



Propulsion of 7,000-10,000 dwt Small Tanker

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Propulsion of 7,000-10,000 dwt Small Tanker

Introduction

The main ship particulars of 7,000-10,000 dwt small tankers are normally approximately as follows: the overall ship length is 116 m, breadth 18 m and scantling draught 7.0-8.0 m, see Fig. 1.

Recent development steps have made it possible to offer solutions which will enable significantly lower transportation costs for small tankers (and bulk carriers) as outlined in the following.

One of the goals in the marine industry today is to reduce the impact of CO₂ emissions from ships and, therefore, to reduce the fuel consumption for the

propulsion of ships to the widest possible extent at any load.

This also means that the inherent design CO₂ index of a new ship, the so-called Energy Efficiency Design Index (EEDI), will be reduced. Based on an average reference CO₂ emission from existing tankers, the CO₂ emission from new tankers in gram per dwt per nautical mile must be equal to or lower than the reference emission figures valid for the specific tanker.

This drive may often result in operation at lower than normal service ship speeds compared to earlier, resulting in reduced

propulsion power utilisation. The design ship speed at Normal Continuous Rating (NCR), including 15% sea margin, used to be as high as 14.0 knots. Today, the ship speed may be expected to be lower, possibly 13 knots, or even lower.

A more technically advanced development drive is to optimise the aftbody and hull lines of the ship – including bulbous bow, also considering operation in ballast condition. This makes it possible to install propellers with a larger propeller diameter and, thereby, obtaining higher propeller efficiency, but at a reduced optimum propeller speed, i.e. using less power for the same ship speed.



Fig. 1: Small tanker

As the two-stroke main engine is directly coupled with the propeller, the introduction of the super long stroke S30ME-B9.3 engine with even lower than usual shaft speed will meet this goal. The main dimensions for this engine type, and for the existing small-size tanker (and bulk carrier) engine L35MC6.1, are shown in Fig. 2.

On the basis of a case study of an 8,000 dwt small tanker in compliance with IMO Tier II emission rules, this paper shows the influence on fuel consumption when choosing the new S30ME-B engine compared with the old and normally used L35MC6 engine. The layout ranges of 5 and 6S30ME-B9.3 engines compared with 5 and 6L35MC6.1 together with the 5S35ME-B9.3 are shown later in Fig. 5.

EEDI and Major Ship and Main Engine Parameters

Energy Efficiency Design Index (EEDI)

The IMO (International Maritime Organisation) based Energy Efficiency Design Index (EEDI) is a mandatory index required on all new ships contracted after 1 January 2013. The index is used as an instrument to fulfil international requirements regarding CO₂ emissions on ships. EEDI represents the amount of CO₂ emitted by a ship in relation to the transported cargo and is measured in gram CO₂ per dwt per nautical mile.

The EEDI value is calculated on the basis of maximum cargo capacity (70% for container ships), propulsion power, ship speed, SFOC (Specific Fuel Oil Consumption) and fuel type. Depend-

ing on the date of contract, the EEDI is required to be a certain percentage lower than an IMO defined reference value depending on the type and capacity of the ship.

The main engine's 75% SMCR (Specified Maximum Continuous Rating) figure is as standard applied in the calculation of the EEDI figure, in which also the CO₂ emission from the auxiliary engines of the ship is included.

According to the rules finally decided on 15 July 2011, the EEDI of a new ship is reduced to a certain factor compared to a reference value. Thus, a ship bigger than 20,000 dwt and built after 2025 is required to have a 30% lower EEDI than the 2013 reference figure.

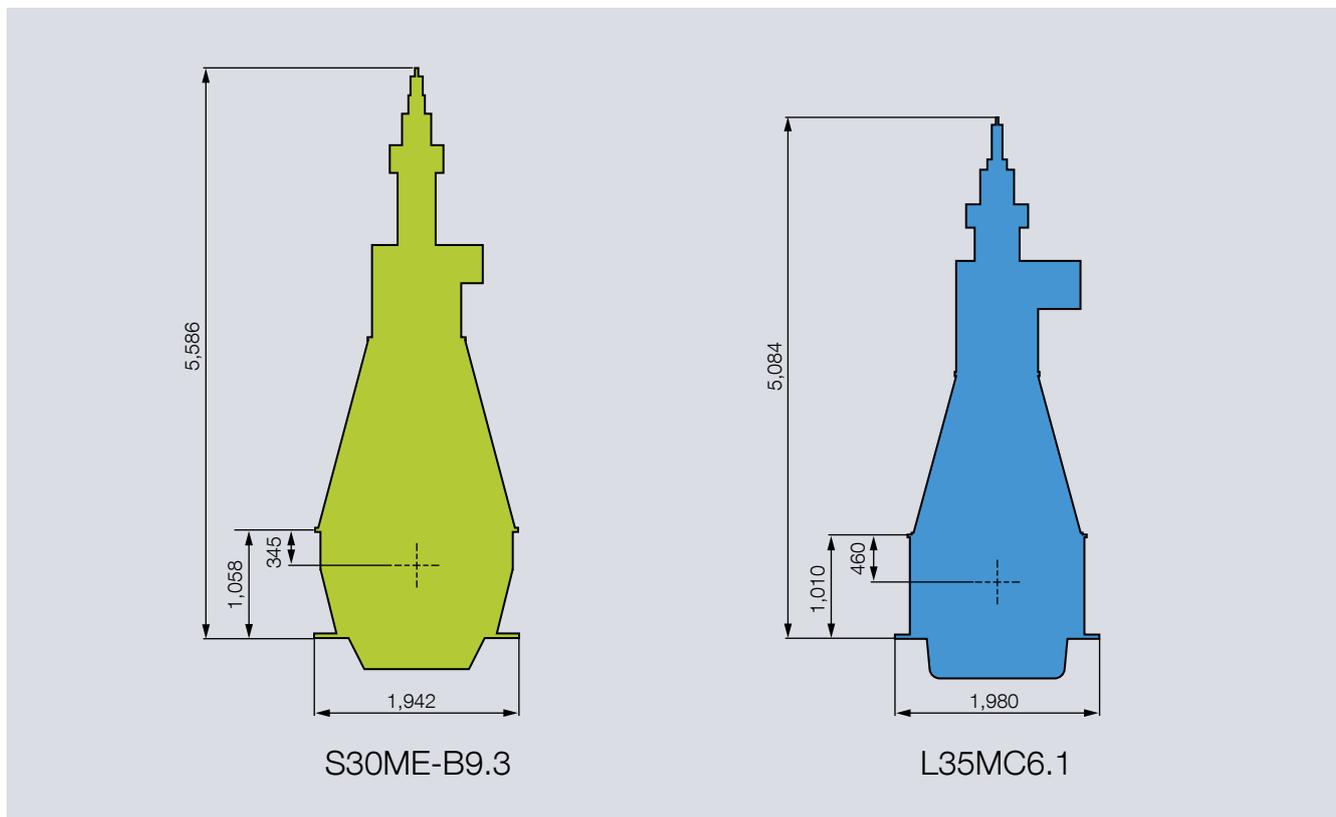


Fig. 2: Main dimensions for the new S30ME-B9.3 engine and the old L35MC6.1 applied earlier

For ships smaller than 4,000 dwt, there are no lower limitation demands. For the 8,000 dwt small tanker in question, the EEDI reference value required after 2025 will be 7.5% lower, i.e. equal to 92.5% of the 2013 reference EEDI value, see Fig. 3.

Major propeller and engine parameters

In general, the highest possible propulsive efficiency required to provide a given ship speed is obtained with the largest possible propeller diameter d , in combination with the corresponding, optimum pitch/diameter ratio p/d .

As an example, this is illustrated for an 8,000 dwt small tanker with a service ship speed of 14 knots, see the black curve in Fig. 4. The needed propulsion SMCR (Specified Maximum Continuous Rating) power and speed is shown for a given optimum propeller diameter d and p/d ratio.

According to the black curve, the existing propeller diameter of 3.5 m may have the optimum pitch/diameter ratio of 0.72, and the lowest possible SMCR shaft power of about 3,625 kW at about 219 r/min.

