US 20090151236A1

(19) **United States**

(12) **Patent Application Publication**

SHIBATA

(10) **Pub. No.: US 2009/0151236 A1**

(43) **Pub. Date: Jun. 18, 2009**

(54) FUELS FOR HOMOGENEOUS CHARGE COMPRESSION IGNITION COMBUSTION ENGINE

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(21) Appl. No.: **12/335,894**

(22) Filed: **Dec. 16, 2008**

(30) **Foreign Application Priority Data**

Dec. 17, 2007 (JP) 2007-324363

Publication Classification

(51) **Int. Cl.**
C10L 1/18 (2006.01)

(52) **U.S. Cl.** **44/447**; 44/451

(57) ABSTRACT

The present invention provides a fuel capable of controlling the combustion reaction during homogeneous charge compression auto-ignition combustion to improve the engine thermal efficiency. The fuel satisfies specified characteristic requirements relating to: (1) the total content of C5 to C10 normal paraffins; (2) the total content of C6 to C11 aromatic hydrocarbons; (3) the content of olefinic hydrocarbons; (4) the content of oxygenates; (5) the research octane number; (6) the initial boiling point and end point in distillation characteristics; (7) the averaged maximum pressure rise rate of the fuel over continuous 400 cycles; and (8) the averaged IMEP of the fuel over continuous 400 cycles.

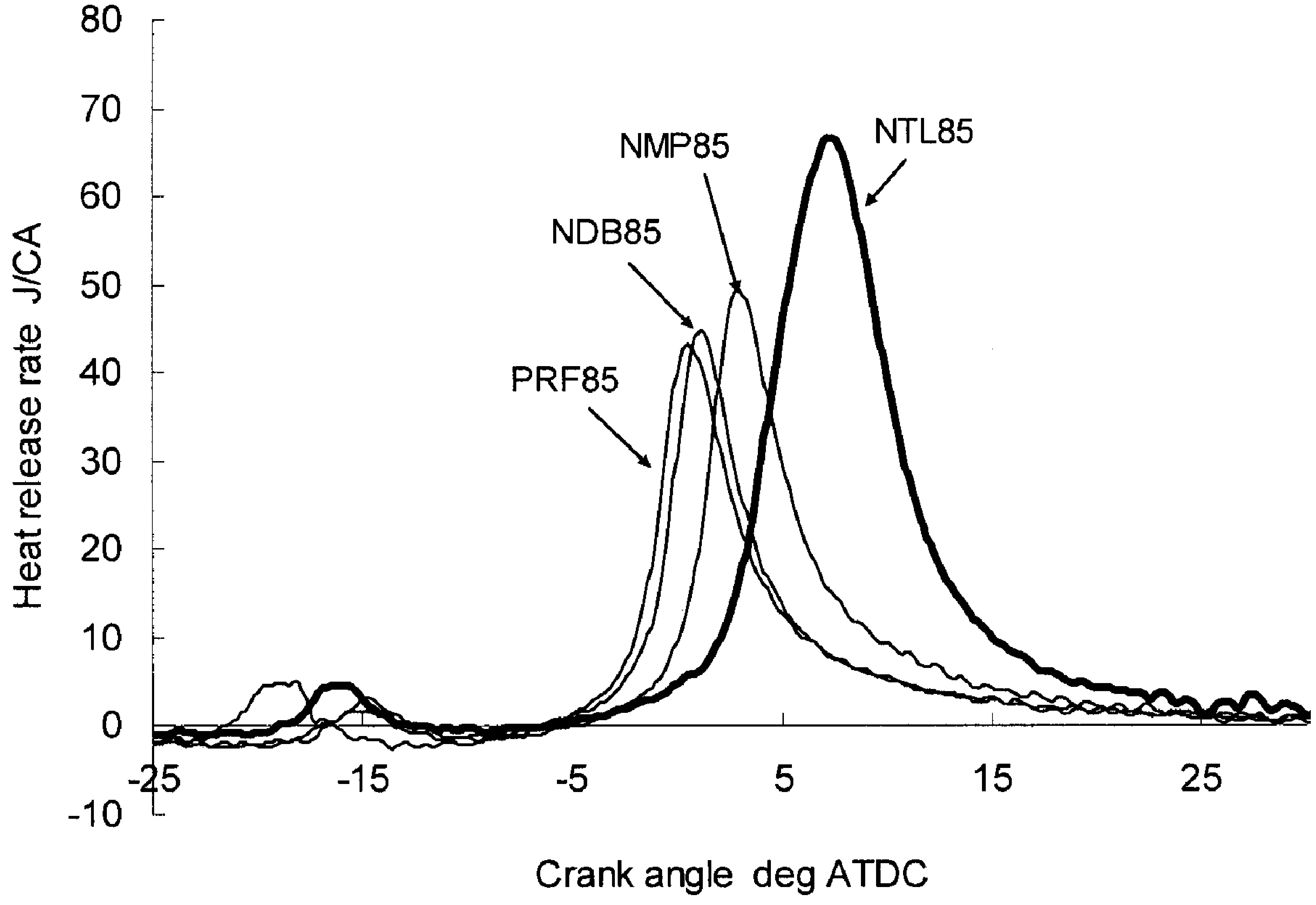


Fig. 1

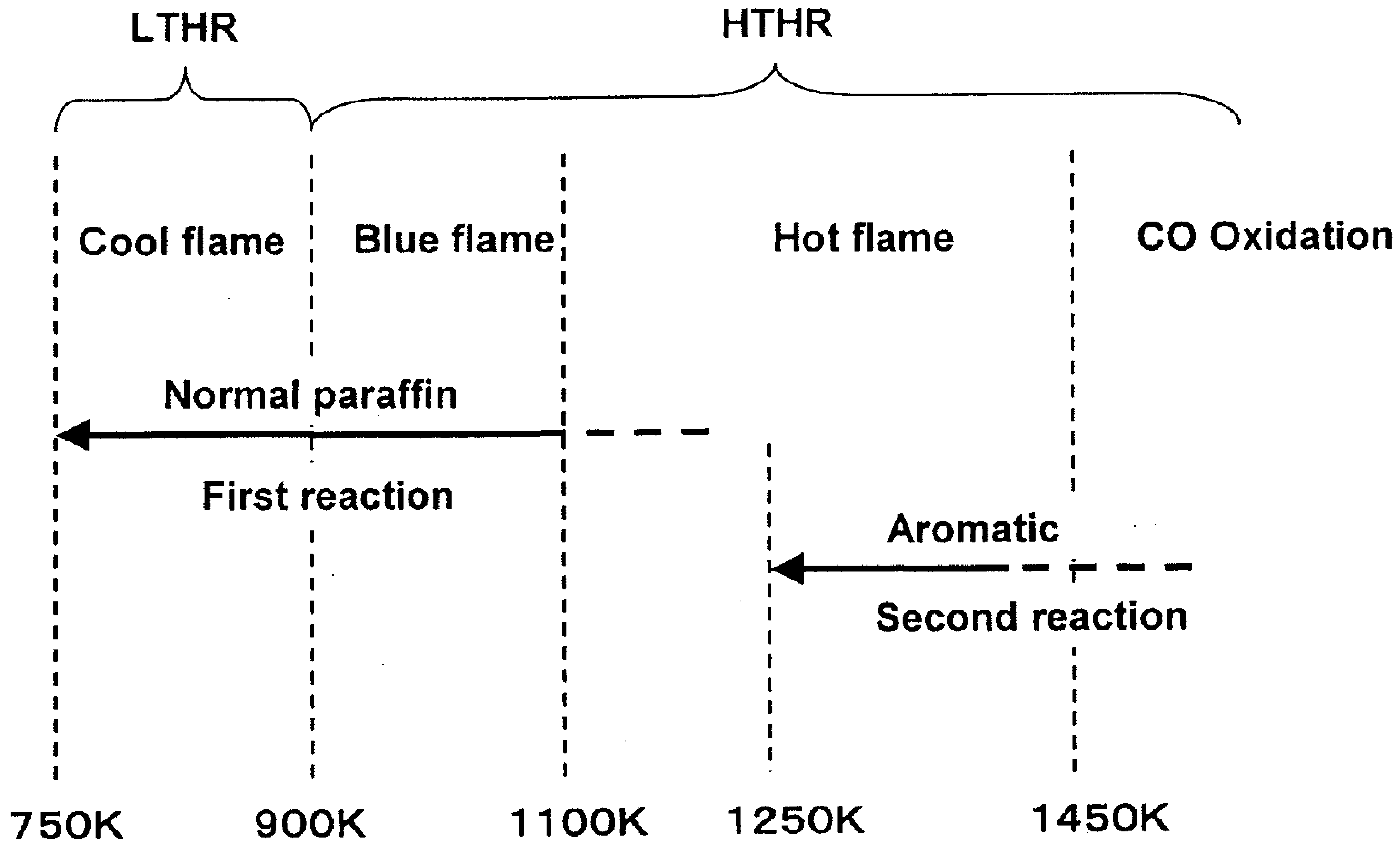

LTHR
HTHR
Cool flame
Blue flame
Hot flame
CO Oxidation
Normal paraffin
First reaction
Aromatic
Second reaction
750K
900K
1100K
1250K
1450K

