Fuel Ignition Analysis as a Method for Determining Catalyst Activity in Liquid Hydrocarbon Fuels

Contents

Summary	
Table I	Data for Fuel Tested
Table II	Summary of Fuel Ignition Analysis Data from DNV Petroleum Services
Figure 1	Overlay graphs of Pressure – Time and Rate of Heat Returned (ROHR) curves
Figure 2	Overlay graphs for No. 2 fuel and biodiesel combinations
Test Report	DNV Test Report for Fuel Without Catalyst
Test Report	DNV Test Report for Fuel With Catalyst
Fueltech Solutions	FIA-100 FCA Fuel Combustion Analyzer for Heavy Fuel Oil

Fuel Ignition Analysis as a Method for Determining Catalyst Activity in Liquid Hydrocarbon Fuels

Walter R. May
SFA International, Inc.
Houston, Texas, USA

SFA International has observed the effects of combustion catalysts and other fuel additive products on the performance of various fuels in reciprocating engines, combustion turbines, process heaters and steam boilers. These observations have been in field equipment and large engine laboratory settings. We have sought a laboratory method for measuring the effects of catalysts on the combustion reaction. Various approaches have been taken for evaluation of ignition quality of residual and lighter fuels.[1] Ignition quality is generally a function of aromatic content of the fuel. From this concept, the Calculated Carbon Aromaticity Index (CCAI) was developed. There is considerable variability in results for various fuels compared with CCAI. From this, the Calculated Vapor Aromaticity Index (CVAI) concept was developed. This requires measuring the micro carbon residue (MCR).

Fuel Ignition Analysis

Ignition analysis test rigs have been developed to study combustion characteristics of residual fuels. Fueltech Solutions AS of Trondheim, Norway[2] automated the test with their CRU – Combustion Research Unit. This is now a standardized test procedure known as Method IP 541/06 and available in fuel testing laboratories worldwide.

The test consists of injecting a small sample of fuel into a heated pressurized cylinder emulating the compression stroke of a compression-ignited reciprocating engine. The primary difference is that the volume remains constant whereas in a reciprocating engine, the volume increases. The following measurements are taken. All times are in milliseconds from injection of fuel. Fuel is injected in milligrams; it can be assumed that there is a large excess of oxygen and reaction kinetics are reduced to pseudo zero order.

Ignition Delay: The time when pressure increases by 0.2 millibars pressure.
Main Combustion Delay: The time when a pressure of 3.0 millibars is measured.
End of Main Combustion: The time when pressure reaches 85% of final pressure.
End of Combustion: The time when 95% of final pressure is reached.

A pressure – time curve is plotted. Slopes of the line are computed and plotted. This plot is known as the Rate of Heat Return (ROHR). The maximum slope in mbars/msec and time of this position are calculated.

An Estimated Cetane Number (ECN) is calculated from the equation

---

[1] F. A. Valencia, I. P. Arimas, “Ignition Quality of Residual Fuel Oils,” Journal of Maritime Research, Vol. II, No. 3, pp. 77-97, 2005.
[2] Fueltech Solutions AS, Mellomila 90, 7018 Trondheim, Norway. www.fueltechsolutions.com.

$$ECN = 153.15\ e^{-0.2861*MCD}$$

This equation was developed from measurements on ASTM reference fuels T23 and U16. ECN is a function of Main Combustion Delay.

Fuel Sample

We obtained a sample of high sulfur residual oil from Panama. The parameters for this sample are given in Table I. It had about 2.5% sulfur and 11.9% carbon residue indicating a reasonably high aromatic content. Flash point was 94^{o} indicating high molecular weights. The density was 0.986 gm/cc.

Test Results

The sample was tested as received and with 1 part by weight catalyst to 2,500 parts fuel. This amount of catalyst, SFA International FuelSpec® 117-2505, yielded 10 ppm iron and 2 ppm magnesium in the fuel. The results are summarized in Table II.[3] Overlay graphs are presented in Figure 1 for the time-pressure curve and slopes of the time-pressure curve. The DNV reports are attached as Appendices.

Statistical variations in the test procedure are minimized by running twenty-five ignitions on each fuel sample. From this the average and standard deviation are calculated. Because of the large number of measurements the data sets are independent populations.

Observations

We expect the catalyst to improve combustion of higher molecular weight, condensed aromatic molecules that make up the asphaltenic portion of the fuel. These molecules react at a slower rate than aliphatic molecules extending the time of combustion. Therefore, we expected an extension of the combustion reaction reflected in the main and after burning periods.

There was a 1.9% extension in ignition delay. It is possible that this can be explained by absorption of energy by the iron and magnesium atoms. The main combustion delay for both samples was the same (6.72 vs. 6.81 milliseconds) after subtracting out the ignition delay (0.1 ms).

The End of Main Combustion occurred 0.34 ms later with the catalyst or 0.24 ms after taking out the initial change from ignition delay. End of combustion was further extended by 0.59 ms or 0.49 ms after taking out the ignition delay.

The Rate of Heat Release (ROHR) is a plot of the slope (dp/dt) of the pressure – time curve with time.

$$\frac{dP}{dT}\left(f_{(P,\ T)}\right) = \text{slope}$$

This generates a sinusoidal shaped curve showing increase in slope as combustion proceeds and decrease in slope as the fuel is consumed. The position of maximum ROHR was 0.13 ms longer with

[3] DNV Petroleum Services, Inc., La Porte, Texas. Reports FCA 110214.MV.01 and FCA 110214.MV.02, 14-Feb -2011.

catalyst or 0.03 ms after removing the ignition delay. The ROHR curve was somewhat flattened as observed in Figure 1. This indicates a longer combustion period. The Accumulated ROHR or area under the ROHR curve was 7.63 compared with 7.58 with catalyst.

The calculated ECN value indicated an acceptable fuel for general use. We had hoped to test a lower quality fuel to show more differences.

Fueltech Solutions presented a similar curve for No. 2 fuel with biodiesel fuel. Biodiesel fuel is known to burn hotter than pure No. 2 fuel resulting in more NOx. The curve presented in Figure 2 shows a similar earlier ignition with biodiesel as seen with our sample of residual fuel without catalyst.

Conclusions

The End of Combustion was significantly longer with catalyst and the maximum position of the ROHR plot was about 10% lower with catalyst. These observations are consistent with lower rates of combustion for the asphaltenic portions of the fuel. The Accumulated ROHR or area under the ROHR curve was 0.39% less with catalyst which is not a statistically significant observation. Accumulated ROHR is not a direct measurement of heat released as the combustion chamber is not a bomb calorimeter and does not accurately measure heat of combustion.

This work is the first example of using a recognized laboratory test method to observe the effects of our catalyst on the rate of the combustion reaction. These results demonstrated a longer combustion period consistent with slower rates of reaction for asphaltenic portions of the fuel.

Acknowledgements

Jørn Solli, Nordic Fueltech Systems AS, Mo i rana, Norway for finding and evaluating Fueltech Solutions AS fuel ignition analysis equipment and methods for testing combustion reactions.

Jorge Carbonell and Diego Bethancourth, Dobac Internacional, SA, Panama for working with Inspectorate Laboratories and locating a high sulfur residual oil sample.

February 28, 2011

Table I

Test Report Fuel Parameters

Source	Panama Canal Zone Chevron Tank Farm Shore Tank D 2136		
Laboratory	Inspectorate Panama	DNV Houston	
Density, 15^{o} C	0.986	0.9866	gm./cc.
Viscosity, 50^{o} C	375	378	mm^2/s
Sulfur	2.48%	2.55%	
CCAI	847	845	
Flash Point	94^{o}		Centrigrade
Pour Point	-9^{o}		Centrigrade
Water & Sediment	0.30%		Minimum
Ash	0.06%		Minimum
Carbon Residue (MCRT)	11.9%		
Compatibility	1		

