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# COMPARATIVE STUDY OF TWO SIMPLE MARINE ENGINE BSFC ESTIMATION METHODS

## Summary

Due to increasingly strict environmental regulations and dwindling oil reserves, fuel consumption and its minimisation play a more and more important role in shipping as well. Based on trends in recent years, the easiest way to solve the problem so far is the so-called "Slow steaming". Other option is the use of alternative fuels, which are increasingly present in shipping with more and more variations. In inland navigation, the above mentioned solutions are also functional, but less achievable. On the one hand, the slower delivery reduces the competitive position of inland navigation in the market, and on the other hand, the number of propulsion systems with alternative fuels are very small in this area. Therefore, the greatest innovation potential can be found in optimising the drive system for minimise the fuel consumption.

To do this, the operating profile of the ship being built / built, the parameters influencing the fuel consumption and the more detailed consumption characteristics of the engines need to be known. Many methods have been published in the past decade to determine the latter component. In this research, the authors review the factors influencing fuel consumption of inland navigation, the measurement of fuel consumption and the estimation procedures by any means of transportation based on the literature. They present their modeling results, which are transplanted from several areas into water transport. The proposed methods are validated by engine brake measurements.

*Key words: fuel consumption; diesel engine; inland navigation; simple estimation methods*

## 1. Introduction

The optimisation of the energy system of ships has received increasing attention over the last two decades. Alternative propulsion systems and alternative fuels are emerging. The main driving forces behind the developments are environmental protection, lowering cost of fuel as well as operating and maintenance costs [1].

In order to slow down climate change, all vehicles and polluting plants have to fulfil more strict environmental regulations. Inland navigation also has to be equal to stricter regulations from 2019, according to the European Stage V non-road emission standards – EU regulation 2016/1628. Currently, almost all of the inland ships are equipped with an oil-powered engine. We already know that oil resources are terminate, so this kind of energy source will become more and more expensive (Fig. 1, 2).
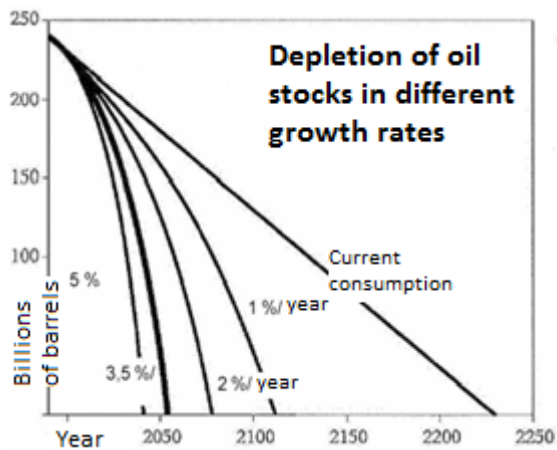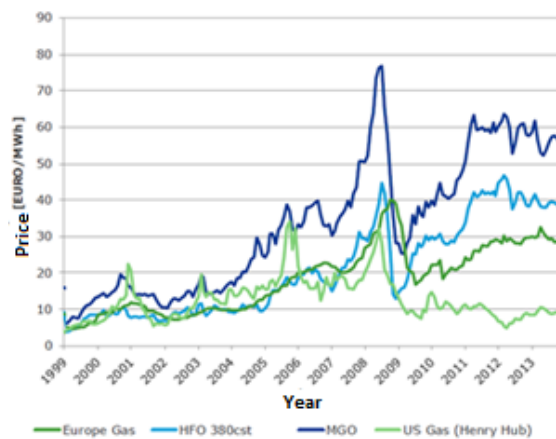
**Fig. 1** Depletion of oil stocks [2]



**Fig. 2** Marine fuel price changes [3]

Accordingly, it is necessary to minimise the consumption or develop alternative fuels and gradually incorporate them into marine propulsion systems.

At inland shipping in most cases the fuel costs account for almost half of the operating costs. It is therefore also in the interest of the operator that the ship is as energy efficient as possible. In addition to alternative fuels, other types of alternative drive systems have been developed. Diesel engines also provide propulsion and auxiliary power in these systems, but provide much more efficient use. Such a drive system is a hybrid propulsion system that is gaining ground in road traffic and a ship specific diesel-electric drive.