Fig. 2

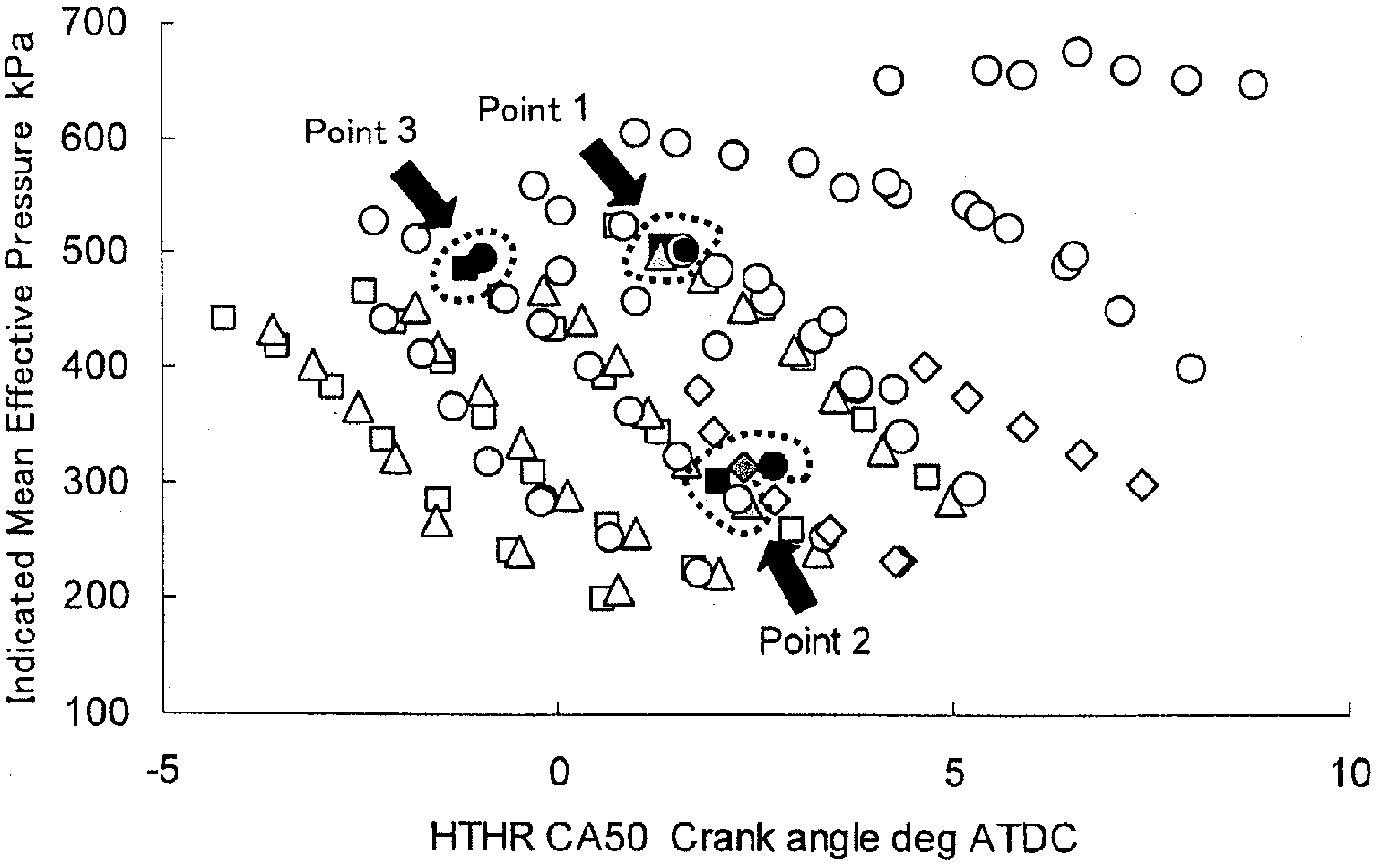

Indicated Mean Effective Pressure kPa
700
600
500
400
300
200
100
-5
0
5
10
HTHR CA50 Crank angle deg ATDC
Point 1
Point 2
Point 3

Fig. 3

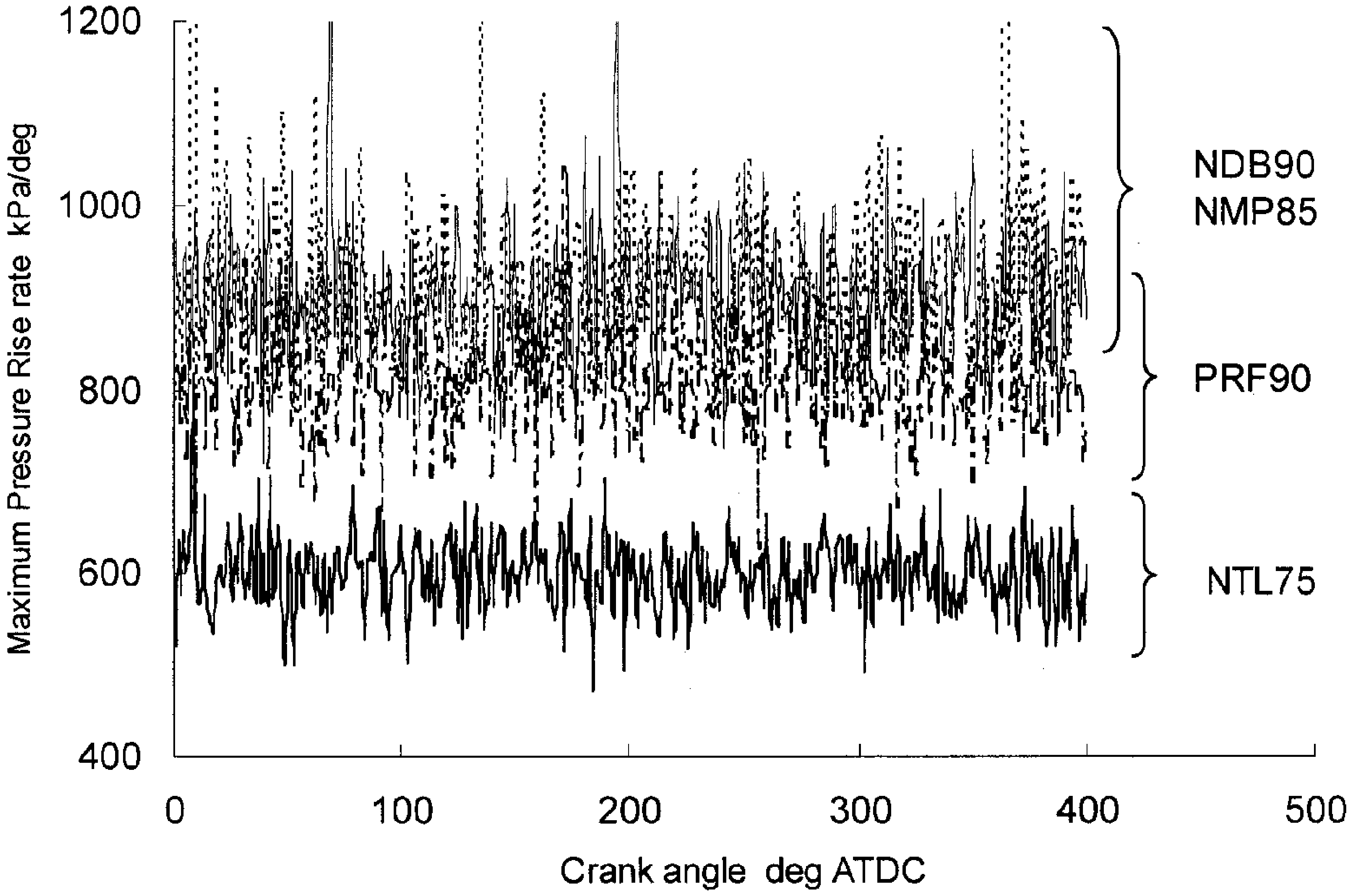

1200
1000
800
600
400
Maximum Pressure Rise rate kPa/deg
0
100
200
300
400
500
Crank angle deg ATDC
NDB90
NMP85
PRF90
NTL75

Fig. 4

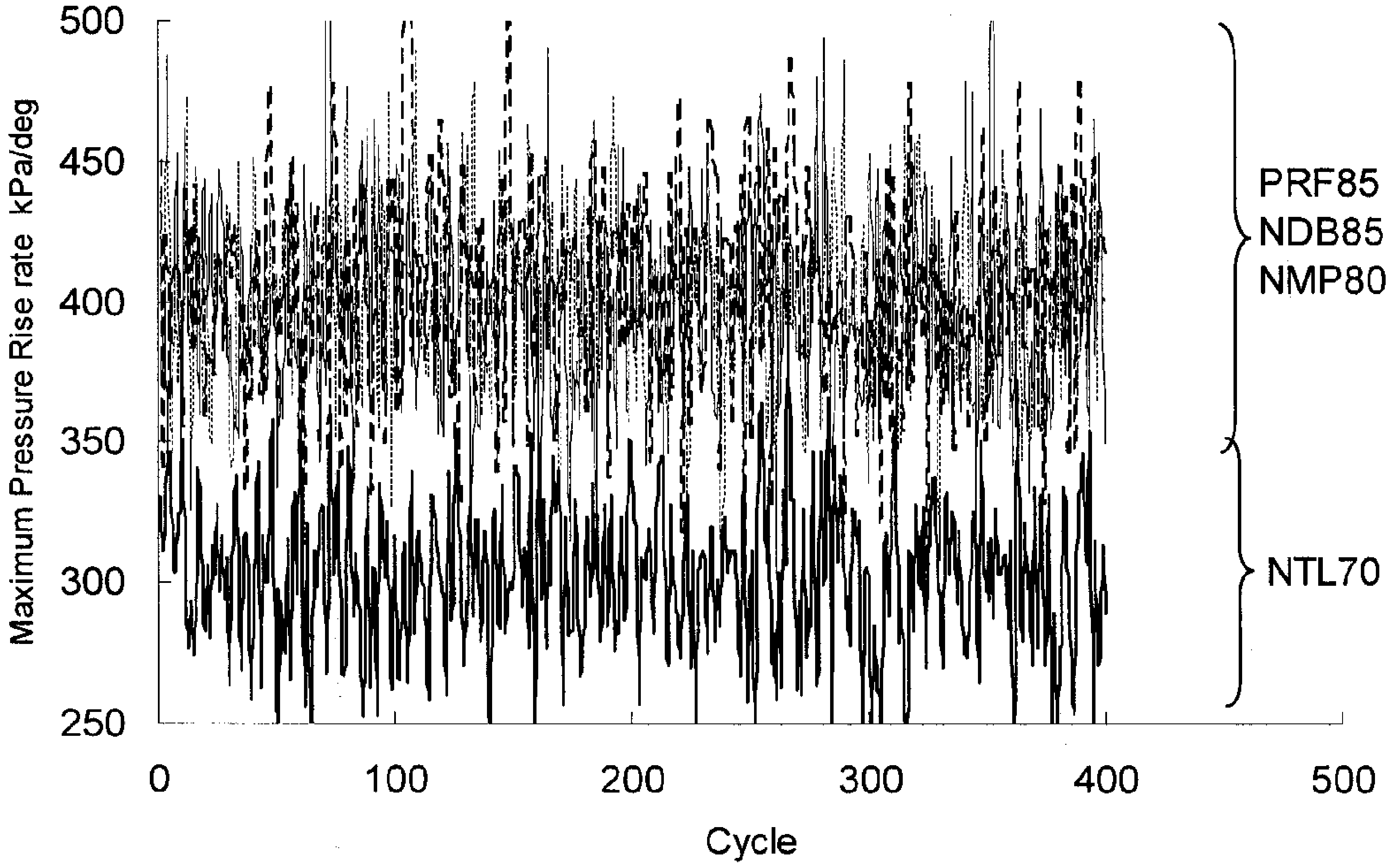

500
450
400
350
300
250
Maximum Pressure Rise rate kPa/deg
0
100
200
300
400
500
Cycle
PRF85
NDB85
NMP80
NTL70

