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ADVANCED CONCEPTS FOR CONTROLLED COMBUSTION IN ENGINES

Final Report

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by

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ABSTRACT

Studies carried out at the University of California, Berkeley, over a period of four years were concerned with fluid mechanical properties of turbulent pulsed jet plumes - systems that are of particular relevance to the initiation and control of combustion in engines. The eventual purpose of this program was to provide a rational background for a fundamental refinement of stratified charge diesel engines - the development of a combustion system where the formation of pollutants is minimized, fuel economy is maximized, while fuel tolerance is optimized. The results demonstrated that this goal is attainable by means of appropriate Pulsed Jet Combustion (PJC) generators. The exothermic process of combustion is executed thereby in the form of a fireball taking place in a stratified charge generated by turbulent plumes of a PJC system.

STATEMENT OF THE PROBLEM

The essential purpose of the research program was to provide a rational background for a fundamental refinement of diesel engines: the development of combustion systems operating in cylinders fitted with reciprocating pistons, where the formation of pollutants is minimized, fuel economy is maximized, while fuel tolerance is optimized. The methodology to be applied for this purpose involves the execution of control over the exothermic process of combustion. This goal is attainable by the use of turbulent plumes generated by pulsed jets. The mode of the process realized in this manner is referred to as Pulsed Jet Combustion (PJC).

In particular, it is the determination of the fluid mechanical properties of PJC that formed the principal objective of the studies carried out in this connection. The implementation included the use of liquid diesel fuels as well as gaseous fuel-air mixtures.

In any case, the use of a PJC system in engines should provide a significant refinement of the stratified charge concept, in that it would affect not only the composition of the combustible mixture, as is usually the case, but also the scale and intensity of turbulence, and, above all, the entrainment produced by the large scale vortex structures of turbulent jet plumes. This process is associated with beneficial effects upon mixing of the reacting substance and, concomitantly, the management of the exothermic process of combustion.

Technological implementation of such systems is associated with the development of electronically controlled, solenoid activated, air-blast or air-assisted atomizers, whose design and performance formed one of the integral tasks of the study. This effort was culminated with three U.S. Patents.

SUMMARY OF THE MOST IMPORTANT RESULTS

Major accomplishments of the project were as follows:

1. Identification of the principal feature of controlled combustion engines: management of the exothermic process of combustion attained by means of Pulsed Jet Combustion (PJC) operating under the governance of a microprocessor system (1)*.

2. Demonstration of the operational superiority of PJC over the standard technique of executing combustion in engines (2).

3. Establishment of three fundamental stages in the operation of a PJC system: 1) efflux of an intrinsically non-reacting jet, with concomitant formation of an intense shear layer at its boundaries; 2) generation of a turbulent plume made out of large scale vortex structures whose cores provide the sites for the initiation of the exothermic process of combustion - the essential action of a PJC system associated with a significant effect of entrainment; 3) a gradual decay of the active process of PJC into a puff - a cloud of the products of combustion surrounded by a turbulent flame front whereby the influence of entrainment is subsiding (3,5).

4. Experimental investigation of the performance of advanced, electronically controlled, conventionally operating, liquid fueled, diesel injectors in the hectobar, as well as kilobar, pressure ranges, performed by the use of a high pressure shock tube built especially for this purpose (4,5).

5. Theoretical study of mixing and deformation of a fuel droplet in a spray at high temperatures and pressures (5).

6. Development of a methodology for keeping the products of combustion away from the walls of the enclosure by executing the exothermic process in the

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* numbers in parentheses refer to publications cited in the next section.

form of a fireball - a task attainable by the use of a multiple stream PJC system (8).

7. Reproduction of the salient features of turbulent combustion, deduced from numerical analysis of exothermic flow fields involving shear layers giving rise to large scale vortex structures with concomitant effects of entrainment (9).

8. Clarification of hitherto unexplored thermodynamic properties of combustion in an enclosure, such as an engine cylinder (10).

9. Introduction of basic refinement in the operation of a PJC system: a two-step process consisting of (i) injection forming a turbulent plume followed, upon the elapse of an appropriate time delay, with (ii) ignition by the jet of products of incomplete combustion executed in the cavity of the generator (11).

