

## Correlation of Ignition and Combustion Properties of Bunker Fuels with their True Worth Index (TWI)

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### ABSTRACT

Heavy fuels do not have a Cetane Number to give an indication about ignition quality. However, various ignition and combustion properties may be determined using an instrument, Fuel Ignition Analyzer (FIA-100). An Equivalent Cetane Number (ECN) is obtained, based on the time delay between the start of ignition and the rise of chamber pressure to 3.0 bars. This time delay is referred to as Start of Main Combustion (SMC).

More than 50% of global fuels have ECN values less than 19. Since the instrument fails to give such low values, it is proposed that SMC may be used instead of ECN, as it is obtained for the entire range of fuels. Two hundred and fourteen samples, collected worldwide, were tested. A very good correlation of 0.88 is observed between SMC and True Worth Index, an overall fuel worth indicator presented to the bunker world community since 2001, from Viswa Lab. The true worth of a fuel can be obtained using a single parameter, SMC, derived from FIA-100.

**Key Words:** Ignition and Combustion Properties, Bunker fuel, Diesel Engine, Cetane Number, Fuel Worth

### 1. INTRODUCTION

Bunker fuels have not yet become commodities that can be traded in e-commerce. The question arises, how to commoditize bunker fuels, at least in the future. It is only possible if the quality of the fuel can be quantified. This quantification has to be approached at 2 levels. The first is a quantification that will give an idea of the potential of the fuel to cause wear and tear damage to the machinery using the fuel. The second is the total and true worth of the fuel – which is defined as a measure of the total energy in a fuel that can be converted into useful work while causing minimum wear and tear damage to the machinery.

Viswa Lab has pioneered Engine Friendliness Number (EFN) since 1993 [1]. Each and every analysis report carries EFN. Each parametric value of analyzed fuel is evaluated for its position in the range of acceptable values and given a score. A weightage factor is superimposed on this score depending upon the potential of that test parameter to cause damage. All these scores are then aggregated and placed on a scale of 1 to 100. Over the last 13 years clear patterns have emerged on the fuel quality based on EFN. If EFN is greater than 60, generally the fuel does not cause any problem. If it is less than 40, there is invariably a problem with the fuel.

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### 2. TRUE WORTH INDEX

Bunker fuels are purchased and stemmed all over the world. The only quality requirement applicable to this fuel is based on ISO 8217. The specification for various grades provides a very broad range. It is therefore possible to get a bunker fuel, which in terms of its usefulness to the marine engine can vary widely and yet conform to the specifications.

True Worth Index (TWI) (c) 2001 is a new Index proposed by Viswa Lab to indicate the true worth of a bunker fuel.

The three most important properties of the bunker fuel that determine its true worth to the marine engine are:

- a) Calorific Value, which is the energy content in the fuel,
- b) Ignition and combustion properties of the fuel
- c) Engine Friendliness Number, which provides information on the potential of the fuel to cause wear and tear and increased maintenance expenses of the engine.

The difference in calorific value between very good fuel and very bad fuel is only 5% (41 MJ/Kg for very good fuel and 39 MJ/Kg for very bad fuel).

Engine Friendliness Number can vary from 40 for an unfriendly fuel to 60 and above for a very friendly fuel.

Instruments duplicating a diesel engine combustion chamber (constant volume condition) are now used to evaluate ignition & combustion properties of fuels. It is now generally accepted that CCAI is not a good indicator of the ignition quality of today's residual bunker fuel. FIA instrument from Norway can be used to actually determine the ignition and combustion properties and present this data in the form of Equivalent Cetane Number (ECN).

ECN of bad fuel will be less than 19 and those of good fuels can be 40 and above.

### 2.1 TWI – How does it work?

Here is how True Worth Index (c) 2001 is derived. Several assumptions are made in order to quantify the quality aspects of the fuel. These assumptions are made on the best technical knowledge and experience available today. Obviously, the way TWI is calculated can change in future based on further experience in the usage of this Index. No claim is made that TWI is infallible. Viswa Lab started using EFN on the same basis more than 13 years ago. It has passed the test of time and has been widely accepted by all Viswa Lab customers and many others in the bunker industry. Viswa Lab believes that an unfinished tool is better than no tool at all.