Fig. 5

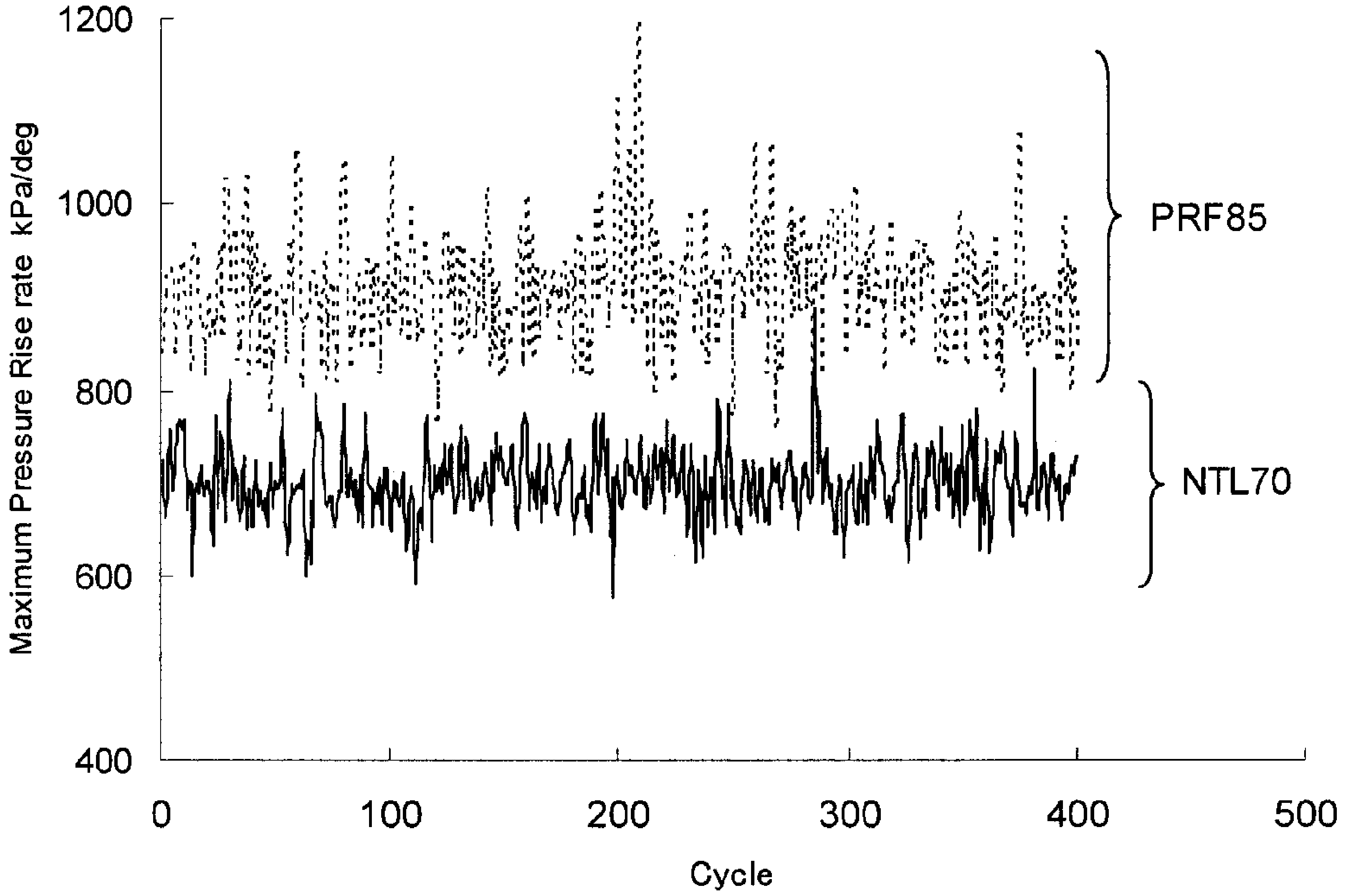

1200
1000
800
600
400
Maximum Pressure Rise rate kPa/deg
0
100
200
300
400
500
Cycle
PRF85
NTL70

Fig. 6

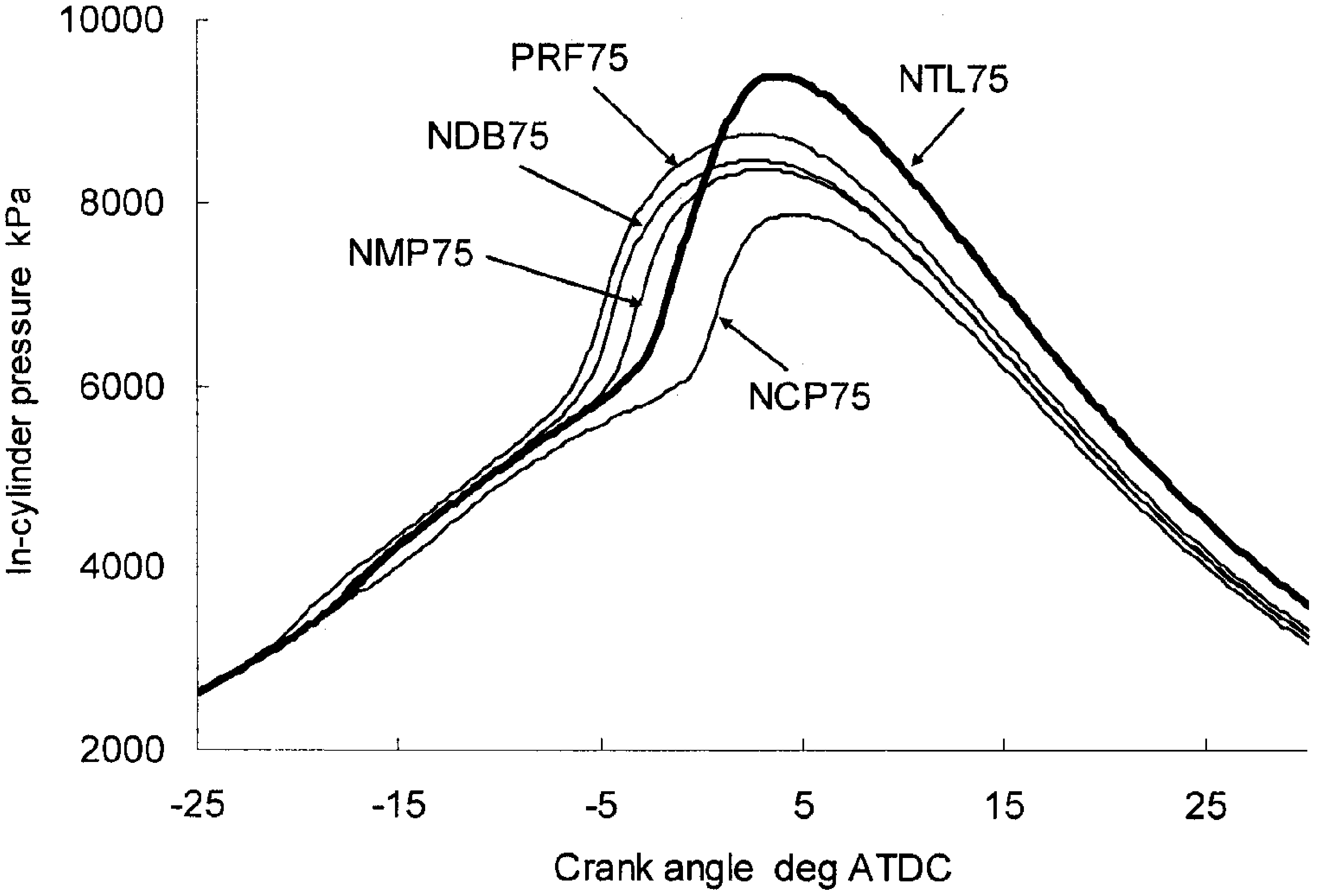

10000
8000
6000
4000
2000
In-cylinder pressure kPa
-25
-15
-5
5
15
25
Crank angle deg ATDC
PRF75
NDB75
NMP75
NCP75
NTL75

