THERMAL ANALYSIS OF DIESEL PARTICULATE MATTER

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Introduction

Thermal barrier coatings (TBCs) may be applied to the combustion chamber surfaces in a heat engine to reduce heat transfer from the combustion gas as well as reduce component thermal loadings. Heat conservation also increases the thermal efficiency and offers greater exhaust temperatures for energy recovery using turbomachinery. The application of the low heat rejection (LHR) concept to diesel engines has been reviewed by Amman [1].

Thermal insulation produces significant changes in the nature of the combustion process in diesel engines and frequently results in degraded combustion. The effect of thermal insulation on exhaust emissions is unclear. Generally speaking, the higher combustion gas temperatures in LHR engines result in higher levels of nitrogen oxides and lower emissions of UHC and particulates. Thermal insulation also produces a significant change in the composition of diesel particulate. Diesel particulate matter is a complex mixture of organic and inorganic (e.g., sulfate) compounds in solid and liquid phases. The total particulate matter consists principally of carbonaceous material on which some (extractable) hydrocarbons have become adsorbed. The extractable fraction is primarily responsible for the biological activity of diesel particulate.

Thermoanalytical methods for determining the composition of particulate emissions have been developed. Very recently, an on-line thermoanalytical method for measuring the volatile fraction in diesel exhaust particulates has been described [2]. The Series 5100 Diesel Particulate Measurement System from R&P Co., Albany, NY, is based on this method. It is convenient and fast because it incorporates particulate collection and analysis procedures in a single unit. In this work, thermal analysis of diesel particulates from a pre-chamber type diesel engine was performed using a Series 5100 Diesel Particulate Measurement System. The objective was to study the effect of combustion chamber thermal insulation on the volatile fraction of the particulates.

Experimental

A Yanmar single-cylinder, prechamber-type diesel engine (0.866 liter displacement, 19.5 compression ratio) coupled to a Clayton waterbrake dynamometer was used in this work. The piston crown, cylinder head, and valves were given thin thermal barrier coatings by Turbine Components Corporation of Branford, CT. The parts were given a bond coat of NiCoCrAly, followed by a top coat of Metco pre-alloyed, yttria stabilized zirconia. The duty cycle for the engine was similar to that for test cycle type E3 defined in ISO 8178, Part 4.

For thermal analysis studies, a Series 5100 Diesel Particulate Measurement System from R&P Co. was attached to the exhaust stack by means of a heated sample tube. The instrument cycle has two phases which are controlled by an instrument computer. During the collection phase, the system draws a sample of particulate-laden gas from the exhaust and traps the particulates on a quartz filter. During the analysis phase, the collected sample is heated according to a user-defined temperature program. As the filter temperature increases, volatiles leave the filter, enter the gas stream, and travel to an afterburner set for 750°C. Oxidation of the carbonaceous materials produces CO_2, which is read by an NDIR CO_2 analyzer. The instrument computer converts the reading into a carbon concentration (mg of carbon per ml of exhaust gas collected). The collection and analysis parameters used in this work were as follows. Particulate-laden exhaust gas was sampled at a rate of 8.0 liter/min for 60 sec at operating modes 1 and 2, and 120 sec at modes 3 and 4. The collection temperature was 75°C. After collection, the filter temperature was ramped from 200° to 750°C at a rate of 5°C/min.

Results and Discussion

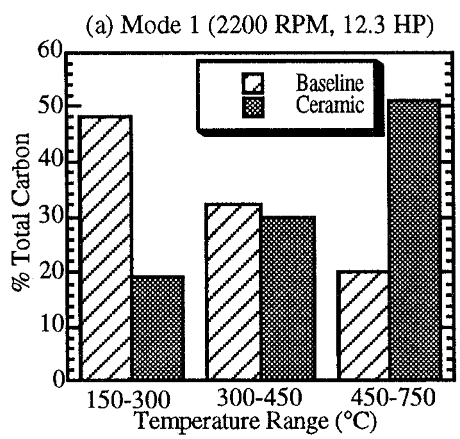
Thermal analysis of diesel particulate matter yields the boiling point distribution of its volatile components. Figure 1 (a)–(d) shows the particulate carbon distribution for the baseline and ceramic-coated engines. The ceramic-coated engine particulates contain less low-to-medium boiling (150-300°C) hydrocarbons from diesel fuel. The material evolving between 300-450°C consists of high-boiling components from the lubricating oil and does not seem to be affected by the insulation very much. The dry soot fraction of the particulate is higher across all the operating modes for the ceramic-coated engine. Clearly, the thermally insulated engine produces particulates with more dry soot and fewer volatiles. This is attributed to the difference in engine exhaust conditions between the two engines [3]. The hotter exhaust temperatures in the ceramic-coated engine result in less hydrocarbon condensation on particulates. The observed decrease in total particulate emissions from the ceramic-coated engine was likely due to the decrease in the volatile portion.

