STUDY ON INJECTION, SPRAY AND COMBUSTION CHARACTERISTICS OF A BIODIESEL FUELLED COMPRESSION IGNITION ENGINE

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Dedicated to the Lotus feet of Goddess Sharda, heart of my parents & children and hands of my husband.

CERTIFICATE

This is to certify that the thesis entitled, "**Study on injection, spray and combustion characteristics of a biodiesel fuelled compression ignition engine"** submitted by **Mrs Shweta Tripathi** to Indian Institute of Technology Delhi, for the award of the degree of the **Doctor of Philosophy** is a record of bonafide research work carried out by her. She worked under my supervision for the submission of this thesis, which to the best of my knowledge has reached the requisite standard.

The research reports and the results presented in this thesis have not been submitted in parts or in full to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

Biodiesel fuelled diesel engine has lower Carbon monoxide (CO), Hydrocarbons (HC) and smoke emissions compared to base diesel. However, it emits higher oxides of Nitrogen (NO_x) emission and associated problems of wall impingement and injector coking. The present study is aimed at assessment of impact of injection and spray characteristics on NO_x emission and spray-wall impingement of a biodiesel fuelled compression ignition engine. In addition, coking formation in fuel injector is studied.

In the first phase, injection, spray, combustion, performance and emission characteristics of the diesel engine are analyzed in detail. The engine used for this study was an automotive diesel engine delivering 5.5 kW rated power output. The soya soap stock-based acid oil biodiesel and palm soap stock-based acid oil biodiesel were used as fuels in the engine. The experimental tests were conducted on the engine under varied speed (2200 rpm and 3000 rpm) and torque (25%, 50%, 75%, and 100%) to analyze the performance and emission characteristics. The spray, injection and combustion characteristics are analyzed at Tmax (maximum torque condition: 2200 rpm at 17 Nm torque) and Pmax (maximum power: 3000 rpm at 14 Nm) conditions. The experimental results indicate NOx emission is higher with the biodiesels than that of base diesel due to automatic advanced injection timing, higher adiabatic flame temperature and presence of oxygen in biodiesel. Moreover, higher bulk modulus of biodiesel results in high in-line pressure (ILP) which leads to longer spray penetration distance. The increased spray penetration distance leads to more probability of wall impingement on piston bowl.

In the next phase of study, the technical issues such as NO_x emission, reduction of brake thermal efficiency and probability of spray-wall impingement on piston bowl is addressed. The effects of operating and design parameters of the engine such as compression ratio, fuel

injection timing and exhaust gas recirculation (EGR) on injection, spray, combustion, performance and emissions characteristics for palm acid oil (PAO) biodiesel are studied in detail for Tmax and Pmax conditions of the engine. The spray characteristics were calculated by using correlations/models available in literature. The measured injection and combustion characteristics such as fuel line pressure, combustion chamber pressure and injection duration were used as input data for these models/correlations. It is concluded that retarding injection timing by 2.5°CA is one of the alternative to reduce NOx emission and probability of wall impingement but the brake thermal efficiency (BTE) is reduced marginally. Modifying the compression ratio of the engine as 21:1 (original 19:1) and 20% EGR improved BTE along with reduction in NOx emission and eliminated the probability of spray-wall impingement. In the last phase, the effect of palm acid oil biodiesel on coking of injector and dilution of lubricating oil was studied for 50 hours endurance test of the engine at Tmax condition. Coking formation in the injector is observed with the biodiesel and the reason for the formation is mainly due to biodiesel having higher viscosity and density.

On the basis of this research study, it is recommended that PAO biodiesel (100%) could be used in this automotive diesel engine by modifying its CR to 21:1 and using 20% EGR simultaneously. It would not only reduce the probability of spray-wall impingement and NOx emission but would also increase the BTE of the engine.

सार

बायोडीजल द्वारा संचालित डीजल इंजन में डीजल की तुलना में कार्बन मोनोऑक्साइड , हाइड्रोकार्बन और स्मोक उत्सर्जन कम होता है | हालांकि, यह नाइट्रोजन के ऑक्साइड्स (एनओएक्स) उत्सर्जन ,वाल इम्पिन्ज्मेंट और इंजेक्टर कोकिंग संबंधित समस्याओं को बढ़ा देता है | वर्तमान अध्ययन का उद्देश्य इंजेक्शन और स्प्रे विशेषताओं के आधार पर बायोडीजल द्वारा संचालित संपीड़न इग्निशन इंजन हेतु नॉक्स उत्सर्जन और स्प्रे-वाल इम्पिन्ज्मेंट का अवलोकन है। इसके अलावा, इंजेक्टर में कोकिंग के विन्यास का अध्ययन भी किया गया है।