Fig. 7

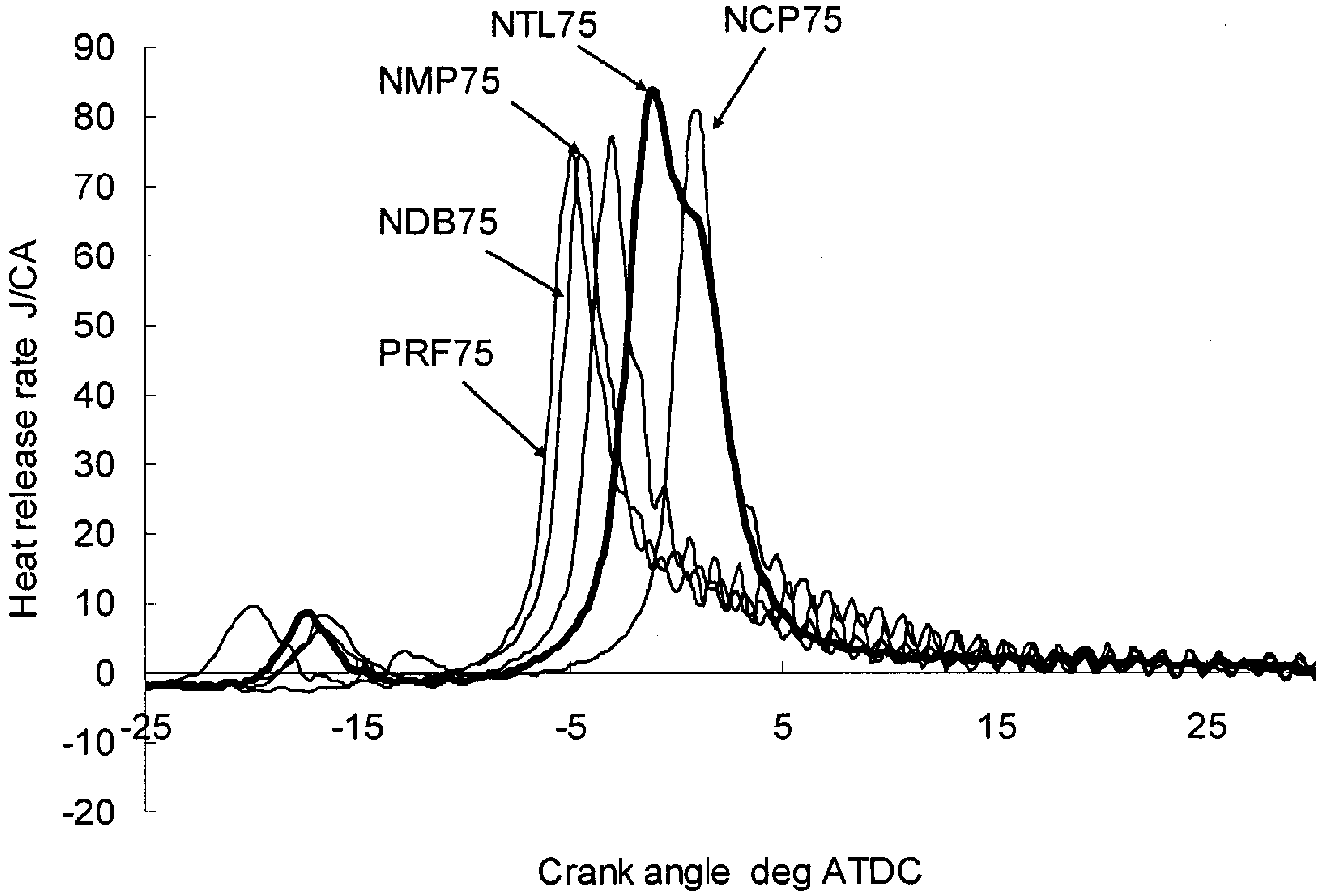

NTL75
NCP75
NMP75
NDB75
PRF75
90
80
70
60
50
40
30
20
10
0
-10
-20
-25
-15
-5
5
15
25
Heat release rate J/CA
Crank angle deg ATDC

Fig. 8

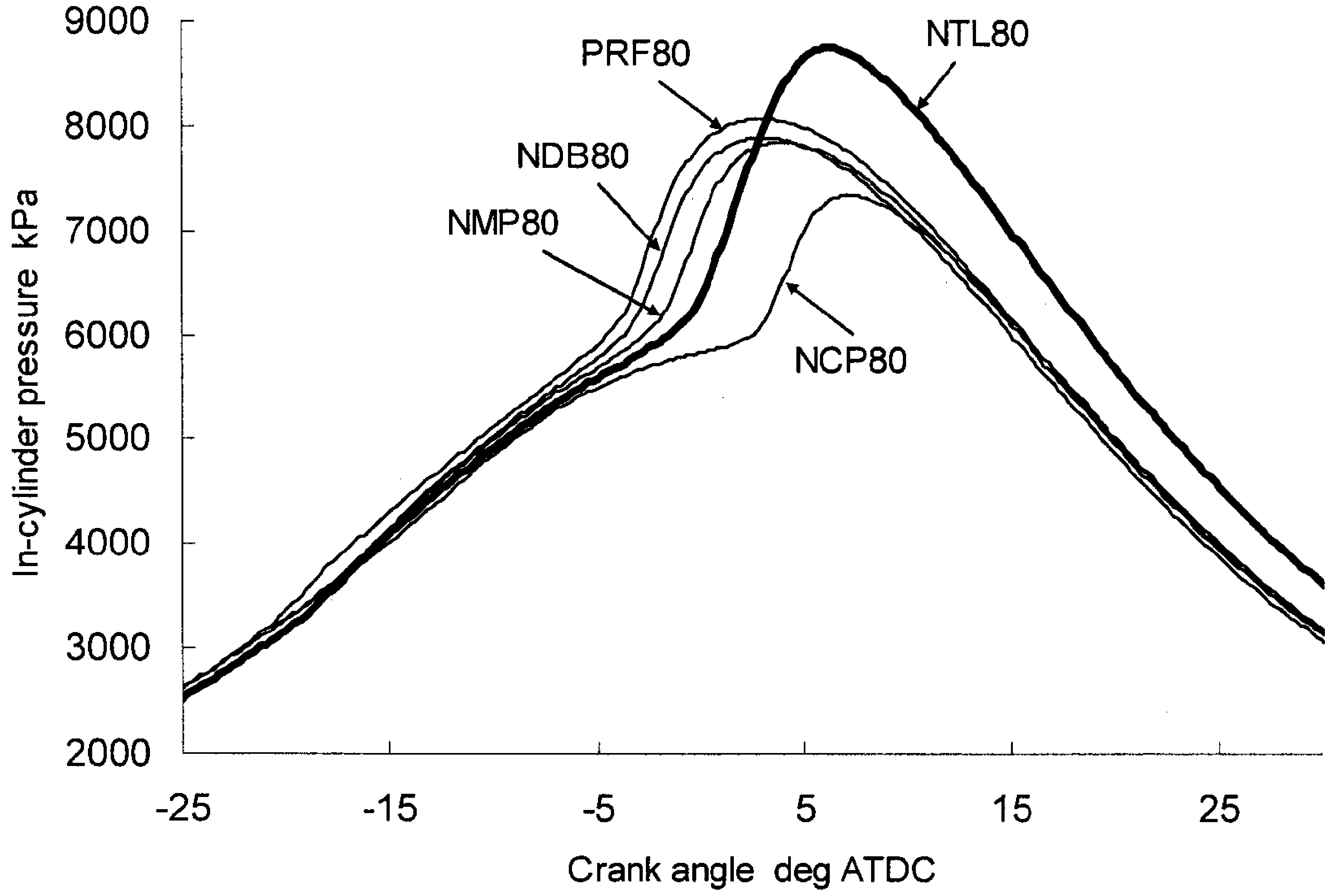

PRF80
NTL80
NDB80
NMP80
NCP80
9000
8000
7000
6000
5000
4000
3000
2000
-25
-15
-5
5
15
25
In-cylinder pressure kPa
Crank angle deg ATDC

Fig. 9

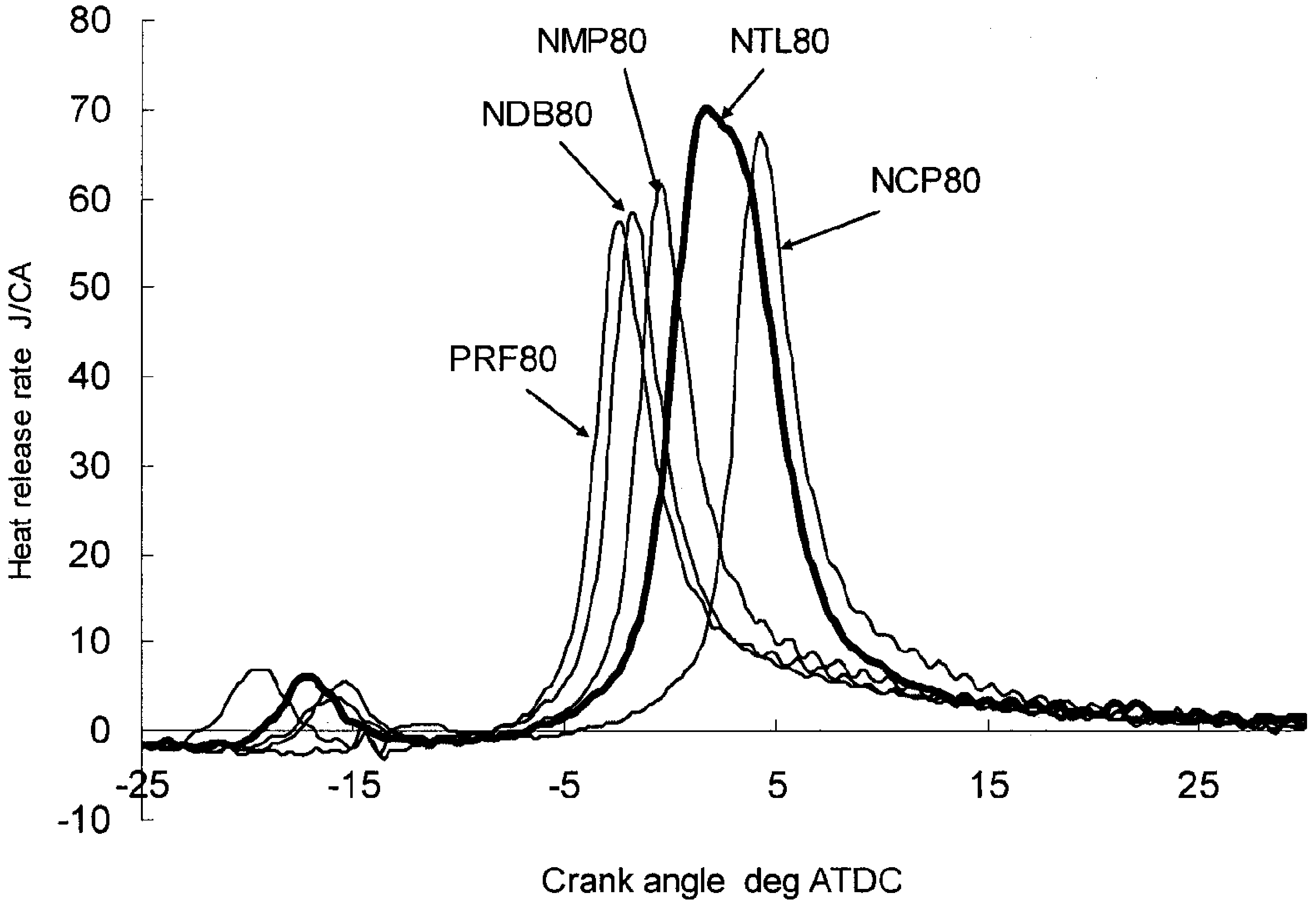

Heat release rate J/CA
80
70
60
50
40
30
20
10
0
-10
-25
-15
-5
5
15
25
Crank angle deg ATDC
NMP80
NTL80
NDB80
NCP80
PRF80

