

**STUDIES ON ETHANOL CARBURATION IN
COMPRESSION IGNITION ENGINES-
PERFORMANCE, COMBUSTION AND EXHAUST
EMISSION CHARACTERISTICS**

by

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Thesis submitted in fulfilment
of the requirements for the degree of
DOCTOR OF PHILOSOPHY

DEPARTMENT OF MECHANICAL ENGINEERING
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JULY 1985

DEDICATED
TO
MY PARENTS

CERTIFICATE

I, the undersigned, certify that the thesis entitled, "Studies on Ethanol Carburation in Compression Ignition Engines- Performance, Combustion and Exhaust Emission Characteristics" submitted by Mr. K.C. Singhai for the award of the degree of 'Doctor of Philosophy' is a record of the candidate's own bonafide research work carried out under my guidance and supervision. The matter embodied in this thesis has not been submitted in part or full, elsewhere for the award of any degree.



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ACKNOWLEDGEMENTS

The author wishes to express his deep sense of gratitude to Dr. H.B. Mathur, Professor of Mechanical Engineering for his invaluable guidance and supervision throughout the course of this work. His words of solace and encouragement specially during difficult times are ever remembered.

Sincere thanks are due to Dr. M.K. Gajendra Babu, Assistant Professor in Centre of Energy Studies, for his help in computational and experimental work. To him I am very much indebted for his kind attitude, suggestions and sustained interest in the work.

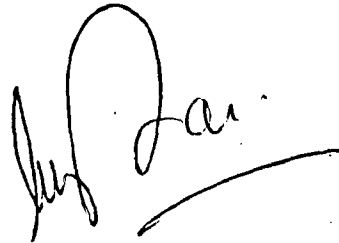
The help rendered by Dr. N. Singh, Dr. J.P. Subrahmanyam, Shri K.C. Kathore and Shri Uma Shankar from time to time is gratefully acknowledged. I express my heartfelt thanks to Shri K.C. Jain, Shri Yash Pal Jain and Shri S. Bhagavat Rao for extending their kind hospitality and help to me during the last phase of my work.

The author is thankful to Shri Ram Parsad, Shri Sultan Singh, Shri O.P. Chawla, Shri Kuldip Singh and other technical staff of I.C. Engines Laboratory and Unconventional Fuels Laboratory for their help in conducting the experiments. Thanks are due to Shri V.P. Gulati for typing the manuscript of the thesis.

Many thanks are due to friends in my parent institution for giving constant encouragement and looking after my interests in the Institute.

The financial assistance received from the Ministry of Education and Culture, under Q.I.P. scheme is gratefully acknowledged.

Finally I express my heartfelt indebtedness to my wife, children and other family members who were deprived of the privileges and prerogatives, due to my pre-occupation with the research project.

A handwritten signature in black ink, appearing to read 'K.C. Singhai', with a long horizontal flourish extending to the right.

(K.C. SINGHAI)

July 1985

ABSTRACT

✓ It is a well known fact that there are limited resources of petroleum fuels and that with their growing rate of consumption these fuels are likely to be exhausted in a couple of decades. With growing urbanisation and rapid industrialisation there has been an ever growing demand of petroleum fueled transport vehicles for the transportation of man and material over long distances. Their growing numbers have created great scarcities of petroleum fuels, whose prices have sky rocketed causing great hardships, particularly in developing countries dependent on imports to meet their fuel oil requirements. The problems of growing economic strain due to this price hike, uncertainties involved in procurement, and the environmental pollution caused by the combustion of petroleum fuels in vehicular engines, have necessitated intensive search for renewable alternate clean burning fuels. ✓

Hydrogen, biogas and alcohols are considered as suitable substitute fuels for internal combustion engines. Hydrogen may prove to be a long term possible fuel since many problems relating to its production, hazardous nature, storage and handling are yet to be sorted out. Use of Bio-gas is confined to stationary engines only as it is difficult to bottle it for mobile applications. On the other hand alcohols-ethanol and methanol are liquids at normal ambient temperatures and pressures, hence can be handled like gasoline and diesel oil.