When experience and commonsense are combined, the chances are that the results are right on the mark. After all, the diameter of the earth was calculated most accurately more than 2000 years ago without any of today's measuring tools, simply based on commonsense and scientific enquiry. Suggestions to improve the accuracy of this Index are welcome. We believe that the bunker industry and the bunker fuel deserve greater research and efforts to delve more into the quality aspects in order to arrive at equitable commercial value for the fuel.

Calorific value (CV), Engine Friendliness Number (EFN), Equivalent Cetane Number (ECN) - all 3 contribute towards True Worth Index (TWI) that are determined at Viswa Lab.

### 2.2 Assumptions

CV: Varies from 39 to 41 MJ/kgm. This variance is equal to 5% of the energy content of the fuel.

EFN: Varies from 40 for bad fuels to 60 and above for good fuels. EFN has a direct bearing on the maintenance cost of the vessel. This maintenance cost is normally taken at 9.5% of operation cost. In other words a normal ship using normal fuel will spend 9.5% on maintenance cost. In this case a poor fuel with EFN as 40 will add 50% of the maintenance cost i.e. 4.75% more to operations cost. Fuel cost is 60% of operations cost - therefore, this amounts to  $4.75/0.6 = 7.9\%$  of fuel cost.

ECN: This represents the Ignition and Combustion properties of fuel. This is normally represented by CCAI. However, CCAI is not considered a trustworthy parameter since residual fuels undergo thermal & catalytic cracking. Therefore, FIA instrument is used to determine Ignition and Combustion properties. It is represented as ECN. If the ECN is 19 or less the fuel has very poor Ignition & Combustion properties. If it is >40 then it is considered as very good. Difference in Ignition and Combustion properties contribute at least 15% to the thermal efficiency of the engine.

### 2.3 Calculation of TWI

Effect on fuel consumption:  
 CV effect = 5%  
 EFN effect = 7.9%  
 ECN effect = 15%  
 Total =  $5+7.9+15 = 27.9$

Proportions:  
 CV =  $5/27.9 = 18\%$  or 0.18  
 EFN =  $7.9/27.9 = 28\%$  or 0.28  
 ECN =  $15/27.9 = 54\%$  or 0.54

So, A sample's TWI would be:  
 $(CV \times 0.18) + (EFN \times 0.28) + (ECN \times 0.54)$

The above is then normalized by multiplying with the factor 40/28 to arrive at TWI. It turns out that the TWI (just like EFN) has good values above 60 and bad, below 40. TWI represents the true worth of the fuel based on the assumptions and calculations above. The assumptions may have to be fine-tuned. However, for the first time in the bunker industry there will be a number that represents the worth of the fuel. How easy and convenient this would be to relate this to the price paid for the bunker fuel!

### 2.4 General Explanation for TWI figures

Table 1: TWI Table for August 2004

	EFN	ECN	CV		
Proportions	0.28	0.54	0.18		
				Multiplier Effect	TWI
Upper level	60	35	41	43.1	62
Lower level	40	18	39	27.9	40

Region					
Japan/Korea	73	37.7	40.70	48.1	69
Middle East	75	33.6	41.07	46.5	66
ARA - high	66	18.7	40.48	35.9	51
ARA - low	58	21.5	40.46	35.1	50
Singapore - high	63	23.9	40.20	37.8	54
Singapore - low	53	22.4	40.09	34.2	49
U.S. Gulf - high	59	18.7	40.08	33.8	48
U.S. Gulf - low	58	18.7	40.14	33.6	48
Durban	48	18.7	40.14	30.8	44
U.S. Northwest	49	18.7	40.42	31.1	44
U.S. Southeast	59	27.6	41.43	38.9	56

The TWI table has the upper and lower limits of 40 and 62. An increase of 22 points in the TWI represents a saving of 27.9% on the fuel cost. If fuel cost constitutes of 60% of operation cost this will be a saving of 16.74% on operations cost. This also means that the price differential in bunker fuels should have a spread of 27.9% based on the TWI.