Fig. 10

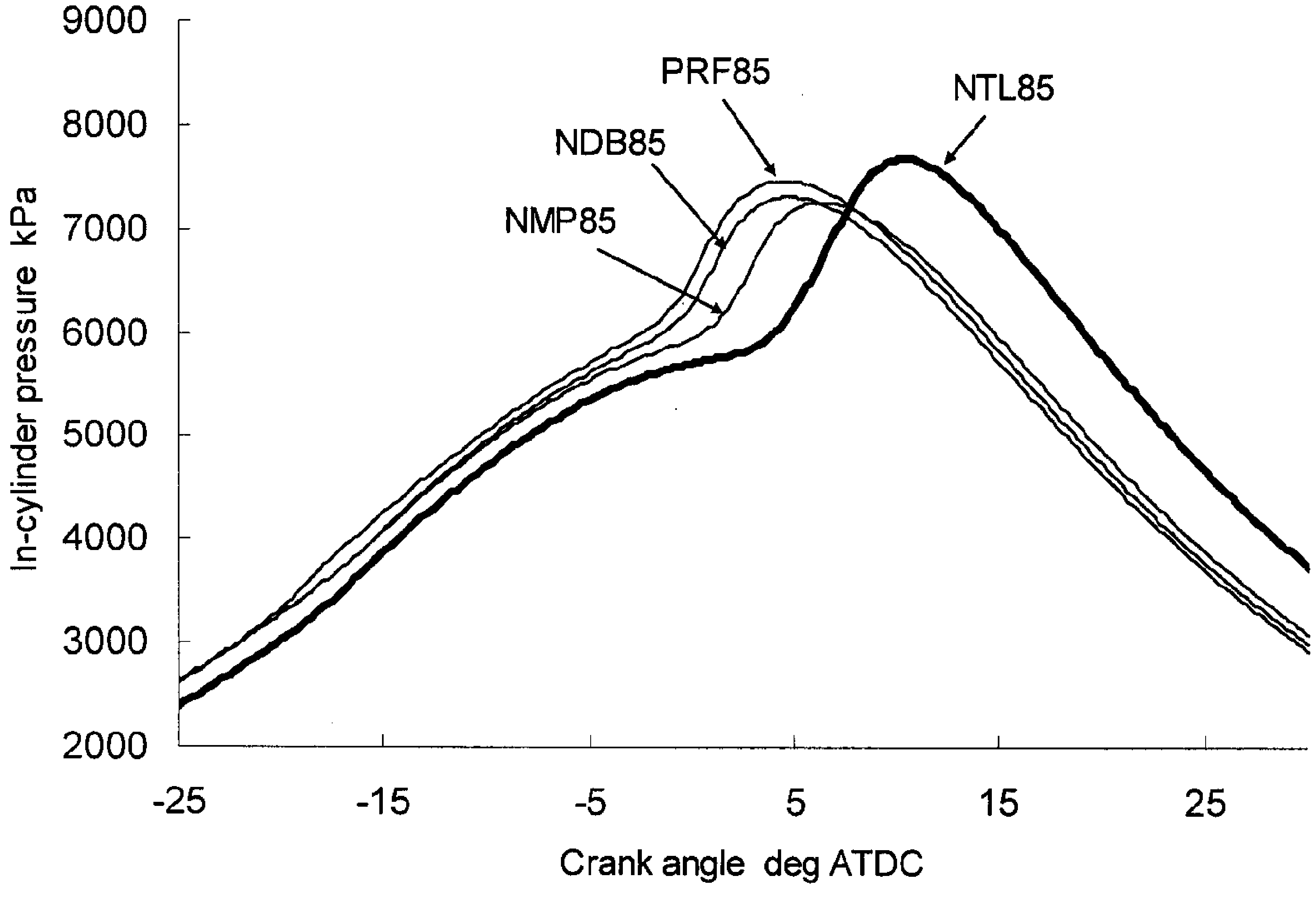
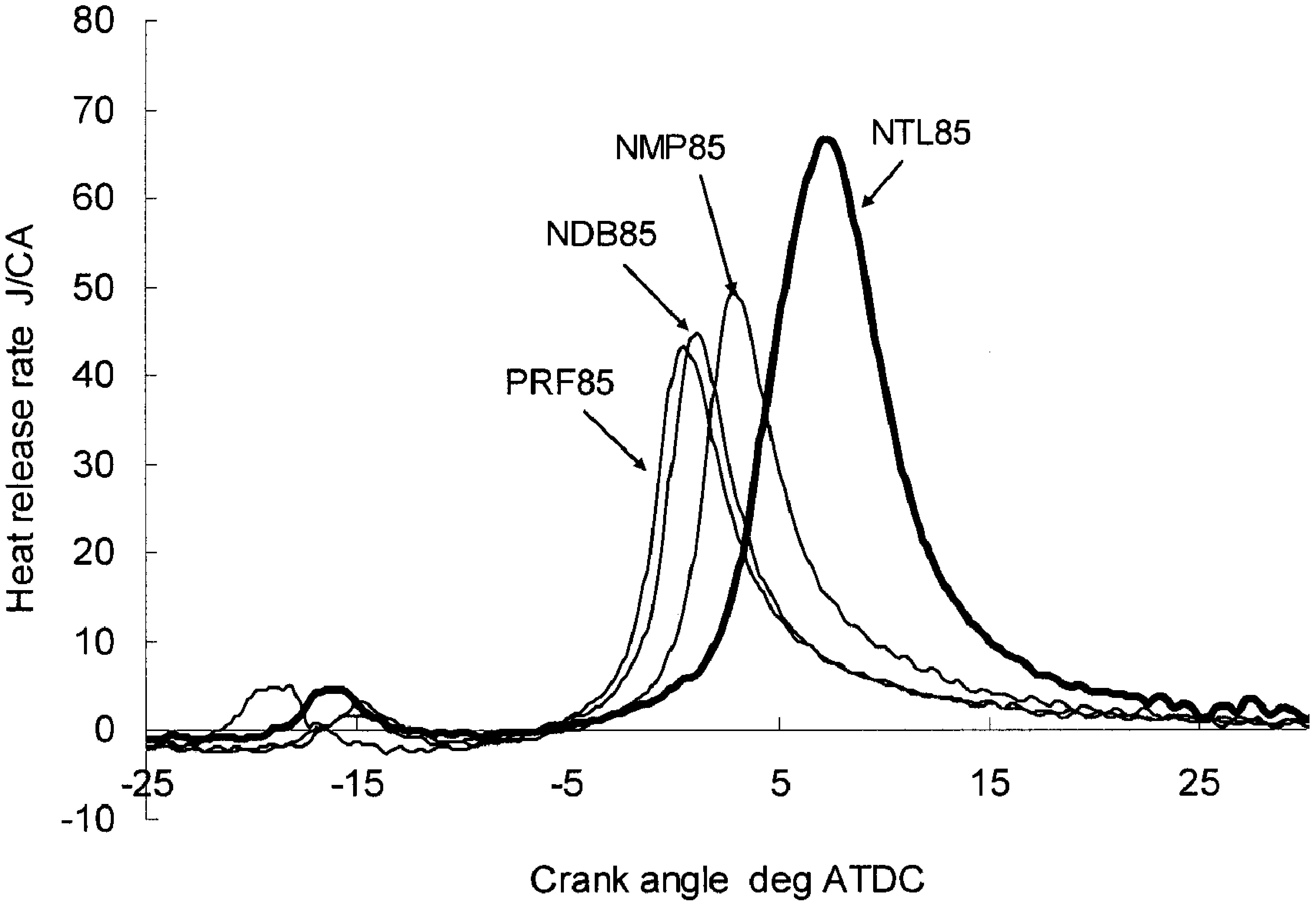

In-cylinder pressure kPa
9000
8000
7000
6000
5000
4000
3000
2000
-25
-15
-5
5
15
25
Crank angle deg ATDC
PRF85
NTL85
NDB85
NMP85

Fig. 11


80
70
60
50
40
30
20
10
0
-10
Heat release rate J/CA
-25
-15
-5
5
15
25
Crank angle deg ATDC
NMP85
NTL85
NDB85
PRF85

FUELS FOR HOMOGENEOUS CHARGE COMPRESSION IGNITION COMBUSTION ENGINE

BACKGROUND OF THE INVENTION

[0001] The present invention relates to fuels for homogeneous charge compression ignition engines, more specifically to those capable of controlling the combustion reaction during homogeneous charge compression combustion to improve the engine thermal efficiency.

[0002] Nowadays, two types of engines have been widely used, one of which is a spark ignition gasoline engine and the other of which is a compression ignition engine (diesel engine).

[0003] For the spark ignition gasoline engine, fuel is injected into the intake port or the combustion chamber, and premixed gas of air fuel mixture is formed. Then the premixed gas is ignited by a spark plug and combusted. The fuel is required to have high vaporization and low auto-ignitability characteristics. Since the spark ignition gasoline engine emits nitrogen oxides (NOx) , hydrocarbons (HC) and carbon monoxide, a three-way catalyst has been widely used for purifying these emissions. However, an exhaust gas purification system such as a three-way catalyst is only applicable to a range where the air-fuel ratio is in a very narrow range of stoichiometric air-fuel ratio and it is the causes of low thermal efficiency and poor fuel consumption comparing with the compression ignition diesel engine.

[0004] For the diesel engine, a diesel fuel is directly injected into the cylinder and mixed with the air during compression stroke. The air-fuel mixture is auto-ignited by increasing the temperature and pressure by piston compression. The diesel fuel is required to have high ignitability characteristics. The compression auto-ignition diesel engine is excellent in fuel consumption and thermal efficiency but has disadvantages of NOx and soot emissions caused by the heterogeneous air fuel mixture. Furthermore, severe control of an after treatment system such as an oxidation catalyst, NOx trap, a diesel particulate filter or an SCR system is required to reduce NOx and soot to meet political regulations.

[0005] Therefore, the conventional spark ignition gasoline engine can purify the exhaust gas to a certain extent but has problems regarding fuel consumption and thermal efficiency. On the contrary, the diesel engine is excellent in fuel consumption and has high thermal efficiency, but it has problems of emission of NOx. Therefore, a homogeneous charge compression ignition engine has been studied to achieve low NOx exhaust gas, excellent fuel consumption and high thermal efficiency.

