel characteristics vary from fuel type to fuel type. It was therefore evaluated that a new material selection would be relevant especially in the fuel injection system, as the content of TAN was expected to lead to corrosion of any component in direct contact with the alternative fuel, ref. Fig. 3.

MAN Diesel & Turbo decided to test the alternative fuel in the category tallow with a TAN of 40. In 2006, at the Diesel Research Centre in Copenhagen, a test was conducted on one cylinder on the research engine with standard material for all engine components directly in contact with the alternative fuel. The test confirmed the expectations of the necessity of changing the material selection as well as the sizing of the fuel injection equipment due to the calorific value of the alternative fuel.

Table 2 shows the guiding biofuel specifications. This guiding biofuel specification

### Guiding Biofuel Specification 1)

<table>
<thead>
<tr>
<th>Designation</th>
<th>kg/m³</th>
<th>cSt</th>
<th>°C</th>
<th>% (m/m)</th>
<th>ppm (m/m)</th>
<th>mg/kg</th>
<th>mg KOH/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density at 15°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kinematic viscosity at 100°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flash point</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon residue</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphur</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vanadium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminium + silicon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium plus potassium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAN (total acid number)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAN (strong acid number)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1) Maximum values valid at inlet to centrifuge plant
2) Pre-heating down to 15 cSt at engine inlet flange is to be ensured
3) Lodine, phosphorus and sulphur content according to agreement with emission controls maker
4) TBO of engine fuel systems to be adjusted according to actual value and experience

Table 2: Guiding biofuel specification

<table>
<thead>
<tr>
<th>TAN limit of 25</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.17</td>
</tr>
<tr>
<td>0.00</td>
</tr>
<tr>
<td>&gt;230</td>
</tr>
<tr>
<td>36.94</td>
</tr>
<tr>
<td>0.9216</td>
</tr>
<tr>
<td>28.75</td>
</tr>
<tr>
<td>0.002</td>
</tr>
</tbody>
</table>
tion enables clients to operate on crude biofuel. This meant that for MAN B&W two-stroke low speed engines there was no need to install a special treatment or cleaning system for biofuel before the fuel enters the conventional centrifugal system. Biofuels typically have a low sulphur content – but as the sulphur content does not influence the fuel combustion, it was decided to allow the high sulphur content in case alternative fuels with a high sulphur content would eventually become available.

In 2007, the Polish licensee H. Cegielski – Poznan S.A. got an order for a 7L35MC-S engine to be installed in Germany for operation on crude palm oil. MAN Diesel & Turbo had agreed to follow this installation closely to monitor the condition of the engine components in direct contact with the crude biofuel. The components were inspected after 6,000 operating hours, and the condition of the fuel plunger is shown in Fig. 4. The parts from the fuel pump were examined by detailed measuring equipment, and the conclusion was that the slight colouring of the surface was cosmetic. No change of the surface could be measured. The engine continued operation up to 10,000 operating hours, after which the client decided to stop operating on crude biofuel because a stable crude biofuel price could not be ensured.

In 2008 the H. Cegielski – Poznan S.A. secured the next order for a 7K60MC-S engine to be installed in the UK for operation on a wide range of bioliquids. During the project, the client wished to utilise the wide TAN range accepted by MAN Diesel & Turbo, and the client also decided to include fats, oils and grease (FOG) in the fuel supply chain, which includes various types of animal fats and recycled cooking oils.

Fuel supply system
A high TAN number is also to be considered for the design of the fuel supply system, as the material selected must prevent corrosion of fuel pipes and fuel treatment systems. MAN Diesel & Turbo recommends the application of stainless steel or other corrosion resistant material for both the pipes and the fuel treatment system. The operating experience from the fuel supply system on the installation in Germany was positive. Accordingly, we continue to recommend this material selection for the fuel supply system.

The fuel oil treatment system is shown in Fig. 5.

It is important that the fuel treatment makers receive a copy of the complete biofuel specification and, even better yet, a copy of the chemical analysis of the biofuel.

The fuel treatment system components are well-known in the marine industry.

Other auxiliary systems
As regards other auxiliary system components, which are not in direct contact with the biofuel, they may be designed as per the standard guidelines for liquid fuel handling systems.

