The uni-fuel system, a simple and modern way to improve fuel consumption and energy generating costs - the Sulzer S20 diesel engine as a basic model

W. Klinkmann

New Sulzer Diesel Ltd, CH-8401 Winterthur, Switzerland

Introduction

Much has been written and will still be written on the subject of uni-fuel ships and generating shipboard electrical power. Recently, however, there has been slightly less written; probably because the number of newbuildings characterized by uni-fuel systems is growing and fuel prices are relatively stable.

Independent of the technical side of the uni-fuel philosophy, one thing is undeniable – costs put pressure on profits. Now, when freight rates are not always satisfactory, costs can be a matter of life or death.

Fig. 1: Operating costs of 10–12 years-old 100 000 tdw tankers
The Principal Economic Parameter

Shipping and related activities are risky businesses with high investments and market environments which are highly volatile.

The output of ships (tonne-miles) only takes place when vessels are at sea. Reliability of ships and their machinery are therefore of eminent economical importance. The following formula gives us a good basis for judging the influence which different parameters have on the profitability of shipping activities:

\[
g_{s} = \frac{R \cdot W}{d} - Cr - p \cdot k \cdot s
\]

\(g_{s}\) = gross profit or surplus per day
\(R\) = freight rate per ton of cargo
\(W\) = deadweight available for cargo
\(Cr\) = running costs per day
\(p\) = price of bunker fuel per tonne
\(d\) = distance steamed including ballast passage, if applicable
\(s\) = speed in nautical miles per day
\(k\) = constant in proportionality

If we consider that the cost structure has the distribution as shown in figure 2, then it is immediately clear what importance fuel costs have and which activities in some way influence the fuel costs. If fuel costs have a dominant weight, running costs can also influence the profitability of a specific shipping business.

<table>
<thead>
<tr>
<th>Cost Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Cost</td>
<td>28%</td>
</tr>
<tr>
<td>Fuel Cost</td>
<td>42%</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>30%</td>
</tr>
</tbody>
</table>

Fig. 2: Structure of total ship costs

Many readers will be familiar with the structure of shipping costs, although definitions are not always precise. For example ‘operating costs’ sometimes include capital costs and sometimes they are synonymous with running costs.
For further consideration of this matter, running costs should be clearly defined. These comprise certain costs that must be incurred, provided the vessel is in service. Essentially, they do not vary with the specific voyage and are time related. For our subject, the following cost elements which make up part of the running costs comprise:

- Maintenance of hull and equipment including paints and cleaning; the overhaul of machinery, fire-fighting and life-saving appliances.

- Lubricating oil. This is an expensive item for diesel-powered ships. Although included as a running cost, it should be considered more as a voyage cost.

- Spares. Mainly for machinery

Thus, taking all the above factors into account, we can see that a good and efficient solution in the field of electricity generation can be one of the important influences on the profitability of a specific vessel. In favourable periods this could mean maximizing profits and in periods of adverse economical conditions minimizing losses.

**The Generation of Onboard Electrical Energy**

For the propulsion of merchant ships of all sizes and types, there exists today practically only one solution – the diesel engine – because it is currently the most economical form of internal combustion engine.

For the generation of electricity, there are more variations for the same problem. Here may be mentioned above all the possibility to enhance electrical power generation by power take-off from the propulsion plant.

Looking at the description of newbuildings, the majority are equipped with the traditional power package for merchant ships:

One propulsion engine and three diesel generating sets

Probably the often considerably higher investment for any other solution favours the adoption of the classical theme.

**The Basis of the Uni-Fuel Concept and Its Repercussions on the Cost of Electricity Generation**

The ability of modern diesel engines, such as the Sulzer S20, to run on the same grade of heavy fuel oil as the main engine, has made possible the introduction of the so-called ‘uni-fuel’ ship or one-fuel ship. The ‘uni-fuel’ ship is characterized by

- All engines, both main and auxiliary, running on the same grade of heavy fuel oil (HFO)

- The auxiliary engines start and stop on heavy fuel

- Marine diesel oil (MDO) is only used for emergency operation, starting up with a dead ship, and for flushing through the fuel system before overhaul
Plan at generator flat

Fig. 3: Typical configuration of one main engine and three diesel generating sets

Fig. 4: Uni-fuel concept
1 Main engine
2 S20 - engine
3 HFO daily tank
4 MDO daily tank
5 Suction filter
6 Low pressure feed pumps
7 Automatic filter
8 Flowmeter
9 Buffer tank
10 High pressure booster pumps
11 End heater
12 Viscosimeter
13 Change over valves
14 Buffer tank
15 Duplex filters
16 MDO suction filter
17 MDO booster pump
18 MDO connections to and from additional gensets
19 HFO connections to and from additional gensets

Fig. 4a: Fuel system – single booster module
1 Main engine
2 S20 - engine
3 HFO daily tank
4 MDO daily tank
5 Suction filter
6 Low pressure feed pumps
7 Automatic filter
8 Flowmeter
9 Buffer tank
10 High pressure booster pumps
11 End heaters
12 Viscosimeters
13 Change over valves
14 Buffer tank
15 Duplex filters
16 MDO suction filter
17 MDO booster pump
18 MDO connections to and from additional gensets
19 HFO connections to and from additional gensets

Fig. 4b: Fuel system – double booster module
Blending equipment is no longer needed, thus avoiding one of the risks of causing instability and incompatibility when mixing two different fuels.

