

A Study of Controlled Auto-Ignition in Small Natural Gas Engines

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ABSTRACT

Research has been conducted on Controlled Auto-Ignition (CAI) engine with natural gas. CAI engine has the potential to be highly efficient and to produce low emissions. CAI engine is potentially applicable to automobile engine. However due to narrow operating range, CAI engine for automobile engine which require various speed and load in real world operation is still remaining at research level. In comparison some natural gas engines for electricity generation only require continuous operation at constant load. There is possibility of efficiency enhancement by CAI combustion which is running same speed at constant load.

Since natural gas is primary consisting of methane (CH₄), high auto-ignition temperature is required to occur stable auto-ignition. Usually additional intake heat required to keep stable auto-ignition. To keep high compression temperature, single cylinder natural gas engine with high compression ratio (CR=26) was constructed.

Since high compression ratio (CR=26), CAI engine with natural gas would improve thermal efficiency due to higher theoretical thermal efficiency. However, indicated thermal efficiency of CAI engine does not improved as expected due to increasing heat loss from cylinder wall. To increase indicated thermal efficiency, combustion chamber shape modification is also required.

To analyze combustion chamber shape effect, comparison between standard engine with same stroke and bore (S/B=1.0) and modified engine with same displacement, longer stroke and smaller bore (S/B=2.1) was conducted. Brake thermal efficiency of longer stroke engine (S/B=2.1) was 39.1% while keeping low NO_x level, which was an increase of 9.2 points over the 29.9% for the conventional engine (S/B=1.0). Heat release analysis shows major factor of enhanced efficiency is reduced heat loss from cylinder wall and exhausted unburned fuel.

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INTRODUCTION

The global demand for energy is increasing as the economy of a lot of emerging nations are remarkably growing. According to the World Energy Outlook (2012), the International Energy Agency (IEA) estimates the global energy demand to increase by over 1/3 from 2010 to 2035. However, crude oil resources from currently-producing fields have already begun to decline. Internal combustion engines, which take the central role as a source of mechanical and electrical power, depend primarily on crude oil to operate. For further progress in terms of their efficiency, it is strongly desired for these engines to tap into the usage of alternative fuels.

In recent years, natural gas has attracted attention as an inexpensive alternative fuel to solve the problem of the issue

of energy demand. The price of natural gas has been decreased significantly due to factors such as increased production of shale gas. Additionally, natural gas produces fewer emissions per heat generating unit and the fuel itself has a smaller impact on the air as its main component is methane.

The power generation efficiency of various forms of existing natural gas engines was shown in Fig.1. This graph indicates that power generation efficiency rises with increasing output power. The efficiency of large stationary generators rise by up to 60%, by contrast maximum efficiency of small engine downs to 26%[1][2][3]. In general, one of the main reasons for factors that worsen efficiency of the small internal combustion engines is increasing the heat loss. Therefore, for increasing efficiency of smaller engines, to decrease the heat loss is absolutely essential.

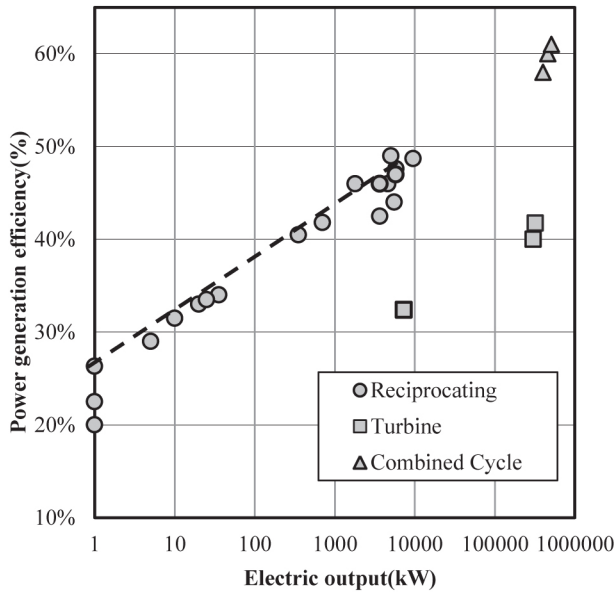


Fig.1. Power generation efficiency

To achieve higher efficiency, Controlled Auto-Ignition (CAI) combustion has been researched as a measure to increase the efficiency of engines. CAI combustion is also known as Low Temperature Combustion (LTC). Decreasing the heat loss from the cylinder wall is expected.