Selection of cylinder lube oil
During operation on biofuel on the first engine, it was observed that the choice of cylinder lube oil and the application of the lowest possible feed rate had to be adapted to the ultra-low sulphur content of the fuel injected. The formation of CaCO$_3$ in the combustion chamber is expected to be at a higher level if the cylinder lube oil is not adapted. Accordingly, the cylinder lube oil feed rate must be lowered compared with operation on high-sulphur liquid fuels.
The power plant in Germany is therefore a good starting point for today’s focus on the reduction of SO\textsubscript{x} emissions, where the marine market is moving in the direction towards applying ultra-low sulphur fuels, both in liquid form and in gaseous form.

It is also worth noting that a cement mill installation in Germany, with a directly coupled 4L35MC-S engine, has been operating on ultra-low sulphur fuel complying with the standard for furnace oil for home appliances since 2007 without any technical problems.

In any case, it is important that the cylinder lube oil maker selected receives all information about the composition of the alternative fuel.

**Emission control**

Relevant emission control equipment is selected on the basis of the site requirements for NO\textsubscript{x}, SO\textsubscript{x} and particulate matter (PM). For alternative fuels, the very low sulphur content, which is unaffected by the combustion process, allows installation of SCR after the turbocharger. Low-pressure SCR is therefore to be applied. For control of PM emissions, it is suggested to apply an electrostatic precipitator and monitor the market for new emerging technologies for collection of PM.

**Status in 2015**

Operation of the MAN B&W 7K60MC-S engine has started, and we have seen varying TAN from the very beginning of the operation, ranging from 1 to 25. The calorific value varies around 36 kJ/kg. The engine parts are in good condition, and the mechanical operation follows our expectations. This power plant has been designed and constructed according to the latest standards in order to comply with the vision of the client and the local legislation at site.
Evaluation of alternative fuels

MAN Diesel & Turbo always welcomes questions about application of alternative fuels, and each request is addressed systematically step-by-step as outlined in the following:

1. Clarification about the feedstock applied.

2. Explanation of the production process.

3. The amount of the alternative fuel available in the world market.

4. Expected fuel price when large scale production is in place.

Items 1-4 provide information and a basic understanding. It is acknowledged that what is at the initial stage today may give new prospects tomorrow – but it is always good to have a strategy that is shared by all related parties.

5. One-litre sample (minimum) to be sent to MAN Diesel & Turbo for chemical analysis.

6. One-litre sample (minimum) to be sent to MAN Diesel & Turbo for stability analysis.

7. Pump rig test without combustion at the Diesel Research Centre in Copenhagen.

8. Combustion test for minimum 20 hours on one cylinder at the Diesel Research Centre in Copenhagen.

9. Service test for minimum 4,000 hours.

The basic understanding of items 7-9 is that the each step is commenced when MAN Diesel & Turbo sees a possibility of realising a positive outcome and, of course, the steps 5-9 are subject to a non-exclusive commercial and confidential agreement.

With a positive outcome of step 9, it will be possible for MAN Diesel & Turbo to issue a no objection letter for the alternative fuel with a given specification. Changes of the alternative fuel composition is to be reviewed and commented by MAN Diesel & Turbo in each case, as some of the steps may have to be repeated in order to clarify expected challenges relevant for the engine design.

Outlook

Fuel flexibility is important for MAN Diesel & Turbo as this can contribute positively to the diversity in the energy supply together with the unrivalled efficiency of the MAN B&W two-stroke engine in a single cycle. Clients deserve the right to select new possibilities that may become available as a result of the constant technological development in any technical field. There is a first time for everything, and we are ready to explore the combustion of alternative fuels in reciprocating internal combustion engines of our design already at the early stage of production.
Reference
Stationary MAN B&W MC-S Engine
For Biofuel Applications
5510-0098-00ppr
MAN Diesel & Turbo, Copenhagen,
Denmark, September 2010
All data provided in this document is non-binding. This data serves informational purposes only and is especially not guaranteed in any way. Depending on the subsequent specific individual projects, the relevant data may be subject to changes and will be assessed and determined individually for each project. This will depend on the particular characteristics of each individual project, especially specific site and operational conditions. Copyright © MAN Diesel & Turbo. 5510-0177-00ppr Nov 2015 Printed in Denmark