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Development of a Pre-chamber Spark Plug for GHP

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1. ABSTRACT

The gas engine-driven heat pump air-conditioner (GHP) has compressors powered by a gas engine. This is a gas air-conditioning system that heats and cools by means of heat-pump operation. This article reports on the development of the pre-chamber spark plug for GHP, which helps improve gas engine efficiency and is at the center of the elemental technologies used to boost GHP efficiency.

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2. Body of Paper

2.1. What is GHP

The gas engine-driven heat pump air-conditioner (GHP) has compressors powered by a gas engine. This is a gas air-conditioning system that heats and cools by means of heat-pump operation. (Figure 1) The GHP, in contrast to an electric type of heat pump air conditioner (EHP) that drives the compressor by means of an electric motor, drives the compressor by means of a gas engine. Thus it follows that the GHP has the advantage of using very little electrical power as compared to EHP.

Since the GHP were introduced for sale in 1987, they have been widely spread mainly in Japan because of its advantages such as savings in electrical power consumption as well as low operational cost. This article reports on the development of the pre-chamber spark plug for GHP, which helps improve gas engine efficiency and is at the center of the elemental technologies used to boost GHP efficiency. (Figure 2)

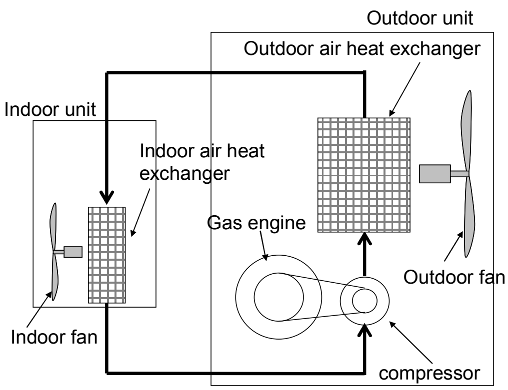


Figure 1: GHP system

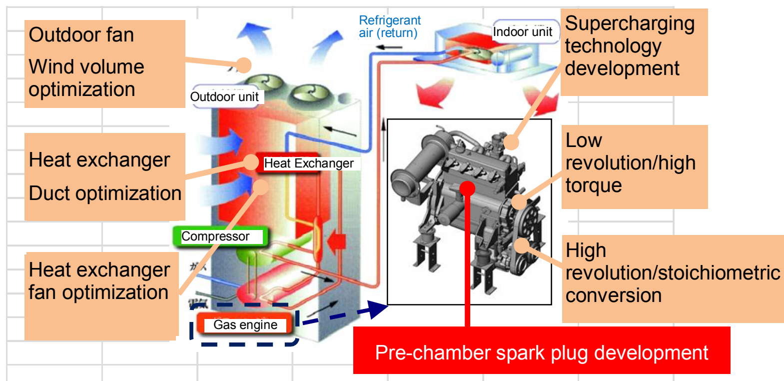
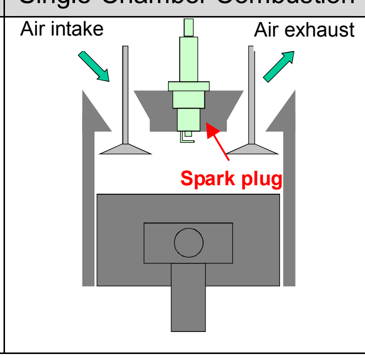
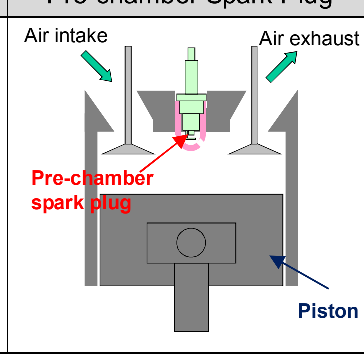
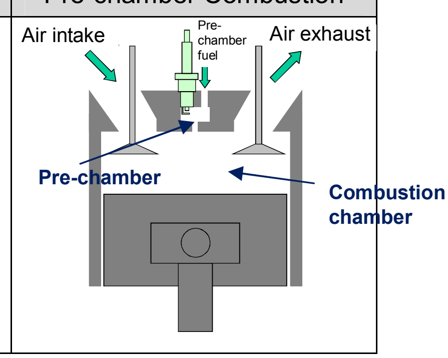


