A STUDY ON PRESSURIZED CERAMIC BURNER FOR CARBON DIOXIDE GAS DYNAMIC LASER DRIVEN BY COMBUSTION OF GASEOUS FUELS

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ABSTRACT

A gas dynamic laser (GDL) is a promising technology that can generate high laser power driven directly by combustion energy. When a gas containing carbon dioxide at high temperature and high pressure is expanded adiabatically through a supersonic nozzle, the population inversion between the two vibrational energy levels, (001) and (100) of carbon dioxide molecules can be achieved. Then it leads to emit a laser power of wavelength 10.6 micrometer. In the present study, a tri-generation system applying GDL is proposed. Figure 1 shows schematic diagram of the tri-generation system. The tri-generation system is a system combined by photo energy conversion and conventional co-generation, i.e. electric power generation and heat energy utilization from fuels.

As the first step for R&D of this system, the fundamental study on the GDL working in pressurized combustion of a methane-air mixture was carried out. The combustor consists of triple annular tubes, whose inner annular zone is pressurized by nitrogen so to balance to the pressure in the combustion zone and is cooled down by water flowing in the outer annular zone. Combustion takes place above a ceramic honeycomb placed in the inner tube of 100.1 mm in diameter. Compressed air and methane are supplied independently from the bottom of a bed of (glass beads (2, 5, 8 mm)). A supersonic layer nozzle designed at Mach 4.7 was assembled in the downward of the combustor. A condition necessary for the ignition and a stable flammability region were examined in the combustor by temperatures and the combustion gas composition. The supersonic flow through the nozzle was confirmed from the pressure distribution.

KEYWORDS
gas-dynamic laser (GDL), tri-generation, and carbon dioxide, combustion

INTRODUCTION

Most energy used in the world today is not maintainable. The fossil fuel on which we depend greatly as energy source is limited and irreproducible, and it is required for us to use energy efficient with alternative energy development. In order to use energy efficient, to make energy conversion more efficient is one of the important element subjects, and finishing this leads also to reducing energy demand sharply. The present conversion technology from heat to optical energy is applied only as promotion of radiative heat transfer or lighting, and isn’t developed as new energy technology. Then, if high laser oscillation as optical energy is realized by heat drive and efficiency improvement of the energy and output improvement are attained, the steel plate can be cut with hot in the iron-manufacture process. Therefore not only can heat recovery of the steel plate be carried out efficiently, but the application to precision
processing can be expected also. GDL is considered as such a laser oscillation principle. In GDL, which is of interest both from theoretical and experimental points of view, population inversion is achieved via rapid expansion of the laser gas. In the first step the premixed gas is heated to a high temperature by combustion, leading to a considerable population of the upper and lower levels. The gas expands through a super sonic nozzle, the temperature of gases drop very rapidly. The lower energy levels are rapidly and selectively depopulated while the upper energy levels remain energized. In this way, population inversion would be achieved. One of the most interesting properties of GDL is the ability to produce high power output continuous radiation. Additionally, since the hot gas exhausted after a laser oscillation in GDL is available as resource for electric power generation and heat energy utilization, a tri-generation system applying GDL is proposed in the present study. Figure 1 shows schematic diagram of the tri-generation system. The tri-generation system is a system combined by photo energy conversion and conventional co-generation, i.e. electric power generation and heat energy utilization from fuels. In the previous research of the GDL, the development as a special use was carried out. And the relaxation phenomenon and the gain in the three components of carbon dioxide, nitrogen and steam were measured and estimated. However, there is no research which tried the gas dynamic laser oscillation with the high fuel of the H/C ratio like blast furnace gas or the natural gas. On the other hand, it is necessary to lengthen optical length in the cavity part in order to obtain the high output of laser about high-pressure combustion equipment. Ceramic burner is unique in that forming spread and stable flame, and having large flammability range and easy structure¹⁻⁴).

In this study, the development of the GDL equipment used methane as fuel for the realization of tri-generation was investigated. It is important to develop the system of combustion, supersonic, and optics laser for the development of the GDL equipment. Therefore, as the first step, the fundamental characteristics of the combustor with ceramic burner using methane/air at atmosphere pressure were experimentally investigated. The operating condition (methane flow rate=15.5, 20.0, 30.5 l/min) was kept constant, temperature profile in combustor, gas composition, flammability range were measured, and were evaluated.