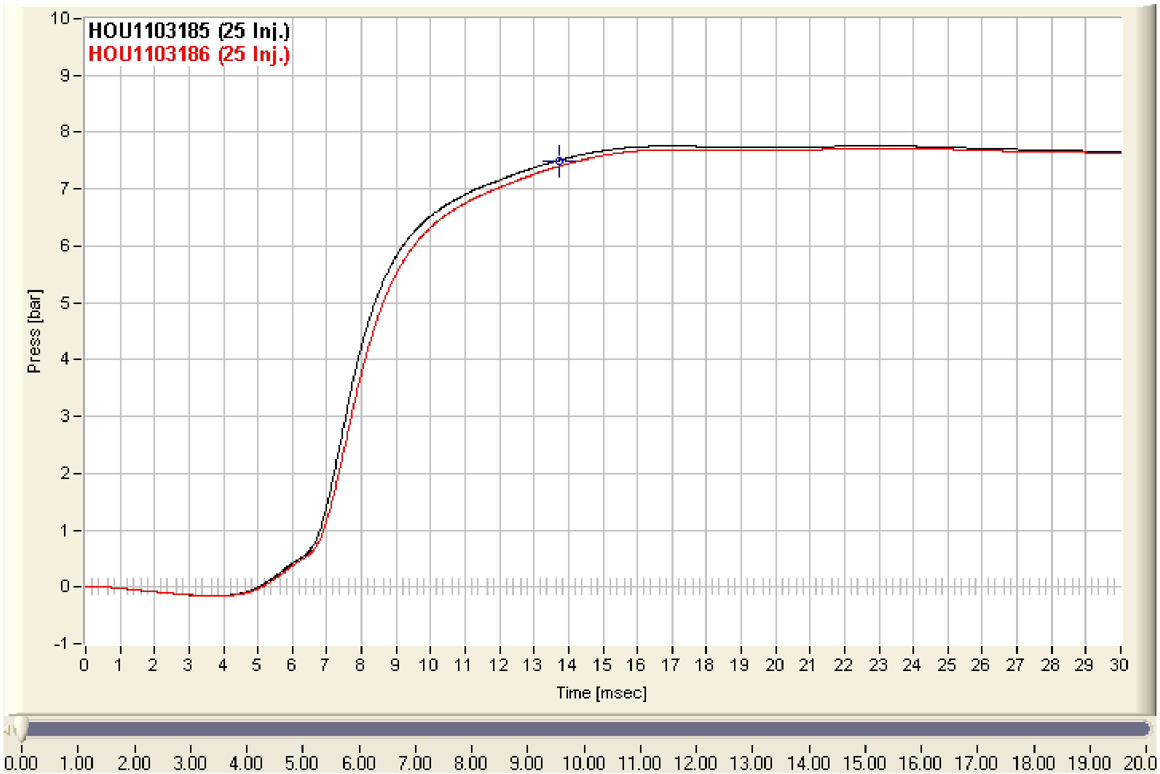
Table II

DNV Fuel Ignition Analysis
Method IP 541/06

Fuel Ignition and Combustion Test Results

Parameter	Description	wo/Catalyst	w/Catalyst	Unit	Pressure mbar	Value	Change
ECN	Estimated Cetane Number	22.4	21.80			Calculated	-2.68%
ID	Ignition Delay	5.26	5.36	ms	0.2	Measured	1.90%
MCD	Main Combustion Delay	6.72	6.81	ms	3.0	Measured	
PCP	Precombustion Period	1.46	1.45	ms		ID - MCD	-0.68%
EMC	End of Main Combustion	11.31	11.65	ms	85%	Measured	3.01%
EC	End of Combustion	15.47	16.06	ms	95%	Measured	3.81%
MCP	Main Combustion Period	4.6	4.84	ms		EMC - MCD	5.22%
ABP	After Burning Period	4.16	4.41	ms		EC - EMC	6.01%
Max ROHR	Maximum ROHR	3.33	3.00	Bar/ms		Maximum dP/dt	-9.91%
PMR	Position of max ROHR	7.5	7.64	ms		Calculated	1.87%
AR	Accumulated ROHR	7.63	7.58			Calculated	-0.66%

OVERLAY GRAPHS FOR HOU1103185 AND HOU1103186



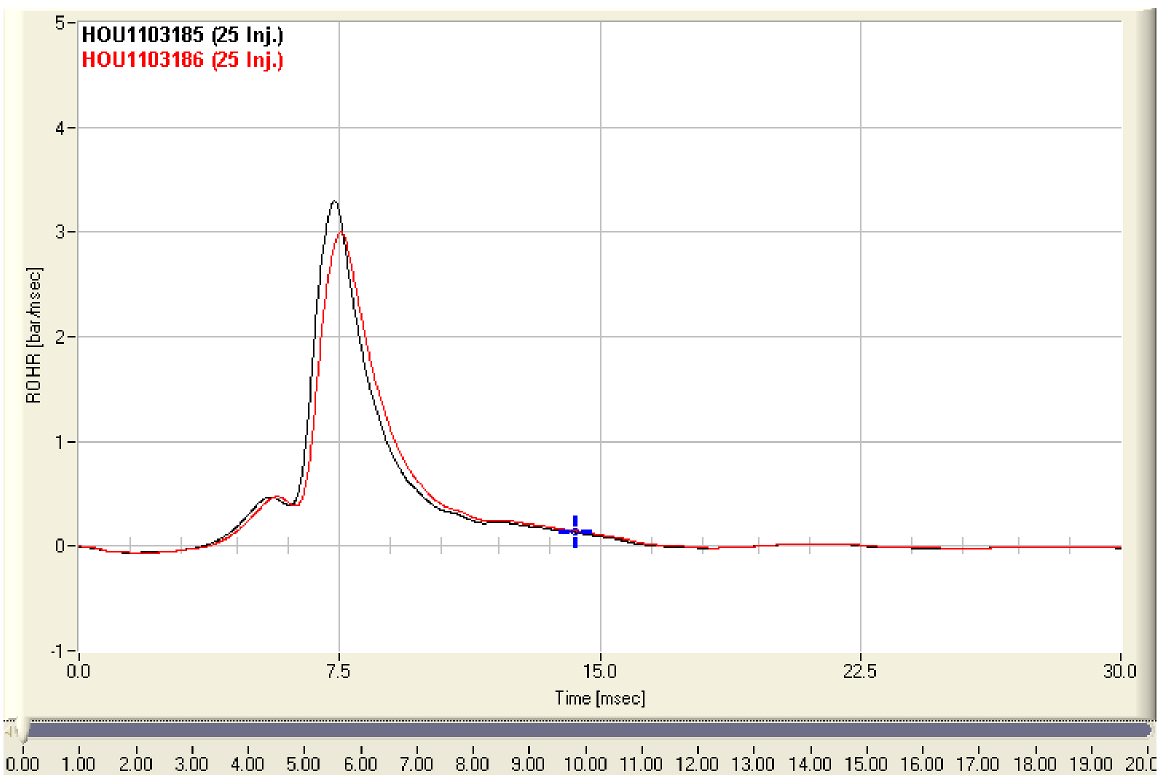
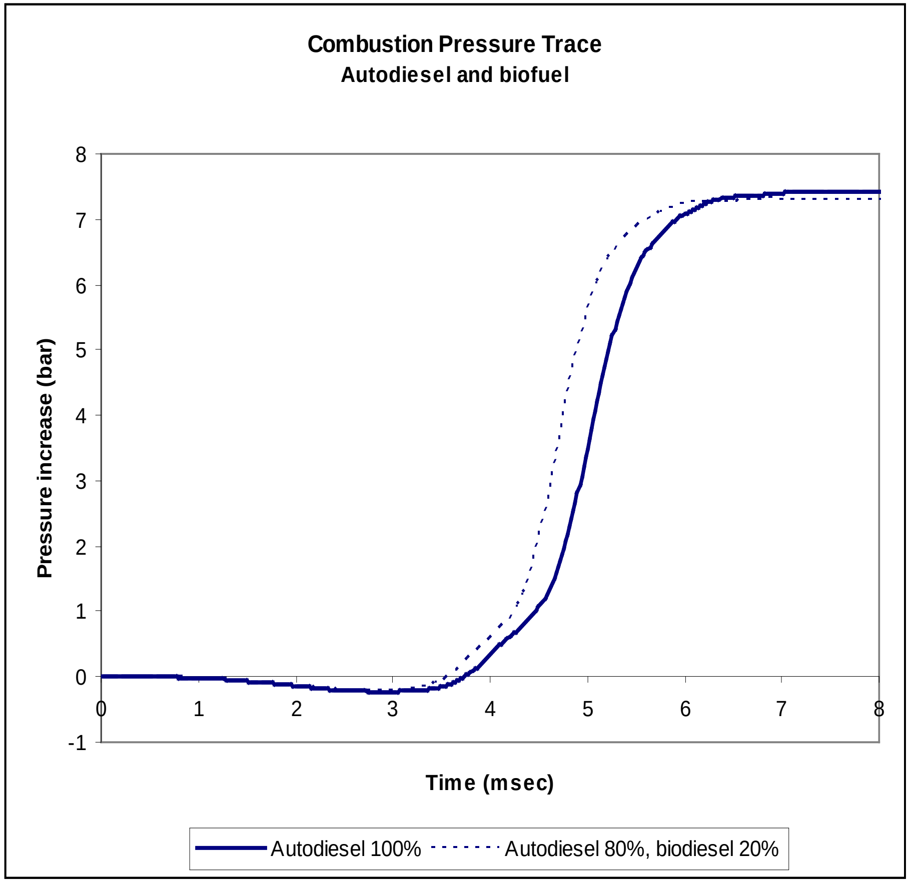
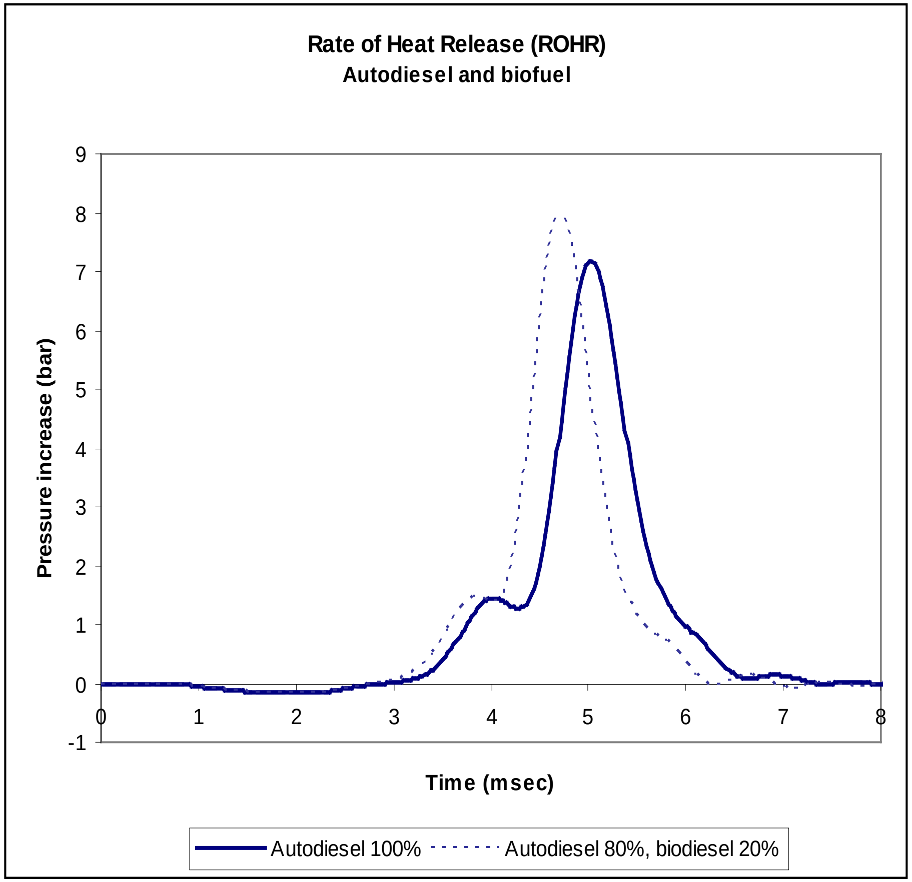