The black curve shows that if a bigger propeller diameter of 3.9 m is possible, the necessary SMCR shaft power will be reduced to about 3,425 kW at about 179 r/min, i.e. the bigger the propeller, the lower the optimum propeller speed.

If the pitch for this diameter is changed, the propulsive efficiency will be reduced, i.e. the necessary SMCR shaft power will increase, see the red curve.

The red curve also shows that propulsion-wise it will always be an advantage to choose the largest possible propeller diameter, even though the optimum pitch/diameter ratio would involve a too low propeller speed (in relation to

the required main engine speed). Thus, when using a somewhat lower pitch/diameter ratio, compared with the optimum ratio, the propeller/engine speed may be increased and will only cause a minor extra power increase.

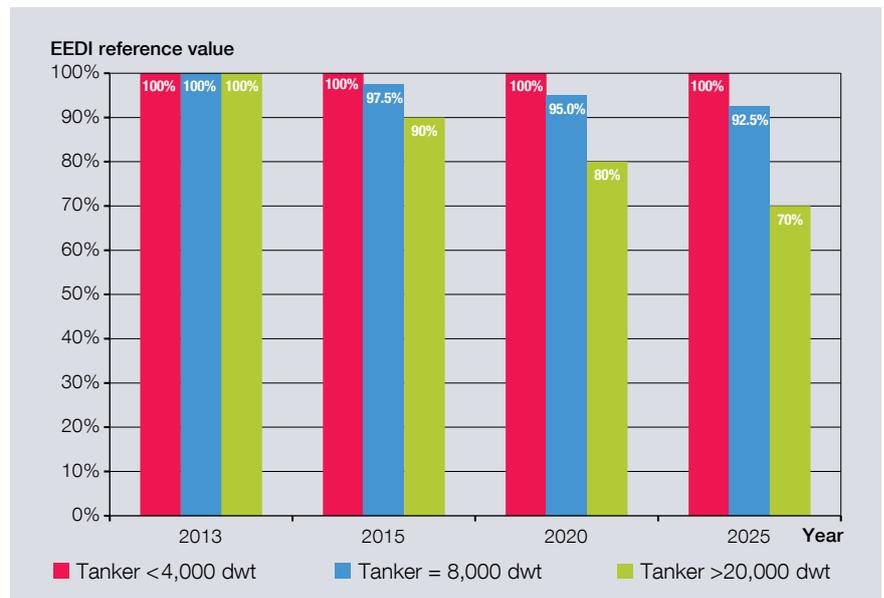


Fig. 3: EEDI reference requirements in the future valid for tankers

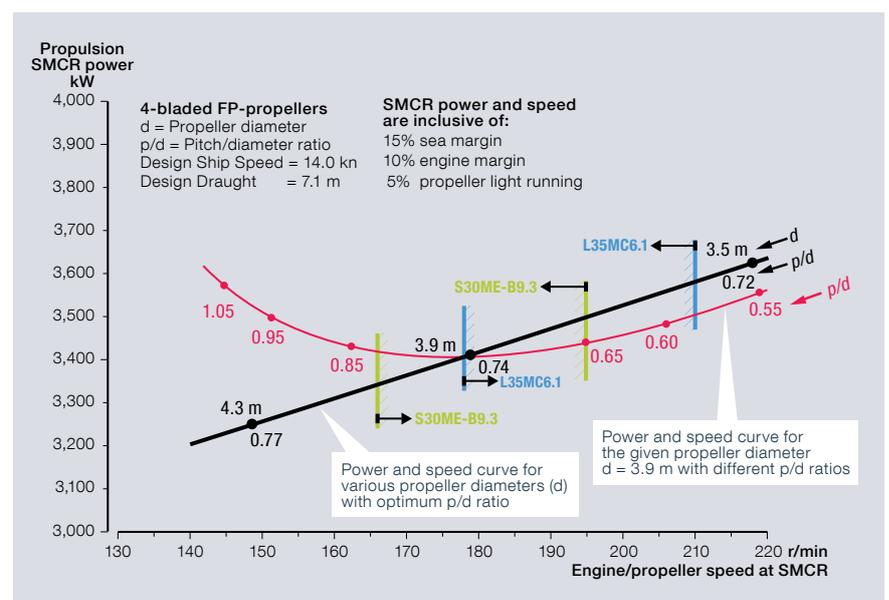


Fig. 4: Influence of propeller diameter and pitch on SMCR for an 8,000 dwt small tanker operating at 14.0 knots

The efficiency of a two-stroke main engine particularly depends on the ratio of the maximum (firing) pressure and the mean effective pressure. The higher the ratio, the higher the engine efficiency, i.e. the lower the Specific Fuel Oil Consumption (SFOC).

Furthermore, the higher the stroke/bore ratio of a two-stroke engine, the higher the engine efficiency. This means, for example, that a super long stroke en-

gine type, as the S30ME-B9.3, may have a higher efficiency compared with a shorter stroke engine type, like an L35MC6.1.

The application of new propeller design technologies may also motivate use of main engines with lower rpm. Thus, for the same propeller diameter, these propeller types can demonstrate an up to 6% improved overall efficiency gain at about 10% lower propeller speed.

This is valid for propellers with Kappel technology available at MAN Diesel & Turbo, Frederikshavn, Denmark.

Hence, with such a propeller type, the advantage of the new low speed S30ME-B9.3 engine can be utilised also in case a correspondingly larger propeller cannot be accommodated.

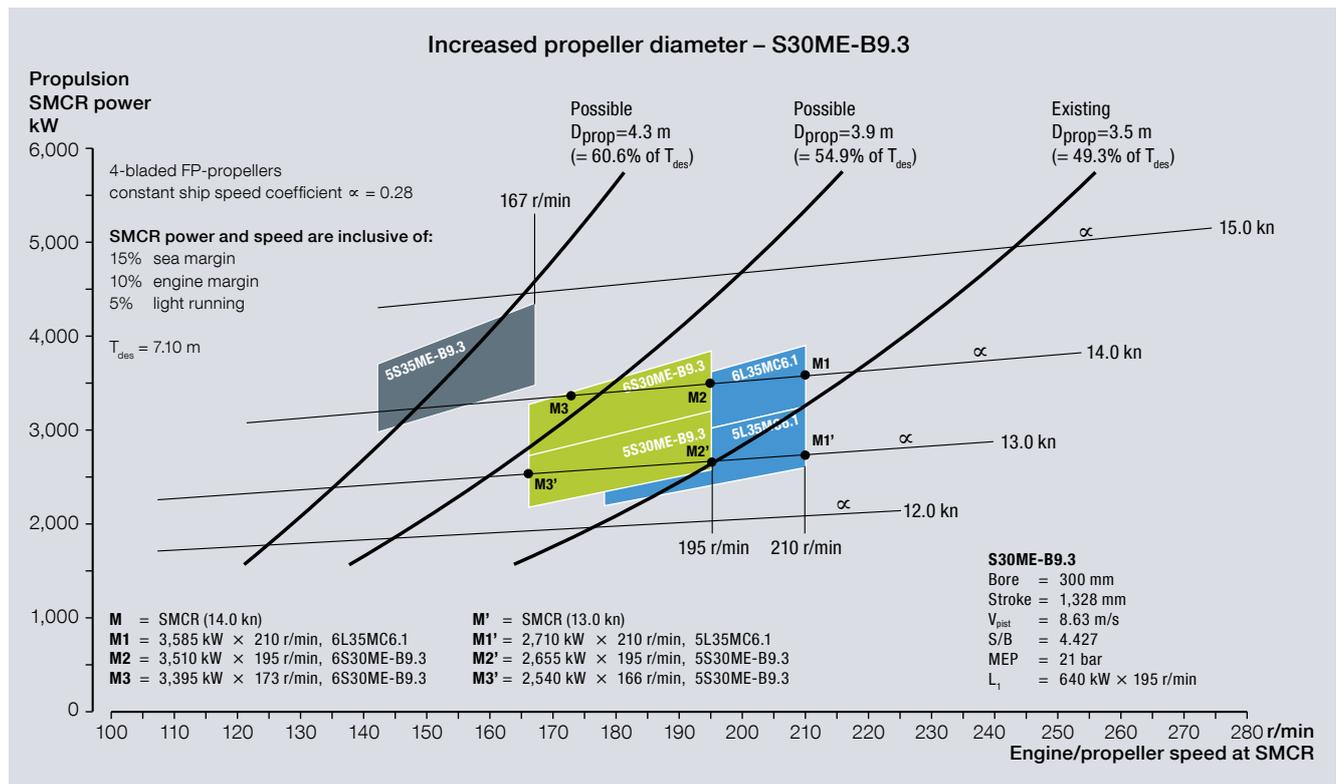


Fig. 5: Different main engine and propeller layouts and SMCR possibilities (M1, M2, M3 for 14.0 knots and M1', M2', M3' for 13.0 knots) for an 8,000 dwt small tanker operating at 14.0 knots and 13.0 knots, respectively