Figure 2: GHP Efficiency Enhancing Technology

2.2. What is a pre-chamber spark plug

A pre-chamber spark plug is a spark plug with a cap that has a rounded tip and makes it possible to easily convert single-chamber combustion engines into pre-chamber combustion. (Diagram 1, Figure 3). When compared to other engine efficiency enhancing methods, we can expect that efficiency can be improved without having to make major alterations to the engine. Development of this plug is progressing for automobiles and for medium to large sized cogeneration models but there are no examples of GHP application so we aim to apply this to GHP as one proposal for efficiency enhancing technology.

Diagram 1: Comparison of Combustion Types

Name	Single-Chamber Combustion	Pre-chamber Spark Plug	Pre-chamber Combustion
Simplified View			

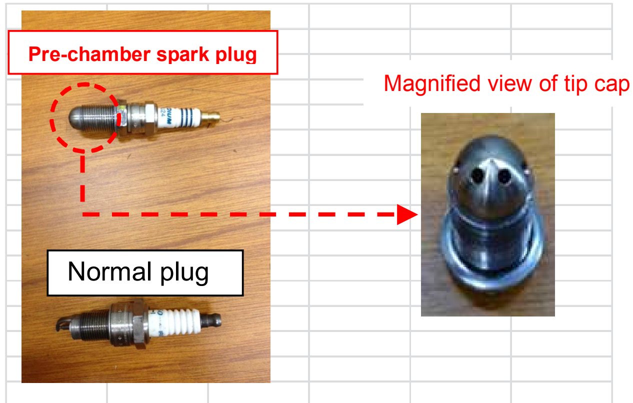


Figure 3: Exterior view of pre-chamber plug

2.3. Summary of Evaluation Tests

The first step we took in application of a pre-chamber plug to GHP was to confirm how the application of the pre-chamber spark plug on a GHP gas engine affected efficiency and combustion. Also, with the purpose of investigating the cap shape of the pre-chamber plug, we carried out comparative tests on combustion status including engine efficiency, NOx density contained in exhaust gases and other tests, based on the experimental parameters detailed below.

In addition, for the evaluation tests, we used GHP (air conditioning capacity 15-20kW grade) fitted with a 2,000cc exhaust engine, measured engine output with engine load ratio set to three values of 100%, 30%, and 15%, while all evaluation parameters for air ratio were standardized.

For evaluation subjects, we trialed six types of plugs (Test plugs A – F) with parameters of two to eight holes in rounded cap tip and cap diameter from 1.0 mm – 2.0 mm. Additionally, we carried out experiments on how pre-chamber volume between 0.60cc and 0.99cc was affected by inserting four kinds of spacers between the plug and cap.

2.4. Evaluation Test Results

Figure 4 shows comparison results for test plugs A – F where pre-chamber data showing greatest effect on efficiency improvement based on 100% engine load is represented for each plug. We confirmed that effect on efficiency improvement of test plugs B and C was greater than normal plugs.

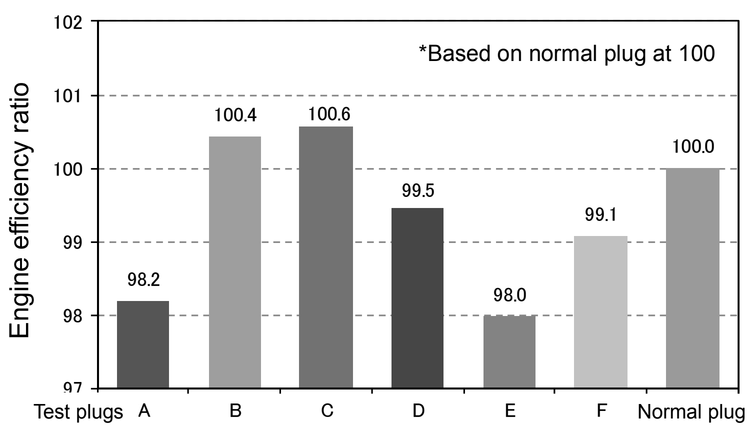


Figure 4: Test plug engine efficiency comparison (Engine load 100%)