Figure 2: Autodiesel and biofuel





TEST REPORT

Fuel Ignition & Combustion Characteristics

DNV Petroleum Services Inc.

318 North 16th Street La Porte,
Texas 77571 USA
Tel: 1.2814701030
Fax: 1.2814701035
houston@dnvps.com

Test Method	:	IP 541/06		
Report No.	:	FCA110214.MV.01	Date :	14-Feb-2011
To	:	SFA INTERNATIONAL INC		
Attn	:	MR. WALTER MAY		
Reference	:	HFO		
IMO No.	:	N/A		

1. Sample Details :					
1.1 Sample No	:	HOU1103185			
1.2 Bunker Port	:	N/A	1.3 Bunker Date	:	N/A
1.4 Sampling Point	:	UNKNOWN	1.5 Sampling Date	:	N/A
1.6 Supplier	:	N/A			
1.7 Seal Number	:	NOT SEALED			
1.8 Grade Ordered	:	N/A	1.9 Quantity Ordered	:	N/A

2. Summary Of Fuel Ignition & Combustion Test Results : (See Appendix 7.4)
Fuel with acceptable ignition qualities and acceptable combustion characteristics.

3. Previous FCA Sample Reference :		
3.1 DNVPS Sample No	:	N/A
3.2 DNVPS Sample No	:	N/A

4. Engine Details :		
4.1 Main Engine Make & Type	:	N/A
4.2 Auxiliary Engine Make & Type	:	N/A
4.3 Chief Engineer Report On The Engine Problem	:	N/A

5 Fuel Parameters	**Test Results**		**Method**
Density @15 ^{0}C	986.6	kg/m^3	ISO 12185
Viscosity @50 ^{0}C	378	mm^2/s	ISO 3104
Sulfur	2.55	% mm	ISO 8754
CCAI	848		Calculated

Cont.: Report No : FCA110214.MV.01
Sample No : HOU1103185

6. Fuel Ignition & Combustion Test Results			
Parameter	**Description**	**Value**	**Unit**
ECN	Estimated Cetane Number	22.4	-
ID	Ignition Delay	5.26	ms
MCD	Main Combustion Delay	6.72	ms
PCP	Pre Combustion Period	1.46	ms
EMC	End of Main Combustion	11.31	ms
EC	End of Combustion	15.47	ms
MCP	Main Combustion Period	4.60	ms
ABP	After Burning Period	4.16	ms
maxROHR	Maximum ROHR	3.33	Bar/ms
PMR	Position of maxROHR	7.50	ms
AR	Accumulated ROHR	7.63	-

1 bar = 0.1 MPa
See appendix for Explanation of Terms

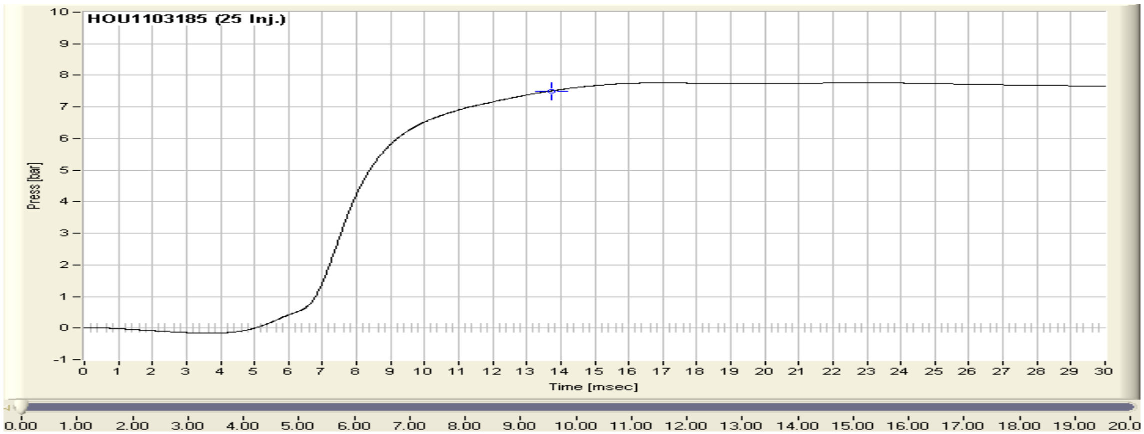
Comments

ECN (Estimated Cetane Number, ref. IP 541/06, Annex F) indicates that the ignition quality is acceptable.

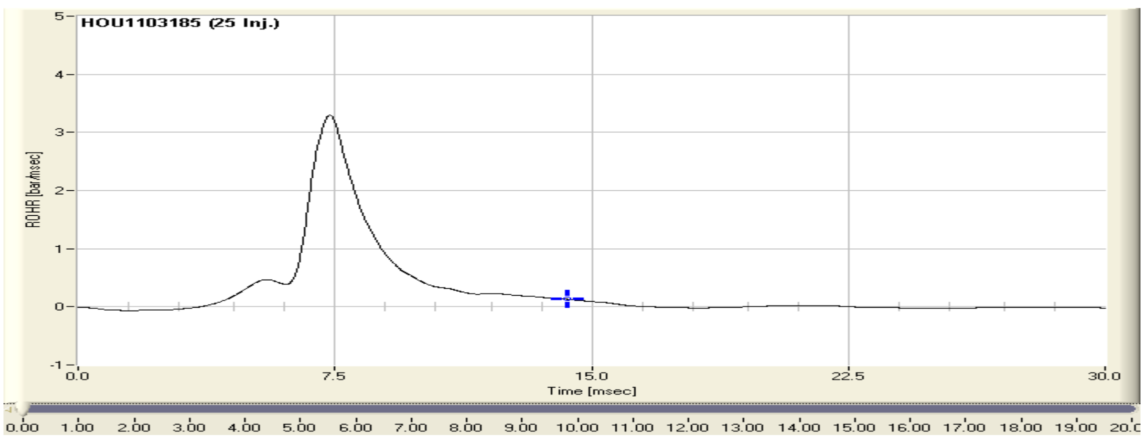
Tested results indicate that the combustion characteristics are acceptable.