**Fuel oil system**

The standard heavy fuel system consists of the following three main groups:

a) **The storage system** Bunker, settling and daily service tanks with transfer pumps.

b) **The HFO treatment or cleaning system** The treatment or cleaning system is of extreme importance for the correct and successful operation of the main and auxiliary engines running on heavy fuel. Proper onboard fuel treatment must be carried out to remove sea water and abrasive particles including catalytic fines. The key to correct fuel treatment lies in good centrifugal separation; the centrifugal separators being the most important part of the fuel treatment system. The use of separators of the new generation which do not have gravity discs and meet the requirements for future heavy fuel separation up to 700 cSt at 50°C, is advisable. The effective separator throughput must be in accordance with the maximum fuel oil consumption of the diesel engine plant plus a margin of about 20 per cent.

c) **Supply or conditioning system** Two types of supply systems are shown in figures 4a and 4b. Both supply systems are now common for all installations intended for use with lower quality heavy fuel oils. They avoid problems with gassing up at the high supply temperature which is required by the high viscosity fuels in order to achieve the required viscosity for injection into the engines.

When auxiliary engines are running on heavy fuel, an extremely interesting comparison can be made between electricity generating costs and the various alternatives (Fig. 5).

![Fig. 5: Comparison of electricity generation costs](image-url)
Considering this obvious advantage, one may ask why all vessels do not use the uni-fuel concept. There is a basic condition – the auxiliary engine must be absolutely capable of running on heavy fuel. If this condition must be respected, there is normally a restricted selection of the engines destined for vessels running with the uni-fuel concept.

What are the principal components of the heavy fuel oil which must be considered when designing an engine to be perfectly compatible to HFO?

**Sulphur** Sulphur is an element which occurs naturally in all crude oils. When fuel oil containing sulphur is burned in an engine’s combustion chamber, oxides of sulphur form and react with water vapour to create sulphuric and sulphurous acid. If this acid vapour condenses, it chemically attacks the metal surfaces of valves and cylinder liners and may affect bearings.

**Vanadium** Vanadium is a metal present in some heavy fuels. Vanadium in the fuel quickly corrodes hot components. It will often appear in the form of molten slag on exhaust valve seats.

**Catalytic ‘fines’** Catalytic ‘fines’ are small hard particles which originate in refinery processes. They are usually composed of alumina and silica particles which can cause very rapid abrasive wear.

**Carbon residue** Carbon residue is a measure of the tendency of a fuel to form carbon during combustion. Carbon-rich fuels are more difficult to burn and lead to the formation of soot and carbon deposits. High carbon levels can cause incorrect combustion, hot spots on the liners and a burnt oil film can also result. This fact can cause piston scuffing, cylinder liner wear, stuck rings and turbocharger deposits.

**Ash** Ash consists of metal and other contaminants that cannot be burnt in the engine. Ash deposits can cause localized overheating of metal surfaces such as exhaust valve seats.

Considering the effects of the different contaminants, the importance of a reliable and efficient fuel treatment and conditioning system appears clear although centrifugal treatment can only eliminate a portion of these contaminants. The design of the engine has the main influence on the future reliability of operation. For somebody who knows how many imponderable factors influences the good functioning of a main diesel engine, it is clear that besides good engineering practice, experience and a well-organized data base of operating parameters are of basic importance.

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>First Commissioning</th>
<th>Longest Operating Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>A25</td>
<td>Oct. 1970</td>
<td>97,000</td>
</tr>
<tr>
<td>Z40</td>
<td>Sept. 1973</td>
<td>110,000</td>
</tr>
<tr>
<td>AT25</td>
<td>April 1983</td>
<td>27,000</td>
</tr>
<tr>
<td>ZA40S</td>
<td>May 1987</td>
<td>24,000</td>
</tr>
</tbody>
</table>

Fig. 6: Four-stroke engine family – the background to the Sulzer S20
The data about the running of the different four-stroke engines show what a wealth of experience was used during the design and testing phase of the Sulzer S20 engine. The interface between maintenance and design functions is crucial to achieve plants of optimum reliability. The close cooperation between the design department and the customers of Sulzer auxiliary engines guaranteed a continuous feedback.