The spirit of the conventional and the above mentioned alternative drive systems is always one or more diesel engines. In order to minimise consumption, the fuel map of the motor must be known accurately to be used. However, this is rarely made public by the manufacturers. In most cases, the expected (specific) fuel consumption is indicated at some load levels. This is not enough to design the optimum drive, because the engine is forced to operate in a variety of speed and loading conditions, where consumption values are unknown. As a result, more and more publications have recently been published on various fuel consumption estimation procedures. Methods and tools are very diverse, as engine processes are extremely complex and can be approached in many ways to estimate fuel consumption.

Ship fuel consumption varies by operating area, but it is influenced by many factors. This is especially true for river navigation, as the difference in power demand between upstream and downstream is usually significant, and continuous water level fluctuations create different conditions from week to week. Shallow water and sewer effects are often more serious resistance increasing effects. Vessels traveling on the Rhine-Main-Danube route have to undergo a lot of flood gates, which means a lot low time, low load part of the engine(s).

After presenting several estimation methods, the authors will compare two methods through the results of a brake test. An important consideration in choosing two methods was to make it as easy, fast, and accurate to estimate the engine fuel map from the manufacturer's published basic data as it is possible.

## 2. Parameters influencing fuel consumption of inland navigation

The power consumption and, at the same time, fuel consumption can be influenced by a number of parameters, which can be grouped into the following categories: design, environmental and vehicle driving or operating factors. These are described in more details below.

2.1    Design factors

When designing a ship, engineers are trying to achieve the least possible resistance to the hull and the best drive system that fits into it. With the advancement of technology, the emergence of innovative ideas, the performance and efficiency of the propulsion system of an operating ship can be improved. Resistance can increase with the contamination on the ships, which is why it is advisable to wreck and free the contamination every few years. Another method of reducing resistance can be blast technology used at sea on some ships. At this time, air bubbles are generated on the hull surface, which reduces friction and thus resistance. Less resistance means less power to be built at the same speed that results in lower fuel consumption. A few percent increase in drive system efficiency results in high fuel savings over the long term. This can be achieved by increasing the partial efficiency of the components (cascade factor [4]).

2.2    Environmental factors

The environmental factors are the external circumstances that the ship driver and the operator have no influence, so they must be accepted as an asset.

Wind and waves are intended to steer the ship from its intended direction of travel, and generally maintaining it (except for the wind coming from behind) requires extra power [5].

Flowing the river has a drastic impact on power consumption. It is well known that the power demand at downstream of a ship for the same speed is a fraction of the power at upstream, or at the same power with a significantly higher speed at downstream. This effect depends primarily on the rate of the river flow, and is therefore of greater importance on the free ridden (non-swollen) sections of rivers. It is also obvious that inland waterway vessels are usually forced to spend half of their lifetime in downstream mode, while the other half is spent in upstream mode. In the case of conventional propulsion systems, it must be dimensioned for the highest power requirement, and consequently it is evident that in a substantial part of the in-service life of the inland vessels, the engine(s) will be subjected to partial load. This results in higher fuel consumption, because the motor cannot work around its optimum working point.

The effect of the current depth of water and width of the ship can be attributed to the same reason, and both significantly increase the resistance of the ship and consequently the power demand [6]. Both parameters can be considered beforehand, although in the case of the water depth the power requirement for the smallest shipping depth, the ship can operate under more favorable conditions (so called "lighter screws").

Vessel traffic - especially high traffic - usually requires speed reduction and possibly otherwise unnecessary maneuvers, reducing power consumption and breaking its uniformity, resulting in higher specific fuel consumption values.

The quality of the diesel fuel has as well an important role on fuel consumption [7]. Not only the fossil components [2] but as well the blended biocomponents have effect on vessels fuel consumption [8]. Biocomponent blending into the main fuels are prescribed by the EU [9]. In some countries, it is prescribed as a litre-by-litre bioblending in other countries it can be fulfilled by pool blending of biofuels [10]. In most of the cases biofuels are containing oxygen and it results poorer combustion parameters as the replaced fossil fuels [11]. Winter regulation can be kept in most of the cases with lighter components and it has a negative effect on fuel consumption [12].

2.3    Operation, driving factors

These include the influencing factors that can be influenced by the ship's navigator. The load of the ship, especially the cargo ship, the amount of cargo and supplies carried influences the dive, the shape of the submerged part of the ship and the resistance and power consumption of the ship. While it is obvious that the maximum allowable load is to be picked up, it is not certain that the market environment or the water level will always be an opportunity, so the fuel consumption of the marine engines may therefore vary from one road to another. (For inland passenger ships, this effect is almost negligible, because the mass of persons even in the case of a river cruise ship is much smaller than the weight of the ship.)