[0006] For the homogeneous charge compression ignition engine, the fuel is injected into the intake port or combustion chamber at an injection pressure of 20 MPa or lower, which is extremely lower than the diesel engine and the fuel injection is completed at a crank angle of 60 degrees before the top dead center so that a premixed air-fuel mixture is combusted by auto-ignition but not by spark ignition. The homogeneous charge compression ignition engine takes a longer period to prepare a well-mixed air-fuel mixture in the cylinder, comparing with the diesel engine. Therefore, for the homogeneous charge compression ignition engine, a high temperature combustion region, the temperature of which is higher than 2200K, is not locally formed in the cylinder and this is the cause of low NOx emission characteristics (less than 10 ppm by mass) without a reduction catalyst. The thermal efficiency and fuel consumption of the homogeneous charge compression ignition engine are equivalent to those of the diesel engine.

[0007] Various fuels for the homogeneous charge compression auto-ignition combustion engine have been proposed, focusing on various indices such as ignitability, volatility, cetane number and octane number (for example, see Patent Documents 1 to 13 below) However, more optimum and suitable fuels for homogeneous charge compression ignition have been demanded from the point of engine performances.

[0008] Patent Document 1: Japanese Patent Laid-Open Publication No. 2004-919657

[0009] Patent Document 2: Japanese Patent Laid-Open Publication No. 2004-919658

[0010] Patent Document 3: Japanese Patent Laid-Open Publication No. 2004-919659

[0011] Patent Document 4: Japanese Patent Laid-Open Publication No. 2004-919660

[0012] Patent Document 5: Japanese Patent Laid-Open Publication No. 2004-919661

[0013] Patent Document 6: Japanese Patent Laid-Open Publication No. 2004-919662

[0014] Patent Document 7: Japanese Patent Laid-Open Publication No. 2004-919663

[0015] Patent Document 8: Japanese Patent Laid-Open Publication No. 2004-919664

[0016] Patent Document 9: Japanese Patent Laid-Open Publication No. 2004-919665

[0017] Patent Document 10: Japanese Patent Laid-Open Publication No. 2004-919666

[0018] Patent Document 11: Japanese Patent Laid-Open Publication No. 2004-919667

[0019] Patent Document 12: Japanese Patent Laid-Open Publication No. 2004-919668

[0020] Patent Document 13: Japanese Patent Laid-Open Publication No. 2004-315604

BRIEF SUMMARY OF THE INVENTION

[0021] For the homogeneous charge compression ignition engine (hereinafter referred to as "HCCI combustion"), a well mixed air-fuel mixture is compressed by a piston which raises the temperature and pressure, and the auto-ignition is initiated. For the HCCI engine, the engine operation is restricted at a low load range because of heavy engine noises (high maximum pressure rise rate) over the middle range of the engine load.

[0022] The present invention has an object to provide a fuel for the HCCI engine that enhances the HCCI operational range to a higher load range.

[0023] The present invention can be achieved by mixing high ignitability hydrocarbons (mainly C5 to C10 normal paraffins) and C6-C11 aromatics whose benzene rings start to break over 1100K or higher, where the hot flame reaction starts. The fuel of the present invention can prolong the combustion period, reduce the maximum pressure rise rate and enables the HCCI engine to operate in a higher load rage.

[0024] That is, the present invention relates to a fuel for an HCCI engine satisfying all of the following characteristic requirements (1) to (6) and the following requirement (7) or (8):

[0025] (1) the total content of C5 to C10 normal paraffins is 25 percent by volume or more, and 70 percent by volume or less;

[0026] (2) the total content of C6 to C11 aromatic hydrocarbons is 30 percent by volume or more, and 75 percent by volume or less;

[0027] (3) the content of olefinic hydrocarbons is 20 percent by volume or less;

[0028] (4) the content of oxygenates is 5 percent by mass or less in terms of oxygen;

[0029] (5) the research octane number is 70 or greater, and less than 92;

[0030] (6) the initial boiling point and end point in distillation characteristics are 30° C. or higher and 220° C. or lower, respectively;

[0031] (7) the averaged maximum pressure rise rate of the fuel over continuous 400 cycles is smaller by 15 percent or more, comparing with that of a primary reference fuel (PRF) which exhibits the same indicated mean effective pressure (IMEP) and crank angle of 50% burn of high temperature heat release (HTHR CA50) as the fuel under the same engine operating conditions such as compression ratio of the engine, engine speed, boost pressure, temperature in the intake manifold, air flow rate, intake-exhaust valve timing, EGR rate and fuel injection initiation timing; and

[0032] (8) the average IMEP of the fuel over continuous 400 cycles is increased by 20 percent or more, comparing with a primary reference fuel (PRF) with the same research octane number as the fuel, the IMEPs of the fuel and PRF being measured at the same maximum pressure rise rate under the same engine operating conditions such as compression ratio of the engine, engine speed, boost pressure, temperature in the intake manifold, air flow rate, intake-exhaust valve timing, EGR rate and fuel injection initiation timing.

EFFECTS OF THE INVENTION

[0033] The fuel of the present invention can lower the maximum pressure rise rate of homogeneous charge compression ignition combustion and thus achieves a quiet engine combustion. Furthermore, the fuel can enhance the engine output by 20 percent or more under the same maximum pressure rise rate, comparing with the conventional fuels.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0034] The foregoing summary, as well as the following detailed description of the invention will be better understood when read in conjunction with the appended drawings. FIGS. **1-11** are the comparisons of the tangible engine test data obtained by fuels according to the present invention and the comparative test results obtained by other fuels. For the purpose of illustrating the invention, there are shown in the drawings embodiments which are presently preferred. It should be understood, however, that the invention is not limited to the precise arrangements and instrumentalities shown.

[0035] In the drawings:

[0036] FIG. **1** shows how the HCCI combustion (dual phase high temperature heat release combustion) of the present invention occurs.

[0037] FIG. **2** indicates the relation between averaged HTHR CA50s and IMEPs over 400 cycles under the operation conditions in Example 1.

[0038] FIG. **3** shows the change in maximum pressure rise rate at Point 1 over 400 cycles.

[0039] FIG. **4** shows the change in maximum pressure rise rate at Point 2 over 400 cycles.

[0040] FIG. **5** shows the change in maximum pressure rise rate at Point 3 over 400 cycles.

[0041] FIG. **6** shows the in-cylinder pressure at measurement Point A in FIG. **2**.

[0042] FIG. **7** shows the heat release rate at measurement Point A in FIG. **2**.

[0043] FIG. **8** shows the in-cylinder pressure at measurement Point B in FIG. **2**.

[0044] FIG. **9** shows the heat release rate at measurement Point B in FIG. **2**.

[0045] FIG. **10** shows the in-cylinder pressure at measurement Point C in FIG. **2**.

[0046] FIG. **11** shows the heat release rate at measurement Point C in FIG. **2**.

DETAILED DESCRIPTION OF THE INVENTION

[0047] The present invention will be described in more detail below.

[0048] The fuel of the present invention is suitable for a homogeneous charge compression ignition engine (hereinafter the homogeneous charge compression ignition is abbreviated as HCCI). The term "HCCI" herein denotes a combustion mode wherein fuel is combusted by auto-ignition under the following conditions (A), (B) and (C):

(A) fuel injection pressure: 20 MPa or lower;

(B) fuel injection position: the intake port and/or the direct injection into the cylinder; and

(C) timing of completion of fuel injection: 60 degrees crank angle before the top dead center.

[0049] The HCCI is lower in (A) fuel injection pressure than conventional diesel engines and longer in (C) time period after the end of injection to the initiation of combustion to prepare a well-mixed air fuel mixture in the cylinder, than conventional diesel engines. Therefore, for the HCCI engine, a high temperature combustion region, the temperature of which is higher than 2200k, is not locally formed in the cylinder and this is the cause of low NOx emission characteristics (less than 10 ppm by mass) without a reduction catalyst.

[0050] The homogeneous charge compression auto-ignition combustion mode may also be referred to as HCCI (Homogeneous Charge Compression Ignition), PCCI (Premixed Charge Compression Ignition), PCI (Premixed Compression Ignition), CAI (Controlled Auto-Ignition) or AR (Active Radical (Combustion)).

[0051] The fuel of the present invention is suitably used in an HCCI engine. However, the fuel is also applicable to the following types of engines such as HCCI-SI gasoline engines (SI: spark ignition), HCCI-CI diesel engines (CI: compression ignition), and electric motored hybrid engines with HCCI, HCCI-SI and HCCI-DI engines.

[0052] When fuel auto-ignites, low temperature heat release (LTHR) reaction occurs first and then high temperature heat release (HTHR) reaction occurs. The fuel for an HCCI engine of the present invention is characterized by the combination of a fuel (normal paraffin rich fuel) that has a high decomposability and a fuel (aromatic and olefin rich fuel) that has a low decomposability. Therefore, the fuel of the present invention exhibits a dual phase high temperature heat release combustion as shown in FIG. **1**. The paraffinic hydrocarbons are first decomposed and oxidized during cool frame and blue flame periods and then decomposition and oxidation of the aromatic radicals and aromatic hydrocarbons starts during a hot flame period.

[0053] The fuel of the present invention needs to satisfy the following characteristics requirements (1) to (6):

[0054] (1) the total content of C5 to C10 normal paraffins is 25 percent by volume or more and 70 percent by volume or less, preferably 30 percent by volume or more and 50 percent by volume or less because normal paraffinic hydrocarbons of C4 or less can not exhibit sufficient low temperature heat release (LTHR) reaction while hydrocarbons of C11 or more has a high boiling point and are not suitable for an HCCI engine;

[0055] (2) the total content of C6 to C11 aromatic hydrocarbons is 30 percent by volume or more and 75 percent by volume or less, preferably 50 percent by volume or more and 65 percent by volume or less because hydrocarbons of C12 or more are poor in volatility and not suitable for an HCCI engine and the presence of more than 75 percent by volume of aromatics restricts the operational range against engine speed and load;

[0056] (3) the content of an olefin is 20 percent by volume or less, preferably 10 percent by volume or less;

[0057] (4) the content of oxygenates is 5 percent by mass or less in terms of oxygen;

[0058] (5) the research octane number is 70 or greater and less than 92, preferably 70 or greater and 86 or less; and

[0059] (6) the initial boiling point in distillation is 30° C. or higher, and end point in distillation is 220° C. or lower, preferably 150° C. or lower.

[0060] The definition of the hydrocarbon contents used herein denotes the value measured in accordance with JIS K 2536 "Liquid petroleum products-Testing method of components" using gas chromatography. The term "normal paraffin" used herein denotes straight-chain hydrocarbon containing no naphthene (cyclic saturated hydrocarbon).