The FIA instrument does not record ECN values less than 19. Therefore, ECN values hit a plateau on the lower end. At the upper end they go up to 40 and occasionally up to 45. Nevertheless, there is sufficient range from 19 - 45 to address this variation in Ignition and Combustion properties of the fuel.

### 2.5 Explanation for August 2004 - TWI

Based on the above, Viswa Lab tests fuels from 8 global regions, calculates the TWI and publishes this data at

www.bunkerworld.com. The best fuel in Korea has a TWI of 69 and the worst fuel in US Northwest has a TWI of 44. Calculating on the basis of paragraph 1 above and if the fuel cost in US Northwest is \$270/ton it ought to sell in Korea for \$350 to \$360 (by applying a price spread of 31.7%) - not taking into account any other logistics cost.

It is hoped that over a period of time this number will become a benchmark on which commercial fuel transactions will be based. It will also provide an easy tool for those dealing with bunker fuel all across the bunker industry. It will reduce the need to go through the 28 parameters of the analysis test results, which are often appear confusing and contradictory to the layman. Viswa Lab hopes that the bunker industry will participate in using and providing suggestions in improving the accuracy and the usefulness of this index TWI (c) 2001.

### 3. A UNIQUE CORRELATION BETWEEN TWI AND A PARAMETER OF IGNITION AND COMBUSTION PROPERTY OF FUEL

Heavy fuels do not have a Cetane Number. Ignition and combustion properties of these bunker residual fuels can be determined using Fuel Tech instrument, Fuel Ignition Analyzer FIA-100 (for schematic diagram see figure 1).

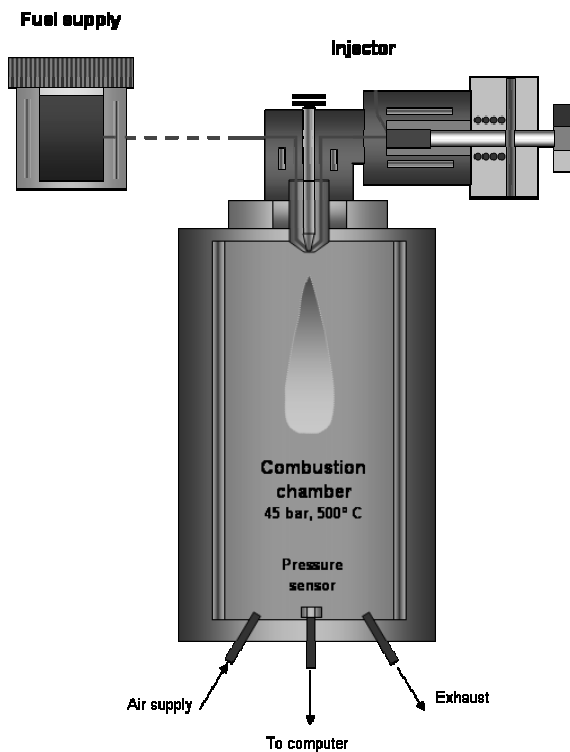


Fig. 1: Fuel Ignition Analyzer [2]

This instrument gives ignition delay, time for start of main combustion (SMC) or Main Combustion Delay (MCD), combustion period and other parameters related to the combustion cycle (see figures 2 & 3).

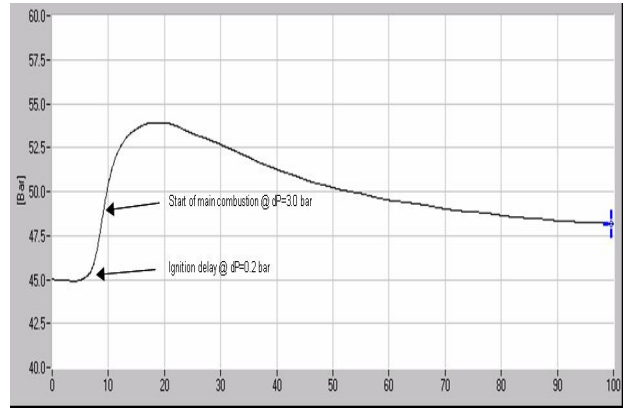


Fig. 2: Pressure graph showing Ignition delay and SMC [2]

