2004-01-0553

The Effect of Fuel Properties on Low and High Temperature Heat Release and Resulting Performance of an HCCI Engine

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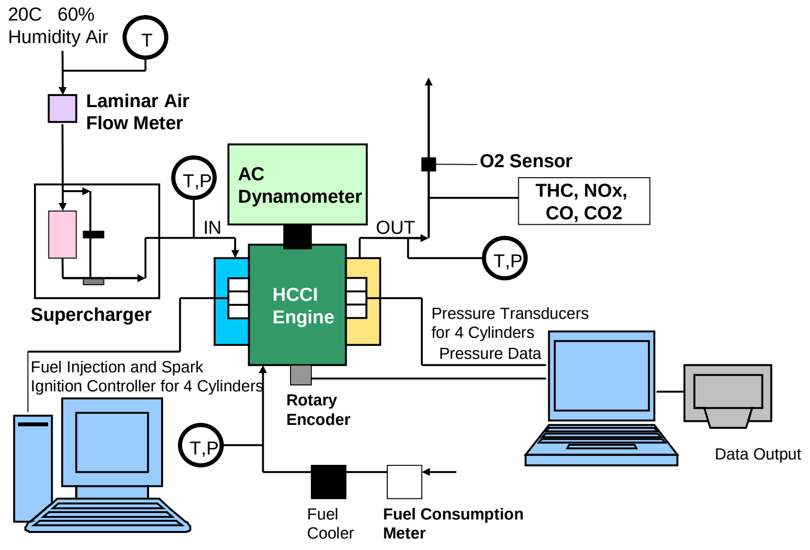
What Influences HCCI Operation?

- **Engine side**
  - **Intake Air Conditions**
    - **Temperature and Pressure**
- **Fuel Side**
  - **Fuel Properties**
    - **Chemical Component ignition properties**
    - **Fuel Vaporization Characteristics**

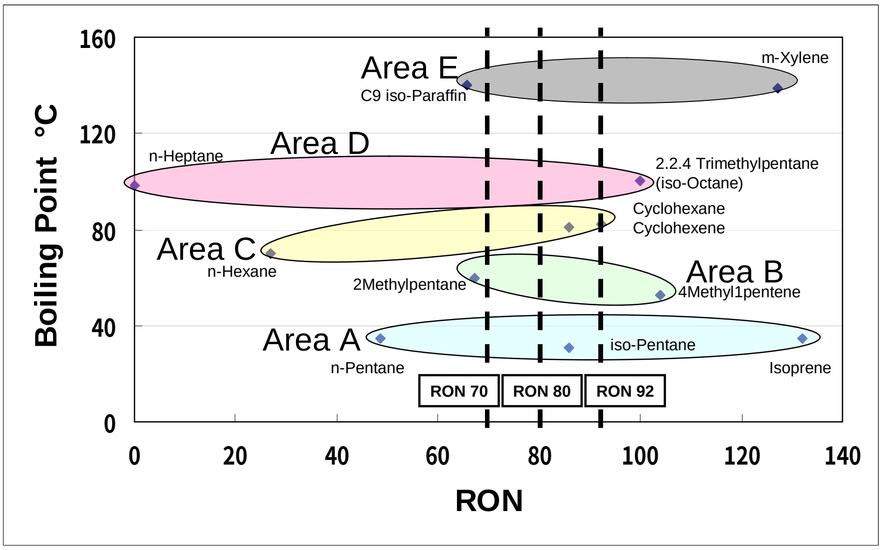
Experimental Schematic



Engine Specification

Engine type	4 cylinder MPI
Compression ratio	15
Bore	86mm
Stroke	86mm
Displacement	1998cc
Exhaust valve open	53°CA BBDC
Exhaust valve close	7°CA ATDC
Intake valve open	1°CA ATDC
Intake valve close	19°CA ABDC