Next, regarding normal plugs and test plug C which had the greatest effect on efficiency improvement, we performed efficiency comparisons on each based on engine load ratios. (Figure 5) Engine efficiency was the same as normal plugs when engine load was 100% but with partial load parameters, we confirmed effect on efficiency improvement is approximately from 2% to 7%. As shown in Figures 6 and 7, combustion duration is shortened and we suppose that a major factor is minimization of heat radiation loss due to rapid generation of combustion heat.

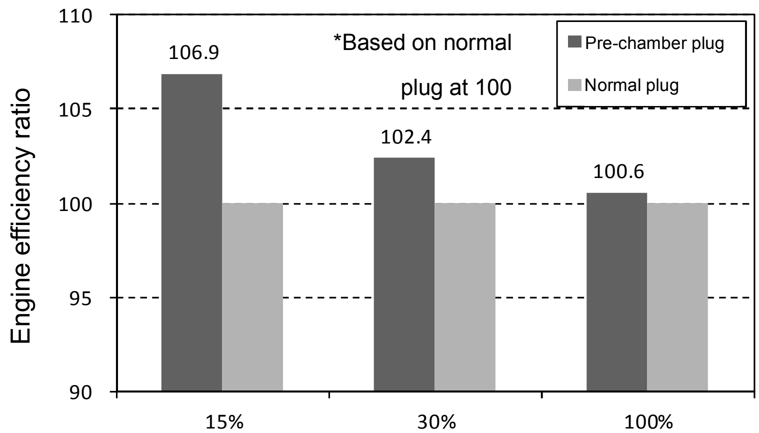


Figure 5: Efficiency comparison by engine load ratio

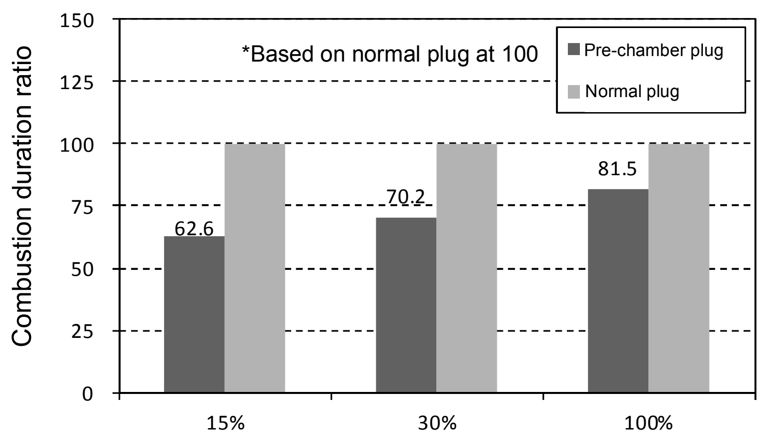


Figure 6: Combustion duration by engine load ratio (θ10-90)