Manoeuvres (such as approaching and leaving stops for passenger ships used in public transport, or navigating the craft into or out of the port, or shipping through locks) are generally carried out at reduced engine power. Their number (timerate) and nature have a clear impact on fuel consumption.

The energy needs of the auxiliary plant should not be completely forgotten either. In the case of inland waterway vessels, this is of greater importance only for certain types (such as cabin passenger ships, or tankers, other special vessels), while for other vessels the auxiliary power requirement is significantly lower than the energy demand for propulsion and is therefore neglected in this article.

And last but not least, the desired or expedient speed of the ship, and the associated charge control, fundamentally affect fuel consumption [13]. The desired or appropriate speed of the vessel may be influenced by environmental characteristics (eg. fog, wading conditions), but in the case of public passenger ships, the timetable may also be such a controlling factor. In cargo ships, the turnover of the locks, the knowledge of the expected take-off time, or the possible time of loading also have an impact on the speed of the ship (it makes no sense to sail at the design speed if we know that, (un)loading can only hours or even days happen later compared to the originally planned arrival time, eg. due to port overload). Taking all of these into account, the so-called "Smart steaming" technologies are designed to dynamically optimise vessel speed based on real time nautical and environmental conditions, also destination port and loading information [14].

## 3.    Fuel consumption estimation methods

Fuel consumption in diesel engines is a very complex chemical and physical process, the extent of which is influenced by many factors (ignition pressure and time, cooling, etc.).

## 3.1    GT-POWER and SEECAT

The subtitle covers the names of 2 software packages, the former of which provides a highly detailed engine modeling, while the latter provides full drive system modeling. The biggest drawback is that none of this software is free, so it can only be used at a high cost.

In GT-Power it can be build a detailed motor model with different modules. The software is a great help in the development of new engines, thanks to the extremely detailed setup and change options. A very exact simulation can be achieved with its use. It is also possible to simulate built in engines, but this requires very detailed data, which is usually not available.

The SEECAT software developed by Bureau Veritas is specifically designed for modeling marine propulsion systems. Here the motors are already used as a whole unit. In addition to the number and type of propulsion engines, boilers, auxiliaries, screws, thread diagrams, and so on can be connected to the system. The simulation based on the thread diagram produces nearly the same results as the real measurements [15].

## 3.2  **Specific fuel consumption maps**

Engine manufacturers rarely, but sometimes, make the specific fuel consumption data in the engine speed and torque / power range of each motor public. These are the so called shell curves and charts from the above data are referred to in the literature as fuel map / performance map. Such a diagram is shown in the Fig. 3 below.

Geting a set of points by charting the value pairs that can be read from the chart. For example, the set of points MATLAB can be used to match a polynomial equation with an even surface and get the coefficients of the equation. The variables will be the speed and the torque / power. It allows two pairs of points to be assigned the current BSFC instantly.
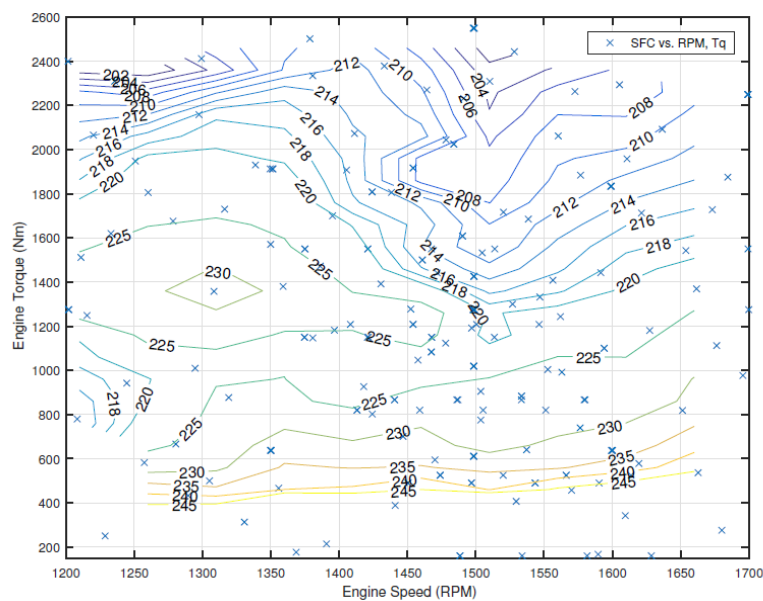


**Fig. 3**  Fuel map of Perkins 2506C [16]

### 3.2.1  Scaling

A similar diagram of another engine can be generated by matching the readings of the read table with the available BSFC data of the other motor. The proportioning retains the character of the clamshell curves, only the numerical values change. Because each engine has a unique fuel folder, this solution can produce greater variations if the performance and design differences between the two engines are significant. Thus, this method can result in quick but inaccurate calculations and can be applied just to approximate comparisons.