[0061] In addition to the foregoing requirements, the fuel of the present invention needs to satisfy the following requirement (7) or (8):

[0062] (7) the averaged maximum pressure rise rate of the fuel over continuous 400 cycle is smaller by 15 percent or more, preferably 20 percent or more, comparing with that of a primary reference fuel (PRF) which exhibits the same indicated mean effective pressure (IMEP) and crank angle of 50% burn of high temperature heat release combustion (HTHR CA50) as the fuel under the same engine operating conditions (compression ratio of the engine, engine speed, boost pressure, temperature in the intake manifold, air flow rate, intake-exhaust valve timing, EGR rate and fuel injection initiation timing).

[0063] The terms "the same mean effective pressure and crank angle of 50% burn of high temperature heat release combustion" are defined as being within +20 kPa in indicated mean effective pressure and within ±0.8 degree crank angle in HTHR CA 50, respectively, comparing with a comparative fuel, i.e., PRF. The "PRF" is an abbreviation of primary reference fuel used for the measurement of octane numbers. For example, "PRF80" means a fuel with a research octane number of 80, produced by mixing 80 percent by volume of iso-octane and 20 percent by volume of normal heptane. The method of measuring the mean effective pressure and definition of HTHR CA50 are described in an SAE technical paper, No. SAE2006-01-0207.

[0064] (8) the averaged IMEP of the fuel over continuous 400 cycles is increased by 20 percent or more, preferably 25 percent or more, more preferably 50 percent, comparing with that of a primary reference fuel (PRF) with the same research octane number as the fuel, the IMEPs of the fuel and PRF being measured at the same maximum pressure rise rate under the same engine operating conditions (compression ratio of the engine, engine speed, boost pressure, temperature in the intake manifold, air flow rate, intake-exhaust valve timing, EGR rate and fuel injection initiation timing).

[0065] The measurement inaccuracy in the maximum pressure rise rate is defined as being within ±4 kPa/deg comparing with PRF.

[0066] There is no particular restriction on the sulfur content of the fuel. However, the sulfur content is preferably 10 ppm by mass or less, and with the objective of keeping the performances of a catalyst in a high level, more preferably 5 ppm by mass, most preferably 1 ppm by mass or less. A sulfur content of more than 10 ppm by mass is not preferable because an exhaust gas-purifying catalyst equipped in an engine is poisoned with sulfur, resulting in a poor exhaust gas-purifying performance. The sulfur content used herein denotes the value measured in accordance with JIS K 2541 "Crude oil and petroleum products-Determination of sulfur content".

[0067] The fuel of the present invention contains hydrocarbons as the main component but may further contain oxygenates such as ethers, alcohols, ketones, esters, and glycols. Examples of the oxygenates include methanol, ethanol, normalpropyl alcohol, isopropyl alcohol, normalbutyl alcohol, isobutyl alcohol, dimethyl ether, diisopropyl ether, methyl-tert-butyl ether (MTBE), ethyl-tert-butyl ether (ETBE) , tert-amyl methyl ether (TAME) , tert-amyl ethyl ether, fatty acid methyl ester, and fatty acid ethyl ester.

[0068] The fuel of the present invention can reduce unburnt hydrocarbon (HC) and fine particulate matters due to the presence of the foregoing oxygenates. When the fuel contains a biomass-originating oxygenate, it contributes to reduce carbon dioxide. However, as the case may be, the oxygenates cause an increase in nitrogen compounds. Therefore, the content of the oxygenates is preferably 5 percent by mass or less in terms of oxygen on the basis of the total mass of the fuel.

[0069] There is no particular restriction on the base oil of the fuel of the present invention as long as the fuel characteristics described above can be attained. For example, the base oil may be any one or more of base oils selected from naphtha fractions produced by atmospheric distillation of crude oil (full-range naphtha); light fractions of naphtha (light naphtha); heavy fractions of naphtha (heavy naphtha) ; desulfurized full-range naphtha produced by desulfurization of full-range naphtha; desulfurized light naphtha produced by desulfurization of light naphtha; desulfurized heavy naphtha produced by desulfurization of heavy naphtha; isomerized gasolines produced by converting light naphthas to isoparaffin in an isomerization unit; alkylates produced by addition (alkylation) of lower olefins to hydrocarbons such as isobutane; reformed gasolines produced by a catalytic reforming process; raffinates which are residues produced by extracting aromatic components from reformed gasolines; light reformed gasolines that are light fractions of reformed gasolines; middle reformed gasolines that are middle fractions of reformed gasolines; heavy reformed gasolines that are heavy fractions of reformed gasolines; cracked gasolines produced by catalytic cracking or hydrocracking; light fraction of cracked gasolines; heavy fraction of cracked gasolines; straight gas oils and straight kerosene produced through an atmospheric distillation unit for crude oil; vacuum gas oils produced by processing straight heavy oil or residue produced through an atmospheric distillation unit, in a vacuum distillation unit; catalytically cracked or hydrocracked gas oils and kerosenes produced by catalytically cracking or hydrocracking vacuum heavy gas oils or desulfurized heavy oils; hydrorefined gas oils, hydrodesulfurized gas oils or hydrorefined kerosenes produced by hydrorefining the foregoing petroleum hydrocarbons; and naphtha fractions, kerosene fractions and gas oil fractions of GTL (Gas to liquids) produced by F-T (Fischer-Tropsch) synthesizing natural gas that have been decomposed to carbon monoxide or hydrogen.

[0070] The fuel of the present invention may contain known fuel additives if necessary. Examples of such fuel additives include friction modifiers such as amide compounds of carboxylic acids and alcohol amines; detergent-dispersants such as succinimide, polyalkyl amine, and polyether amine; antioxidants such as
N,N'-diisopropyl-p-phenylene diamine,
N,N'-diisobutyl-p-phenylene diamine,
2,6-di-t-butyl-4-methyl phenol and hindered phenols; metal deactivators such as amine carbonyl condensation compounds, for example,
N,N'-disalicylidene-1,2-diamino propane; surface ignition inhibitors such as organic phosphorus compounds; anti-icing agents such as polyhydric alcohols and ethers thereof; combustion improvers such as alkali or alkaline metal salts of organic acids and sulfuric esters of higher alcohols; anti-static additives such as anionic, cationic, and amphoteric surface active agents; coloring agents such as azo dye; rust inhibitors such as organic carboxylic acids, their derivatives and alkenyl succinic acid esters; water draining agents such as sorbitan esters; cetane number improvers such as nitrate esters and organic peroxides; lubricity improvers such as carboxylic acid-, ester-, alcohol- and phenol-based lubricity improvers; silicone-based defoaming agents; cold flow improvers such as ethylene vinyl acetate copolymers and alkenylsuccinic imides; markers such as quinizarin and coumarin; and odorants. These additives may be added alone or in combination and are desirously added so that the total amount of these additives is 0.5 percent by mass or less, more preferably 0.2 percent by mass on the basis of the total amount of the fuel. The total amount of the additives denotes the amount in terms of their effective components.

EXAMPLES

[0071] Hereinafter, the present invention will be described in more detail by way of the following examples and comparative examples, which should not be construed as limiting the scope of the invention.

[0072] Fuels of the present invention (Examples 1 and 2) and those for comparison (Comparative Examples 1 and 2) were produced in accordance with the formulations set forth in Table 1 below in a conventional manner. Table 1 also shows the ratio of hydrocarbons and characteristics of each of the resulting fuel.

TABLE 1

		Fuels used in Comparative Examples								
Items		PRF75	PRF80	PRF85	PRF90	NDB75	NDB80	NDB85	NDB90	NMP75
Density 15C	g/cm3	0.6936	0.694	0.6942	0.6945	0.7043	0.7057	0.7071	0.7085	0.6746
RON		75.0	80.0	85.0	90.0	75.0	80.0	85.0	89.3	75.3
C %	wt %	84.06	84.07	84.08	84.09	84.77	84.84	84.92	84.99	85.09
H %	wt %	15.94	15.93	15.92	15.91	15.23	15.16	15.08	15.01	14.91
H/C		2.275	2.273	2.271	2.270	2.156	2.144	2.132	2.119	2.102
Stoic A/F		15.13	15.13	15.12	15.12	14.97	14.95	14.93	14.92	14.89
Heating value	kJ/kg	44399	44388	44378	44367	44312	44291	44270	44249	44290
n-Heptane	vol %	25.00	20.00	15.00	10.00	50.89	46.62	42.35	38.08	30.27
iso-Octane	vol %	75.00	80.00	85.00	90.00					
Diiso-butylene	vol %					49.11	53.38	57.65	61.92	
4Methyl-1-pentene	vol %									69.73
Toluene	vol %									
Cyclo-pentane	vol %									
n-Heptane	mass %	24.78	19.81	14.85	9.90	49.77	45.52	41.26	37.02	30.88
iso-Octane	mass %	75.22	80.19	85.15	90.10					
Diiso-butylene	mass %					50.23	54.48	58.74	62.98	
4Methyl-1-pentene	mass %									69.12
Toluene	mass %									
Cyclo-pentane	mass %									

		Fuels used in Comparative Examples				Fuels used in Examples			
Items		NMP80	NMP85	NCP75	NCP80	NTL70	NTL75	NTL80	NTL85
Density 15C	g/cm3	0.6735	0.6725	0.721	0.724	0.792	0.799	0.807	0.815
RON		80.0	85.0	74.5	79.8	70.0	74.5	80.0	84.8
C %	wt %	85.19	85.28	84.88	84.95	88.38	88.69	89.00	89.31

TABLE 1-continued

H %	wt %	14.81	14.72	15.12	15.05	11.62	11.31	11.00	10.69
H/C		2.087	2.071	2.138	2.126	1.578	1.530	1.483	1.437
Stoic A/F		14.87	14.85	14.94	14.93	14.14	14.07	14.00	13.93
Heating value	kJ/kg	44270	44249	44122	44090	42101	41928	41759	41592
n-Heptane	vol %	24.98	19.69	45.57	41.39	44.82	40.31	35.80	31.29
iso-Octane	vol %								
Diisobutylene	vol %								
4Methyl-1-pentene	vol %	75.02	80.31						
Toluene	vol %					55.18	59.69	64.20	68.71
Cyclopentane	vol %			54.43	58.61				
n-Heptane	mass %	25.51	20.13	43.46	39.33	39.05	34.76	30.55	26.43
iso-Octane	mass %								
Diisobutylene	mass %								
4Methyl-1-pentene	mass %	74.49	79.87						
Toluene	mass %					60.95	65.24	69.45	73.57
Cyclopentane	mass %			56.54	60.67				

[0073] (Engine Specifications)

[0074] Type of Engine: in-line 4 cylinder HCCI engine with a compression ratio of 15. The engine specifications are described in the document "SAE2006-01-0207" (published in April, 2006)

Example 1

[0075] (Engine Operation Conditions)

[0076] The engine was operated at an engine speed of 1000 rpm, an absolute boost pressure of 155 kPa and an intake manifold temperature of 58° C. The experiment described below was carried out for each fuel under the same engine conditions such as compression ratio, engine speed, boost pressure, intake manifold temperature, air flow rate, intake-exhaust valve timing and EGR rate except that the fuel injection quantity was varied.