The comments in this report must be regarded as guidance only. Operation, adjustment, maintenance and overhaul of diesel engines and associated systems should be carried out according to the owner's/operator's procedures and/or engine maker's recommendations

Combustion Pressure Trace :



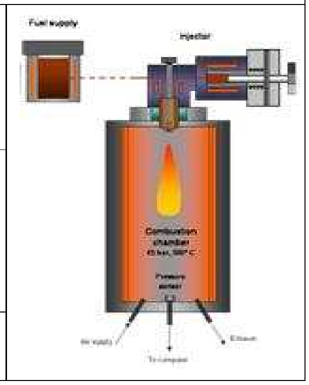
ROHR Curve :



Martin A. T. Verle
Area Manager
Email : Martin.Verle@dnvps.com
End of DNVPS – Fuel Combustion Test Report

Enclosure attached : Explanation of terms

Appendix
Explanation of Terms

7.0 Fuel Ignition & Combustion Analysis	
7.1 Description of test method and measured parameters	
7.2 Summary: FIA-100 FCA has been used for this test. The fuel is injected into a constant volume chamber which is heated to 500°C and pressurized to 45 bar initial pressure. During the combustion of the fuel, the pressure increase is measured and transferred to a computer for further computation and reporting. The parameters reported are a calculated average of 25 different injections.	
7.3 Calculation of Estimated Cetane number, ECN Annex F IP 541. ECN is a calculated value which is based on the measured MCD (Main Combustion Delay) The value of the ECN will be within a range of 5 to 40. The Equation has been established by measuring MCD with known Cetane number (ASTM reference fuels)	
7.4 Ignition and Combustion statement. The comments are related to the fuel ignition & combustion results as obtained under the prevailing test condition	

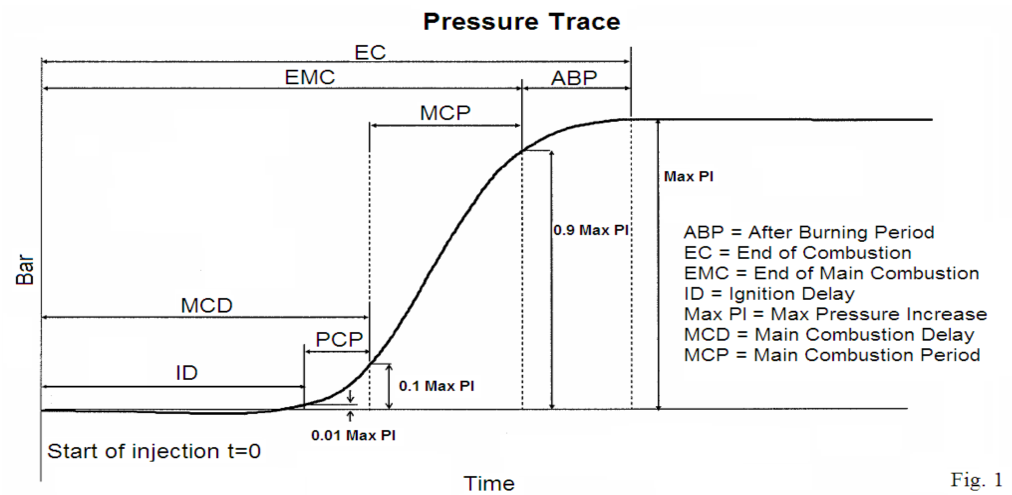


Fig. 1

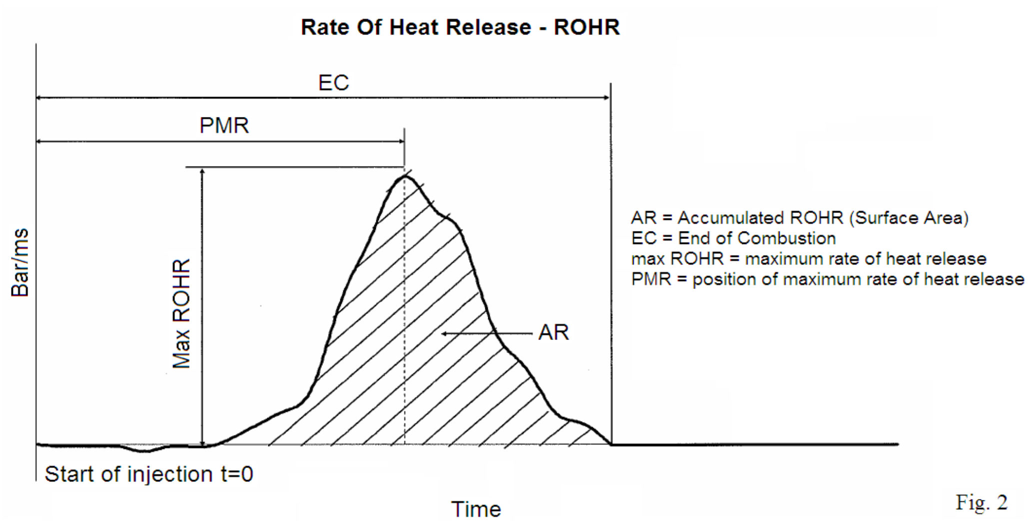


Fig. 2

TEST REPORT

Fuel Ignition & Combustion Characteristics

DNV Petroleum Services Inc.

318 North 16th Street La Porte,
Texas 77571 USA
Tel: 1.2814701030
Fax: 1.2814701035
houston@dnvps.com

Test Method	**:**	IP 541/06		
Report No.	:	FCA110214.MV.02	Date :	14-Feb-2011
To	:	SFA INTERNATIONAL INC		
Attn	:	MR. WALTER MAY		
Reference	:	HFO + ADDITIVE		
IMO No.	:	N/A		

1. Sample Details :					
1.1 Sample No	:	HOU1103186			
1.2 Bunker Port	:	N/A	1.3 Bunker Date	:	N/A
1.4 Sampling Point	:	UNKNOWN	1.5 Sampling Date	:	N/A
1.6 Supplier	:	N/A			
1.7 Seal Number	:	NOT SEALED			
1.8 Grade Ordered	:	N/A	1.9 Quantity Ordered	:	N/A

2. Summary Of Fuel Ignition & Combustion Test Results : (See Appendix 7.4)
Fuel with acceptable ignition qualities and acceptable combustion characteristics.

3. Previous FCA Sample Reference :		
3.1 DNVPS Sample No	:	N/A
3.2 DNVPS Sample No	:	N/A

4. Engine Details :		
4.1 Main Engine Make & Type	:	N/A
4.2 Auxiliary Engine Make & Type	:	N/A
4.3 Chief Engineer Report On The Engine Problem	:	N/A

5 Fuel Parameters	**Test Results**		**Method**
Density @15 ^{0}C		kg/m^3	Provided by SFA INTERNATIONAL INC
Viscosity @50 0C		mm^2/s	
Sulfur		% mm	
CCAI			Calculated

Cont.: Report No : FCA110214.MV.02
Sample No : HOU1103186

6. Fuel Ignition & Combustion Test Results

Parameter	Description	Value	Unit
ECN	Estimated Cetane Number	21.8	-
ID	Ignition Delay	5.36	ms
MCD	Main Combustion Delay	6.81	ms
PCP	Pre Combustion Period	1.45	ms
EMC	End of Main Combustion	11.65	ms
EC	End of Combustion	16.06	ms
MCP	Main Combustion Period	4.84	ms
ABP	After Burning Period	4.41	ms
maxROHR	Maximum ROHR	3.00	Bar/ms
PMR	Position of maxROHR	7.64	ms
AR	Accumulated ROHR	7.58	-

1 bar = 0.1 MPa
See appendix for Explanation of Terms

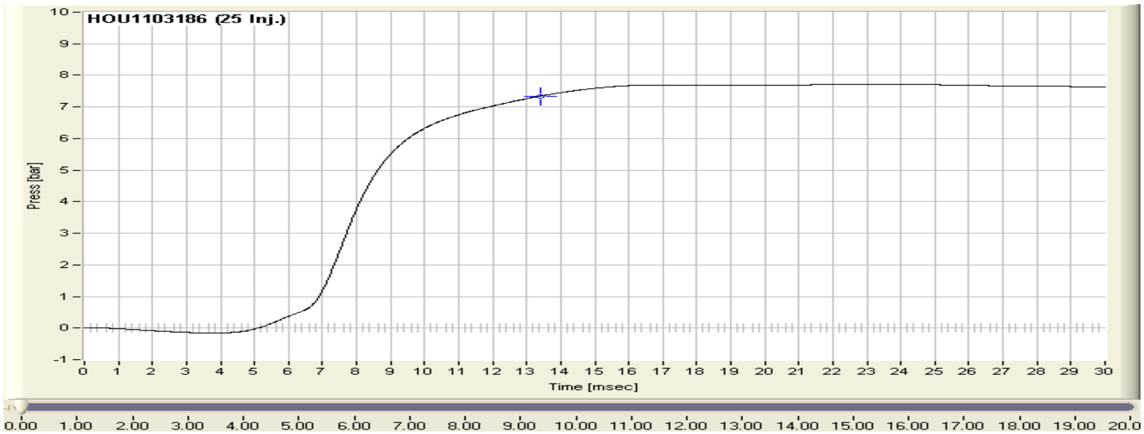
Comments

ECN (Estimated Cetane Number, ref. IP 541/06, Annex F) indicates that the ignition quality is acceptable.

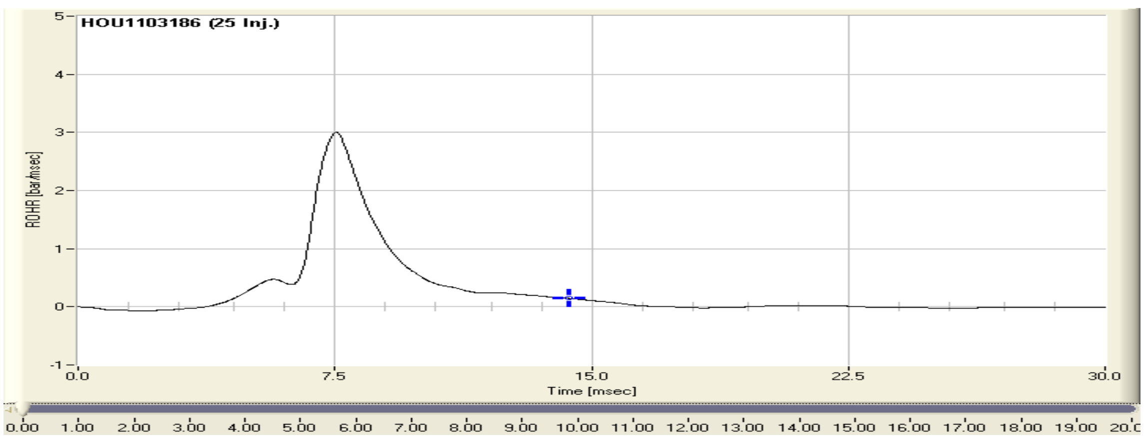
Tested results indicate that the combustion characteristics are acceptable.