10. Experimental evaluation of energy losses from combustion in an enclosure caused by heat transfer to the walls (12).

11. Direct measurement of the evolution of density in the course of combustion in an enclosure by means of a Rayleigh scattering laser probe (13).

Thus the stage was set for a systematic study of the chemistry and fluid mechanics of turbulent combustion in engines, including, in particular, its management by a microprocessor controlled PJC system, to provide the necessary background for the design and development of an industrially viable instruments. Unfortunately, funding of this project was at this moment terminated.

LIST OF PUBLICATIONS

1. Oppenheim, A. K., "Quest for Controlled Combustion Engines," SAE 1988 Transactions, The Journal of Engines, Vol. 97, pp. 6.1033-6.1039, 1988.

2. Oppenheim, A. K., Beltramo, J., Faris, D. W., Maxson, J. A., Hom, K., and Stewart, H. E., "Combustion by Pulsed Jet Plumes-Key to Controlled Combustion Engines," SAE 1989 Transactions, The Journal of Engines, Vol. 98, pp. 175-182, 1989.

3. Oppenheim, A. K., "Pulsed Jet Plume Combustion - an exothermic process under fluid mechanical control," 12th Canadian Congress of Applied Mechanics, Carleton University, Ottawa, Canada, pp. 736-737, 1989.

4. Beck, N. J., Hom, K., Maxson, J. A., Stewart, H. E., and Oppenheim, A. K., "Studies of Advanced Fuel Injection Concepts for Diesel Engines," Diesel Fuel Injection Systems, pp. 41-48, The Institution of Mechanical Engineers, London, England, 1989.

5. Oppenheim, A. K., Beck, N. J., Hom, K., Maxson, J. A., and Stewart, H. E., "A Methodology for Inhibiting the Formation of Pollutants in Diesel Engines," SAE Paper 900394, 10 pp., 1990.

6. Lee, H. S., Fernandez-Pello, A. C., Corcos, G. M., and Oppenheim, A. K., "A Mixing and Deformation Mechanism for a Supercritical Fuel Droplet," Combustion and Flame, Vol. 81, pp. 50-58, 1990.

7. Maxson, J. A., and Oppenheim, A. K., "Pulsed Jet Combustion - Key to a Refinement of the Stratified Charge Concept," Twenty-Third Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pa., pp. 1041-1046, 1991.

8. Maxson, J. A., Hensinger, D. M., Hom, K., and Oppenheim, A. K., "Performance of Multiple Stream Pulsed Jet Combustion Systems," SAE Paper 910565, 9 pp., 1991.

9. Oppenheim, A. K., "Mechanics of Turbulent Flow in Combustors for Premixed Gases," Modern Research Topics in Aerospace Propulsion, (Edited by G. Angelino, L. DeLuca, and W. A. Sirignano), pp. 3-17, Springer-Verlag, New York, 1991.

10. Oppenheim, A. K., "Thermodynamics of Combustion in an Enclosure," 13th International Colloquium on Dynamics of Explosions and Reactive Systems, Nagoya, Japan, 1991 (in press).

11. Hensinger, D. M., Maxson, J. A., Hom, K., and Oppenheim, A. K., "Jet Plume Injection and Combustion," SAE Paper 92---, pp., 1992 (in press).

12. Maxson, J. A., Ezekoye, O. A., Hensinger, D. M., Greif, R., and Oppenheim, A. K., "Heat Transfer from Combustion in an Enclosure," Twenty-Fourth International Symposium on Combustion, Sydney, Australia, 1992 (in press).

13. Tamai, R., Maxson, J. A., Shepherd, I., Cheng, R. K., and Oppenheim, A. K., "Rayleigh Scattering Density Measurements of Combustion in an Enclosure," Twenty-Fourth International Symposium on Combustion, Sydney, Australia, 1992 (in press).

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REPORT OF INVENTIONS

"Method and System for Controlled Combustion Engines," by A. K. Oppenheim, U.S. Patent No. 4,924,828, May 15, 1990.

"Pulsed Jet Combustion Generator for Premixed Charge Engines," by A. K. Oppenheim, H. E. Stewart, and K. Hom, U.S. Patent No. 4,926,818, May 22, 1990.

"Pulsed Jet Combustion Generator for Non-Premixed Charge Engines," by A. K. Oppenheim, and H. E. Stewart, U.S. Patent No. 4,974,571, December 4, 1990.

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