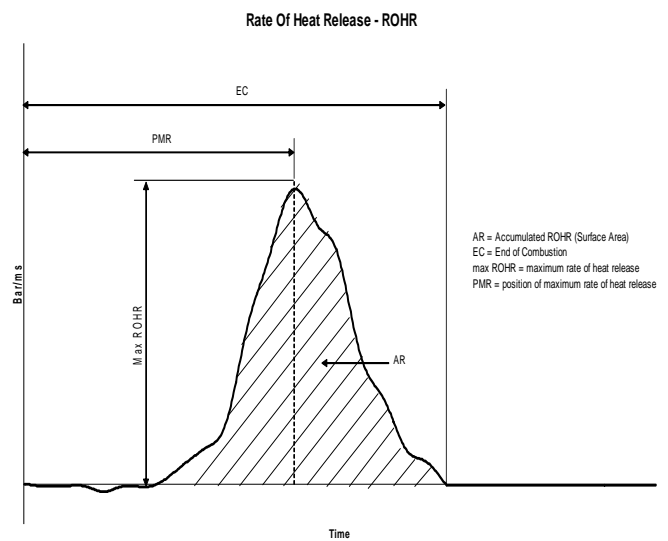


Fig. 3: Graph showing other Ignition and Combustion properties [6]

The instrument also gives an equivalent cetane number (ECN) termed as FIA Cetane Number (FIA-CN) by the manufacturer. ECN is a function of Start of Main Combustion (SMC), that is the time taken in milliseconds from the time of fuel injection to the rise in chamber pressure of 3.0 bars. The instrument manufacturer states that a conversion factor is applied to the Start of Main Combustion based on the individual instrument calibration curves, to obtain ECN. The problem has been that ECN from the instrument can record values, only up to 19. However, more than 50% of the global fuel samples have ECN values less than 19. So, the question remains how to assess the quality of these fuels in the absence of ECN. Another issue is that, since ECN value is specific to the calibration curve of each instrument, same fuel tested on different instruments will have additional variability introduced.

By relating the quality of bunker fuels (TWI) to SMC instead of ECN, we would be able to circumvent the above-mentioned shortcomings because SMC can be obtained for the entire range of fuels. Hence the instrument's limitation in not giving ECN values less than 19 would no longer be a hindrance in evaluating the fuel quality.

In an R&D effort carried out by Viswa Lab, two hundred and fourteen samples were collected, representing various global ports, and tested for routine parameters, EFN, CCAI and Calorific Values. Ignition and combustion properties were measured using Fuel Tech instrument including ECN or FIA-CN.

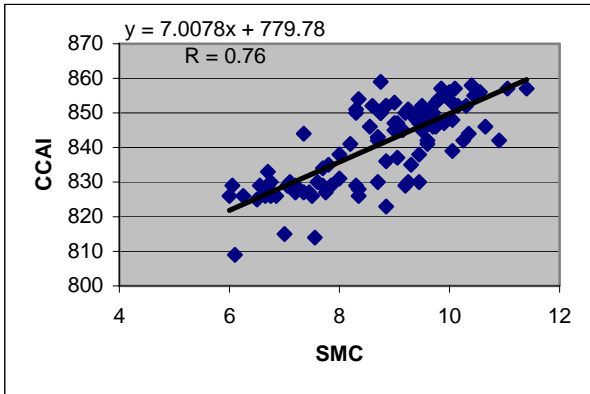


Fig. 4: Correlation between SMC & CCAI (for ECN > 19)

A correlation graph between SMC and CCAI was produced to find the existence of relationship between the two parameters (see figure 4).

It is clear from figure 4 that the correlation between CCAI and SMC is not very good since the correlation coefficient is only 0.76. As expected, this is similar to the findings between CCAI and ECN [3] (see figure 5) from which it is clear that CCAI cannot be a reliable indicator of ignition property of the fuel.