Whereas alcohols which have a high octane rating were used in spark ignition engines in the past, little or no effort had been made to commercially utilise them in compression ignition engines. Now-a-days these engines are widely used as prime movers for surface transport, power generation, farm equipment, earth moving and road making machinery etc. They have varied and many applications and their numbers are growing rapidly.

✓ In India, the number of compression ignition engines is very large and this has created great demand for diesel fuel. This demand is partly being met through import of diesel oil, at exhorbitant price. ✓ Hence, studies relating to the utilisation of alcohols as fuels in diesel engines are of considerable socio-economic significance. Of the two alcohols commonly considered for automotive application, ethanol has an edge over methanol which has a lower calorific value and is more toxic in nature. ✓ Ethanol is an attractive fuel for agricultural countries like India since it can be economically produced from a large variety of agricultural crops, as also from farm wastes and tropical grasses.

Ethanol or for that matter even methanol, because of the poor ignition qualities cannot be used alone as fuel in existing compression ignition engines without major engine modifications. Its use as part substitute for diesel oil resulting in dual fuel operation of the engine is easier. This requires either the use of Dual injection technique for

major ethanol energy substitution, or ethanol carburation. While ethanol injection is an inherently involved method ethanol substitution by carburation is a simpler technique which requires relatively minor engine modifications.

In the work reported here an attempt has been made to study the extent to which ethanol can be carburetted in diesel engines and the effects of this carburation on engine performance and exhaust emission characteristics. Combustion studies have been carried out to analyse dual fuel engine performance. Experiments have been conducted using both swirl type combustion chamber and open type combustion chamber engines.

For the experiments on Ricardo swirl chamber engine, the entire speed range from 1200 rev/min to 2200 rev/min and static injection timing variations from 30 degrees BTDC to 40 degrees BTDC have been covered. Knock limited ethanol quantity (KLEQ) has been obtained for different speeds and injection timings. At each speed and injection timing the corresponding KLEQ has been kept fixed while load variation, from full load to almost no load, has been obtained by varying the diesel quantity. Tests have also been conducted at 50 per cent knock limited ethanol quantity. On Petter open combustion chamber engine experiments have been conducted at 1300, 1500 and 1700 rev/min at fixed diesel injection timing.

✓ In the present work the term full load, at a given speed and injection timing, has been defined as the load which gives 50 HSU smoke level in neat diesel operation. While

running the engine at full load, when ethanol is introduced in steps, with simultaneous reduction in diesel quantity (to maintain constant speed and load), the quantity of ethanol at which knocking commences (as depicted on the connected cathode ray oscilloscope), has been termed as knock limited ethanol quantity (KLEQ). This is the maximum ethanol quantity that could be substituted at full load at a given speed and injection timing. Even a slight increase in ethanol quantity over KLEQ results in very high rate of pressure rise associated with severe knocking.

In order to assess the engine performance over its entire operating range of speed, load and injection timing, the engine has been instrumented for obtaining ignition delay, combustion duration, peak cylinder pressure, rate of pressure rise, specific energy consumption, exhaust gas temperature, power output, ethanol and diesel fuel flow rates etc. Various exhaust pollutants such as unburnt hydrocarbons (HC), oxides of nitrogen (NO_x), carbon monoxide (CO), and aldehydes have also been measured under different engine operating conditions. Exhaust HC and CO concentrations have been measured with the help of an infra red exhaust analyser & NO_x with NO-NO_x exhaust gas analyser. Hartridge Smoke Meter has been used for the measurement of smoke density (HSU) while aldehyde concentrations have been determined using Wet Chemical Technique.

It has been revealed from the test results that the possible level of ethanol substitution in direct injection

engine is much higher compared to indirect injection engine. Injection timing of diesel fuel seems to have considerable influence on the extent of ethanol substitution. Retarding the injection timing permits higher ethanol substitution together with larger improvement in engine performance. Tests on open combustion chamber engine with overloads at 1500 rev/min revealed that the engine could run smoothly even at loads that could not be reached in neat diesel operation. At 40 per cent overload, the engine could take in about 60 per cent energy through ethanol, giving wide improvement in brake specific energy consumption in dual fuel mode over pure diesel operation, and a very clean exhaust with smoke density as low as 10 HSU.