CAI research began with research by Ohnishi et al. [4] on two-stroke engines with Active Thermo-Atmosphere Combustion (ATAC). Generator and combined generator-blower equipped with this ATAC engine showed better fuel consumption than similar generators equipped with conventional two- or four-stroke engines. This has been followed by many researches for more than decades, but due to issues such as difficulty of control, this has only been produced for some products [5] and has not yet been practically applied on a wide scale. And also for general purpose machinery no actual products exist as yet.

CAI combustion makes it possible to avoid knocking, an issue in Spark Ignition (SI) combustion, and achieve a high compression ratio which means high expansion ratio. This is expected to increase efficiency. In Fig.2 [6], the minimum auto-ignition temperatures of hydrocarbon with various types were shown at standard temperature and pressure. As methane does not contain double bonds, it has a higher auto-ignition temperature than other hydrocarbons such as octane. Therefore, as methane is the main component of natural gas, an auto-ignition engine fueled by natural gas is expected to allow a higher compression ratio and a higher theoretical thermal efficiency than any other hydrocarbon-fueled engine. (Fig.3)

Several studies on auto-ignition combustion using natural gas have been conducted on the experimental stage [7][8][9][10][11][12], and practical application projects are underway [13][14]. However, only studies on auto-ignition combustion with small engine were studied with a displacement of 800cm³ or higher.

Therefore the purpose of this study is to achieve higher efficiency for small reciprocating engine fueled by natural gas. And in order to minimize heat loss, Controlled Auto-Ignition (CAI) is applied as the combustion system.

TEST METHODS

Prototype Engine Specificaion

Table 1 shows the specifications of the engine used in this experiment. The engine was an OHV water cooled single cylinder engine that is usually used in small cogeneration systems. The displacement was 247cm³, suitable for the output anticipated in household use. The stroke/bore ratio was 1.0, the same as in the engine of a standard vehicle. The combustion chamber had a flat top like that in a diesel engine to achieve a high compression ratio, and the compression ratio could be adjusted from 12, the ratio of an SI engine, to between 26 and 35, where compression auto-ignition was possible, by changing the shape of the piston crown. A spark plug was not attached, to maintain the ideal shape of the combustion chamber.

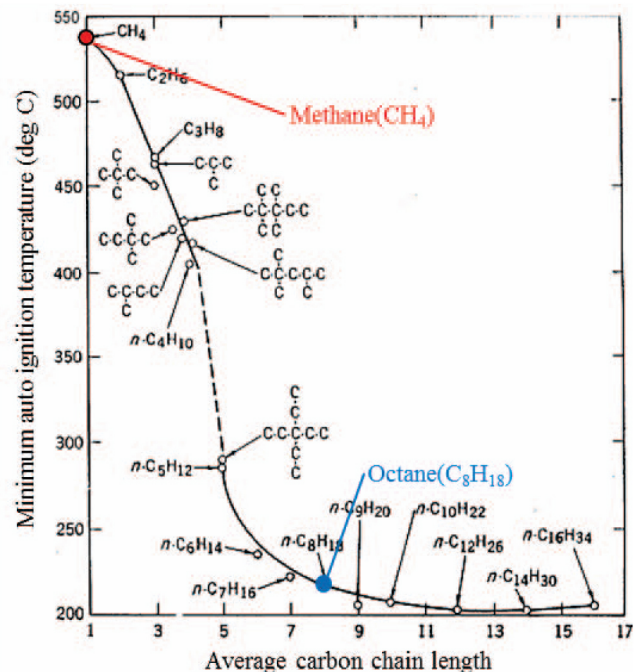


Fig.2. Auto-ignition temperature of CnHm

Fuel	Compression ratio range			
Gasoline	8.5	SI	14	
Diesel			16	Diesel 23
Natural Gas	11	SI	13	26 CAI? 35