In some cases, the analysis of life cycle costs gives valuable indication for the design of an improved engine. It gives also dependable indications about predictable reliability; a fact often required by the shipowner. This was the case with the S20 engine.

The key measures during the developing programme were as follows:

- Low fuel consumption
- Real heavy fuel capability being specifically designed to burn heavy fuel oils up to ISO class RMH55 with viscosity up to 700cSt at 50°C.
- Clean combustion even at part load due to the high stroke/bore ratio (1.5), highly efficient fuel injection system and adaptable turbocharging system
- In-line configuration is preferred with a maximum speed not higher than 1000 rev/min.
- Designed for times between major overhauls (TBO) greater than 8000–12000 hours, which means up to two years of virtually undisturbed operation until components such as exhaust valves and piston rings would need attention. Furthermore, the length of times out of service for overhaul are kept to a minimum by accessibility, suitable tools and simplicity being within the design.
- Quick load pick-up capability which is essential for the sudden loading of generating sets.

Principal S20 design features from the point of view of heavy fuel operating capability

Large stroke/bore ratio for optimized combustion

The influence of maximum cylinder pressure (Pmax) on BSFC is very much determined by the ratio Pmax/Pcomp and a high compression ratio is necessary to achieve the favourable Pmax/Pcomp ratio.

In the S20, a suitably high compression is facilitated by its high stroke/bore ratio. The limit for compression ratio in a given engine is set by the depth of the combustion space with the piston at the top dead centre position.

The higher S/B ratio gives more freedom in increasing the compression ratio while, at the same time, permitting a deep combustion space that allows an undisturbed fuel spray pattern without wall impingement or hot spots. The high compression ratio of the S20 also gives the high temperature at the end of compression which is a prerequisite for quick ignition and clean combustion of HFO especially at low load.
All dimensions in millimetres and masses in tonnes, not binding.

*Dimension "1780" is the minimum withdrawal height for piston and cylinder liner (without crane).
Turbocharger at driving end for propulsion engines only.

**Fig. 7: Dimensions and masses**
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bore</td>
<td>200mm</td>
</tr>
<tr>
<td>Stroke</td>
<td>300mm</td>
</tr>
<tr>
<td>Stroke/bore</td>
<td>1.5</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>14:1</td>
</tr>
<tr>
<td>BMEP</td>
<td>18.5bar</td>
</tr>
<tr>
<td>Max. cylinder pressure</td>
<td>160bar</td>
</tr>
<tr>
<td>Nominal speeds</td>
<td>720, 750, 900, 1000rpm</td>
</tr>
<tr>
<td>Cyl. outputs</td>
<td>105–145kW</td>
</tr>
<tr>
<td>Number of cylinders</td>
<td>4, 6, 8, 9 in-line</td>
</tr>
<tr>
<td>Overal power range</td>
<td>520 – 1305kW</td>
</tr>
<tr>
<td>HFO specification</td>
<td>ISO RMH55</td>
</tr>
<tr>
<td>BSFC (MCR)</td>
<td>188g/kWh (720rpm)</td>
</tr>
<tr>
<td></td>
<td>193g/kWh (1000rpm)</td>
</tr>
<tr>
<td>Lub. oil consumption</td>
<td>1.5g/kWh</td>
</tr>
</tbody>
</table>

Fig. 8: Performance data on heavy fuel oil
Apart from the HFO burning capability, a very wide load range for continuous operation is essential for an auxiliary engine. A diesel generating set should thus be able to run continuously down to 20–30 per cent load on HFO.

The higher S/B ratio also gives more space available for combustion which is important for the slow burning rate of high viscosity fuel oils.

**Bore-cooled combustion space**

It is a key design feature for heavy fuel operation. The bore-cooling principle combines the advantage of efficient cooling and high mechanical rigidity.

**Highly efficient, load-adaptable turbocharging**

The optimization of turbocharging systems for modern engines must often fulfil contradictory requirements.

The unique turbocharging system of the S20 thus consists of the following elements:

- The single-pipe exhaust system providing optimum recovery of the exhaust gas energy in the turbine
Bore-cooled design for:
• Optimum surface temperatures
• Small bottom plate deformation under gas load and thus best valve sealing

Fig. 10: Cylinder head – design features

Two-part piston with rigid, oil cooled steel piston crown and nodular iron skirt

• Top ring, either
  Plasma X20-coated for HFO operation
  Chrome-plated for MDO operation
• Second and third rings, chrome plated

Fig. 11: Piston – design features
160kW/cyl at 1000rev/min

Fig. 12: Combustion chamber temperatures

Fig. 13: Turbocharging system
The valve overlap has been minimized for best fuel efficiency at full load.