The comments in this report must be regarded as guidance only. Operation, adjustment, maintenance and overhaul of diesel engines and associated systems should be carried out according to the owner's/operator's procedures and/or engine maker's recommendations

Combustion Pressure Trace :



ROHR Curve :



Martin A. T. Verle
Area Manager
Email : Martin.Verle@dnvps.com
End of DNVPS – Fuel Combustion Test Report

Enclosure attached : Explanation of terms

Appendix
Explanation of Terms

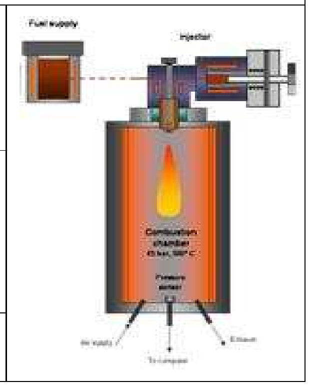
7.0 Fuel Ignition & Combustion Analysis

7.1 Description of test method and measured parameters

7.2 Summary: FIA-100 FCA has been used for this test.
The fuel is injected into a constant volume chamber which is heated to 500°C and pressurized to 45 bar initial pressure. During the combustion of the fuel, the pressure increase is measured and transferred to a computer for further computation and reporting. The parameters reported are a calculated average of 25 different injections.

7.3 Calculation of Estimated Cetane number, ECN
Annex F IP 541. ECN is a calculated value which is based on the measured MCD (Main Combustion Delay) The value of the ECN will be within a range of 5 to 40. The Equation has been established by measuring MCD with known Cetane number (ASTM reference fuels)

7.4 Ignition and Combustion statement. The comments are related to the fuel ignition & combustion results as obtained under the prevailing test condition



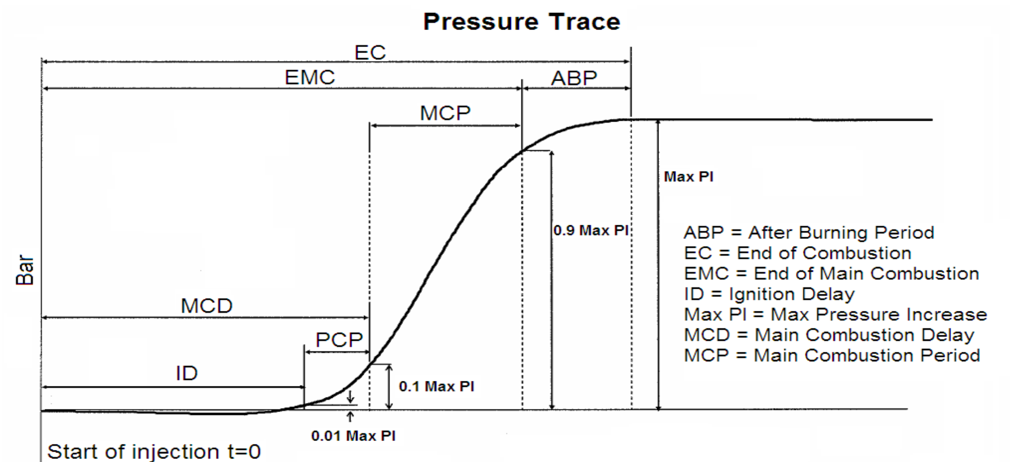


Fig. 1

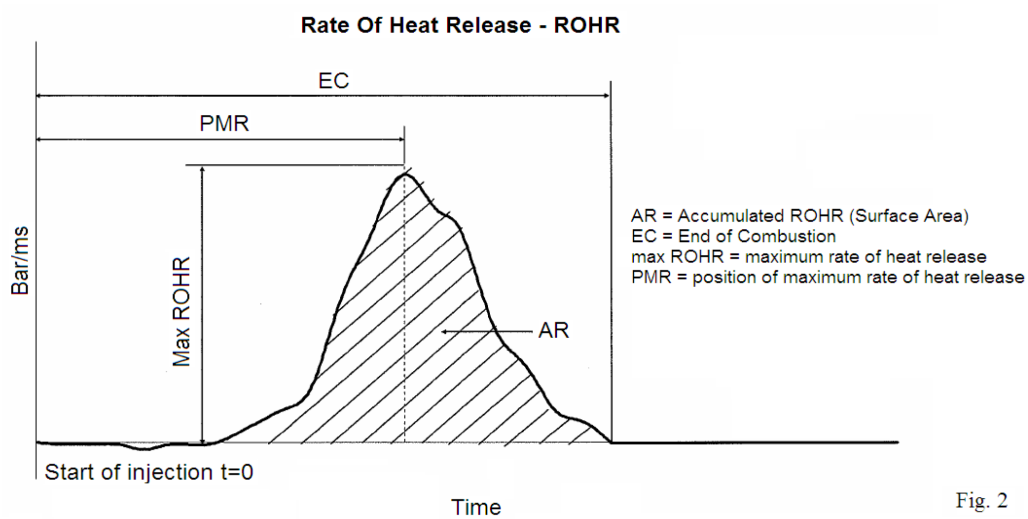


Fig. 2

FIA-100 FCA

Fuel Combustion Analyzer

for Heavy Fuel Oil

Fueltech Solutions AS

fueltech solutions

FIA-100 FCA Fuel Combustion Analyzer for Heavy Fuel oil

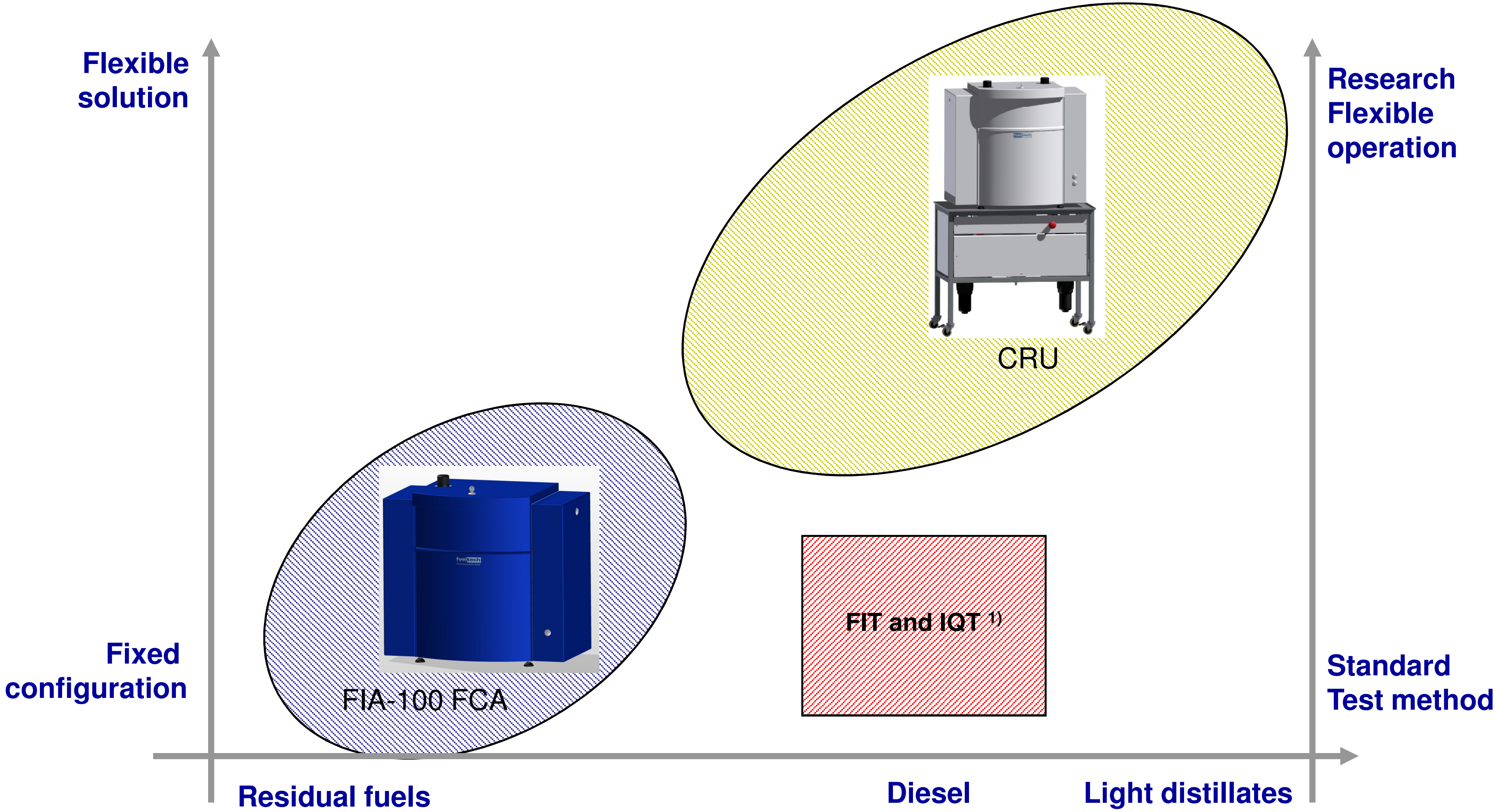
- FIA-100 FCA features:
  - Test according to method **IP 541/06**
  - New test parameters implemented
  - Automated operation