Conclusions

Ceramic insulation of the combustion chamber walls of a diesel engine reduced the total particulate emissions. Thermal analysis data suggest that the insulation is effective in reducing the volatile portion of the particulate emissions.

References

1. Amann, C.A. "The Low-Heat-Rejection Diesel (Also called the 'Adiabatic Diesel')." in Advanced Diesel Engineering and Operation. ed. S.D. Haddad, Ellis Horworth, Chichester, UK, pp. 173-239, 1988.
2. Okrent, D.A. 1996. "Description of an On-Line Method for Measuring the Ratio of Soot to Organics in Diesel Exhaust Particulates." SAE Paper 960252.
3. Heywood, J.B. Internal Combustion Engine Fundamentals. McGraw-Hill, 1988.



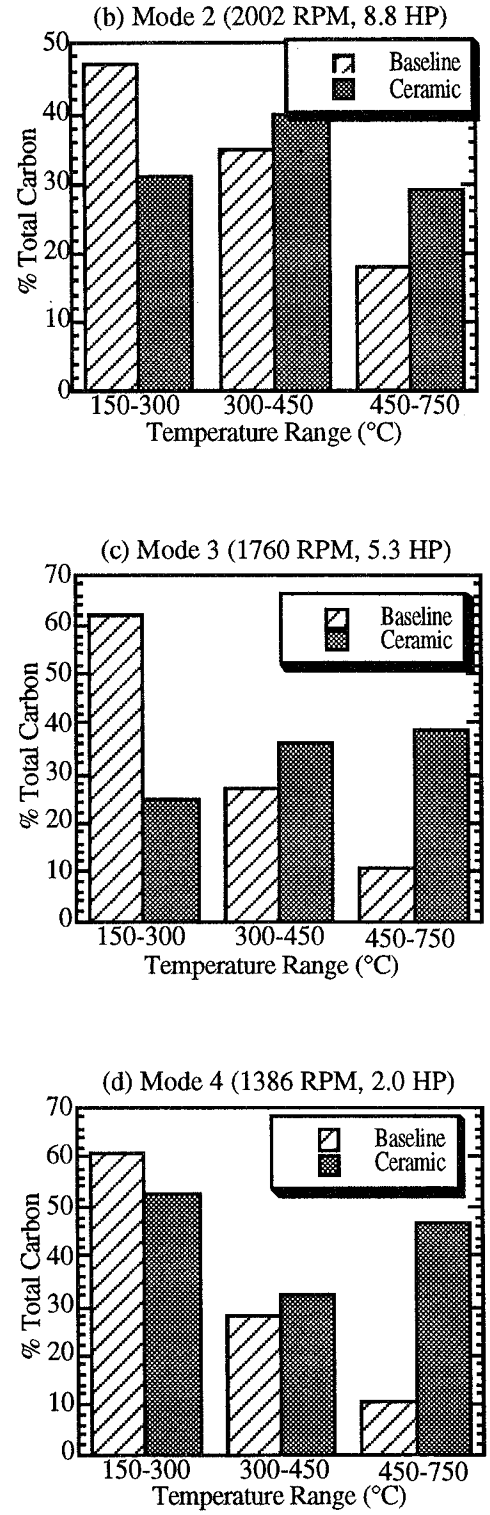


Figure 1. Compositional differences between exhaust particulates from baseline and ceramic-coated engines.