8,000 dwt small tanker

For an 8,000 dwt small tanker, the following case study illustrates the potential for reducing fuel consumption by increasing the propeller diameter and introducing the S30ME-B9.3 as main engine. The ship particulars assumed are as follows:

Scantling draught	m	7.5
Design draught	m	7.1
Length overall	m	116.0
Length between pp	m	110.0
Breadth	m	18.0
Sea margin	%	15
Engine margin	%	10
Design ship speed	kn	14.0 and 13.0
Type of propeller		FPP
No. of propeller blades		4
Propeller diameter	m	target

Based on the above-stated average ship particulars assumed, we have

made a power prediction calculation (Holtrop & Mennen's Method) for different design ship speeds and propeller diameters, and the corresponding SMCR power and speed, point M, for propulsion of the small tanker is found, see Fig. 5. The propeller diameter change corresponds approximately to the constant ship speed factor $\alpha = 0.28$ [ref. $P_{M2} = P_{M1} \times (n2/n1)^\alpha$].

Referring to the two ship speeds of 14.0 knots and 13.0 knots, respectively, three potential main engine types, pertaining layout diagrams and SMCR points have been drawn-in in Fig. 5, and the main engine operating costs have been calculated and described.

The L35MC6.1 engine type (210 r/min) has often been used in the past as prime movers in projects for small tankers. Therefore, a comparison be-

tween the new S30ME-B9.3 and the old L35MC6.1 is of major interest in this paper.

In this connection, the existing 5S35ME-B9.3 seems to have the ideal low engine speed, however powerwise, it is too big.

It should be noted that the ship speed stated refers to NCR = 90% SMCR including 15% sea margin. If based on calm weather, i.e. without sea margin, the obtainable ship speed at NCR = 90% SMCR will be about 0.5 knots higher.

If based on 75% SMCR, as applied for calculation of the EEDI, the ship speed will be about 0.2 knot lower, still based on calm weather conditions, i.e. without any sea margin.

**Main Engine Operating Costs –
14.0 knots**

The calculated main engine examples are as follows:

14.0 knots

1.	6L35MC6.1 ($D_{prop} = 3.6$ m)
	$M1 = 3,585$ kW \times 210.0 r/min
2.	6S30ME-B9.3 ($D_{prop} = 3.7$ m)
	$M2 = 3,510$ kW \times 195.0 r/min.
3.	6S30ME-B9.3 ($D_{prop} = 4.0$ m)
	$M3 = 3,395$ kW \times 173.0 r/min.

The main engine fuel consumption and operating costs at $N = NCR = 90\%$ SMCR have been calculated for the above three main engine/propeller cases operating on the relatively high ship speed of 14.0 knots, as often used earlier. Furthermore, the corresponding EEDI has been calculated on the basis of the 75% SMCR-related figures (without sea margin).

Fuel consumption and EEDI

Fig. 6 shows the influence of the propeller diameter with four propeller blades when going from about 3.6 m to 4.0 m. Thus, N3 for the 6S30ME-B9.3 with a 4.0 m propeller diameter has a propulsion power demand that is about 5.3% lower compared with N1 valid for the 6L35MC6.1 with a propeller diameter of about 3.6 m.

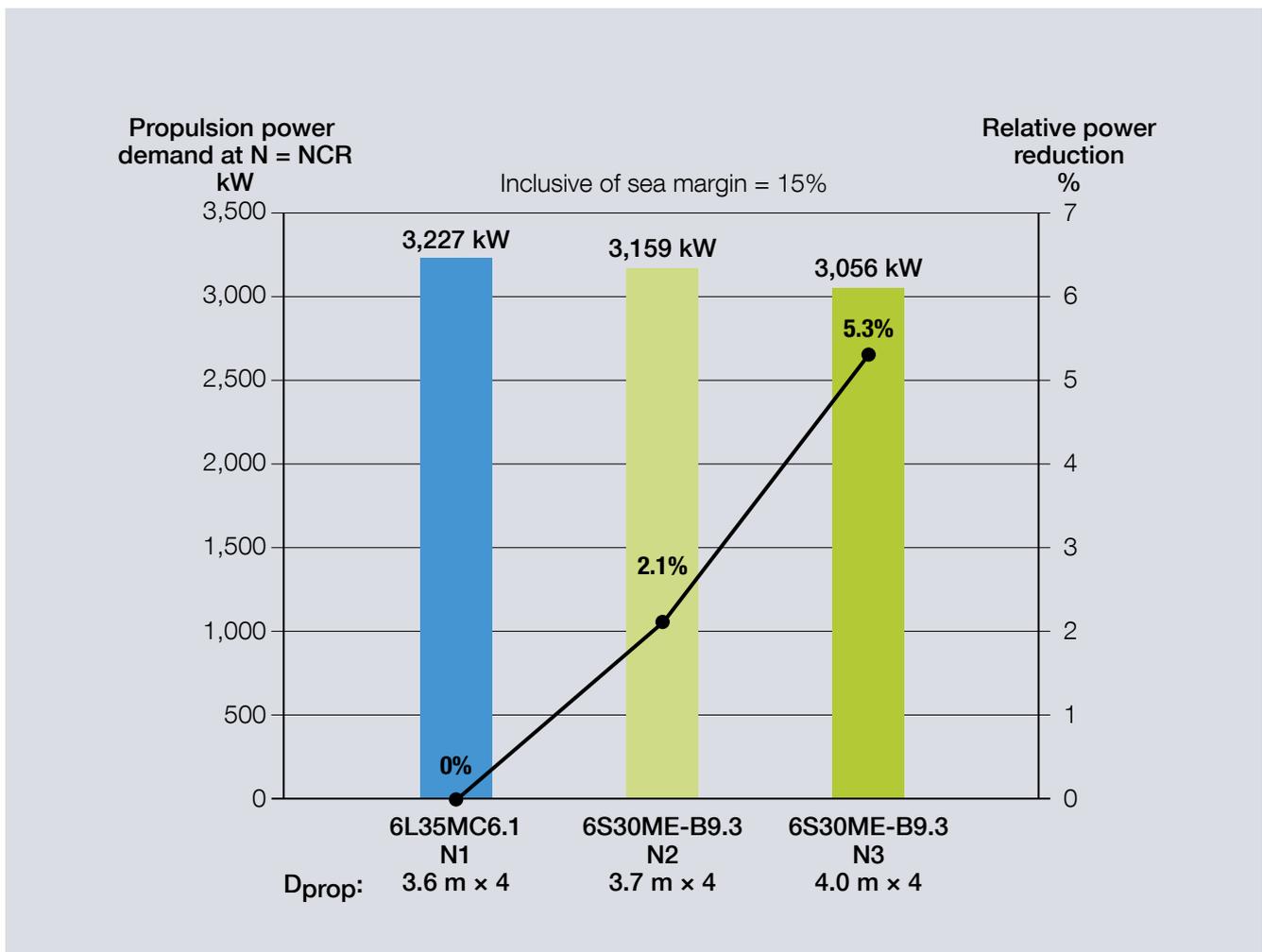
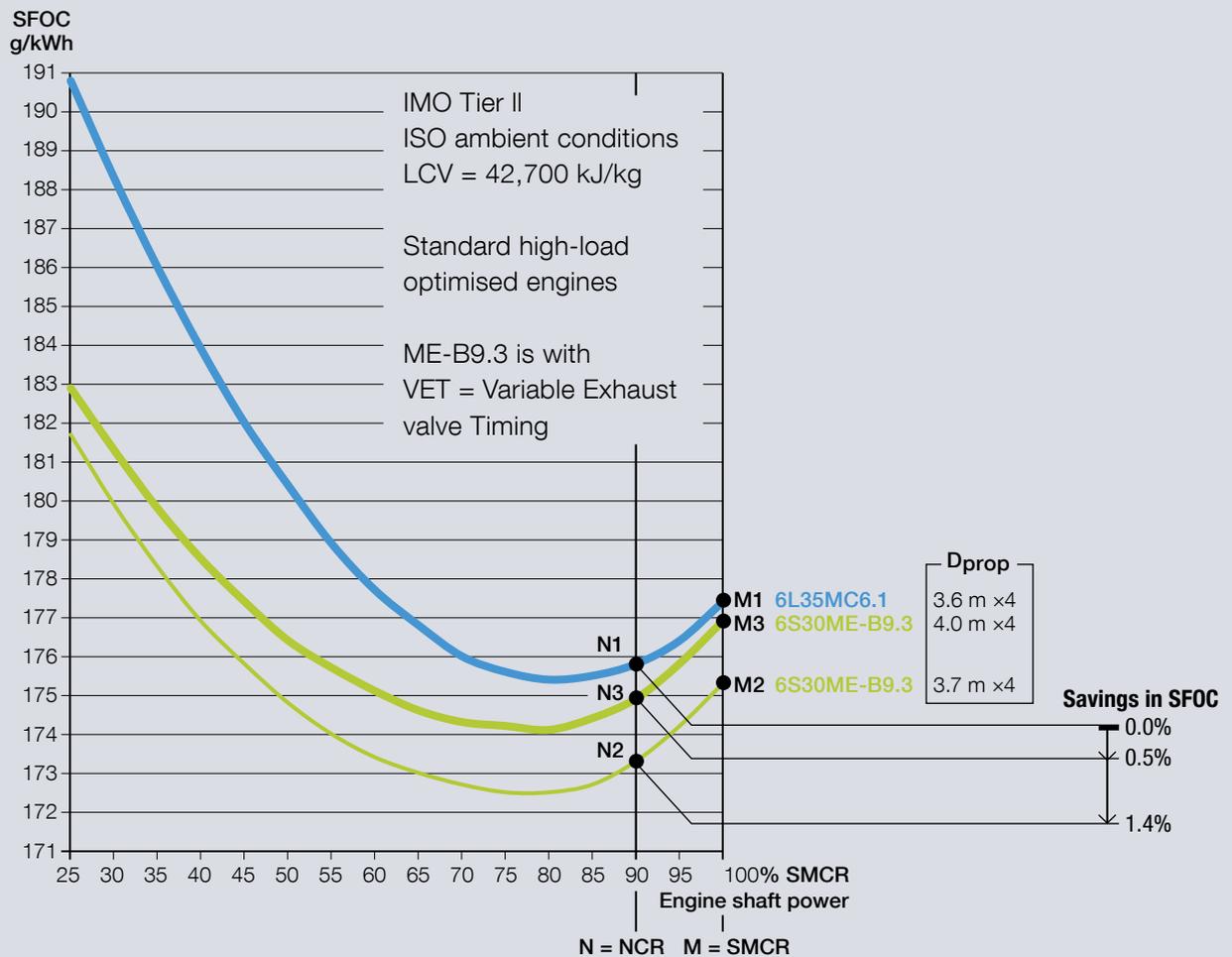


