

**EXPERIMENTAL INVESTIGATIONS ON PERFORMANCE,
COMBUSTION AND EMISSION CHARACTERISTICS OF
METHANOL AND ETHANOL FUELLED SPARK IGNITION
ENGINE WITH OXYGEN-ENRICHED AIR**

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Experimental investigations on performance, combustion and emission characteristics of methanol and ethanol fuelled spark ignition engine with oxygen-enriched air

by

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to the



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***Dedicated
to
Lord Shri Krishna
and
my Family***

CERTIFICATE

This is to certify that the thesis, **“Experimental investigations on performance, combustion and emission characteristics of methanol and ethanol fuelled spark ignition engine with oxygen-enriched air”** submitted by **Nidhi** (2017 ESZ 8213), to the **Indian Institute of Technology Delhi** for the award of the Doctor of Philosophy degree is a record of the bonafide research conducted by her under my supervision in compliance with the Indian Institute of Technology Delhi’s rules and regulations. She met all the criteria for the submission of this thesis, which achieved the level required for the Institute’s Ph.D. degree. The findings and results reported in the thesis have not been submitted to any other university or institute for any degree or diploma.

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ABSTRACT

An experimental investigation was carried out on a single-cylinder four-stroke spark-ignition engine fuelled with methanol (M100) and ethanol (E100) to study energy efficiency improvement and emissions reduction using oxygen-enriched air and increased compression ratio. Additional oxygen from the external supply from the cylinder along with the main source of oxygen inducted from the atmosphere called “oxygen-enriched air” was injected into the engine’s intake manifold. The compression ratio of the engine was increased from 9.8:1 (base) to 10.6:1. The performance, emission, and combustion characteristics were analysed with M100 and E100 fuels compared with base gasoline.

The results indicate that brake thermal efficiency of the engine at MBT spark timing increased along with emissions (CO, HC, NO) reduction with M100 and E100 compared to base gasoline. The performance improvement and emissions reduction with M100 are higher than that of E100. The brake thermal efficiency was higher by 4.5% with M100 than E100. The emissions of CO and HC were lower by 4.7% and 23% respectively with M100 and NO emission was higher by more than four times with M100 compared to E100. Further experimental studies were carried out to enhance thermal efficiency and emissions reduction with oxygen-enriched air (30-40% by mass). The emissions of CO and HC decreased drastically along with improved thermal efficiency with the oxygen-enriched air. The brake thermal efficiency increased to 19% with M100 which was 12.8% with base gasoline. The CO and HC emissions decreased by more than 75% compared to base gasoline. However, NO emission increased drastically by more than three times with M100 compared to gasoline. In the last phase, the experimental tests were conducted on the engine with an increased compression ratio and oxygen-enriched air. The brake thermal efficiency increased by 9.4% which was the highest with M100. The CO and HC emissions were the lowest being 0.63 g/kWh and 0.017 g/kWh respectively with M100. The main reasons for

the improved efficiency and emissions reduction include high reactant temperature and pressure at the high compression ratio, increased oxygen concentration, high heat release rate, and better combustion. The performance improvement and emission reductions are higher with M100 than that of gasoline and E100. The main reasons for better performance with M100 include high flame velocity, absence of carbon-to-carbon bond, high oxygen concentration, and fewer intermediate species such as formaldehyde during combustion compared to E100. The performance of the engine with E100 is better than base gasoline.

A notable conclusion emerged from this research study is that a spark ignition engine fuelled with methanol (M100) with oxygen-enriched air (35% to 38% oxygen concentration increased from base 23% in the atmospheric air) and increased compression ratio could provide the best performance improvement and emissions reductions compared to ethanol (E100) and gasoline.

सार

ऑक्सीजन-समृद्ध हवा और बढ़े हुए संपीड़न अनुपात का उपयोग करके ऊर्जा दक्षता में सुधार और उत्सर्जन में कमी का अध्ययन करने के लिए मेथनॉल (M100) और इथेनॉल (E100) के साथ ईंधन वाले सिंगल-सिलेंडर फोर-स्ट्रोक स्पार्क-इग्निशन इंजन पर एक प्रायोगिक जांच की गई। सिलेंडर से बाहरी आपूर्ति से अतिरिक्त ऑक्सीजन के साथ-साथ "ऑक्सीजन-समृद्ध हवा" नामक वातावरण से शामिल ऑक्सीजन के मुख्य स्रोत को इंजन के इनटेक मैनिफोल्ड में इंजेक्ट किया गया था। इंजन का संपीड़न अनुपात 9.8:1 (आधार) से बढ़ाकर 10.6:1 कर दिया गया। बेस गैसोलीन की तुलना में M100 और E100 ईंधन के साथ प्रदर्शन, उत्सर्जन और दहन विशेषताओं का विश्लेषण किया गया।