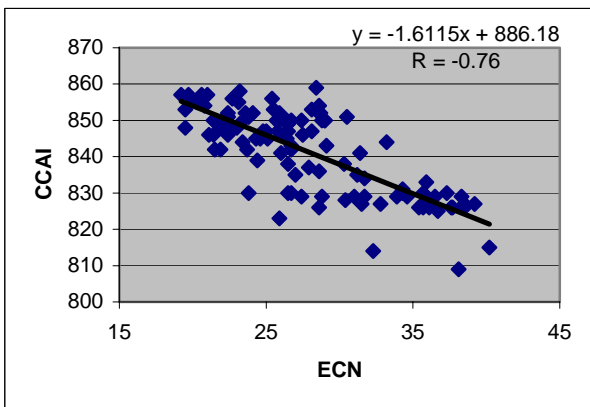


Fig. 5: Correlation between ECN & CCAI (for ECN > 19)

For those fuels that have Equivalent Cetane Number values greater than 19, a study was made to find the correlation between Start of Main Combustion (instead of ECN) and fuel quality expressed in terms of Viswa Lab's own index, True Worth Index (see paragraphs 2.1 to 2.5).

A very good correlation of 0.85 was found between SMC and TWI (see fig 6).

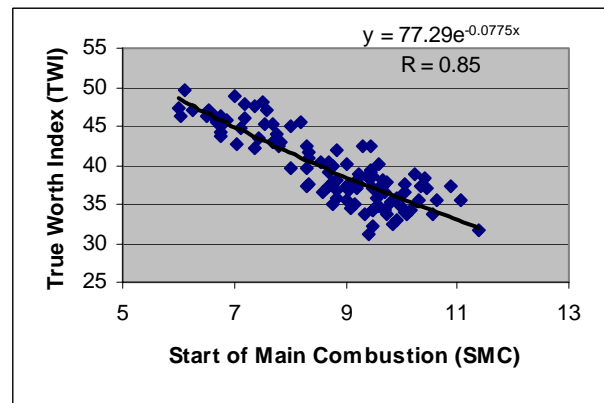


Fig. 6: Correlation between SMC & TWI (for ECN > 19)

Based on the finding that a good correlation exists between SMC and TWI, it is possible to use SMC for the entire range of fuels as a reasonable indicator of the fuel quality. Figure 7 shows a correlation between SMC and TWI for the entire range of fuels. Since original TWI cannot be used for the fuels with ECN values less than 19, a New True Worth Index (NTWI) was defined using SMC to replace ECN in its original equation. A conversion factor was used for SMC to bring NTWI values comparable to TWI.

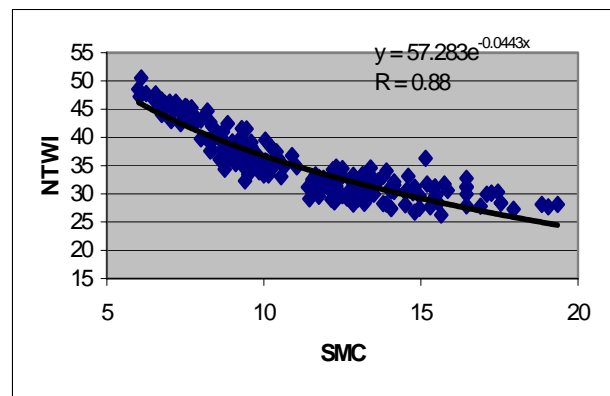


Fig. 7: Correlation between SMC and NTWI for entire range of fuels (both ECN <19 and ECN >19)

From figure 7:

- An excellent correlation is observed between SMC and NTWI. The correlation coefficient is found to be 0.88, in excess of 0.85, which defines "Good" correlation. However, it is recommended that caution may be exercised in using the extrapolated values with higher variation.

Thus, we can determine the true worth of a fuel by testing the fuel in a Fuel Tech Instrument and measuring SMC. This has made the whole process of evaluating the true worth of the fuel very much simpler. However, question remains, if the true worth measurement is indeed reliable. To answer this, we propose to carry out tests on stationary engines (to remove the variability in test conditions of an actual ship mounted engine) with multiple sample fuels and multiple true worth indices. The power generated (with fuel lever in the same fixed position) should correlate with the TWI.