### 3.2.2  Modeling algorithms

In the course of research, most of the systems used to model a system or machine are the ANN (Artifical Neural Network) or RVM (Relevance Vector Machine) algorithms. Although ANN has been accepted in many studies, but in general, there are three main disadvantages to learning in ANN [17]:

1. The architecture of ANN, including the number of hidden neurons, must be prioritised or modified during heuristic training, resulting in a suboptimal network structure.
2. The teaching process (ie minimising the residual square error function) in the ANN can easily get stuck in local minima.
3. The amount of training data is usually high for ANN. Generally, ANN requires at least 200 to 400 training data to create an accurate petrol engine model.

However, in the case of a diesel engine, the collection of motor output and performance data is very time consuming, costly and the motor speed is also tight. Therefore, the size of a representative training dataset is always very small, which means that ANN is not the best solution for modeling diesel engines.

Tipping [18] suggested an algorithm called the relevant vector machine (RVM) to overcome the above-mentioned drawbacks of ANN. The most obvious feature of RVM is that it reduces the number of parameters required by the traditional ANN. The RVM training algorithm also provides a global optimal solution (ie good generalisation), while the ANN learning process can lead to a local optimal solution, so ANN requires representative training data to minimise the risk. With these advantageous features, the RVM does not require too many samples to create an exact model.

Research shows that RVM generally gives better estimates than ANN, but a MLP (Multilayer Perceptron) neural network estimation can provide better results than a general ANN [19]. The application of this algorithms to model diesel engines are still rare solutions.

### 3.2.3 Goering method

The first chosen model was developed by Goering et al. and was built to estimate brake specific fuel consumption by utilising torque, engine speed, and lower indicated efficiency parameters. The model developed by Goering et al. will be presented as the Goering model here and is represented by Eq. (1) [20]:

$$BSFC = \left[\frac{3600}{Hg}\left(1+\frac{P_{fme}}{P_{bme}}\right)\right]\left[\frac{1}{e_{ito}}\left(1+T_b^n\left(B_0 + B_1\left(\frac{N}{1000}\right)^{-1} + B_2\left(\frac{N}{1000}\right)^{-2} + B_3\left(\frac{N}{1000}\right)^{-3} + B_4\left(\frac{N}{1000}\right)^{-4}\right)\right)\right] \quad (1)$$

Where:

$Hg$ – Heating value of diesel kJ kg$^{-1}$ (BTU lb$^{-1}$)

$T$ – Torque N-m (ft-lb)

$N$ – Engine speed (rpm)

$BSFC$ – Brake Specific Fuel Consumption kg kW$^{-1}$ hr$^{-1}$ (lb hp$^{-1}$ hr$^{-1}$)

$P_{fme}$ and $P_{bme}$ – Friction and Brake Mean Effective Pressures – SAE Standard J1995 (SAE, 1995) states that if the mechanical efficiency is not known then the mechanical efficiency can be estimated to be 85%. The portion of the equation, (1+ $P_{fme}$/ $P_{bme}$) is equal to 1/mechanical efficiency = 1/85%

$e_{ito}$ – Average of the indicated efficiency at the lower torque values. The indicated thermal efficiency is the ratio of indicated power and fuel equivalent power

$n, B_i$ – Constants, specific to each engine, calculated with solver via minimisation the sum of squared differences between read and calculated BSFC values

The first limitation of the applicability of the method is that, it must be available at full load the engine power and BSFC characteristics as a function of the engine speed. Based on the data read from the charts, the coefficients should be chosen so that the BSFC values provided by the equation are as close as possible to this points. In the case of 6 variables (n and $B_i$), this is possible only with the help of a solver. It can be useful either Excel Solver or MATLAB for this task. Measurements usually include speed and torque measurement, so this formula instantaneously gives the data value for the data pair.