Fig. 6: Expected propulsion power demand at NCR = 90% SMCR for 14.0 knots



For ME-B engines, the fuel consumption (+1g/kWh) for HPS is included.

Fig. 7: Expected SFOC for 14.0 knots

Fig. 7 shows the influence on the main engine efficiency, indicated by the Specific Fuel Oil Consumption, SFOC, for the three cases. For N3 = 90% M3 with the 6S30ME-B9.3 SFOC is 174.9 g/kWh, for N2 = 90% M2 with 6S30ME-B9.3 SFOC is 173.3 g/kWh and for N1 = 90% M1 with 6L35MC6.1 SFOC is 175.8 g/kWh. In all cases for the ME-B

engines, +1 g/kWh needed for the Hydraulic Power Supply (HPS) system is included. In N2, the SFOC is about 1.4% lower compared with N1.

All ME-B9.3 engine types are as standard fitted with VET (Variable Exhaust valve Timing) reducing the SFOC at part operation.

When multiplying the propulsion power demand at N (Fig. 6) with the SFOC (Fig. 7), the daily fuel consumption is found and is shown in Fig. 8. Compared with N1 for the old 6L35MC6.1, the total reduction of fuel consumption of the new 6S30ME-B9.3 at N3 is about 5.7% (see also the above-mentioned savings of 5.3% and 0.5%).

The reference and the actual EEDI figures have been calculated and are shown in Fig. 9 ($EEDI_{ref} = 1,218.8 \times dwt^{-0.488}$, 15 July 2011). As can be seen for all three cases, the actual EEDI figures are relatively high with the lowest EEDI (96%) for case 3 with 6S30ME-B9.3. Case 3 is the only one to meet the 2013 reference EEDI.

Operating costs

The total main engine operating costs per year, 250 days/year, and fuel price of 700 USD/t, are shown in Fig. 10. The lube oil and maintenance costs are shown too. As can be seen, the major operating costs originate from the fuel costs – about 95%.