- ECN – Measurement of Estimated Cetane Number for Heavy Fuel
  - Measurement range: 5 to 40

- High precision
  - Example ECN:
    - Repeatability r= 0.98
    - Reproducibility R=3.2
  - Precision data established from round robin programme managed by Energy Institute

fueltech solutions

Product comparison



Fuel Ignition Tester - FIT is registered trademark of Waukesha engine Dresser, Inc, USA
Ignition Quality tester - IQT is registered trademark of Advanced Engine Technology, Canada

Practical use of FIA and method IP 541/06

- FIA background:
  - Originally developed to measure **Ignition Quality** of Residual fuel
  - Precise measurement of **Combustion Properties** now available

- Application area:
  - Bunker fuel – standard test method
  - Domestic Heating oil – evaulation of combustion efficiency
  - Distillates and MGO – evaulation of combustion efficiency

  - Compatible with previous FIA models used by the industry since 1995

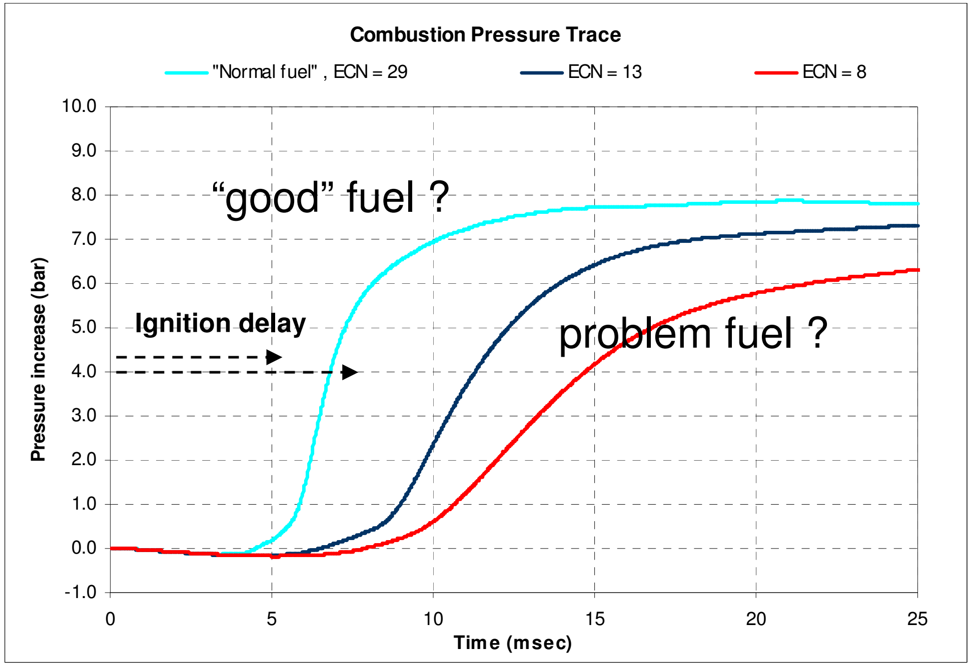
- Relevance to conditions found in real engines (ship engines)
  - Medium-speed engines
  - Low-speed, 2-stroke engines

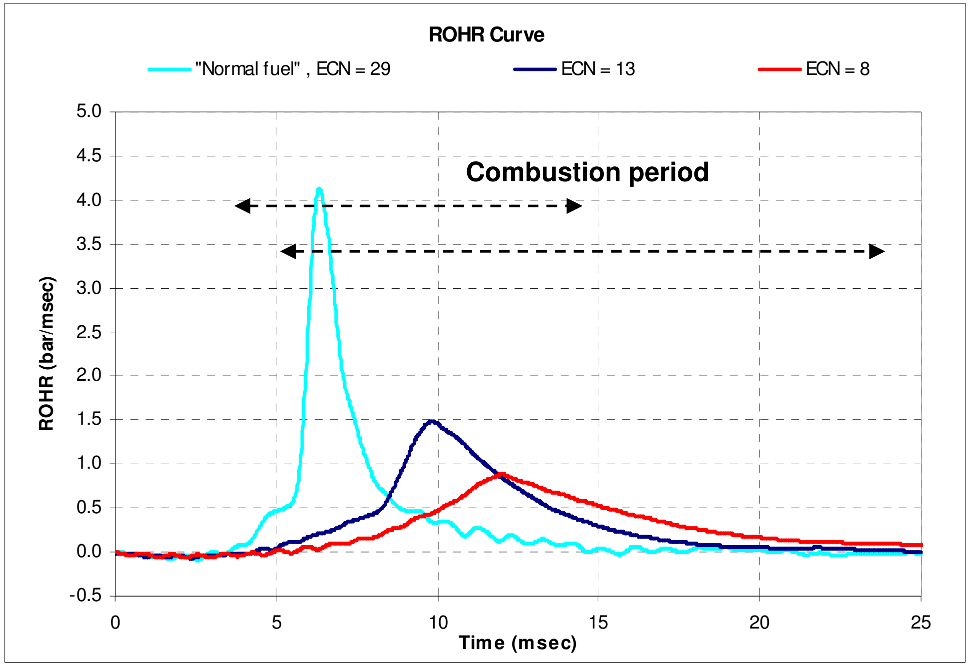
fueltech solutions

FIA test - output

- Combustion Pressure trace
- Rate of heat Release – ROHR
- Calculated parameters:
  - Ignition Properties
  - Combustion Properties

- **ECN** – Estimated Cetane Number
  - Range 5- 40 CN
  - Analogue to Cetane Number for diesel
  - Calculated based on parameter MCD- Main Combustion Delay





Ignition and combustion properties - Easy to differentiate between different fuel quality

FIA testing used by ...

- Major fuel testing agencies
  - Additional information in trouble fuel cases
  - Some ship operators: routine testing for every bunkering

- FIA test results used as evidence in several arbitration cases related to engine damages / bad fuel

- Oil companies
  - Product development , R&D
  - Product quality control

- Engine Manufacturers

FIA testing in use by:

Test agencies

DNV

viswalab

Lloyd's Register

NIPPON YUKA KOGYO CO., LTD.

Oil Companies

Research & Development – Product control

Additive Suppliers
Universities
Engine Manufacturers

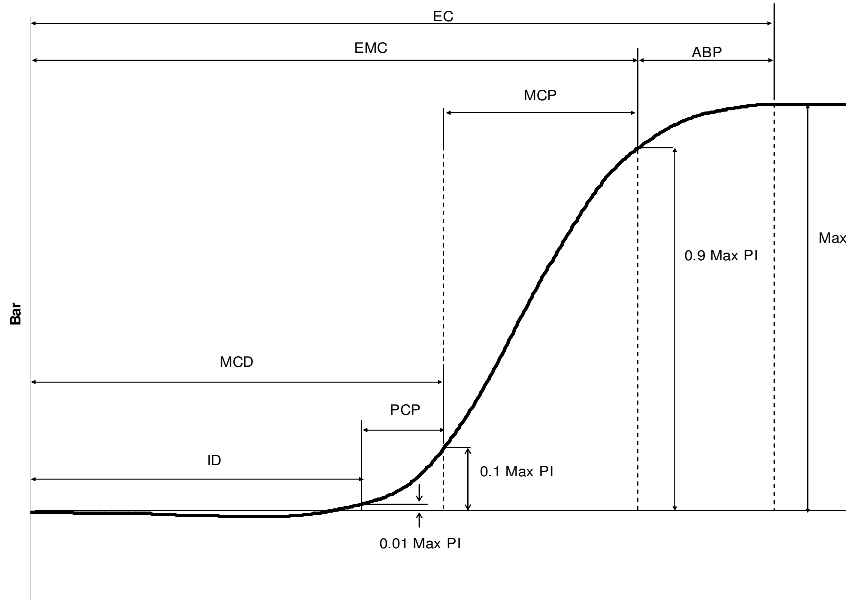
Potential engine problems due to bad ignition and combustion

- Knocking
- Damaged / broken piston rings
- Incomplete combustion
  - Sooting
  - Exhaust valves
  - Turbocharger surging
- Late ignition / long combustion period
  - exposed cylinder liner
  - cylinder liner lubrication burns
  - scuffing