#### 4. QUESTIONS THAT MAY BE ASKED

A question that may be asked is that since a major component of TWI is ECN, what is unique about a good correlation between TWI and a parameter namely SMC, that is an integral part of ECN.

1. The basis for EFN, TWI and the weightage factors were determined based on practical industrial experience and best technical knowledge and, long before this correlation was discovered. These numbers were not manipulated to obtain high correlation.

2. Each of the three constituents of TWI has a relationship with the ultimate TWI value. CV varies only 5% between “Good” and “Bad” fuels. Therefore its contribution to TWI can be assumed to be constant. EFN and ECN vary differently. To study this variation, Table #2 was prepared with varying contribution to TWI from EFN and ECN and the effect of this variation on the correlation between EFN/TWI and ECN/TWI.

**Table 2: Correlation between Equivalent Cetane Number and TWI (for ECN > 19)**

WEIGHTAGE			CORRELATION	
CV	EFN	ECN	EFN/ TWI	ECN/ TWI
0.18	0.82	0.00	1.00	0.57
0.18	0.68	0.14	0.99	0.66
0.18	0.58	0.24	0.98	0.72
0.18	0.48	0.34	0.95	0.79
0.18	0.41	0.41	0.93	0.85
0.18	0.38	0.44	0.91	0.86
0.18	0.34	0.48	0.89	0.88
0.18	0.31	0.51	0.87	0.90
0.18	0.28	0.54	0.85	0.92
0.18	0.18	0.64	0.77	0.96
0.18	0.00	0.82	0.57	1.00

Similarly, table #3 was prepared with varying contribution to TWI from EFN and SMC and the effect of this variation on the correlation between EFN/NTWI and SMC/NTWI.

**Table 3: Correlation between Start of Main Combustion and TWI (for ECN > 19)**

WEIGHTAGE			CORRELATION	
CV	EFN	ECN	EFN/ NTWI	SMC/ NTWI
0.18	0.82	0.00	1.00	-0.17
0.18	0.68	0.14	0.98	-0.34
0.18	0.58	0.24	0.94	-0.48
0.18	0.48	0.34	0.87	-0.62
0.18	0.41	0.41	0.79	-0.71
0.18	0.38	0.44	0.76	-0.75
0.18	0.34	0.48	0.72	-0.79
0.18	0.31	0.51	0.68	-0.82
0.18	0.28	0.54	0.64	-0.88
0.18	0.18	0.64	0.50	-0.93
0.18	0.00	0.82	0.28	-1.00

From the above tables 2 & 3, one can observe that while ECN increases with TWI, an increase in TWI can only come at the cost of a decrease in EFN. This decrease in EFN actually reduces the correlation. The weightage of calorific value is based on solid evidence and it can be fixed at 0.18 (see paragraph 2.2). TWI increases with EFN and it increases with ECN too. However, when EFN increases, ECN decreases and vice versa. In other words, they work in opposite directions with regard to correlation. Therefore this high correlation of 0.88 (when the weightage factor for CV is 0.18, EFN is 0.28 and ECN is 0.54) is not a manipulation of numbers, but a unique relationship that has been established based on practical industry experience and best technical knowledge.

Another question that may arise is whether SMC alone can be used to assess the quality of fuel to be purchased. It is recommended that fuel be tested additionally for a few routine parameters such as Density, Aluminum & Silicon etc., apart from SMC. The routine parameters help us in finding the effect of fuel on engine wear and tear. Every fuel that is tested for routine parameters can be given an EFN. Thus, SMC and EFN put together can provide a good indication for assessing the worth of the fuel.

#### 5. BENEFIT OF STUDY

It is indeed possible to quantify fuel quality and also its true worth. This provides a tool in the hands of those who sell and buy bunker fuels. The market forces of logistics and availability will no longer be the only parameters that dictate the prices of bunker fuels. Hopefully the worth of the fuel will have a say in the pricing of the fuel. In other words, this effort will help in progressing towards commoditizing the bunker fuel.

#### 6. CONCLUSION

The excellent correlation of 0.88 obtained between SMC and NTWI would provide an easy tool to evaluate the true worth of a fuel, which in turn would help in paying the right price for the right fuel in the bunker fuel market.

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