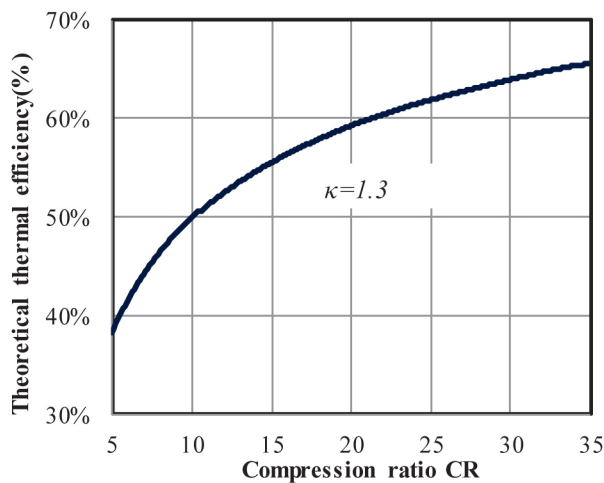


Fig.3. Ideal Otto Cycle thermal efficiency

Fig. 4 is a photograph of the exterior of the engine. The crankcase was designed with sufficient strength to withstand the high cylinder pressure anticipated during auto-ignition combustion. A built-in oil pump was operated by gears attached to the crank gears to lubricate both ends of the crank pins and crank journals.

Auxiliary machinery besides the oil pump was attached as shown in the test system configuration diagram in Fig. 5. Intake air was heated by an electric heater and adjusted to the target temperature. After the temperature of the air was adjusted, the fuel was mixed with the air using a gas mixer before entering the engine. To ensure that only the improvement in thermal efficiency caused by CAI combustion would be evaluated, evaluations of the brake thermal efficiency considered only the output measured by an engine dynamometer and did not take into account factors such as the power consumed to heat the intake air or the power of the cooling water circulation pump.

Test Conditions

The test was conducted at an engine speed of 1700rpm. As an indicator of engine noise caused by fast burn, 1MPa/deg was set as the maximum pressure rise rate ($dP/d\theta$) for each crank angle under cylinder pressure. As an indicator of combustion stability, 5% was set as the maximum coefficient of variance (COV) of the gross indicated mean effective pressure. It was judged that the engine could be run continuously if these conditions were met. To compare combustion efficiency for the purposes of this report, Wide Open Throttle condition (WOT) was used, as this is the throttle position at which thermal efficiency is at its maximum.

All measurements were taken in continuous running conditions in which temperatures such as the cooling water temperature, oil temperature and cylinder head temperature were stable. Combustion pressure was recorded by the Kistler 6041A pressure sensor, Kistler 5051B charge amplifier and Ono Sokki DS-2000 combustion analyzer. The mean values from 300 cycles were evaluated.

TEST RESULTS

Compression Ratio Required For Auto-Ignition Of Natural Gas

To ascertain the compression ratio required for auto-ignition combustion of natural gas, intake air was heated in an engine with different compression ratios and the intake air temperature required for auto-ignition combustion was measured. Fig. 6 shows the results. The minimum intake air temperature required by this engine at a compression ratio of 26 was 120 degrees Celsius.

Table 1. Engine Specifications

Engine type		4-stroke OHV water cooled single cylinder
Bore	(mm)	68
Stroke	(mm)	68
Displacement	(cm ³)	247
Stroke Bore ratio		1
Conrod Length	(mm)	117
Conrod Stroke ratio		3.4
Compression Ratio		12~35 (12,26,30,35)
Fuel		Natural gas(City gas 13A)



Fig.4. External view of test engine