[0077] (Fuels)

[0078] FIG. **2** shows the chart of 400 cycle averaged crank angle of 50% burn of high temperature heat release (HTHR CA50) and indicated mean effective pressure (IMEP) obtained by driving the engine using various fuels. Where fuels with the substantially same IMEP and HTHR gathered were selected as Points 1, 2 and 3, and the change in maximum pressure rise rate over 400 cycles in each of the points were measured (the detail of this experiment should be referred to "SAE2008-01-0007" published in April, 2008).

[0079] FIG. **3** shows the changes in maximum pressure rise rate over 400 cycles at Point 1, FIG. **4** shows the changes in maximum pressure rise rate over 400 cycles at Point 2, and FIG. **5** shows the changes in maximum pressure rise rate over 400 cycles at Point 3. The details are set forth in Tables 2, 3 and 4.

[0080] It is confirmed that NTL series fuels (NTL70, NTL75) corresponding to the fuel of the present invention are reduced in maximum pressure rise rate by 20 percent or greater, comparing with PRF series fuels (PRF90, PRF85) when they were used under the same operation conditions (same IMEP, same HTHR CA50). Further, when the fuels other than Comparative Example 1 (NDB fuel, NMP fuel) are compared with the NTL series fuels of Example 1, none of the other fuels can reduce the maximum pressure rise rate as much as the fuels of Example 1. In the present invention, the rapid combustion of the fuel is avoided by utilizing the difference in temperatures at which a component containing mainly a paraffinic fuel and a component containing mainly an aromatic fuel ignite, thereby achieving HCCI operation wherein the maximum pressure rise rate is suppressed.

TABLE 2

	Fuel	Maximum Pressure Rise rate kPa/deg	Indicated Mean Effective Pressure kPa	HTHR CA50 CA deg ATDC
Comparative Example 1-1	PRF90	799.7	504.5	1.34
Comparative Example 1-2	NDB90	902.7	498	1.3
Comparative Example 1-3	NMP85	903.1	501.6	1.6
Example 1-1	NTL75	599.9	500.4	1.63

Reduction rate in maximum pressure rise rate of NTL75 (against PRF90): 24.9%

	Fuel	Maximum Pressure Rise rate kPa/deg	Indicated Mean Effective Pressure kPa	HTHR CA50 CA deg ATDC
Comparative Example 1-4	PRF85	399.6	299.9	2.05
Comparative Example 1-5	NDB85	399.8	280.7	2.38
Comparative Example 1-6	NMP80	399.4	284.7	2.3
Example 1-2	NTL70	302.6	313	2.74

Reduction rate in maximum pressure rise rate of NTL70 (against PRF85): 24.3%

TABLE 4

	Fuel	Maximum Pressure Rise rate kPa/deg	Indicated Mean Effective Pressure kPa	HTHR CA50 CA deg ATDC
Comparative Example 1-7	PRF85	900.8	485.9	−1.15
Example 1-3	NTL70	699.8	494.9	−0.91

Reduction rate in maximum pressure rise rate of NTL70 (against PRF85): 22.3%

Example 2

[0081] (Fuel)

[0082] The following fuels with the same research octane number were prepared (when the difference in the research octane number between PRF series fuels and NTL series fuels measured on a CFR (Cooperative Fuel Research) engine in accordance with JIS K 2280 is within 3, it was regarded as inaccuracy).

[0083] (1) Fuels with a research octane number of 75

Comparative Examples

PRF75, NDB75, NMP75, NCP75
Example NTL75

[0084] (2) Fuels with a research octane number of 80

Comparative Examples

PRF80, NDB80, NMP80, NCP80
Example NTL80

[0085] (3) Fuels with a research octane number of 85

Comparative Examples

PRF85, NDB85, NMP85,
Example NTL85

[0086] (Engine Operation Conditions)

[0087] The engine was operated at an engine speed of 1000 rpm, an absolute boost pressure of 155 kPa and an intake manifold temperature of 58° C. An experiment was carried out for each fuel under the same engine conditions such as compression ratio, engine speed, boost pressure intake pipe temperature, air flow rate, intake-exhaust valve timing and EGR rate to obtain experimental data of each fuel, at the same averaged maximum pressure rise rate over 400 cycles.

[0088] For fuels with a research octane number of 75, the experimental data were obtained by measurement at a maximum pressure rise rate of 800 kPa/deg (measurement condition A).

[0089] For fuels with a research octane number of 80, the experimental data were obtained by measurement at a maximum pressure rise rate of 600 kPa/deg (measurement condition B).

[0090] For fuels with a research octane number of 85, the experimental data were obtained by measurement at a maximum pressure rise rate of 400 kPa/deg (measurement condition C).

RESULTS

[0091] The average in-cylinder pressure and heat release rate over 400 cycles of each fuel measured under the conditions A, B and C are shown in FIGS. **6** to **11** and set forth in Tables 5 to 7.

TABLE 5

	Fuel	Maximum Pressure Rise rate kPa/deg	Indicated Mean Effective Pressure kPa
Comparative Example 2-1	PRF75	800.7	417.2
Comparative Example 2-2	NDB75	800.4	402.5
Comparative Example 2-3	NMP75	800.1	410.6
Example 2-1	NTL75	800.0	535.0
Comparative Example 2-4	NCP75	801.5	379.6

Reduction rate in indicated mean effective pressure of NTL75 (against PRF75): 28.2%

TABLE 6

	Fuel	Maximum Pressure Rise rate kPa/deg	Indicated Mean Effective Pressure kPa
Comparative Example 2-5	PRF80	600.6	356.7
Comparative Example 2-6	NDB80	599.3	335.0
Comparative Example 2-7	NMP80	600.3	361.3

TABLE 6-continued

	Fuel	Maximum Pressure Rise rate kPa/deg	Indicated Mean Effective Pressure kPa
Example 2-2	NTL80	601.1	576.6
Comparative Example 2-8	NCP80	599.7	372.6

Reduction rate in indicated mean effective pressure of NTL80 (against PRF80): 61.6%

TABLE 7

	Fuel	Maximum Pressure Rise rate kPa/deg	Indicated Mean Effective Pressure kPa
Comparative Example 2-9	PRF85	399.8	299.9
Comparative Example 2-10	NDB85	399.6	280.7
Comparative Example 2-11	NMP85	401.1	339.4
Example 2-3	NTL85	401.0	640.4

Reduction rate in indicated mean effective pressure of NTL85 (against PRF85): 113.5%

[0092] All of FIGS. **6** to **11** show that NTL series fuels (NTL75, NTL80, NTL85) according to the present invention exhibited an increase by 28 to 113 percent in indicated mean effective pressure, compared with comparative fuels (PRF series fuels, NDB series fuels, NMP series fuels, NCP series fuels) under the same maximum pressure rise rate condition. As shown in FIGS. **7**, **9** and **11**, this is because the fuel of the present invention prolongs combustion period by utilizing difference in ignition temperature between a component containing mainly a paraffinic fuel and a component containing mainly an aromatic fuel so as to avoid the rapid combustion of the fuel and thus the more fuel can be combusted under the same maximum pressure rise rate, thereby increasing the heat release rate.

We claim:

1. A fuel for a homogeneous charge compression auto-ignition combustion engine satisfying all of the following characteristic requirements (1) to (6) and the following requirement (7) or (8):

(1) the total content of C5 to C10 normal paraffins is 25 percent by volume or more, and 70 percent by volume or less;

(2) the total content of C6 to C11 aromatic hydrocarbons is 30 percent by volume or more, and 75 percent by volume or less;

(3) the content of olefinic hydrocarbons is 20 percent by volume or less;

(4) the content of oxygenates is 5 percent by mass or less in terms of oxygen;

(5) the research octane number is 70 or greater, and less than 92;

(6) the initial boiling point and end point in distillation characteristics are 30° C. or higher and 220° C. or lower, respectively;

(7) the averaged maximum pressure rise rate of the fuel over continuous 400 cycles is smaller by 15 percent or more, comparing with that of a primary reference fuel (PRF) which exhibits the same indicated mean effective pressure (IMEP) and crank angle of 50% burn of high temperature heat release combustion (HTHR CA50) as the fuel under the same engine operating conditions such as compression ratio of the engine, engine speed, boost pressure, temperature in the intake manifold, air flow rate, intake-exhaust valve timing, EGR rate and fuel injection initiation timing; and

(8) the averaged IMEP of the fuel over continuous 400 cycles is increased by 20 percent or more, comparing with that of a primary reference fuel (PRF) with the same research octane number as the fuel, the IMEPs of the fuel and PRF being measured at the same maximum pressure rise rate under the same engine operating conditions such as compression ratio of the engine, engine speed, boost pressure, temperature in the intake manifold, air flow rate, intake-exhaust valve timing, EGR rate and fuel injection initiation timing.

2. The fuel for a homogeneous charge compression auto-ignition combustion engine according to claim **1**, wherein the sulfur content of the fuel is 10 ppm by mass or less.

3. The fuel for a homogeneous charge compression auto-ignition combustion engine according to claim **1**, comprising oxygenates selected from the group consisting of methanol, ethanol, normalpropyl alcohol, isopropyl alcohol, normalbutyl alcohol, isobutyl alcohol, dimethyl ether, diisopropyl ether, methyl-tert-butyl ether (MTBE), ethyl-tert-butyl ether (ETBE), tert-amyl methyl ether (TAME), tert-amyl ethyl ether, fatty acid methyl ester, and fatty acid ethyl ester.

4. The fuel for a homogeneous charge compression auto-ignition combustion engine according to claim **1**, wherein the fuel is also applicable to the following types of engines selected from the group consisting of HCCI-SI gasoline engines (SI: spark ignition), HCCI-CI diesel engines (CI: compression ignition), and electric motored hybrid engines with HCCI, HCCI-SI and HCCI-DI engines.

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