अध्ययन के पहले चरण में, डीजल इंजन के इंजेक्शन, स्प्रे, दहन, प्रदर्शन और उत्सर्जन विशेषताओं का विस्तार से विश्लेषण किया गया है। इस अध्ययन के लिए इस्तेमाल किया जाने वाला इंजन एक मोटर वाहन डीजल इंजन था जो 5.5 किलोवाट रेटेड पावर आउटपुट प्रदान करता था। सोया सोप स्टॉक द्वारा निर्मित एसिड आयल बायोडीजल और पाम सोप स्टॉक द्वारा निर्मित एसिड आयल बायोडीजल का उपयोग इंजन में ईंधन के रूप में किया गया था। इंजन पर प्रयोगात्मक परीक्षण विभिन्न गति (2200 आरपीएम और 3000 आरपीएम) और बलाघूर्ण (25%, 50%, 75%, और 100%) पर प्रदर्शन और उत्सर्जन विशेषताओं का विश्लेषण करने के लिए आयोजित किए गए थे। स्प्रे, इंजेक्शन और दहन विशेषताओं का विश्लेषण अधिकतम बलाघूर्ण की स्थिति (2200 आरपीएम पर 17Nm बलाघूर्ण) और अधिकतम शक्ति की स्थिति (अधिकतम : 3000 आरपीएम पर 14 Nm) में किया गया था । प्रयोगात्मक परिणामों से यह संकेत मिलता है कि स्वत: उन्नत इंजेक्शन समय, उच्च एडिएबैटिक फ्लेम तापमान और बायोडीज़ल में ऑक्सीजन की उपस्थिति के कारण बेस डीजल की तुलना में बायोडीजल के साथ एनओएक्स उत्सर्जन अधिक होता है। इसके अलावा, बायोडीजल के उच्च बल्क मॉड्यूलस के परिणामस्वरूप उच्च इन-लाइन दबाव (आईएलपी) होता है जो स्प्रे प्रतिच्छेदन दूरी को बढ़ा देता है । बढ़ी हुई स्प्रे प्रतिच्छेदन दूरी बाउल की दिवार पर स्प्रे-इम्पिंज होने की संभावना को बढ़ा देती है।

अध्ययन के अगले चरण में, एनओएक्स उत्सर्जन , ब्रेक थर्मल दक्षता में कमी और पिस्टन बाउल की दिवार पर स्प्रे-इम्पिंज होने की संभावना जैसे तकनीकी मुद्दों को संबोधित किया गया है। पाम एसिड तेल (पीएओ) बायोडीज़ल के इंजेक्शन, स्प्रे, दहन, प्रदर्शन और उत्सर्जन विशेषताओं पर संपीड़न अनुपात, ईंधन इंजेक्शन समय और निष्कासित गैस पुनर्कलन (ईजीआर) जैसे इंजन के संचालन और डिजाइन पैरामीटर के प्रभावों का विस्तृत अध्ययन अधिकतम बलाघूर्ण और अधिकतम शक्ति की स्थिति में किया गया । स्प्रे विशेषताओं की गणना साहित्य में उपलब्ध सहसंबंध / मॉडल का उपयोग करके किया गया था । इन मॉडलों / सहसंबंधों के लिए इनपुट डेटा के रूप में प्रयोग के तहत मापे गए इंजेक्शन और दहन विशेषताएं जैसे ईंधन लाइन में दाब, दहन कक्ष में दाब और इंजेक्शन अवधि का उपयोग किया गया था। यह निष्कर्ष निकाला गया है कि 2.5 °CA तक इंजेक्शन समय को रोकना एनओएक्स उत्सर्जन और दीवार पर स्प्रे- इम्पिंज होने की संभावना को कम करने के विकल्प में से एक है लेकिन ब्रेक थर्मल दक्षता (बीटीई) कम हो जाती है । इंजन के संपीड़न अनुपात (मूल 19: 1)को संशोधित कर 21: 1 तक बढ़ाने के साथ ही 20% ईजीआर का उपयोग करने पर बीटीई में सुधार हुआ और साथ ही एनओएक्स उत्सर्जन में कमी और दीवार पर स्प्रे- इम्पिंज होने की संभावना भी समाप्त हो गयी।

अध्ययन केअंतिम चरण में, इंजन का अधिकतम बलाघूर्ण की स्थिति में 50 घंटे स्थिरता परीक्षण कर के, इंजेक्टर के कोकिंग और ल्युब्रिकेटिंग आयल के मलीन होने पर पाम एसिड तेल (पीएओ) बायोडीजल के प्रभाव का अध्ययन किया गया था। इंजेक्टर में कोकिंग गठन बायोडीजल के साथ प्रायः हो जाता है और गठन का कारण मुख्य रूप से बायोडीजल की उच्च श्यानता और घनत्व है।

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NOMENCLATURE

BMEP	Brake mean effective pressure of engine
BSFC	Brake specific fuel consumption
BTE	Brake thermal Efficiency
B100	100% biodiesel
B 5	Blend of 5% biodiesel and 95% diesel
CA	Crank angle
CR	Compression ratio
D	Bore of cylinder
EGR	Exhaust gas recirculation
ICP	In-cylinder pressure
ICT	In-cylinder temperature
ILP	In-line pressure
PAO	Palm acid oil
Pmax	Maximum power condition
RIT	Retarded injection timing
SAO	Soya acid oil
Tmax	Maximum torque condition
L	Length of connecting rod
L	Stroke length
L_{inst}	Stroke length with respect to crank angle
L_b	Bowl depth
m_f	Mass flow rate of fuel
r_c	Compression ratio

ρ_l, ρ_g	Density of fuel and charge in kg/m^3,
D_p	Discharge pressure
S	Spray penetration distance