The Boiling Point-RON map of the Fuel Components



Description of Test Fuels

			RON70	RON80	RON92	Regular Gas
Octane Number RON			70.0	80.0	92.0	90.0
Octane Number MON			68.5	68.0	67.8	76.0
Cetane Number			15.0	6.0	4.5	3.5
Density		g/cm3	0.6965	0.7076	0.724	0.7306
Reid Vapour Pressure		kPa	45.0	43.5	44.0	73.5
Distillation °C		0%	42.0	45.5	44.0	29.0
		10%	59.0	61.5	60.5	45.5
		30%	68.0	69.5	69.0	62.0
		50%	80.5	81.5	81.5	83.5
		70%	97.5	98.5	99.0	112.5
		90%	129.0	129.0	128.5	139.0
		95%	134.0	133.5	133.0	150.5
		EP	143.0	138.5	141.5	171.5
Fuel Composition		vol%				
Area A	iso-Pentane		11.5	0	0	-
	n-Pentane		8.5	15.7	12.7	-
	Isoprene		0	4.3	7.3	-
Area B	4Methyl1pentene		1.5	6.9	12.4	-
	2Methylpentane		18.5	13.1	7.6	-
Area C	n-Hexane		5.3	2.0	0	-
	Cyclohexane		14.7	18.0	0	-
	Cyclohexene		0	0	20.0	-
Area D	n-Heptane		6.0	4.0	1.6	-
	2.2.4Trimethylpentane		14.0	16.0	18.4	-
Area E	m-Xylene		1.4	4.7	7.9	-
	C9 iso-paraffin		18.6	15.3	12.1	-

Topics in this Presentation

- HCCI Engine Performance Test
  - Engine Speed Test
  - Engine Load Test
- Octane Number Test
- N-Heptane and Toluene Test
- Correlation of HCCI Operation to Octane Sensitivity
- What are RON and MON?

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HCCI Engine Performance Test (1)

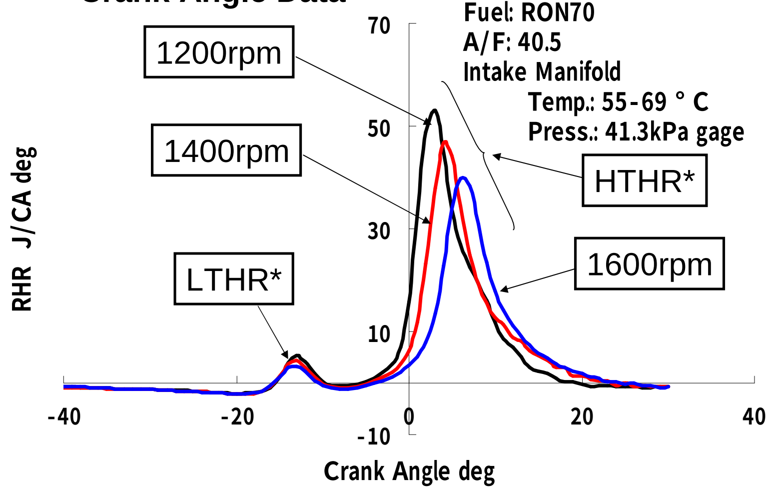
- **Engine Speed Test**

Fuel:	RON70
Engine Speed:	1200, 1400, 1600rpm
Intake Manifold Pressure:	+41.3kPa(gage)
Intake Manifold Temp:	55-60℃
Air/Fuel Ratio:	40.5 constant
Water & Oil Temp:	80℃

- **Engine Load Test**

The Effect of Engine Speed on RHR

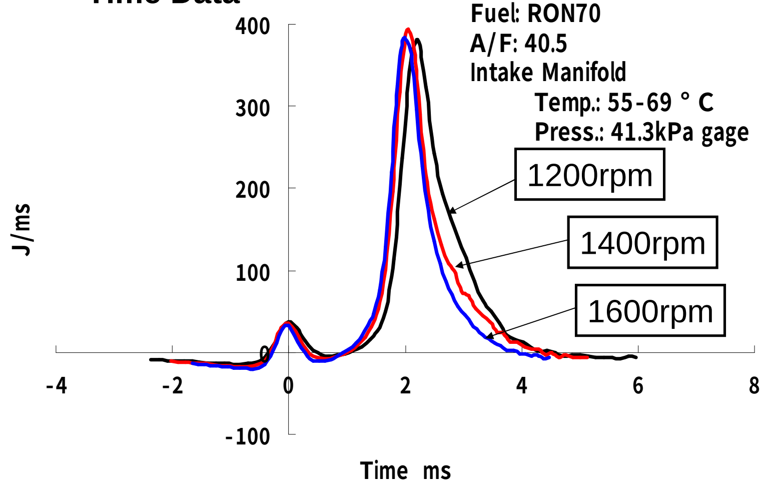
Crank Angle Data



LTHR*--- Low Temperature Heat Release
HTHR*---High Temperature Heat Release

The Effect of Engine Speed on RHR

Time Data



HCCI Engine Performance Test (2)

- **Engine Speed Test**
- **Engine Load Test**

Fuel:	Regular Gasoline (Japan Market)
Engine Speed:	1200rpm
Intake Manifold Pressure:	+41.3kPa(gage)
Intake Manifold Temp:	62-63℃
Air/Fuel Ratio:	28, 29, and 30
Water & Oil Temp:	80℃

HCCI Engine Performance Test (2)

The air-fuel Ratio was changed by holding the air quantity constant and changing the injected fuel quantity.