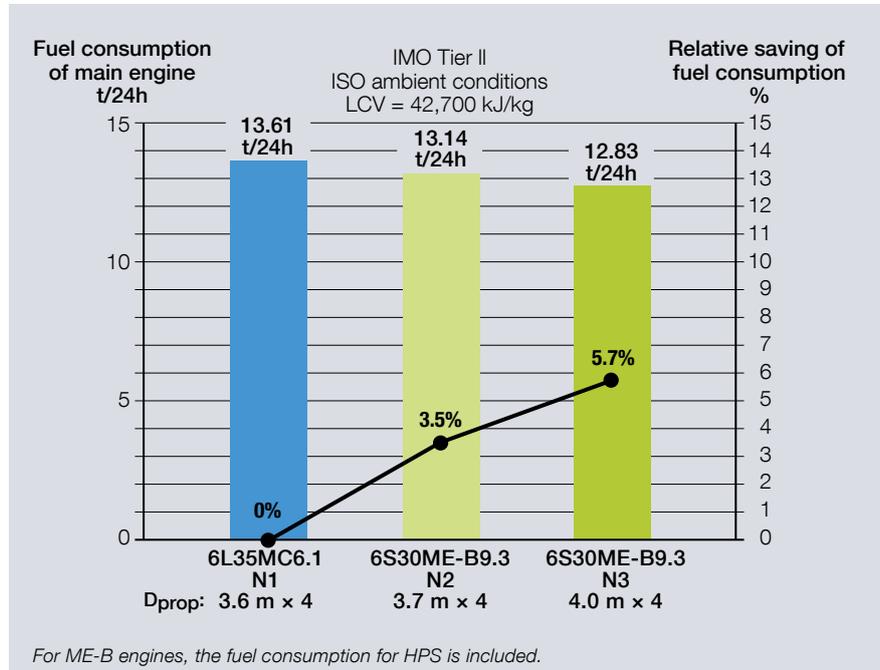


Fig. 8: Expected fuel consumption at NCR = 90% SMCR for 14.0 knots

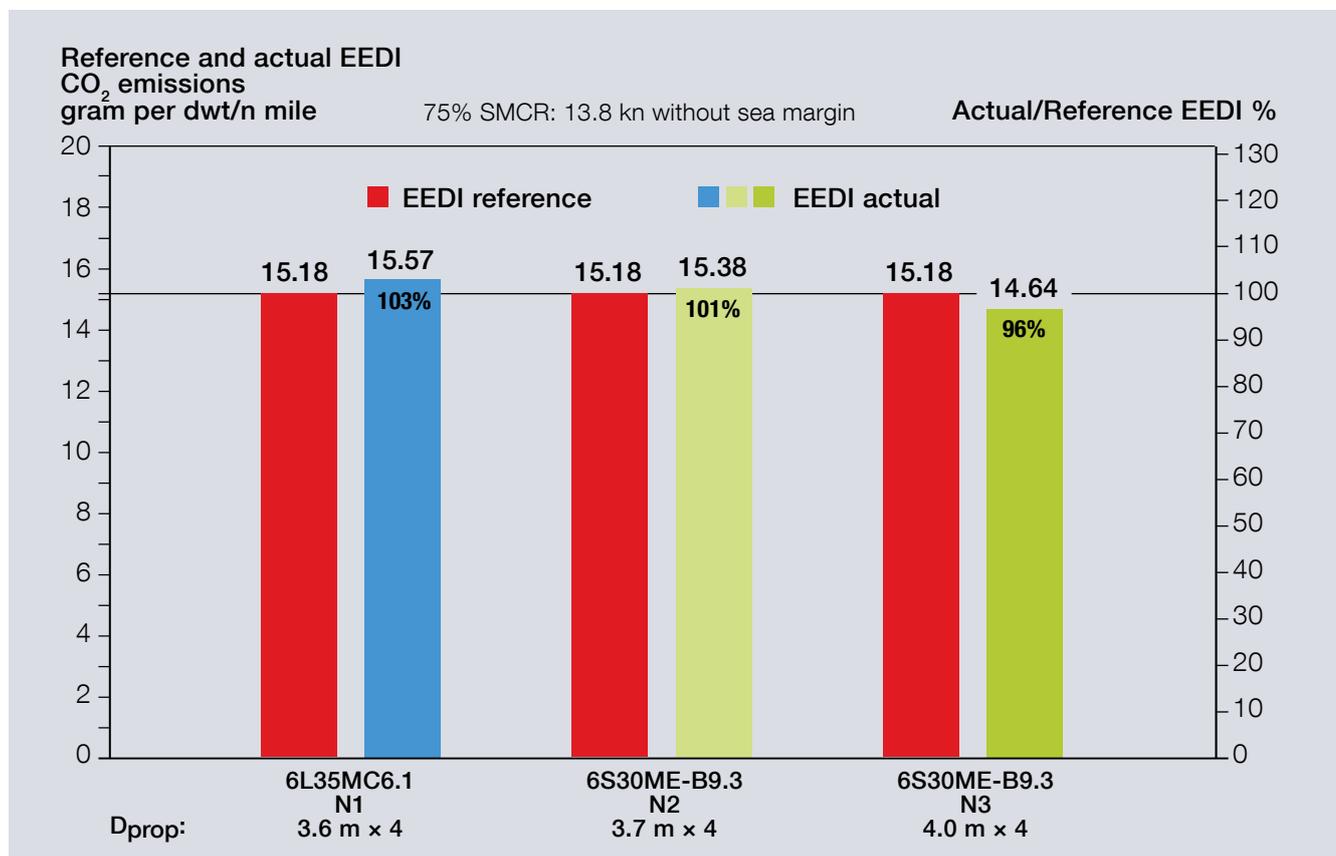


Fig. 9: Reference and actual Energy Efficiency Design Index (EEDI) for 14.0 knots

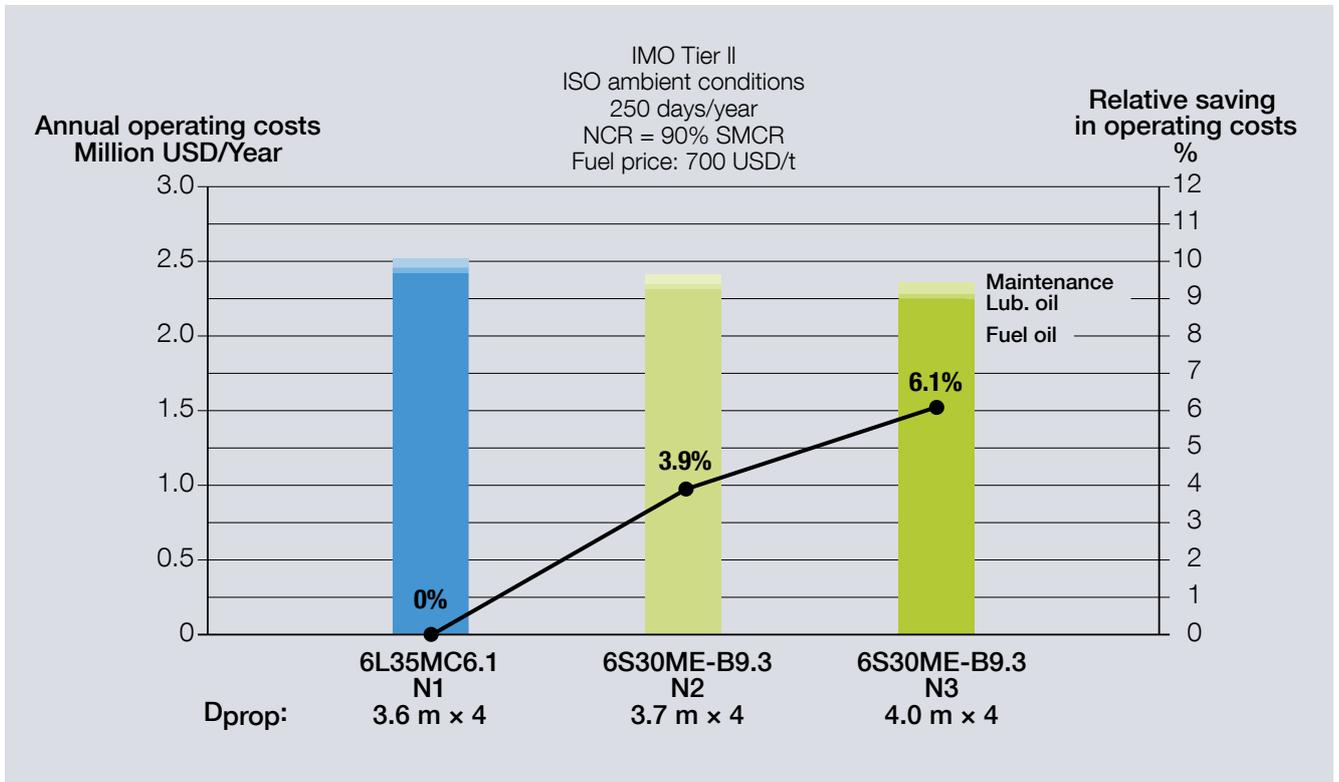


Fig. 10: Total annual main engine operating costs for 14.0 knots

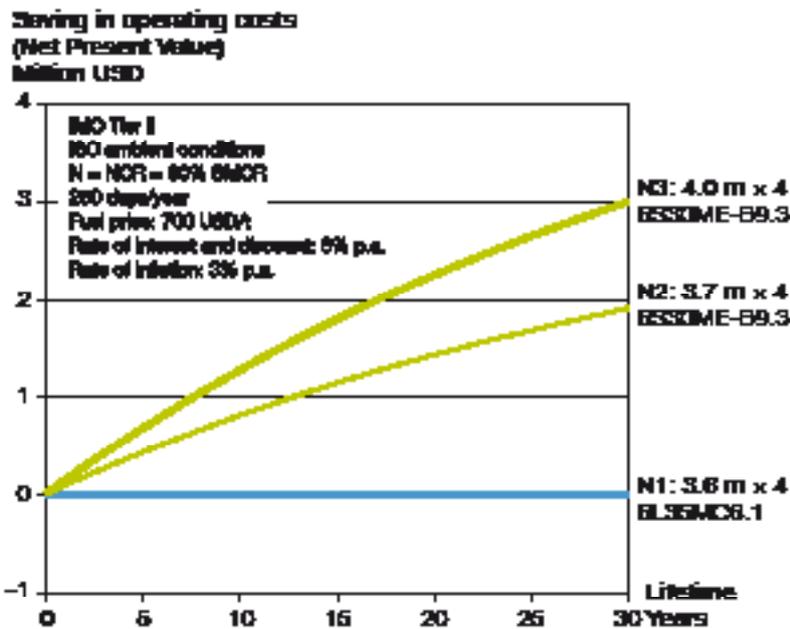


Fig. 11: Relative saving in main engine operating costs (NPV) for 14.0 knots

After some years in service, the relative savings in operating costs in Net Present Value (NPV), see Fig. 11, with the old 6L35MC6.1 used as basis with the propeller diameter of about 3.6 m, indicates an NPV saving for the new 6S30ME-B9.3 engines. After 25 years in operation, the saving is about 2.7 million USD for N3 with 6S30ME-B9.3 with the SMCR speed of 173.0 r/min and propeller diameter of about 4.0 m.

