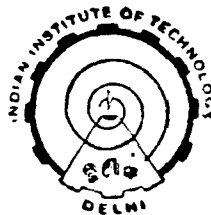


THEORETICAL AND EXPERIMENTAL INVESTIGATIONS ON THE PERFORMANCE AND EMISSION CHARACTERISTICS OF COMPRESSION IGNITION ENGINES WITH BIO-GAS SUBSTITUTION

Thesis submitted to the
Indian Institute of Technology, Delhi
for the award of the degree of
DOCTOR OF PHILOSOPHY

by
Y. N. PRASAD



Department of Mechanical Engineering
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
JULY, 1987

CERTIFICATE

This is to certify that the thesis entitled
'Theoretical and Experimental Investigations on the
Performance and Emission Characteristics of Compression
Ignition Engines with Bio-Gas Substitution' being sub-
mitted by Mr. Y. Nagendra Prasad, for the award of the
degree of Doctor of Philosophy and is a record of the
candidate's original bona fide research work carried out
by him under our guidance and supervision. The matter
embodied in the thesis has not been submitted in part
or full, elsewhere for the award of any degree/diploma.

M. K. Gajendra Babu
Dr. M.K. Gajendra Babu
Assistant Professor
Centre of Energy Studies
Indian Institute of
Technology
Delhi

H.B. Mathur
Dr. H.B. Mathur
Professor
Dept. of Mechanical Engg.
Indian Institute of
Technology
Delhi

ACKNOWLEDGMENTS

The author wishes to express his deep sense of gratitude to Dr. H.B. Mathur, Professor of Mechanical Engineering, and Dr. M.K. Gajendra Babu, Assistant Professor, Centre of Energy Studies, for their invaluable guidance and perspective supervision throughout the course of this work.

Thanks to the staff of the I.C. Engines Laboratory, Mechanical Engineering Workshop, IDDC and Computer Centre, who have helped in his work. Thanks to Mr. Surya Mohan, Mr. S.K. Sud, Dr. S. Subrahmanyam, Dr. R.R. Gaur, Mr. Uma Shankar, Dr. K.C. Rathore, Mr. S.S. Khandare, Mr. K. Prabhakar and Dr. J.P. Subrahmanyam for their suggestions during the work. Thanks to all those who directly or indirectly helped in this endeavour.

Thanks to Mr. P.R. Gauba for his help and cooperation in making neat drawings and Mr. P.M. Padmanabhan Nambiar for his patient and excellent typing of the manuscript.

Finally, the author expresses his heart-felt indebtedness to his family members who were deprived of the privileges and prerogatives, due to his pre-occupation with the research work.

Y.N. PRASAD

ABSTRACT

The theoretical and experimental investigations undertaken to visualise the potential of bio-gas as a compression ignition engine fuel are reported in this thesis.

The analytical study contemplates the simulation of all the engine processes in a four stroke, single cylinder, direct injection compression ignition engine. The salient features of the simulation model include (1) a thermodynamic combustion model for the neat diesel and dual fuel (with diesel and bio-gas) operations; (2) a kinetic model to predict pollutant species such as carbon monoxide and nitric oxide; (3) a gas exchange model based on a finite difference scheme for evaluation of properties in intake and exhaust systems; (4) estimation of wall temperatures; and (5) evaluation of indicated efficiency and power output. Significant parametric studies have also been conducted to indicate the predictive capabilities of the developed model.

Comprehensive experiments have been conducted on a single cylinder direct injection compression ignition engine, not only to obtain the necessary data to validate the model, but also to study the performance and emission characteristics of dual fuel operation at several

proportions of bio-gas substitution relative to neat diesel operation, over the entire range of engine operating conditions, encompassing broad changes in compression ratio, injection timing, speed and load. Methods to improve performance of dual fuel operation have been outlined.

Experiments have also been conducted on an indirect injection compression ignition engine to study the performance and emission characteristics of dual fuel operation, relative to neat diesel operation until the presence of knock is sensed.

A satisfactory correlation has been found between the theoretically predicted and experimentally obtained performance and exhaust emission data generated for both neat diesel and dual fuel operations.

The above comprehensive theoretical and experimental studies have shown that bio-gas is a versatile substitute fuel for compression ignition engines, which can be used in the existing diesel engines without significant engine modifications. Its use can go a long way to meet the energy needs of the agriculture sector and also reduce the menace of diesel smoke from compression ignition engines.