↓

A/F Change = Load Change

HCCI Engine Performance Test (2)

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- **Engine Load Test**

Fuel:	Regular Gasoline (Japan Market)
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Intake Manifold Pressure:	+41.3kPa(gage)
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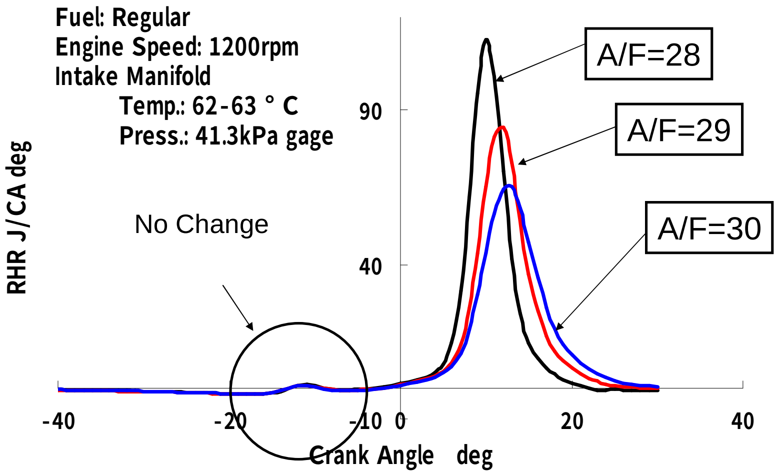
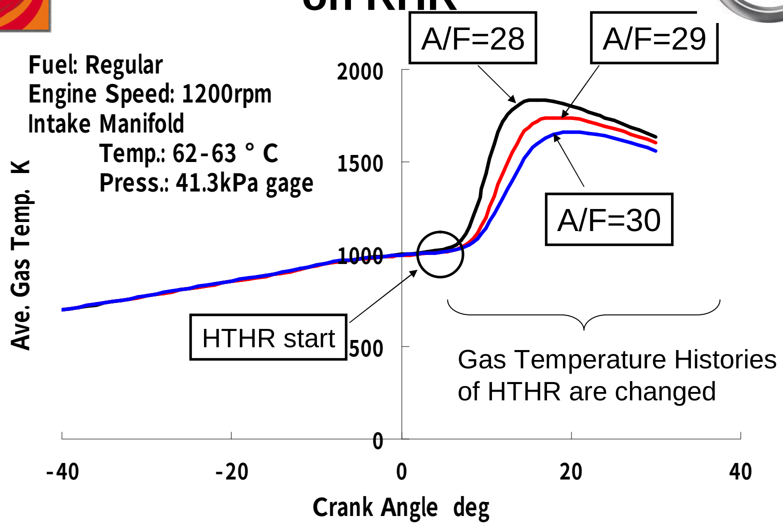
The Effect of Engine Load on RHR



The Effect of Engine Load on RHR



Overview

- **Engine** Speed affects HCCI combustion, which also differs according to load condition

  (Engine operating range is restricted)

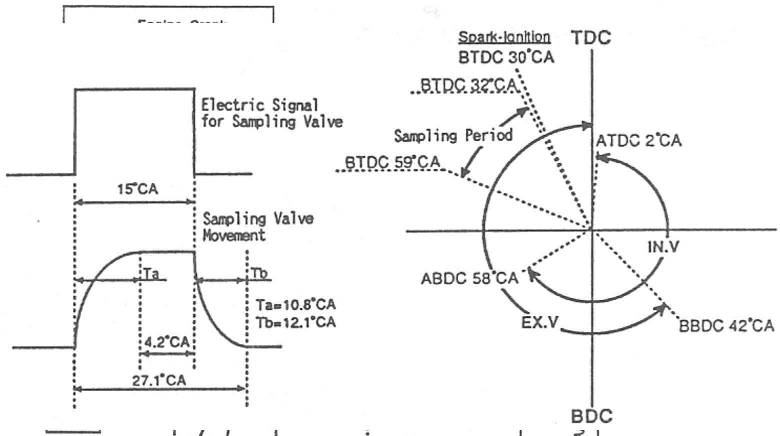
  ⇩

  Fuel volatility and composition also affect the HCCI combustion to the same degree as engine speed and load changes (⇒Octane Number Test)

Topics in this Presentation

- **HCCI Engine Performance Test**
  - **Engine Speed Test**
  - **Engine Load Test**
- **Octane Number Test**
- **N-Heptane and Toluene Test**
- **Correlation of HCCI Operation to Octane Sensitivity**
- **What are RON and MON?**