**Main Engine Operating Costs –
13.0 knots**

The calculated main engine examples are as follows:

13.0 knots

1'. 5L35MC6.1 ($D_{prop} = 3.3$ m)	$M1' = 2,710$ kW \times 210.0 r/min
2'. 5S30ME-B9.3 ($D_{prop} = 3.5$ m)	$M2' = 2,655$ kW \times 195.0 r/min.
3'. 5S30ME-B9.3 ($D_{prop} = 3.8$ m)	$M3' = 2,540$ kW \times 166.0 r/min.

The main engine fuel consumption and operating costs at $N' = NCR = 90\%$

SMCR have been calculated for the above three main engine/propeller cases operating on the relatively lower ship speed of 13.0 knots, which is probably going to be a more normal choice in the future. Furthermore, the EEDI has been calculated on the basis of the 75% SMCR-related figures (without sea margin).

Fuel consumption and EEDI

Fig. 12 shows the influence of the propeller diameter with four propeller blades when going from about 3.3 m to 3.8 m. Thus, $N3'$ for the 5S30ME-B9.3

with an about 3.8 m propeller diameter has a propulsion power demand that is about 6.3% lower compared with the $N1'$ for the 6L35MC6.1 with an about 3.3 m propeller diameter. For the two ME-B engine cases, an extra SFOC of +1 g/kWh has been added corresponding to the power demand needed for the Hydraulic Power Supply (HPS) system.