### 3.2.4 Altosole method

The method was published by Altosole et al. [21]. The process builds on the content of the Fig. 4. The diagram shows the relative performance of a general diesel engine as a function of relative speed and different fuel consumption levels.
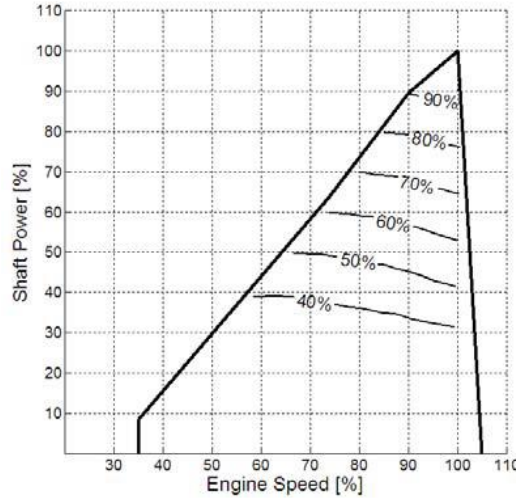
Comparative study of two simple marine engine
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**Fig. 4** Relative power change at the same fuel consumption levels as a function of relative engine speed [21]

The 60% line indicates 60% fuel consumption of the maximum power. With higher engine speeds and low power consumption, the specific consumption is increasing as the performance drops, leading to a steeper reduction in the same fuel consumption curves when approaching the rated speed. The authors developed Eq. (2) to estimate brake performance:

$$P_B = \left(\frac{m_F}{m_{Fd}}\right)^x \left[a \left(\frac{m_{Fd}}{m_F}\right)^x n_E^3 + b \left(\frac{m_{Fd}}{m_F}\right)^y n_E^3 + c \left(\frac{m_{Fd}}{m_F}\right)^z n_E\right] \tag{2}$$

Where:

$P_B$ - current performance

$n_E$ - current engine speed

$m_F$ / $m_{Fd}$ - current and design fuel consumption ratio (charge)

*x, y, z* - engine specific exponents (x = 1.5 * y; z = 0.5 * y)

a, *b, c* - design fuel consumption curve coefficients

Index "d" refers to design value

The curve coefficients are calculated according to the Eq. (3):

$$P_{Bd} = a * n_{Ed}^3 + b * n_{Ed}^2 + c * n_{Ed} \tag{3}$$

The values of the coefficients are given by the intersection coefficients of the tertiary curve fitted to the same design fuel consumption curve. With this in mind, the choice of x, y, z exponents is such that the deviation from the available engine data at any point other than the design point is minimised. The method is extremely accurate in the article.

## 4. Reproduction and verification of Goering and Altosole methods

Altosole bases its equation on quasi-linear relative consumption curves. Goering model works also better, when the design BSFC curve doesn't have large suddenly changes. So more accurate estimate can be given in case of simple (old) diesel motors. Modern (electronically more controlled, turbocharged) engines have a less linear change in (brake specific) fuel consumption over their entire operating range. Therefore this methods rather over-estimate BSFC values in case of modern engines. Since this two methods are relative simple, their learning is not a very energy and time-consuming task. They managed to reproduce them with easy to use Excel spreadsheets, but the uncertainty of importing equations, variables, and coefficients required verification of self-made calculations.

### 4.1    Reproduction and verification of the Goering model

The basic equation of the model was presented in the previous chapter along with the explanation of the variables. In addition to non motor specific variables, the calorific value is easily searchable, whether it is any fuel. In this case the model is specifically designed for diesel engines, so the fuel value of diesel should be used, which is approx. 42.7 MJ / kg. The part to be calculated with the effective mid-pressure can be bridged by the authors' value. The authors did not disclose any data to quantify or offer the average indicated efficiency at low torque values. Dipak P. et al. [22] have compared various characteristics of a diesel motor with the operation of biodiesel fuel. Based on the chart here, the indicated efficiency can be between 64-72% for a low-load engine (Fig. 5).
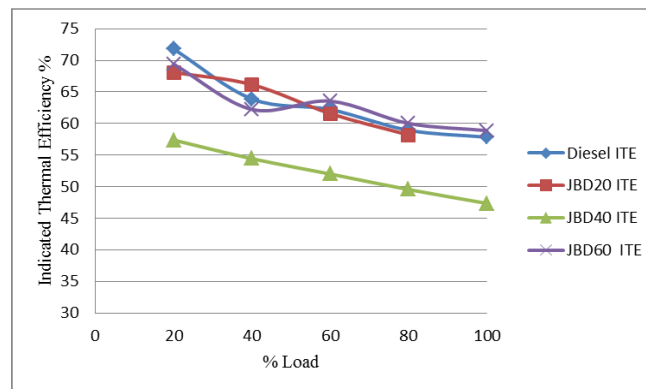


