Residual gas concentration measurement inside a spark-ignition engine using infrared LASER absorption method

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1. Introduction

This paper describes the development and application of an optical fiber sensor using an infrared absorption technique to quantify the instantaneous CO₂ concentration inside a spark-ignition engine cylinder during the compression stroke. An in situ laser infrared absorption method was developed using a fiber sensor and a 4.301-μm quantum cascade laser (QCL) as the light source. This wavelength coincided with the absorption line of CO₂. The molar absorption coefficients of CO₂ were determined for various pressures and temperatures in advance using a constant volume vessel with electric heating system to obtain quantitative measurement results. The measurement accuracy was confirmed by measuring the concentration of a homogeneous mixture with CO₂ gas in the compression-expansion engine.

2. Molar Absorption Coefficient of CO₂

The pressure and temperature inside the combustion chamber change considerably during the engine cycle. The purpose of this study was to quantify the history of the CO₂ concentration inside the combustion chamber. Therefore, the molar absorption coefficient of the CO₂ must be determined in advance at different pressures and temperatures.

Figure 1 shows an example of the effects of the ambient pressure and temperature on the molar absorption coefficient of CO₂. The experimental temperatures were between 300 and 400 K, while the pressures with methane were between 0.1 and 2.0 MPa. The molar absorption coefficient increased as the ambient pressure increased from 0.1 to 1.0 MPa under certain temperature conditions.

![Fig. 1 Effects of pressure and temperature on molar absorption coefficient of CO₂](image1)

The molar absorption coefficient indicates the constant value over 1.0 MPa as ambient pressure. The molar absorption coefficient was not strongly affected by ambient temperature conditions.


We investigated the CO₂ concentration of mixture with CO₂ gas inside a compression-expansion engine to verify the feasibility of the developed optical fiber sensor system for quantitative measurements of CO₂ concentration inside an engine cylinder. Measured CO₂ molar concentration at the spark timing under firing conditions using the transmissivity inferred from the upper line and baseline of the raw IR signal and molar absorption coefficient of CO₂ was compared with preset CO₂ volume fraction of mixture, as shown in Fig. 9. The measured CO₂ molar concentration was in good agreement with the preset CO₂ concentration. The developed measurement technique proved to be helpful in obtaining in situ CO₂ concentrations during the compression stroke of a compression-expansion engine. Figure 2 confirms that the developed fiber sensor system can measure in situ CO₂ concentrations precisely during the compression stroke of a compression-expansion engine.

The newly developed CO₂ concentration measurement system using QCL and optical fiber sensor allowed us to measure the CO₂ concentration inside the combustion chamber of a spark-ignition engine. We could obtain detailed information regarding the effects of the residual gas in the mixture formation process inside engine cylinder and investigate key features of effects of internal EGR ratio on combustion characteristics and chemical reactions in a spark-ignition engine.

![Fig. 2 Measured CO₂ molar concentration](image2)