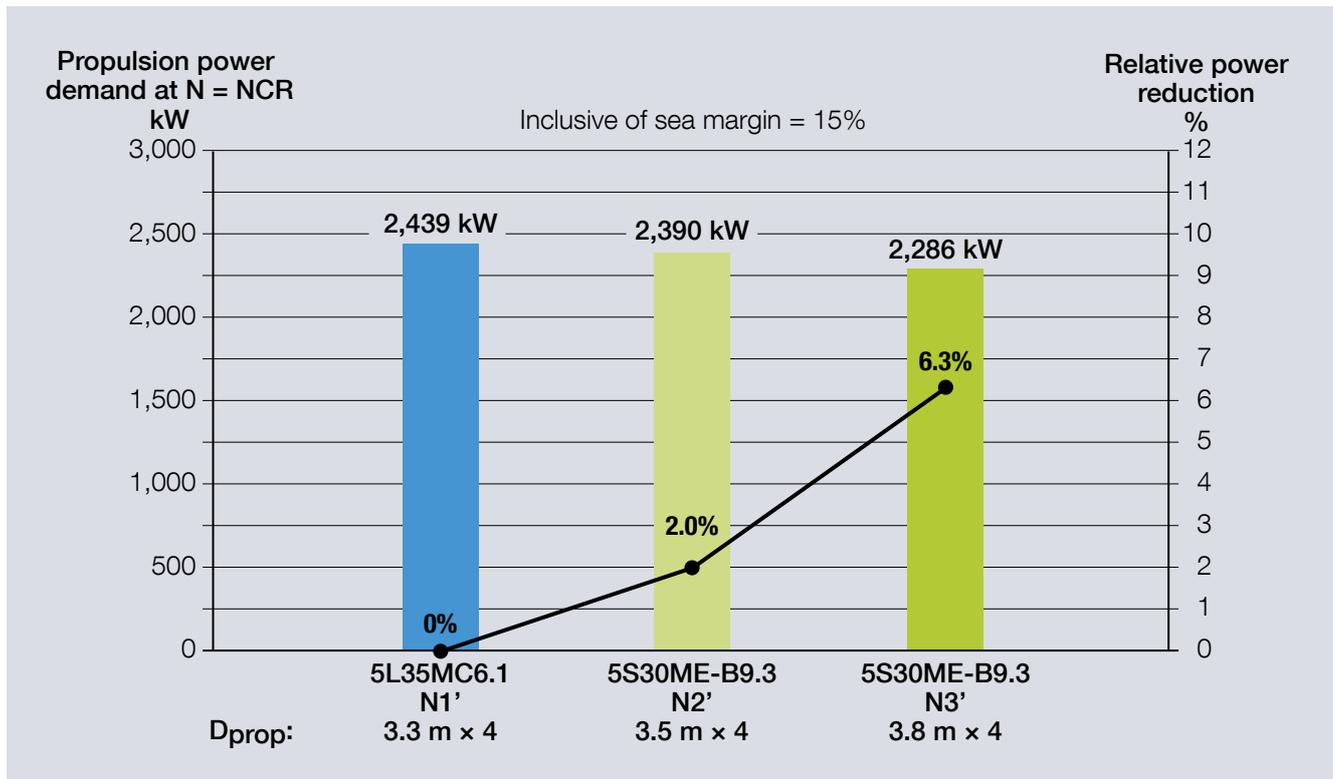


Fig. 12: Expected propulsion power demand at NCR = 90% SMCR for 13.0 knots

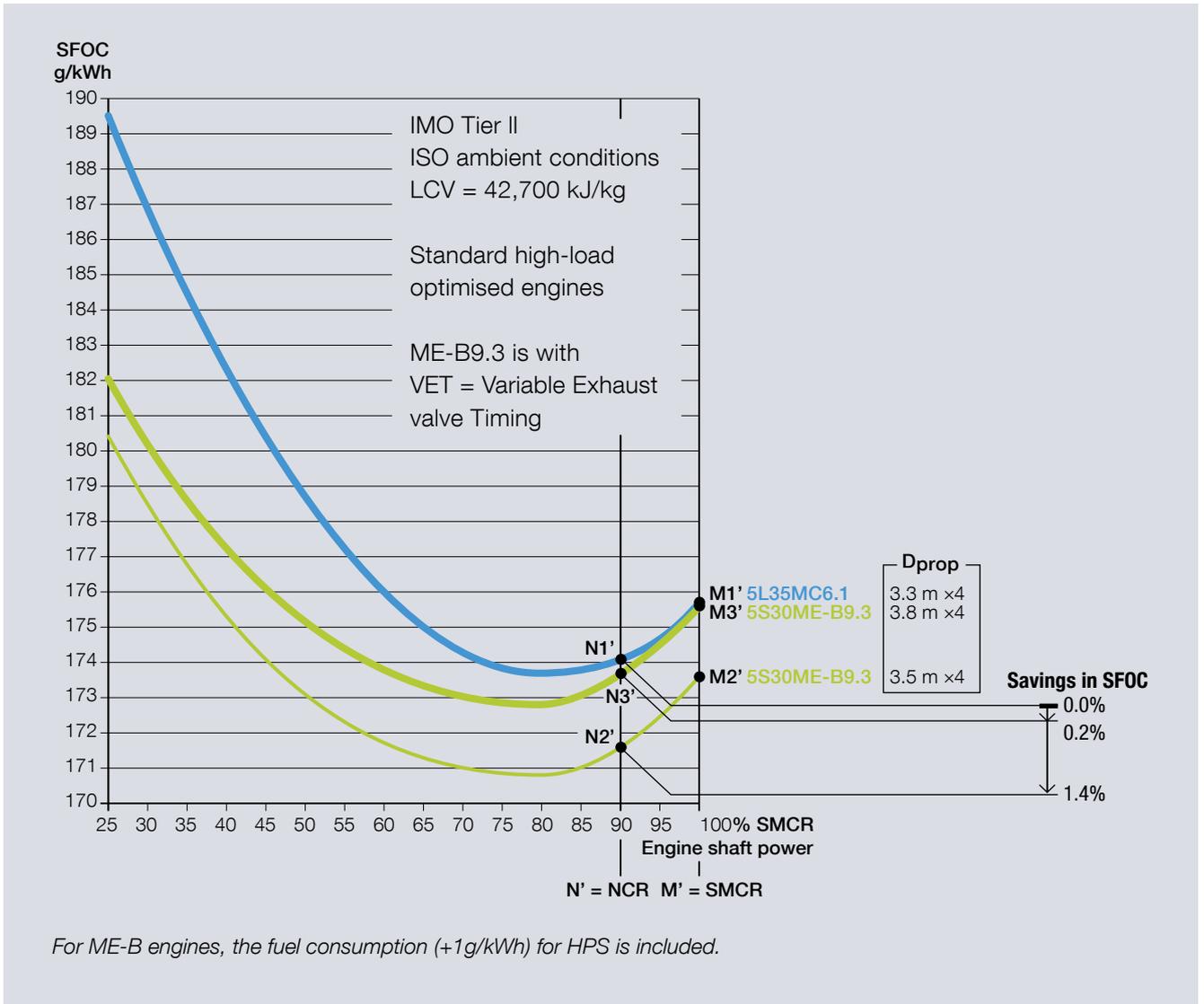


Fig. 13: Expected SFOC for 13.0 knots

Fig. 13 shows the influence on the main engine efficiency, indicated by the Specific Fuel Oil Consumption, SFOC, for the three cases. N3' = 90% M3' with the 5S30ME-B9.3 has a relatively high SFOC of 173.7 g/kWh compared with the 174.1 g/kWh for N1' = 90% M1' for the 6L35MC6.1, i.e. an SFOC reduc-

tion of only about 0.2%, mainly caused by the greater speed derating potential giving higher mep of the 5S30ME-B9.3 engine type, but involving a higher potential propeller efficiency.

The daily fuel consumption is found by multiplying the propulsion power de-

mand at N' (Fig. 12) with the SFOC (Fig. 13), see Fig. 14. The total reduction of fuel consumption of the new 5S30ME-B9.3, N3' with propeller diameter 3.8 m, is about 6.6% compared with the old 5L35MC6.1 (see also the above-mentioned savings of 6.3% and 0.2%).

The reference and the actual EEDI figures have been calculated and are shown in Fig. 15 (EEDI_{ref} = 1,218.8 × dwt^{-0.488}, 15 July 2011). As can be seen for all three cases, the actual EEDI figures are now somewhat lower than the reference figure because of the relatively low ship speed of 13.0 knots. Particularly, case 3' with 5S30ME-B9.3 has a low EEDI – about 77% of the 2013 reference figure. All engine cases will meet the stricter 2025 EEDI reference figures.

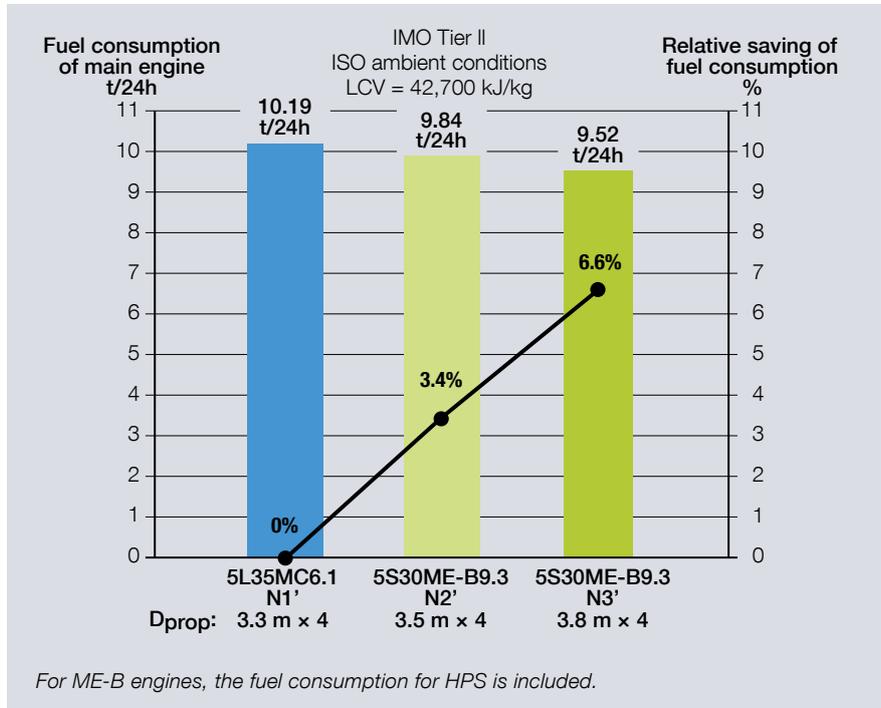


Fig. 14: Expected fuel consumption at NCR = 90% SMCR for 13.0 knots

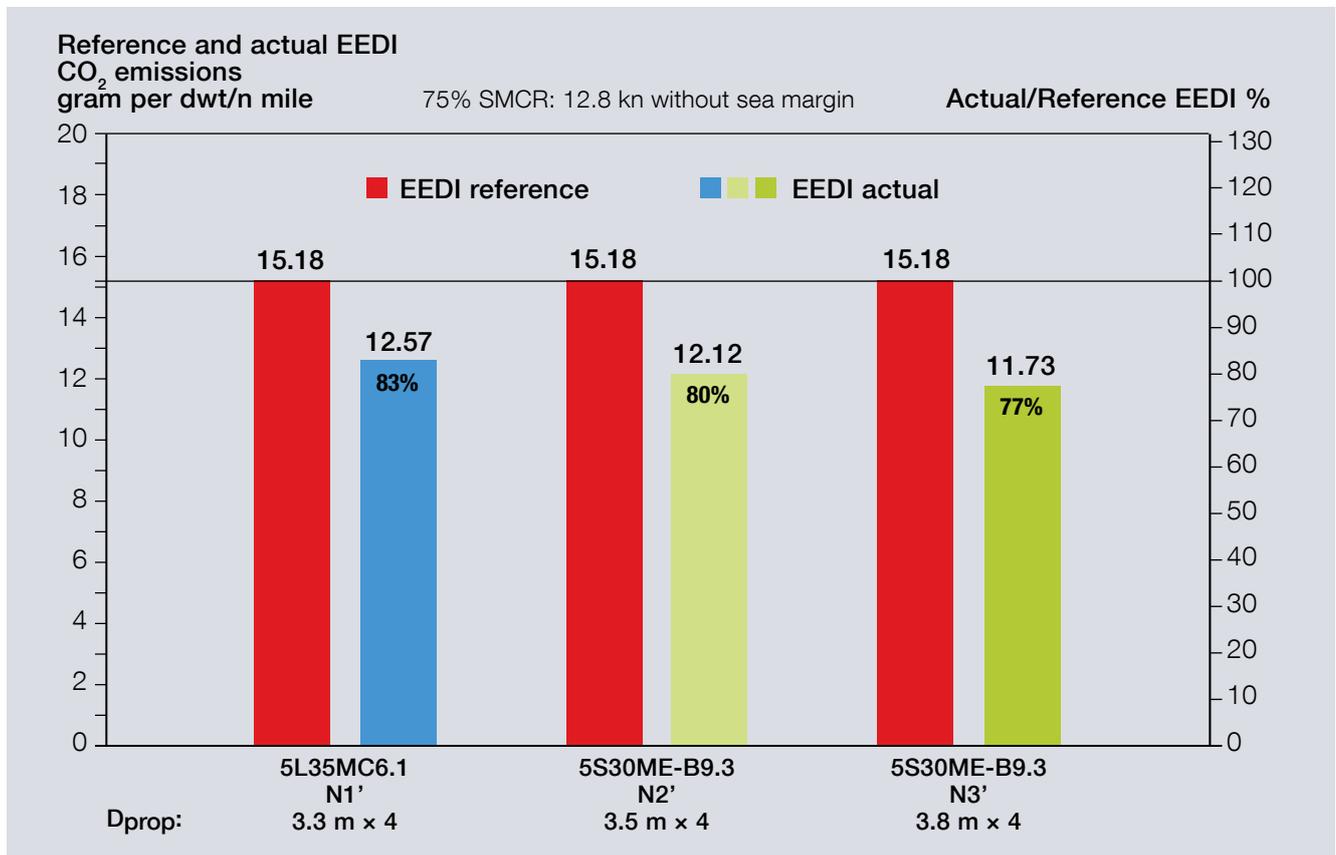


Fig. 15: Reference and actual Energy Efficiency Design Index (EEDI) for 13.0 knots