Pre-Ignition Vaporized Fraction for In-Cylinder Hydrocarbons



Gas Sampling Valve Timing Chart

High Speed In-cylinder Gas Sampling Schematic

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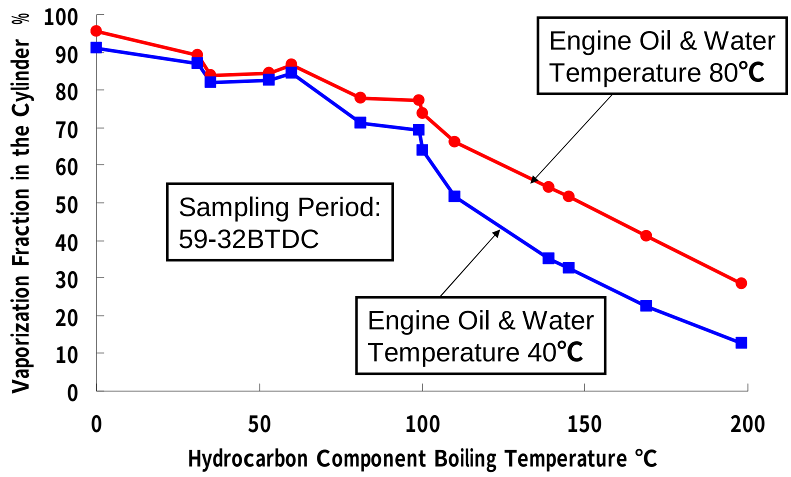
Pre-Ignition Vaporized Fraction for In-Cylinder Hydrocarbons



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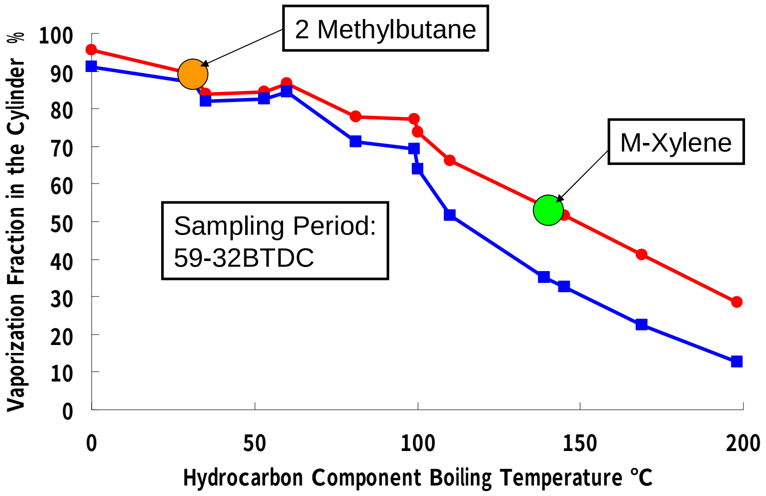

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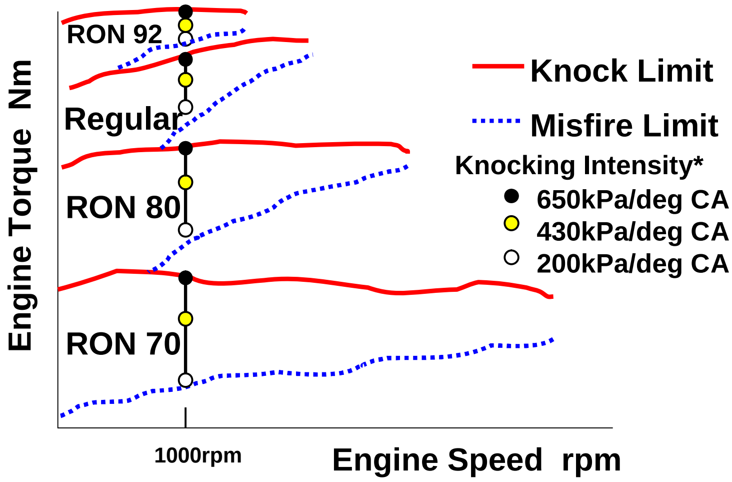
Pre-Ignition Vaporized Fraction for In-Cylinder Hydrocarbons

- The mole fraction distribution in the vaporized fuel changes with crank angle and depends on the fuel even for a warmed up engine
- If the RON distribution against distillation is different, the vaporized fuel RON history during combustion changes