**Fig. 5** Indicated thermal efficiency of a diesel engine at vary loads [22]

The accuracy of the calculations is greatly influenced by reading the power-speed diagrams. Engine coefficients can be generated from Excel Solver. The article [18] contains the diesel motor coefficients of several tractors. Choosing the 129 kW Power Tech E John Deere engine [23], reading as accurately as possible and replacing the coefficients given by the authors gave rise to a very similar diagram. By changing the $e_{ito}$ value from 64 to 72%, and calculating "n" and "$B_i$" values for every % step, the 66% value showed the slightest difference between the read and the BSFC values calculated from the equation.
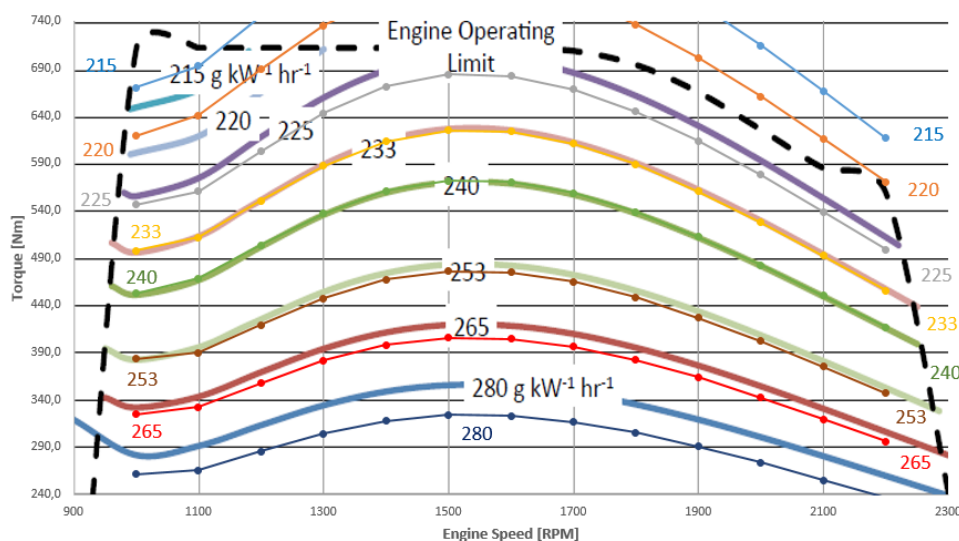


**Fig. 6** Self made calculation differences of BSFC values in case of Goering model

Background of the Fig. 6 are the BSFC contours from the article [20], and the lines with markers show the contours obtained from own calculations. The two charts have almost the same character and max. 2,5% difference in their numerical values. This can be attributed to

reading inaccuracy. Based on all these, we can say that the self-made Excel table is appropriate.

## 4.2    Reproduction and verification of Altosole method

The model is based on the diagram (Fig. 4) and equation (Eq. 2) presented in the previous chapter. According to the diagram, the engine power at the same fuel consumption level will decrease to higher speeds. Rated power can be reduced by up to 10% at rated speed. Based on the fuel map presented (Fig. 3), this is true, as the BSFC value is increasing at a lower torque near the rated speed. The fuel map also shows that a valley like contour appears around 1500 rpm in the larger torque range. This is a feature of the modern diesel engines, where they try to adjust the lowest BSFC values to the propeller power curve. For such motors, a hilly curvature or plateau should appear in the above-mentioned diagram in the vicinity of the highlighted speed value, because with smaller BSFC values the same fuel consumption results in a higher power level. The first step of the estimation is to read the design FC curves of the diagram and the coefficients (a,b,c) of the curve are coming from fitting a third degree curve on data points with zero intersection, even in Excel. In addition, it is need to know at least two different load states of the BSFC values or FC data of the engine, one of which is at full load. The lower load value will be the design fuel consumption ($m_{fd}$). Replacing the total power consumption ($m_f$) of the motor, the power delivered at full load can be obtained in the equation. If this is not the same as the factory data, the direct (and thus x and z indirect) changes of the exponent y should be the same. Only the $m_f$ value should be changed and the engine fuel map can be made. The self-made calculation method is shown in the following diagram (Fig. 7).
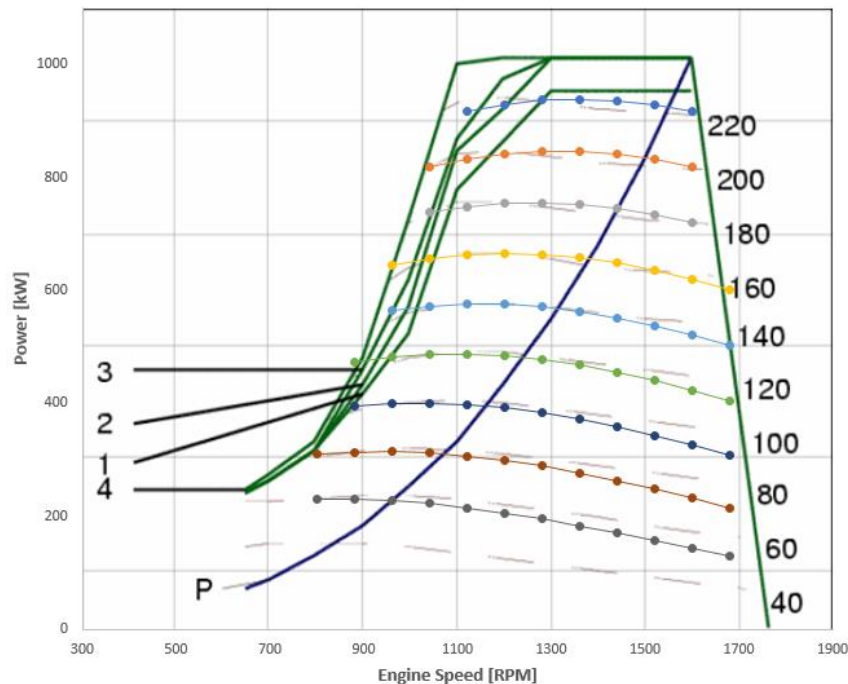