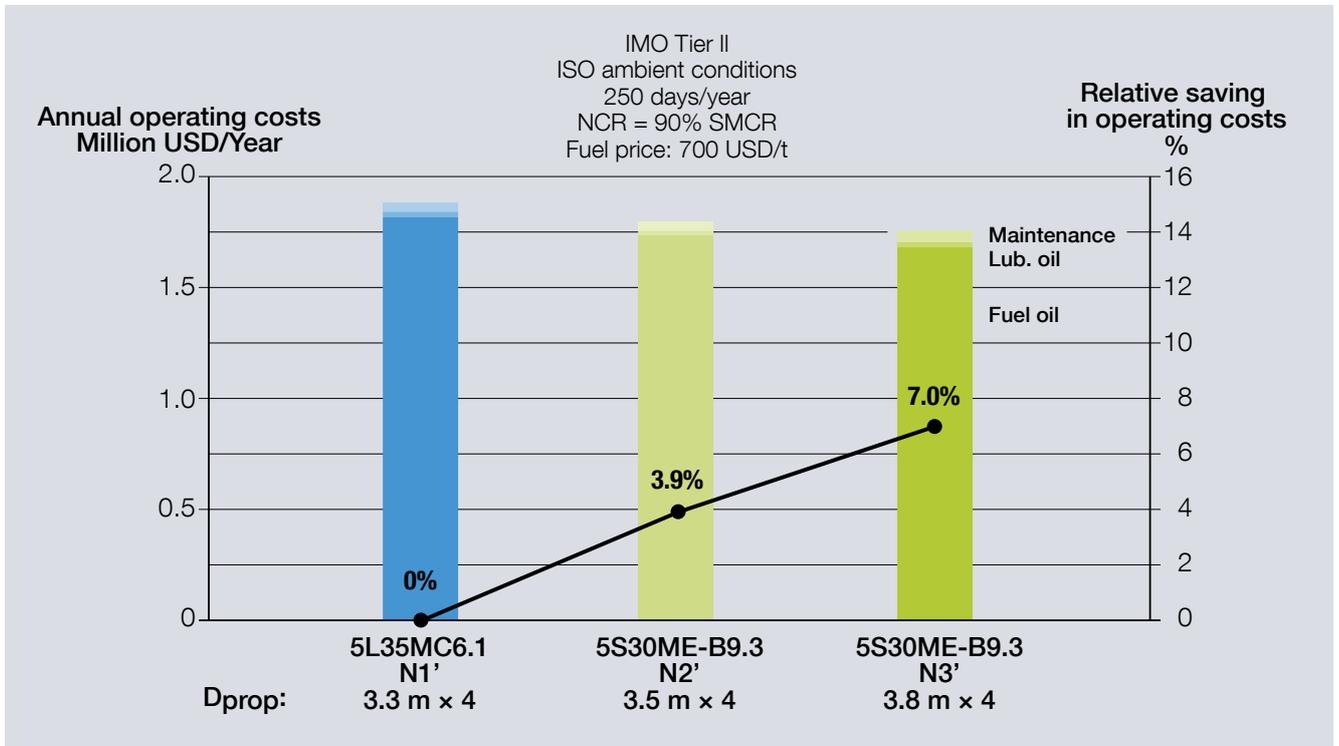


Fig. 16: Total annual main engine operating costs for 13.0 knots

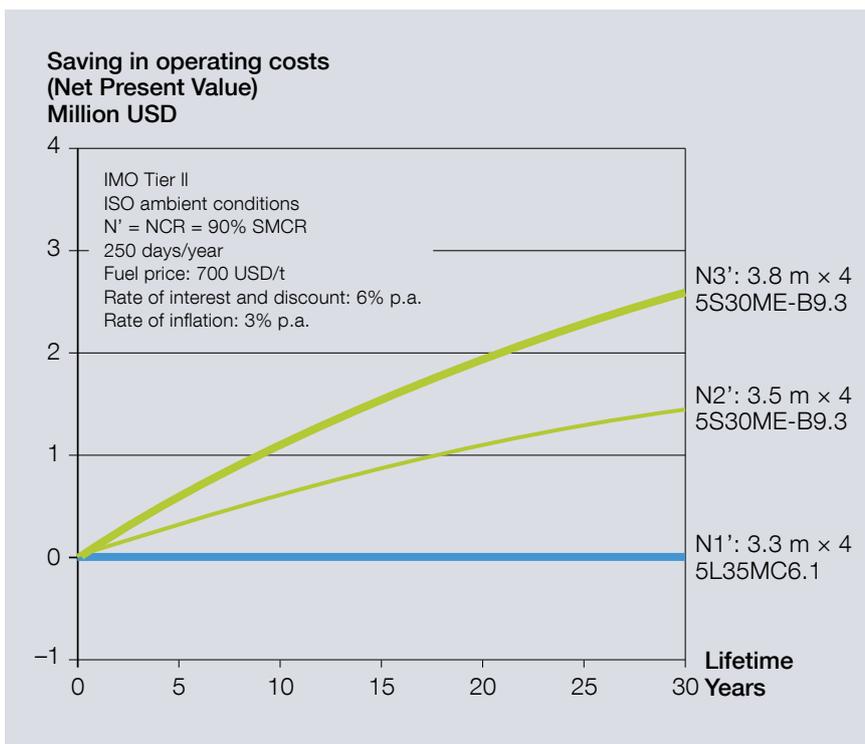


Fig. 17: Relative saving in main engine operating costs (NPV) for 13.0 knots

Operating costs

The total main engine operating costs per year, 250 days/year, and fuel price of 700 USD/t, are shown in Fig. 16. Lube oil and maintenance costs are also shown at the top of each column. As can be seen, the major operating costs originate from the fuel costs – about 95%.

After some years in service, the relative savings in operating costs in Net Present Value, NPV, see Fig. 17, with the old 5L35MC6.1 with the propeller diameter of about 3.3 m used as basis, indicates an NPV saving after some years in service for the new 5S30ME-B9.3 engine. After 25 years in operation, the saving is about 2.3 million USD for N3' with the 5S30ME-B9.3 with the SMCR speed of 166.0 r/min and propeller diameter of about 3.8 m.

Summary

Traditionally, long stroke L-type engines, with relatively high engine speeds, have been applied as prime movers in very small tankers.

Following the efficiency optimisation trends in the market, the possibility of using even larger propellers has been thoroughly evaluated with a view to using engines with even lower speeds for propulsion of particularly small tankers and bulk carriers.

Small tankers and bulk carriers may be compatible with propellers with larger propeller diameters than the current

designs, and thus high efficiencies following an adaptation of the aft hull design to accommodate the larger propeller, together with optimised hull lines and bulbous bow, considering operation in ballast conditions.

The new and small super long stroke S30ME-B9.3 engine type meets this trend in the small tanker and bulk carrier market. This paper indicates, depending on the propeller diameter used, an overall efficiency increase of 3-7% when using S30ME-B9.3, compared with the old main engine type L35MC6.1 applied so far.

The Energy Efficiency Design Index (EEDI) will also be reduced when using S30ME-B9.3. In order to meet the stricter given reference figure in the future, the design of the ship itself and the design ship speed applied (reduced speed) has to be further evaluated by the shipyards to further reduce the EEDI.

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