Figure 1. Schematic diagram of conversion from fuel to photo, heat, electric energy


EXPERIMENTAL APPARATUS AND PROCEDURE

Figure 2 shows the outline drawing of apparatus, and Figure 3 shows the outline drawing of combustor. The apparatus consists of the combustor, super sonic nozzle, vacuum vessel. The combustor consists of triple annular tubes, whose inner annular zone is pressurized by nitrogen so to balance to the pressure in the combustion zone and is cooled down by water flowing in the outer annular zone. In this study, top of the combustor was opened, so pressure of the combustor was atmosphere pressure. Combustion took place above alumina ball (2mm, 5mm, and 8mm) placed in the inner tube of 100.1 mm in diameter and 344 mm in height. After methane supplying combustor, air was gradually supplied by the air compressor. The conditions of methane flow rate are listed in Table 1.

<table>
<thead>
<tr>
<th>Case</th>
<th>Methane flow rate [l/min]</th>
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<tbody>
<tr>
<td>Case 1</td>
<td>15.5</td>
</tr>
<tr>
<td>Case 2</td>
<td>20.0</td>
</tr>
<tr>
<td>Case 3</td>
<td>30.5</td>
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Four components, CO, CO₂, NOₓ, and O₂ included in the produced gas by combustion were monitored continuously by the infrared gas analyzers. CH₄ was measured intermittently by the flame ionization detector. These components were sampled with at point of measurement in Figure 3.
EXPERIMENTAL RESULTS AND DISCUSSION

In this experiment, after methane flow rate was fixed, air flow rate was increased gradually and equivalence ratio was changed. The point of gas sampling is showed in Figure 3. Figure 4 shows the limits of flammability of the combustor. The line A is the limit of flammability of the combustor. And the line B is the boundary line between the zone of luminous flame and the zone of non-luminous flame. As the result, the equivalence ratio blown off in Case 1 was 0.48, and the equivalence ratio blown off in Case 2 was 0.57, the equivalence ratio blown off in Case 3 was 0.7. The more methane flow rate increased, the bigger the equivalence ratios blown off became. And the line B was almost 0.7. The smaller the equivalence ratio became, the wider the zone of non-luminous flame became.
Figure 5 shows the relationship between equivalence ratio and NOx concentration. As the results, the more equivalence ratio closed in on 1, the higher the NOx concentration became. Since every point was located adjacent to each other, the approximated curve \( y = 0.01e^{10x} \) was written. As can be seen, the slope of the curve was large gradually bordering on 0.7.

Figure 6 shows the relationship between equivalence ratio and surface temperature. Where the surface is surface of alumina ball (2mm) in combustor. As can be seen, the more equivalence ratio closed in on 1, the higher the surface temperature became. The surface temperature in Case 3 was higher than other Cases. The highest temperature in the combustor was 1359K in three cases. Theoretically, if the condition of laser oscillation on GDL used methane as fuel was more than 1500K of combustion temperature, it is confirmed that laser oscillation was possible\(^5\). The combustion temperature in this combustor was lower than theoretical one. In this respect, it is necessary to improve the combustor so that it may be insulated more to make combustion temperature higher in the following research.
Figure 7 shows the relationship between equivalence ratio and CO₂ concentration. The more equivalence ratio closed in on 1, the higher the CO₂ concentration became. The slope between CO₂ concentration and equivalence ratio was almost changeless even if methane flow rate was changed.

![Figure 7](image)

Figure 8 shows the relationship between equivalence ratio and CO concentration. The more equivalence ratio in Case 1 closed in on 0.6, the lower the CO concentration became. The more equivalence ratio in Case 2 closed in on 0.7, the lower the CO concentration became. The more equivalence ratio in Case 3 closed in on 0.7, the lower the CO concentration became. The CO concentration was contained from 0.60 to 0.85 in Case 1, from 0.70 to 0.80 in Case 2, from 0.70 to 0.85 in Case 3. The complete combustion in this combustor was taken place from 0.70 to 0.85. Therefore, proper equivalence ratio in this combustor is from 0.70 to 0.85.

![Figure 8](image)
CONCLUSIONS

In this study, the development of the GDL equipment used methane as fuel for the realization of tri-generation was investigated. As the first step, the fundamental characteristics of the combustor with ceramic burner using methane/air at atmosphere pressure were experimentally investigated.

The operating condition (methane flow rate=15.5, 20.0, 30.5 l/min) was kept constant, temperature profile in combustor, gas composition, flammability range were measured, and were evaluated. The following conclusions are summarized as;

(1) The limit of flammability of the combustor was the line A in three cases.
(2) The highest temperature in the combustor was 1359K in three cases. The combustion temperature in this combustor is lower than theoretical one.
(3) The complete combustion in this combustor was taken place from 0.70 to 0.85.

From this study, this result applied that ceramic burner was suitable for stable flame toward the development of the combustor in GDL equipment. However, it is necessary to improve the combustor so that it may be insulated more to make combustion temperature higher in the following research.

REFERENCES