CONTENTS

	Page
Abstract	i
Nomenclature	iii
CHAPTER 1 INTRODUCTION	1
1.1 Energy Crisis and Need for Alternative Fuels	1
1.2 Compression Ignition Engines and Alternative Fuels	2
1.3 Bio-Gas as an Alternative Fuel	4
1.4 Utilisation of Bio-Gas as a Supplementary Fuel for Compression Ignition Engines	7
1.5 Bio-Gas Engine, Performance and Emissions - A Survey of Literature	8
1.6 Mathematical Modelling	13
1.6.1 Classification of Combustion Models	14
1.6.2 Specified Heat Release Pattern	15
1.6.3 Single-Zone Combustion Models	15
1.6.4 Multi-Zone Combustion Models	17
1.6.5 Models for Dual Fuel Compression Ignition Engine	20
1.6.6 Concluding Remarks	20
1.7 Statement of the Problem	21

	Page
CHAPTER 2 MODEL FOR POWER CYCLE	24
2.1 Introduction	24
2.2 Power Cycle Simulation	24
2.3 General Energy Equation	26
2.4 Cylinder Volume	30
2.5 Heat Transfer	31
2.6 Compression Process	33
2.7 Combustion Model	34
2.7.1 Combustion Model for Diesel Operation	36
2.7.2 Combustion Model for Dual Fuel Operation	40
2.8 Pollutants Formation	47
2.8.1 Kinetics of Nitric Oxide Formation	48
2.8.2 Kinetics of Carbon Monoxide Formation	52
2.9 Expansion Process	55
CHAPTER 3 GAS EXCHANGE MODEL	57
3.1 Introduction	57
3.2 Equations of Unsteady Flow	59
3.3 Boundaries	63
3.3.1 Plain Open End	65
3.3.2 Closed End	66
3.3.3 Nozzle	66
3.3.4 Valve	67

	Page
3.4 Exhaust Gas Flow Simulation	72
3.5 Intake Process Simulation	76
CHAPTER 4 COMPUTER PROGRAM	77
4.1 Estimation of Wall Temperatures	78
4.2 Computer Program	83
4.2.1 Subroutines for Computer Program	83
4.2.2 Main Program	86
CHAPTER 5 EXPERIMENTAL EQUIPMENT AND INSTRUMENTATION	88
5.1 Introduction	88
5.2 Direct Injection Compression Ignition Engine	89
5.2.1 Kirloskar Engine and Dynamometer	89
5.2.2 Engine Modifications	90
5.2.3 Fuels and Air Flow Measuring Systems	90
5.3 Indirect Injection Compression Ignition Engine	91
5.3.1 Ricardo Engine	92
5.3.2 Engine Dynamometer	94
5.3.3 Fuels and Air Flow Measuring Systems	94
5.4 Instrumentation	95
5.4.1 Pressure Transducer and Amplifiers	95
5.4.2 Crank Angle Pulse Encoder	96
5.4.3 Needle Lift Diagram Monitor	97

	Page
5.4.4 Smoke Meter	97
5.4.5 Exhaust Gas Analysers	99
5.4.5.1 Non-dispersive Infrared Gas Analyser	99
5.4.5.2 Chemiluminescent NO-NO _x Analyser	100
5.5 Experimental Procedure	101
5.5.1 Calibration of Instruments	102
5.5.2 Performance and Emission Measurement Tests	103
5.5.2.1 Tests on Direct Injection Compression Ignition Engine	103
5.5.2.2 Tests on Indirect Injection Compression Ignition Engine	103
CHAPTER 6 DISCUSSION OF RESULTS	105
6.1 Introduction	105
6.2 Results of Comparison Between Theoretical and Experimental Data	107
6.2.1 Selection of Empirical Constants	107
6.3 Results from Theoretical Studies	110
6.3.1 Parametric Evaluation of the Model	110
6.4 Experimental Results	115
6.4.1 Effects of Bio-gas Substitution on Engine Characteristics	115
6.4.2 Effects of Injection Timing on Engine Characteristics	119

	Page
6.4.3 Effects of Engine Speed on Engine Characteristics	119
6.4.4 Effects of Load Variation on Engine Characteristics	120
6.4.5 Effects of Inlet Air Throttling	121
6.5 Experimental Results on Indirect Injection Compression Ignition Engine	122
CHAPTER 7 CONCLUSIONS	129
REFERENCES	135
APPENDICES	145