- RON distribution against distillation is important
- RON70, RON80 and RON92 fuels were selected to keep the same distillation and same RON distribution against distillation

Engine Speed-Torque Map



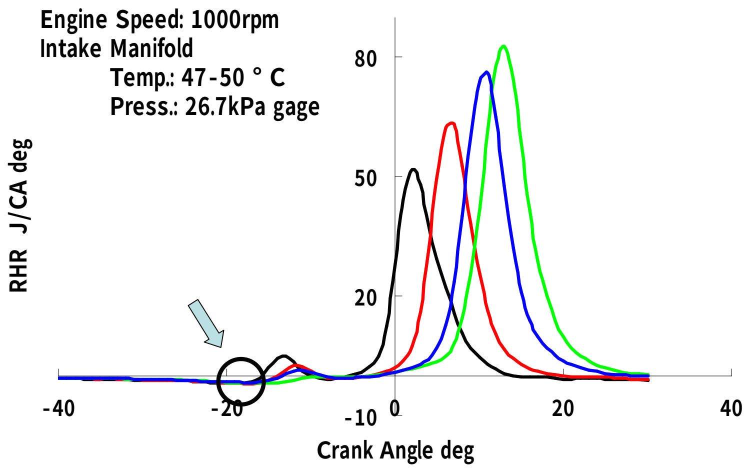
*Knocking Intensity is defined as the 400cycle average of the Maximum rate of pressure increase.

Octane Number Test

- **Test Conditions**

Fuel:	RON70, RON80, RON92, Regular
Engine Speed:	1000rpm
Intake Manifold Pressure:	+26.7kPa(gage)
Intake Manifold Temp:	47-50℃
Knocking Intensity:	430kPa/deg CA
Water & Oil Temp:	80℃

RHR data of Octane Number Test



RHR data of Octane Number Test

			Unit	RON70	RON80	Regular	RON92
Low Temperature Heat Release		Heat Value	J	23.8	16.7	11.2	2.8
	Start	Temperature	° K	859.3	855.9	832.3	853.7
		Crank Angle	BTDC	18.5	18.0	17.5	16.5
High Temperature Heat Release		Heat Value	J	332.8	407.3	528.9	608.6
	Start	Temperature	° K	989.9	968.5	935.9	925.1
		Crank Angle	BTDC	8.0	6.5	6.5	6.0
Crank Angle of 50% Burned			ATDC	2.2	6.3	10.3	12.6
Intake Air Temperature			° C	47.0	47.1	50.2	47.8
IMEP			kPa	373.4	452.5	586.2	654.7
Thermal Efficiency			%	36.11	38.25	40.08	41.40
Air/Fuel Ratio				42.5	33.8	30	28.7

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RON70 fuel has larger LTHR than RON92

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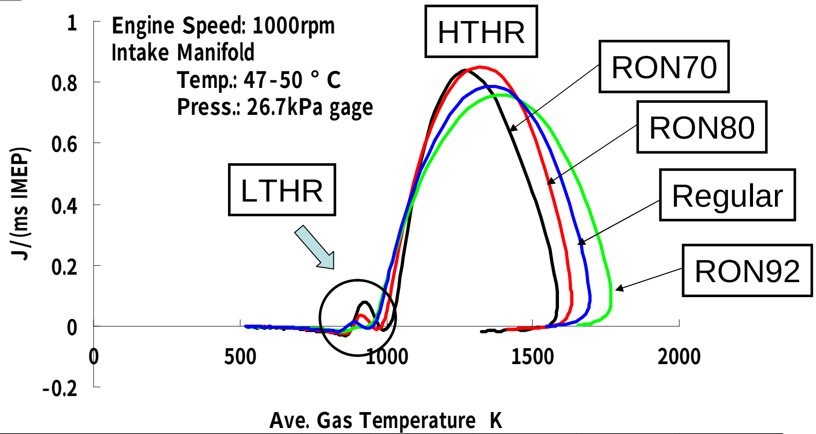
RON70 fuel has a margin for high speed operation!