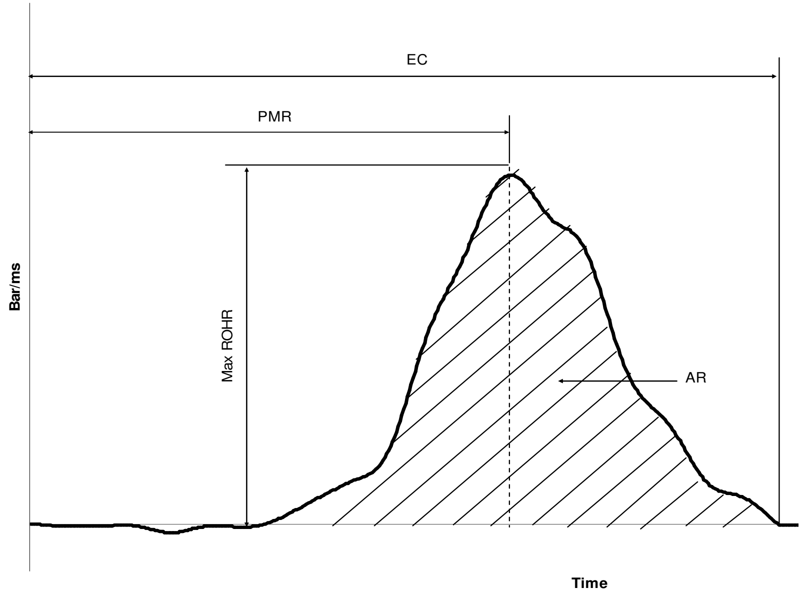
What parameters are important?

Examples:

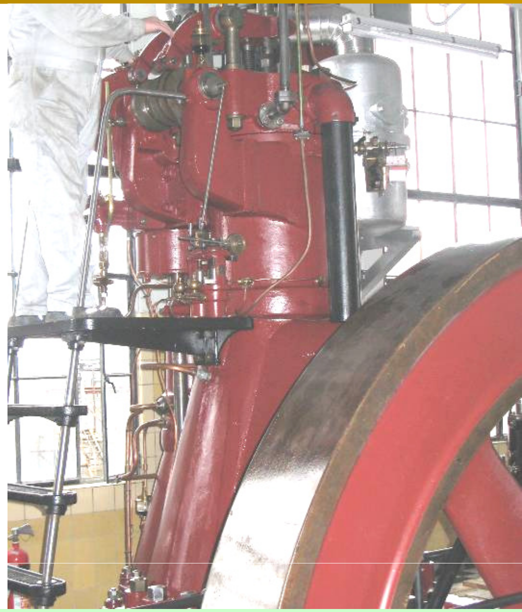
- ID – Ignition Delay
- ECN – Estimated Cetane Number
- MCD – Main Combustion Delay
  - used for calculating ECN
  - start of combustion of the main component
  - can be different from ID, depending on composition light vs. heavy components
- EC – End of Combustion (Combustion Period)
  - long combustion period: heavy molecular weight → difficult to burn → smoke, ash, particulates
  - long afterburning → increased thermal load on cylinder liner
- PMR – Position of maxROHR
  - timing for maximum energy release
  - important for efficient conversion to mechanical energy → reduce excessive load on piston rings
- maxROHR – Maximum ROHR value
  - rate of combustion → rate of pressure increase
  - low value: inefficient burning
  - high value: high pressure increase → may occur for 2-stage combustion



Rate Of Heat Release - ROHR



Can FIA test be used to predict engine problems...



- Different engines have different sensitivity
  - 2-stroke slow-speed
  - 4-stroke medium speed
- Engine model (design year)
- Age and condition
  - maintenance status
  - crew
- Fuel preparation systems

FIA testing can be used to evaluate the real combustion properties of the fuel.

- **What parameters are suitable for your engine?**
- **Find own criteria for ignition and combustion properties that puts you in the ”comfort zone”**
- **Advice from engine manufacturer, test agencies**
- **Price / quality / risk**

Warning from Ship insurance company

Loss Prevention Circular No. 08-07

Warning - Fuel oil quality might be at stake

Fuel oil quality is directly related to the safe operation of ships and it is important for any ship operator to focus on preserving fuel oil quality.

Bearing in mind that the European Union Directive 2005/33/EC which deals with sulphur content comes into force on 11 August 2007 and the North Sea Sox Emission Control Area (SECA) will be fully implemented on 22 November 2007, the refinery industry may explore more advanced production/blending processes to satisfy the global demand for low sulphur fuel. The traditional method of assessing fuel oil quality and suitability may be unreliable in certain circumstances.

http://www.gard.no

The most widely used equipment for fuel ignition tests has been the FIA-100 FCA, which is already available from some test laboratories and comes with an Institute of Petroleum approved test method, IP 541/06.
Typical engine problems experienced when using a fuel oil with poor ignition properties are:

- Difficulties or complete failure in starting the engine
- Undesirable peak pressures which can lead to blow by and collapse of piston rings
- Unstable operation and loss of power
- Varying revolutions, which are highly undesirable for the operation of auxiliary engines
- Increased deposits in the combustion area and in the exhaust gas system, including turbo charger and boiler
- Increased emissions of NOx

In a worst case scenario poor fuel oil ignition and combustion properties can render the engine inoperative and compromise the safe operation of the ship.

Lessons learned:

- It is important to secure adequate quality control of your fuel oil purchase contacts/providers.
- The ship's crew should be better trained to detect these types of problems when they occur in order to minimise costs, vessel's off-hire periods and not least the safety of crew and ship/cargo.
- Fuel oil tests do not always adequately describe the fuel oil's properties, in particular with respect to ignition and combustion quality
- The increased demand for low sulphur fuel will require better understanding of fuel parameters which are not described in the ISO standard.

Please also contact your engine manufacturer and your fuel oil test laboratory service provider to obtain further information on the above.

For more information regarding the Gard loss prevention products, please contact:
Vice President Harald Fotland, ph: +47 55 17 40 67 or email harald.fotland@gard.no , or
Loss Prevention Manager Trygve C Nøkleby, ph.: +47 55 17 41 11 or email trygve.nokleby@gard.no.

gardyourship

IP 541/06 Test method

HOME •

CALENDAR click here

NEW! IP Standard Methods o

access when

About us

Overview

In a competitive world the modern professional body is a vital partner for any
as an individual, you want control of your career and the ability to influence y
want to take a leading role in the energy community and the advancement of
Institute is your vital partner.

The Energy Institute (EI) is the leading professional body for the energy indu
professionals internationally. A Royal Charter membership organisation, the
independence, professionalism and a wealth of expertise in energy matters
professionals and a scientific and technical reservoir for industry. It is licens
to offer Chartered, Incorporated and Engineering Technician status to engin
Science Council to award Chartered Scientist.

IP 541/06

Determination of ignition and combustion characteristics of residual fuels — Constant volume combustion chamber method

This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1 Scope

This standard specifies a procedure for the quantitative determination of ignition and combustion characteristics of residual fuels for use in compression ignition engines.

Ignition Delay (ID) 2,7 - 7,6 ms, Main Combustion Delay (MCD) 3,1 - 9,7 ms, Position of Maximum ROHR (PMR) 3,1 - 11,8 ms, End of Main Combustion (EMC) 9,6 - 18,9 ms, End of Combustion (EC) 15,3 - 28,6 ms, Pre Combustion Period (PCP) 0,28 - 2,06 ms, Main Combustion Period (MCP) 3,9 - 9,3 ms, After Burning Period (ABP) 5,3 - 9,7 ms, maximum Rate Of Heat Release (maxROHR) 0,11 - 0,48 MPa/ms, Accumulated Rate of heat release (AR) 7,2 - 8,3 and the facultative determination of Net Heat of Combustion (NHC) 47,0 - 56,5 MJ/kg at 25 °C.

This standard is applicable to residual fuels of petroleum origin with viscosities up to 2 000 mm^2/s @ 50 °C. However, precision has only been determined for residual fuels with viscosities in the range 25 to 800 mm^2/s @ 50 °C. It is specifically applicable, but not limited, to products typical of Specifications ISO 8217 and CIMAC Recommendation Number 21.

constitute provisions of this standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated. For undated references, the latest edition of the normative document referenced applies.

IP 200, *Petroleum measurement tables*.

IP 367, *Petroleum products — Determination and application of precision data in relation to methods of test* (≡ ISO 4259)

IP 475, *Petroleum liquids — Manual sampling*. (≡ ISO 3170)

IP 476, *Petroleum liquids — Automatic pipeline sampling* (≡ ISO 3171)

ISO 3696, *Water for analytical laboratory use Specification and test methods*.

ISO 8217, *Petroleum product — Fuels (Class F) Specification of marine fuels*.