From the test results various graphs have been plotted to evaluate relative engine performance with and without ethanol carburation. These graphs show the effects of ethanol carburation on various parameters such as specific energy consumption, smoke level, exhaust gas temperature, brake mean effective pressure etc. Plots depicting changes in engine combustion characteristics such as ignition delay, combustion duration, peak cylinder pressure, rate of pressure rise have also been obtained to analyse variations in engine performance and exhaust emission characteristics with ethanol carburation.

In the current investigation it has been found that the engine performance with ethanol carburation is comparable to that in neat diesel mode. Engine could develop power higher than that obtainable with diesel neat as fuel. Ethanol

substitution results in the diesel smoke becoming cleaner, more so at higher loads (where smoke is very dense in diesel neat operation), improved specific energy consumption at loads around 50 per cent full load and above, at moderate speeds and at even lower loads, at higher engine speeds. However, part load performance, with ethanol substitution has been found to be generally slightly inferior.

Analysis of exhaust effluents has revealed that oxides of nitrogen reduce with ethanol substitution under most of the operating conditions, except at higher loads, where increase in NO emission has been observed. Unburnt HC emissions have however been higher with ethanol carburation. This increase has been larger generally at very low loads. Aldehyde levels have also been very high, particularly at part loads in dual fuel mode. CO emission levels do not change much at higher loads, but at part loads CO emission has been found to be higher with ethanol carburation.

Apart from this experimental work, analytical investigations relating to ethanol carburation mode have also been carried out for Ricardo swirl chamber engine. The analytical study involves application of a combustion model to predict cylinder gas pressure and temperature as a function of crank angle, and use of a nitric oxide emission model to predict NO_x emission levels. In the formulation of the combustion model, the combustion chamber has been divided into two portions, prechamber and main chamber connected by a throat passage. As

diesel fuel is injected into the prechamber, combustion is first initiated there, and the products of combustion flow through connecting passage to the main chamber.

In the dual fuel mode, the net energy release depends upon the individual energy release pattern of the two fuels. Rate of heat release by diesel fuel has been estimated using the experimental injection rate diagrams as input and employing the two triangle burning rate scheme of Austen and Lyn. Ethanol burning rate has been predicted considering premixed and diffusive burning of ethanol vapour. Burning rates have been expressed by empirical equations through some in cylinder parameters. This combustion model has been used to predict cylinder gas pressure and temperature and NO formed, as a function of crank angle at baseline condition for both the prechamber and main chamber in neat diesel operation and in dual fuel operation, at different loads. Values predicted have been compared with those obtained experimentally.

This study has clearly shown that in swirl chamber engine at baseline speed of 1500 rev/min and 38 degrees BTDC injection timing about 20 per cent energy at full load could be supplied through ethanol. Lower speeds can tolerate little higher proportion of ethanol whereas higher speeds are able to accept little lower levels of ethanol substitution. About 50 per cent energy contribution through ethanol at full load could be provided in an open combustion chamber engine. Improvements due to ethanol carburation are best reflected at higher loads and overloads.

In general, there has been an improvement in efficiency at higher loads while at part loads, efficiency in dual fuel mode has been less than in neat diesel operation. However, at 2200 rev/min (the maximum speed in swirl chamber engine used in the present investigations) efficiency with ethanol carburation has been better than neat diesel efficiency at all loads. More percentage energy substitution by ethanol could be allowed at retarded injection timings. At 1500 rev/min and 30 degrees BTDC injection timing about 30 per cent energy could be supplied through ethanol, whereas at 40 degrees BTDC injection timing this value dropped down to 16.5 per cent.

Ethanol carburation can be profitably employed in existing compression ignition engines without any major engine modification. Its use can lead to substantial saving of the scarce diesel oil, and also generally reduce exhaust NO emissions. Ethanol carburation can thus provide an immediate though partial solution to the growing diesel oil scarcity in developing countries having little or no oil reserves of their own.

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