Temperature History of Octane Number Test



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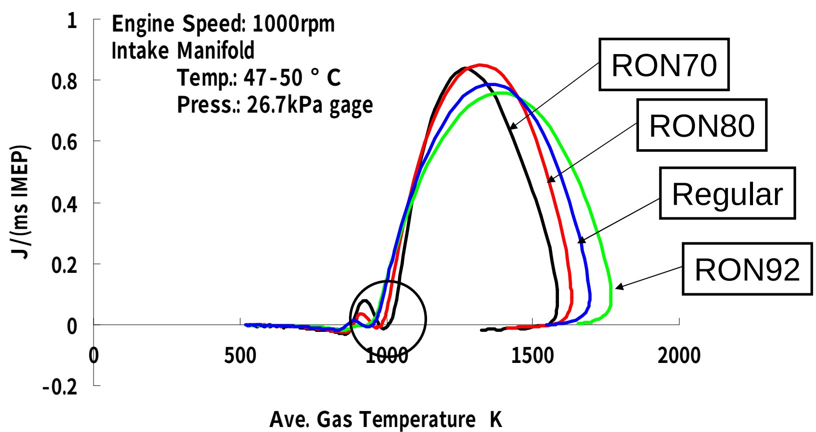

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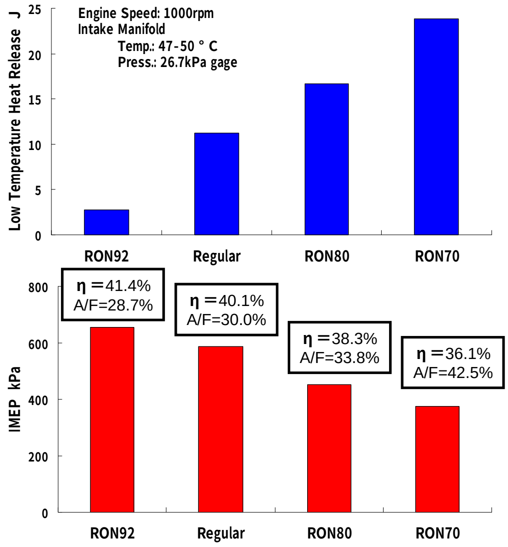
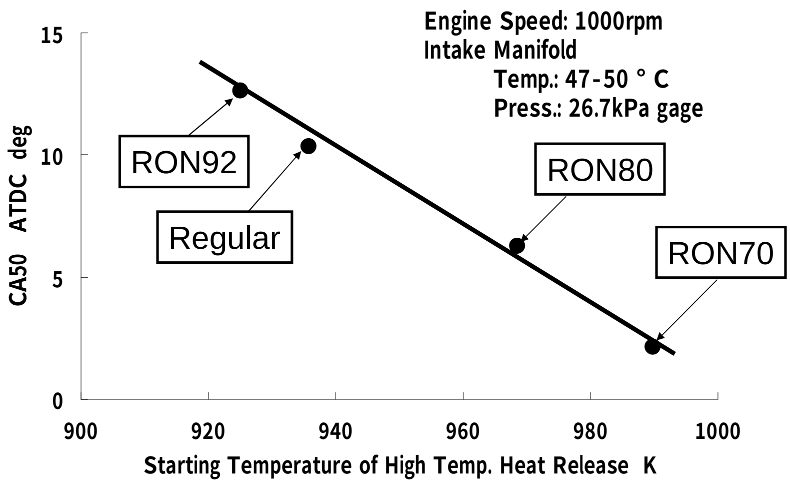
Low Temperature Heat Release and Engine Performance at Constant Knocking Intensity



@ same knocking intensity…

The Relation Between the Starting Temperature of High Temperature Heat Release and CA50



The Relation between fuel Types and Engine Performances

Fuel Type	Engine Torque	Air Fuel Ratio Range	Engine Speed Range	Anti-Knocking Performance	Thermal Efficiency
Large LTHR Fuel	Small	Lean Side	Wide	Poor	Low
Small LTHR Fuel	Large	Rich Side	Narrow	Good	High

Large LTHR fuel ⇨ Easy Knock, High Speed, Low Torque Fuel

Small LTHR fuel ⇨ Difficult knock, low Speed, High Torque Fuel

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- **What are RON and MON?**

N-Heptane and Toluene Test

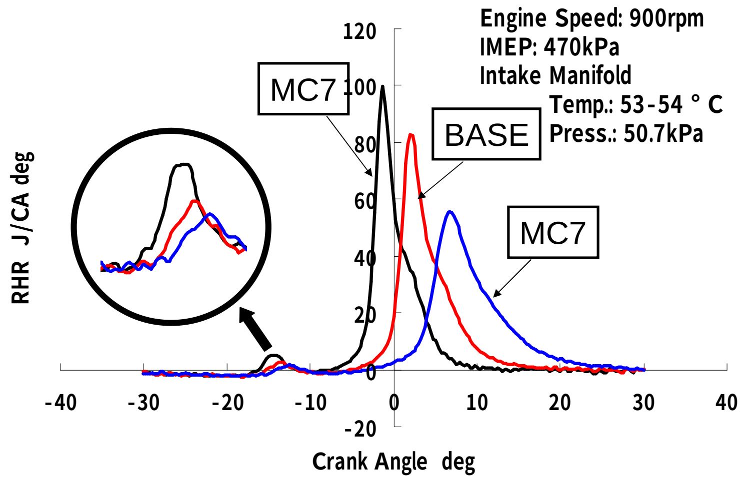
• Test Conditions

Fuel:	Base, MC7, MC10
Engine Speed:	900rpm
Intake Manifold Pressure:	+50.7kPa(gage)
Intake Manifold Temp:	53-54℃
IMEP:	470kPa
Water & Oil Temp:	80℃