**Fig. 7** Self made calculation differences of BSFC values in case of Altosole model

In the background of the diagram, the performance characteristics of a CAT engine [24] can be seen, with a gray dashed line indicating the same fuel consumption levels. The lines with markers show the results of the calculation. The average deviation is 2%, with max. 10% differences only at lower power levels and higher speeds. Thus, the calculation method returns well the manufacturer's reported consumption data here.

## 5.    Comparing the accuracy of Goering and Altosole methods with measurement
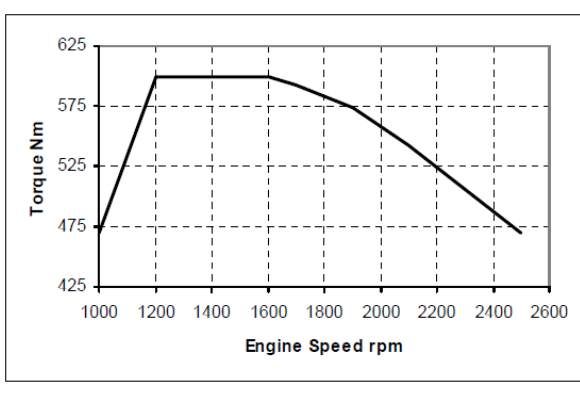
Based on the calculations performed so far, both methods are able to make relatively accurate estimates. The authors had a brake-power data set for a low-power diesel engine that allows comparability of the estimation accuracy of the two models.

### 5.1    Details of the measurement

During the measurement, a Cummins ISBe 170 30 EURO 3 turbocharged diesel engine was used. The basic datas and the characteristics of the motor are shown in Table 1.

**Table 1** Technical specifications of the measured engine [25]

| Engine specification | Unit | Cummins ISBe 170 30 | |
|---|---|---|---|
| Power | kW/HP | 125/170 |  |
| Nominal Speed | rpm | 2500 | |
| Bore/Stroke | mm | 102/120 | |
| Displacement | l | 3,9 | |
| Spec. fuel cons. | g/kWh | ? | |

No fuel consumption data was found for the motor, so the results of the measurements were the input for the method. Measurement is performed at 250 rpm steps in the 1000-2500 speed range. For each speed, the values 50, 100, 200… Mmax are set. The fuel consumption is measured gravimetrically. Some of the measurement results are listed in Table 2.

**Table 2**  Some of the measured data

| RPM | Torque [Nm] | Bt [g/s] | Power [kW] | BSFC [g/kWh] |
|---|---|---|---|---|
| 1749 | 50 | 0,90 | 9,16 | 353,80 |
| 1750 | 100 | 1,44 | 18,33 | 282,88 |
| 1750 | 200 | 2,37 | 36,65 | 232,78 |
| 1752 | 300 | 3,42 | 55,04 | 223,69 |
| 1750 | 400,3 | 4,41 | 73,36 | 216,42 |
| 1752 | 594,5 | 6,19 | 109,07 | 204,30 |

### 5.2    Application of the models, results

The full load data (RPM-Torque-BSFC) required for the Goering method has been measured at all speeds so these data can be easily imported into the calculation process. 7 checkpoints can give accurate results. With the coefficients generated by Solver, the average deviation from the measured data was less than 0.5%. For the Altosole model, full load and multiple lower load data were available at the rated speed. By selecting one of the partial load consumption data, the system of equations needed for the motor was produced by adjusting the exponents to the maximum value.