The engine can be tuned for higher charge air pressures in order to give better fuel consumption at part load and also for marine generating sets to provide a quicker load pick-up as required by classification societies.

Service Experience

It is generally agreed that for electricity generation using heavy fuel oil, high durability and reliability in service have higher priorities than a high power output.

The Sulzer S20 engines in service are successfully coping with the implication of heavy-fuel oil operation.

The maintenance schedule and lifetimes for HFO operation shown in figure 14 give a good idea of the cost effective design of the S20 engine.

<table>
<thead>
<tr>
<th>Component</th>
<th>Inspection or Overhaul</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intervals (hrs)</td>
<td>Time (mins)</td>
</tr>
<tr>
<td>Fuel nozzle</td>
<td>3 000 - 4 000</td>
<td>15</td>
</tr>
<tr>
<td>Cylinder head</td>
<td>9 000 - 12 000</td>
<td>75</td>
</tr>
<tr>
<td>Inlet valve</td>
<td>9 000 - 12 000</td>
<td>5</td>
</tr>
<tr>
<td>Exhaust valve</td>
<td>18 000 - 24 000</td>
<td>5</td>
</tr>
<tr>
<td>Piston</td>
<td>18 000 - 24 000</td>
<td>40</td>
</tr>
<tr>
<td>Piston rings</td>
<td>18 000 - 24 000</td>
<td>10</td>
</tr>
<tr>
<td>Scraper ring</td>
<td>18 000 - 24 000</td>
<td>5</td>
</tr>
<tr>
<td>Piston cooling space</td>
<td>18 000 - 24 000</td>
<td>15</td>
</tr>
<tr>
<td>Gudgeon pin</td>
<td>18 000 - 24 000</td>
<td>10</td>
</tr>
<tr>
<td>Gudgeon pin bush</td>
<td>18 000 - 24 000</td>
<td>20</td>
</tr>
<tr>
<td>Piston ring grooves</td>
<td>18 000 - 24 000</td>
<td>60</td>
</tr>
<tr>
<td>Bottom end bearing</td>
<td>18 000 - 24 000</td>
<td>60</td>
</tr>
<tr>
<td>Main bearing</td>
<td>18 000 - 24 000</td>
<td>35</td>
</tr>
<tr>
<td>Fuel pump plunger and barrel</td>
<td>18 000 - 24 000</td>
<td>20</td>
</tr>
<tr>
<td>Inlet valve seat</td>
<td>18 000 - 24 000</td>
<td>20</td>
</tr>
<tr>
<td>Exhaust valve seat</td>
<td>18 000 - 24 000</td>
<td>30</td>
</tr>
<tr>
<td>Cylinder liner</td>
<td>18 000 - 24 000</td>
<td>30</td>
</tr>
</tbody>
</table>

1) Expected intervals and lifetimes are approximate, may vary and are for guidance only. They are subject to:
   - Environmental and operating conditions
   - Heavy fuel and lubricating oil qualities within the specifications of New Sulzer Diesel Ltd
   - Engine load factor
   - Fuel and lubricating oil care according to the specifications of New Sulzer Diesel Ltd
   - Overhaul according to engine manuals
   - Genuine spare parts used
   - Monitoring of conditions

2) Total time for withdrawing and refitting assuming good conditions with ready tools, devices and lifting arrangements. Time for cleaning, overhaul etc. should be added.

3) Checks at random – all within four or five years depending on respective classification or other rules.

4) Rechroming of piston ring grooves

Fig. 14: Maintenance schedule and lifetimes
The service results so far fully confirm the engineering expertise used in defining and designing the S20 long-stroke engine. As mentioned at the beginning of this paper, the accumulated experience with the Sulzer A-type four-stroke and RTA two-stroke engines was a basic factor for success.

The following figures indicate how the different components have operated under severe conditions:

**Inspection at 8770hrs**

Wear rates, mm/1000hrs:
- Liner: 0.001–0.010
- Top rings: 0.02
- Top rings grooves: 0
Lub. oil consumption: 1.44g/kWh

"Teviot" 3 x 6S20 generating sets
130kW/cyl. at 900rpm
60% load factor
Marine diesel oil

Fig. 15: Piston wear rates
"Teviot" 3 x 6S20 generating sets
Inspection of centre engine

Fig. 16: Exhaust valves

Inspection at 8117hrs and 8317hrs

Wear rates, mm/1000hrs:
- Liner: 0.015–0.036
- Top piston rings: 0.018–0.023
- Top ring grooves: 0

"Prins Johan Willem Friso" 2 x 6S20 generating sets
117.5kW/cyl. at 900rpm
20–70% load factor
HFO viscosity: 355cSt at 50°C

Fig. 17: Cylinder liner wear rates