Description of the Three Test Fuels for N-Heptane and Toluene Test

		BASE	MC7	MC10
Octane Number	RON	87.5	83.5	90
	MON	68	64.5	66.5
Density	g/cm3	0.7292	0.7264	0.7384
Reid Vapour Pressure	kPa	38.0	36.5	36.0
Lower Heating Value	J/g	43487	43556	43260
Distillation °C	0%	51.5	51.5	52.0
	10%	67.0	69.0	69.0
	30%	73.5	75.5	76.0
	50%	82.5	85.0	85.5
	70%	96.5	97.0	98.5
	90%	114.5	113.0	114.5
	95%	128.5	127.0	125.5
	EP	143.5	142.5	144.0
Remarks		-	BASE+6.5% n-Heptane	BASE+6.5% Toluene

Heat Release Data of BASE, MC7 and MC10



LTHR and HTHR Data of N-Heptane and Toluene Test

			Unit	MC7	BASE	MC10
Low Temperature Heat Release		Heat Value	J	23.0	14.5	13.1
	Start	Crank Angle	BTDC	18.5	16.5	16.5
High Temperature Heat Release		Heat Value	J	416.0	442.6	462.8
	Start	Crank Angle	BTDC	9.5	8.5	7
Engine Torque			Nm	71.1	70.2	70.2
Engine Power			kW	6.7	6.6	6.6
Intake Air Temperature			° C	52.8	54.0	54.0
IMEP			kPa	468.4	473.6	470.0
Thermal Efficiency			%	39.97	38.48	37.03
Air/Fuel Ratio (Exhaust O2 Sensor)				41.5	41.7	41.5

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- Chemistry changes the start crank angle of LTHR
- The temperature range of LTHR is dependent on the chemical components

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Heating Value of LTHR → MC10 0.9×BASE

MC10 is a mixture of 93.5% BASE and 6.5% Toluene

Toluene does not exhibit LTHR

LTHR and HTHR Data of N-Heptane and Toluene Test

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The LTHR of MC10 is initiated by the chemical components of BASE

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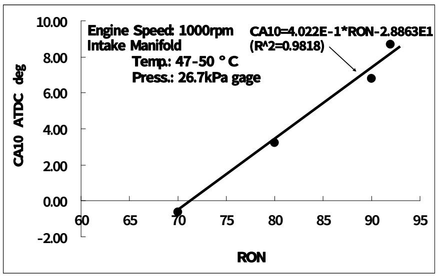
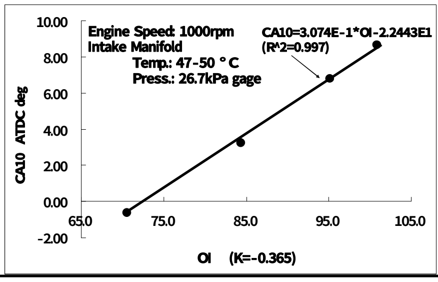
Octane Index





OI=RON-K*(RON-MON)

(K depends on engine operating conditions) SAE 2001-01-3584

In this test… K=-0.365

RON had a much stronger influence on the octane number test results than MON

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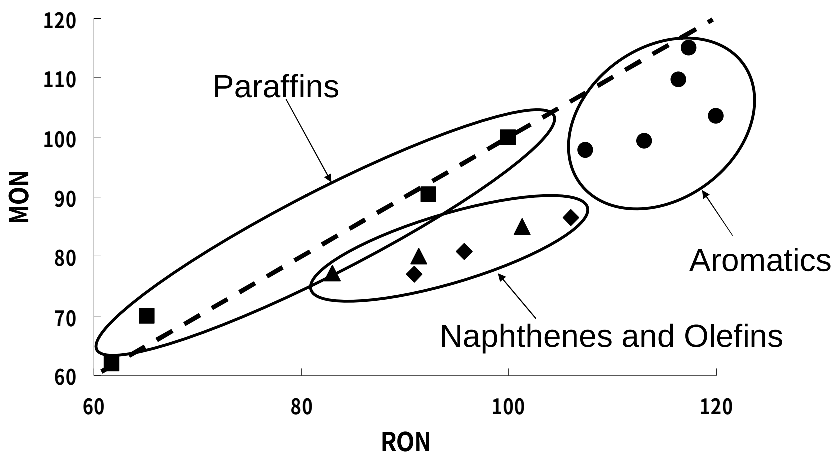
RON-MON Distribution Map for General Chemicals in Gasoline