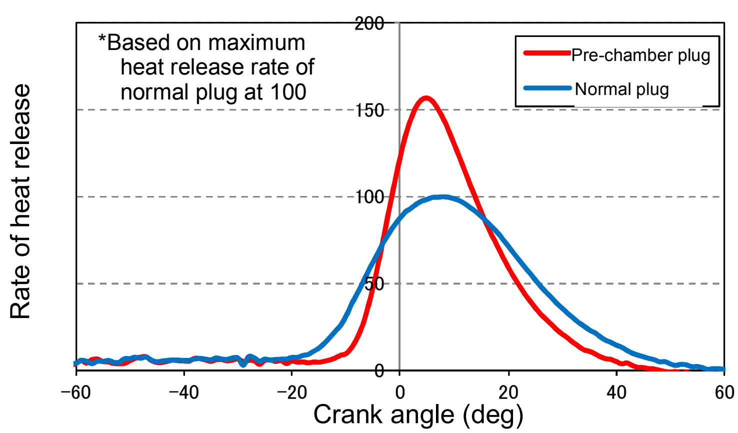


Figure 7: Heat release rate inside engine combustion chamber

Also, regarding the NOx density contained in combustion exhaust gases, we were able to confirm a NOx reduction effect for 100% and 30% engine load (Figure 8). We surmise that the internal EGR effect from remaining exhaust gases inside the pre-chamber spark plug contributed to this.

Figure 9 shows comparison results of rate of change of indicated mean effective pressure (COV) for each engine load ratio. COV was almost equivalent for each engine load. However, pre-chamber spark plugs were found to produce cases of engine misfire with engine load ratio at 15%. We consider the reason for this was combustion exhaust gases trapped inside the pre-chamber plug cap.

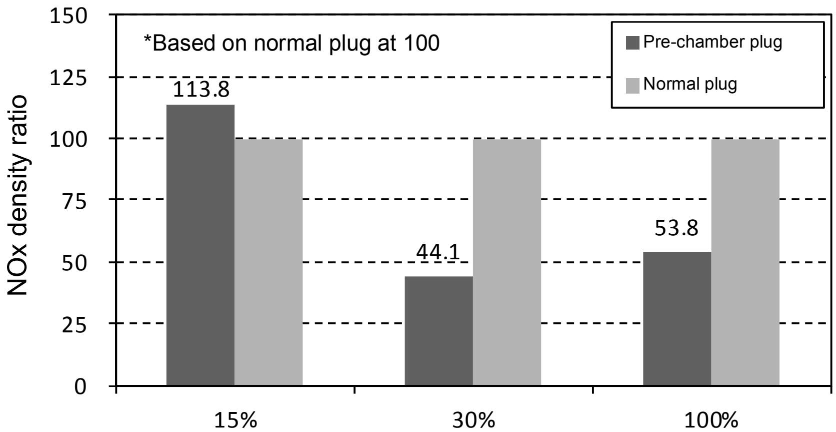


Figure 8: Density of NOx in exhaust gas (O2=0% conversion rate)

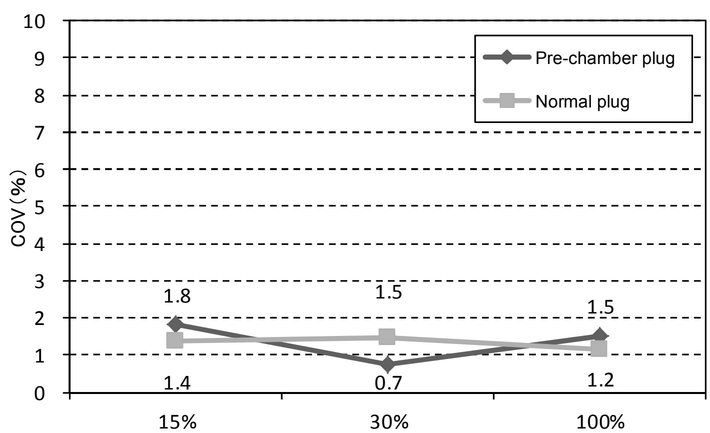


Figure 9: Rate of change of indicated mean effective pressure

2.5. Conclusions and Next Steps

We were able to confirm through this development that using pre-chamber spark plugs is effective in improving efficiency of gas engines for GHP. On the other hand, due to our concern that combustion becomes unstable with pre-chamber spark plugs compared to normal plugs, a strategy is required to enhance combustion stability. Since we were able to obtain positive results from the evaluations detailed above, we will implement performance and durability benchmarks in pursuit of commercialization and continue development for inclusion in GHP.