परिणामों से संकेत मिलता है कि एमबीटी स्पार्क टाइमिंग पर इंजन की ब्रेक थर्मल दक्षता में वृद्धि हुई है, साथ ही बेस गैसोलीन की तुलना में M100 और E100 के साथ उत्सर्जन (सीओ, एचसी, एनओ) में कमी आई है। M100 के साथ प्रदर्शन में सुधार और उत्सर्जन में कमी E100 की तुलना में अधिक है। E100 की तुलना में M100 के साथ ब्रेक थर्मल दक्षता 4.5% अधिक थी। M100 के साथ CO और HC का उत्सर्जन क्रमशः 4.7% और 23% कम था और E100 की तुलना में M100 के साथ NO उत्सर्जन चार गुना अधिक था। ऑक्सीजन-समृद्ध हवा (द्रव्यमान से 30-40%) के साथ थर्मल दक्षता और उत्सर्जन में कमी को बढ़ाने के लिए आगे के प्रायोगिक अध्ययन किए गए। ऑक्सीजन युक्त हवा के साथ बेहतर थर्मल दक्षता के साथ सीओ और एचसी के उत्सर्जन में भारी कमी आई है। M100 के साथ ब्रेक थर्मल दक्षता बढ़कर 19% हो गई जो बेस गैसोलीन के साथ 12.8% थी। बेस गैसोलीन की तुलना में सीओ और एचसी उत्सर्जन में 75% से अधिक की कमी आई है। हालाँकि, गैसोलीन की तुलना में M100 के साथ NO उत्सर्जन में तीन गुना से अधिक की वृद्धि हुई। अंतिम चरण में, बढ़े हुए संपीड़न अनुपात और ऑक्सीजन युक्त हवा के साथ इंजन पर प्रायोगिक परीक्षण किए गए। ब्रेक थर्मल दक्षता में 9.4% की वृद्धि हुई जो M100 के साथ सबसे अधिक थी। M100 के साथ CO और HC उत्सर्जन सबसे कम क्रमशः 0.63 g/kWh और 0.017 g/kWh था। बेहतर दक्षता और उत्सर्जन में कमी के मुख्य कारणों में उच्च प्रतिक्रियाशील तापमान और उच्च संपीड़न अनुपात पर दबाव, ऑक्सीजन एकाग्रता में वृद्धि, उच्च गर्मी रिलीज दर और बेहतर दहन शामिल हैं। प्रदर्शन में सुधार और उत्सर्जन में कमी गैसोलीन और E100 की तुलना में M100 के साथ अधिक है। M100 के साथ बेहतर प्रदर्शन के मुख्य कारणों में उच्च लौ वेग, कार्बन-से-कार्बन बंधन की अनुपस्थिति, उच्च ऑक्सीजन सांद्रता, और कम मध्यवर्ती प्रजातियां जैसे कि E100 की तुलना में दहन के दौरान फॉर्मलाडेहाइड शामिल हैं। E100 वाले इंजन की परफॉर्मेंस बेस गैसोलीन से बेहतर है।

इस शोध अध्ययन से एक उल्लेखनीय निष्कर्ष निकला है कि M100 इंजन के साथ ईंधन वाला एक स्पार्क इग्निशन इंजन ऑक्सीजन युक्त हवा (वायुमंडलीय हवा में बेस 23% से 35% से 38% ऑक्सीजन एकाग्रता वृद्धि) और बढ़े हुए संपीड़न अनुपात के साथ संचालित होने पर E100 और गैसोलीन की तुलना में उच्च दक्षता और कम उत्सर्जन के साथ बेहतर प्रदर्शन कर सकता है।

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NOMENCLATURE

SI	Spark Ignition
CR	Compression Ratio
IC	Internal Combustion
M100	Methanol (100%)
E100	Ethanol (100%)
MX	Methanol blend with X% of gasoline
EX	Ethanol blend with X% of gasoline
BMEP	Brake Mean Effective Pressure
BSFC	Brake Specific Fuel Consumption
IMEP	Indicated Mean Effective Pressure
COV	Coefficient of Variance
BTE	Brake Thermal Efficiency
PV	Pressure Volume
VE	Volumetric Efficiency
CO	Carbonmonoxide
HC	Hydrocarbon
NO _x	Nitrogen oxides
P _{max.}	Peak pressure
ROPR	Rate of Pressure Rise
HRR	Heat Release Rate
(a/b) TDC	After/Before Top Dead Centre
OEA	Oxygen Enriched Air
OE	Oxygen Enrichment
CD	Combustion Duration
ID	Ignition Delay
SEM	Scanning Electron Microscope
PVC	Polyvinyl Chloride
EPDM	Ethylene Propylene Diene Monomer
C.A	Crank Angle