CIMAC Number 21, *Recommendations regarding fuel quality for diesel engines*

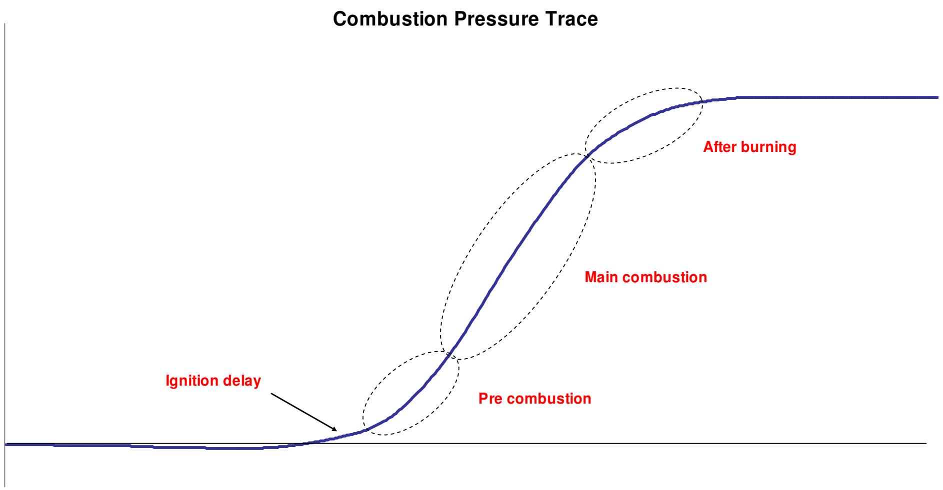
Extract from the test method
Must be purchased from Energy Institute
www.energyinst.org.uk

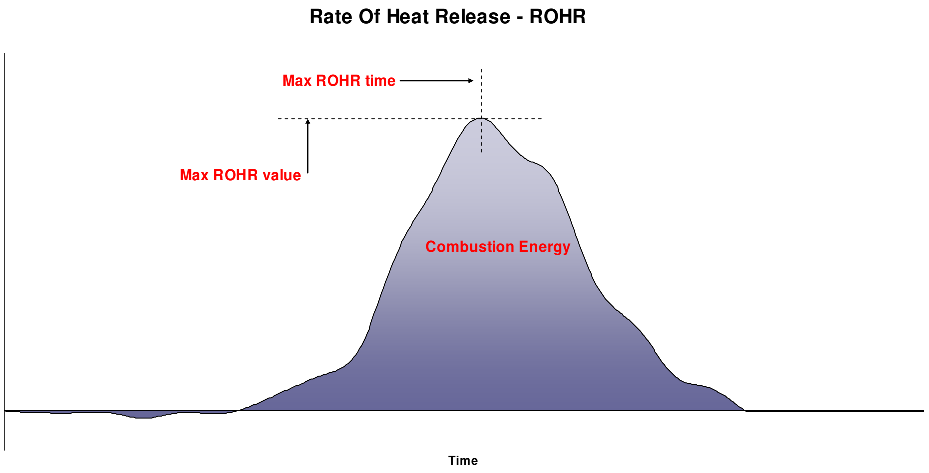
Test method overview

- Process parameters:
  - Temp: approx. 500 ℃ (individual tuning by calibration)
  - Pressure: 45 bar
  - Injection pressure: 400 bar,
- Fuels:
  - Heavy Fuel Oil: ISO8217 up to 2000 cSt @50 ℃
  - Sample quantity: approx 50 ml pr test
  - Filtration of fuel: 75 mycron
- Off-spec or special fuels:
  - Ultra-high viscosity, emulsions, bio fuels etc.
  - This may require special settings and non-standard operating procedure
- Calibration:
  - Based on pure HC compound: Methylcyclohexane (MCH)
  - Verification of calibration with n-Heptane
- Test time: approx. 45 minutes
  - Automated operation – no need for user attendance during test
- Precision:
  - ECN: r=0.98, R=3.22
  - Iignition Delay: r=0.10 msec (~ 2%), R=0.3 (~ 6%)

Method developed by industry partners based on requirements from the Shipping industry

Test parameters





	Parameter	Description	Unit
Ignition properties	ID	Ignition delay	msec
	MCD	Main combustion delay	msec
	ECN	Estimated cetane number	-
	PCP	Pre combustion period	msec
Combustion properties	EMC	End of main combustion	msec
	EC	End of combustion	msec
	MCP	Main combustion period	msec
	ABP	After burning period	msec
	maxROHR	Maximum rate of heat release	MPa/msec
Energy	PMR	Position of maximum rate of heat release	msec

ECN – Estimated Cetane Number
Analogue to Cetane Number for diesel
Calculated based on parameter MCD- Main Combustion Delay

Extract of parameters as defined in IP 541-06 test method

FIA-100 FCA Research Edition (optional)

- Purpose:
  - To be able to use FIA-100 FCA outside the scope of IP541/06 test method
  - User definable settings:
    - Process temperature and pressure, number of injections, fuel temperature, data logging etc.
  - Useful functionality when performing special research programs
- Technical overview:
  - Separate software to be installed in parallell with standard version
  - No modifications of hardware required
  - Standard software for testing according to IP541 can still be used

FIA-100 Features - Summary

	Standard Version	Research Edition
Main purpose:	Standardized operation according to method IP541/06	To be able to use FIA-100 FCA for special research programs. Enable the user to freely change process parameters outside the scope of standard test method
Fuel types:	Heavy Fuel Oil / Residual Fuel Oil Viscosity up to 2000 cSt@50ºC	Distillate fuel, Heavy Fuel oil Biofuel, emulsions, special fuels
Calibration:	Absolute calibration based on fixed reference: different labs can measure same absolute values	User defined
Test method:	Energy Institute IP541/06 Implemented according to recognized principles for official test methods.	User defined
Process temperature: **Chamber pressure** **Injection pressure:** **Injection period:** **# of injections:** **Fuel temperature:**	500 º C (individual calibration by temp adjustment) 45 bar 400 bar Approx 3,5-4 msec (individual calibration) 25 125º C	450-590 10-60 bar Up to 400 bar 2-10 msec User defined Up to 145º C
User software	Standard IP541/06 edition	Research Version
Operational lifetime:	500,000 combustion cycles = 20,000 tests	Operation on higher temperature and pressure than standard conditions may reduce lifetime of the combustion chamber:

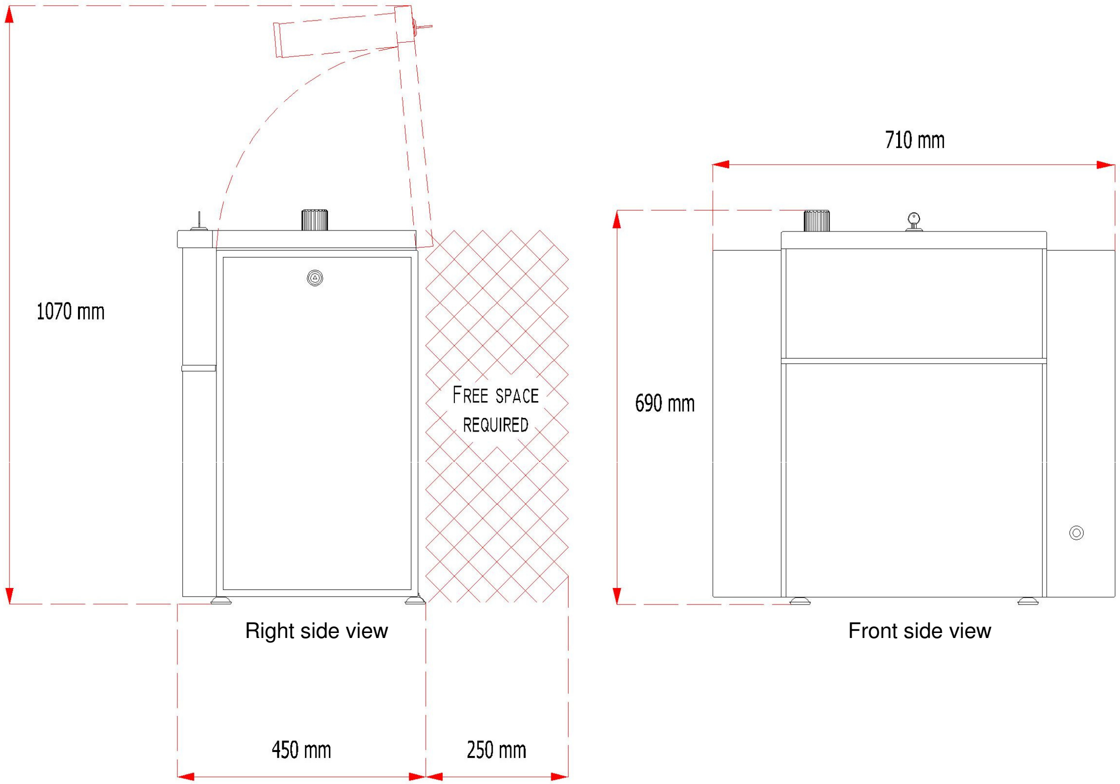
Both versions use the same hardware.
Different operation modes controlled by software

fueltech solutions

FIA-100 FCA Technical summary – installation requirements

- Painted steel cabinet
  - Size (WxHxD): 800x660x400 mm
  - Weight: Approx 70 kg

- External utilities required:
  - Compressed air: “dry and clean”
  - Power supply: 220-240 V, 50Hz
  - Circulation cooler
  - Exhaust vent
  - Computer: Windows XP, Ethernet



Lab utilities and chemicals

- Calibration: Methylcyclohexane, n-Heptane
- Cleaning solvent: Xylene, Technical grade
- Heating oven for preparation of HFO sample