**Table 3**  Some of the measuring and model calculation results

| RPM | Torque [Nm] | BSFC [g/kWh] | | | RPM | Torque [Nm] | BSFC [g/kWh] | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Measure | Altosole | Goering | | | Measure | Altosole | Goering |
| 1749 | 50 | 353,8 | 373,54 | 259,34 | 2501 | 50 | 404,12 | 751,18 | 255,79 |
| 1750 | 100 | 282,88 | 274,59 | 241,33 | 2499 | 99,9 | 287,8 | 402,71 | 238,38 |
| 1750 | 200 | 232,78 | 233,17 | 226,24 | 2498 | 199,8 | 234,19 | 271 | 223,76 |
| 1752 | 300 | 223,69 | 219,38 | 218,57 | 2500 | 300,7 | 218,59 | 233,48 | 216,28 |
| 1750 | 400,3 | 216,42 | 214,55 | 213,58 | 2498 | 349,7 | 211,72 | 224,98 | 213,71 |
| 1752 | 594,5 | 204,3 | 212,35 | 207,3 | 2499 | 486,3 | 208,2 | 209,4 | 208,42 |

In Table 3 some of the calculations are included to show in which cases the values were calculated using the individual estimation procedures. This shows that both methods provide good estimates for the higher torque range. Smaller torque values already show greater differences. The table summarising the magnitude of the average deviations shows, that both methods can estimate the evolution of BSFC values with an average margin of about 10%. However, these results are greatly influenced by the high deviations in low torque values. By ignoring the 50 Nm results, the average deviation for the Altosole model is only 5.8% and for Goering only 7.2%. If even 100 Nm results are not counted, the same values will be reduced to 4.1 and 4.9% (Table 4).

**Table 4**  Average devations in different cases

| Average deviations [%] | | | | | |
|---|---|---|---|---|---|
| With all measured data | | Without 50 Nm datas | | Without 50 & 100 Nm datas | |
| Altosole | Goering | Altosole | Goering | Altosole | Goering |
| 9,88 | 9,83 | 5,76 | 7,20 | 4,09 | 4,93 |

## 6.    Conclusions

Review of the state of the art technique of fuel consumption estimation has shown that the calculation of fuel consumption is an actual research topic. The main reason behind of this phenomenon in case of marine transportation is the increasing strictness of environmental standards, but ship operators also benefit from lower delivery rates. Some methods and software currently available can give accurate estimates, but they are complicated or expensive. Engine manufacturers publish relatively little information about motor consumption. This makes it more difficult to do more accurate estimations with simpler methods. Aim of our research was to validate the adaptability of two methods used in other transportation fields.

The process developed by Goering et al. requires the characteristics of engine power or torque and consumption as a function of speed. These diagrams are not available for all motors. In addition, the accuracy of the reading affects the results. The initial value of the coefficients provided by the solver also affects the accuracy of the model values. Altosole et

al. started from the fuel consumption of the engine and created the model to calculate the resulting power values. The model requires only two consumption values at different load levels, one of which is for full load. The inaccuracy of the reading on the graph underlying the values of the coefficients also affects the results. Goering's method is based on testing diesel engines in agricultural machinery, so it is likely to be more reliable for small boats or low-power (<500 kW) motors. Altosole proved in his article with a 6500 kW motor, and in this article we proved for 2 low-power engines that his method is very accurate. Therefore Altosole's method is more likely to give a more accurate estimate over a wider power range.

Compared to the results of the brake test measurements, both methods produced an average deviation of approx. 10%. However, without taking into account the smaller loads, the difference has decreased to 4% for Altosole and 4.9% for Goering. In this case, the minimum torque value taken into account is 200 Nm, which means a load of cca. 35%. Thus, at higher load levels, both methods are expected to produce estimates that are less than 5% based on comparison with measured values. The right sized engines of inland waterway vessels spend less than 5% of their operating time at less load, so the methods are in principle well suited for comparing different main engines and propulsion systems.

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