The Change of the LTHR Grade on RON and MON Conditions

- HCCI combustion is a "slow and mild knocking phenomenon of SI engines

<Assumption>

LTHR Magnitude — Grade 0 → No LTHR

…

Grade 4 → Large LTHR

	RON Condition Inlet Air Temp. 52C	MON Condition Inlet Air Temp. 142C
iso-Octane	Grade 3	Grade 2
Toluene	Grade 0	Grade 0

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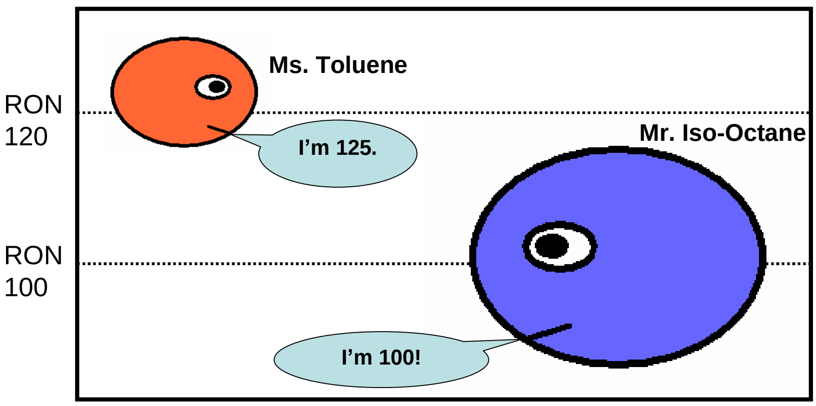
What are RON and MON?

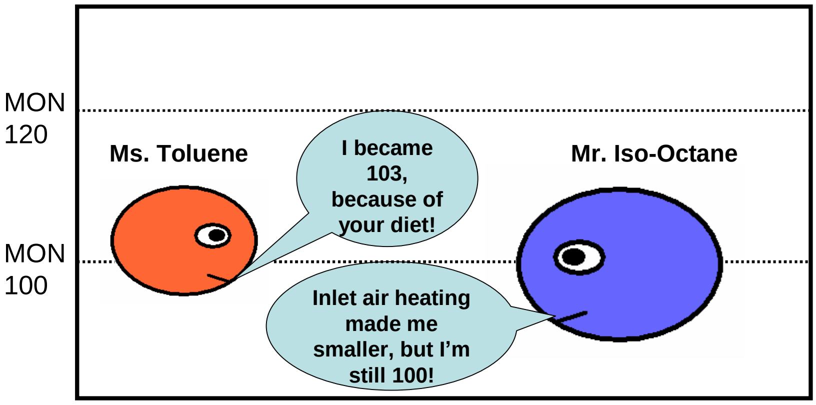
RON



The size of faces refers to the size of LTHR

What are RON and MON?

MON



The size of faces refers to the size of LTHR

What are RON and MON?

- From the point of view of iso-octane, toluene approaches iso-octane behavior with inlet air heating
- The difference in grade for the MON condition is 2-levels in contrast to 3-levels for the RON condition

⇩

RON is larger than MON for aromatic fuels, and the same reasoning may be applied to olefins and naphthenes

Conclusions

1. The reaction time period from LTHR start to HTHR finish is constant for a given fuel and independent of engine speed. As the engine speed increases, the period in crank angles is simply elongated. This effectively restricts the engine speed range where HCCI combustion is practical.

Conclusions

2. A fuel with a large heating value of LTHR is an "Easy Knock, High Speed & Low Torque" fuel, and a fuel with a small heating value of LTHR is a "Difficult Knock, Low Speed &High Torque" fuel. These tendencies were consistent for the fuels with the same distillation and same RON distribution against distillation.

Conclusions

3. A small change in chemical composition can change the HCCI combustion characteristics, including the amount and the phasing of LTHR that significantly affect the HTHR. To develop and test HCCI engines, knowing the effects of fuel characteristics on HCCI combustion is very important.

Conclusions

4. To meet the demand for a fuel compatible with HCCI-SI engine operations, a more versatile and simpler HCCI fuel index, analogous to RON or MON, must be obtained