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Experimental Investigationson Air-Cooled Diesel Engine with Biodiesels asAlternateFuels

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Abstract

Biodiesels of simarouba, rubber seed and rice bran were produced from their respective feed stocks by transesterificationprocessandtestedinanaircooleddieselengineasasubstitutefuels.Theexperimentalinvestigationaims in accessibility of using neat biodiesels in anunmodified stationery diesel engine meant for agriculture and gen-set applications in India. Diesel and neat biodiesels of simarouba, rubber seed (non-edible oils) and rice bran (edibleoil) were used for conducting tests at varying load conditions (0, 25%, 50%, 75% and 100%). The performance (brakethermal efficiency, brake specific fuel consumption), exhaust emissions (CO, HC and smoke opacity) and combustionresults(cylinderpressureriseandheatreleaserate)wereanalyzedandcomparedwithdieseloperation.Theperformance of engine was dropped, peak cylinder pressure rise and heat release rate were reduced as compared toconventional diesel. On the other hand the engine showed significant reductions of exhaust emissions(except NO_x)while running with neat biodiesels. The combustion studies revealed that the ignition delay was shorter for biodieselstested compared to diesel and was increasing with the load. The neat simarouba biodiesel was proved to be bettersubstitute to diesel as it significantly reduced harmful exhaust emissions, showed better performance and combustioncharacteristicscomparedtoother twobiodiesels tested.

Keywords:Transesterification;Biodiesel;Performance;Emissions;Ignitiondelay.

Abbreviations: TDC- Top Dead Centre; D – Diesel; SRBD - Simarouba neat biodiesel; RSBD - Rubber seed neatBiodiesel;RBBD–RiceBranneatBiodiesel;BTE-BrakeThermalEfficiency;BSFC-BrakeSpecificFuelConsumption;CA-Crank Angle;HRR -HeatReleaseRate

1. Introduction

AsIndiaisadevelopingcountry,energydemandsareincreasing day by day at alarming rate due to modernization,urbanization, and globalization and population growth. InIndia,75%ofroadtransportationdependsonvehiclesrunningwithdiesel.Innearfuturethispercentagemayfurther increase and a situation may arise when fossil fuelsgetdepletedandnoalternatetodiesel.Inthisdirectionmany researchers are doinginventions toderive a clean,sustainableandenergyefficientsubstitutefueltodiesel,whichcanbesuccessfullyusedinanunmodifieddieselenginewithlittlecompromiseinperformance.FromtheliteratureitrevealsthatStraightVegetableOils(SVOs)derived from tree borne seeds can be used as an alternate todiesel[1].However,SVOscannotbedirectlyusedinadiesel engine due to their higher viscosity, higher boilingpoint relative to diesel fuel. The viscosity of SVO is muchhigherthanthatofdieselfuelatnormaloperatingtemperatures [2]. High fuel viscosity can cause prematurewearofthefuelpumpsandinjectors.Itcanalsodramatically alter the structure of the fuel spray coming outof the injectors: increasingdroplet size,decreasing sprayangle,andincreasing spray penetration.Theseeffects tendto increase wetting of the engine’s internal surfaces, therebydiluting the engine lubricant and increasing the tendency forcoking and leads the problem of reduced engine life [2]. Thecarbonbuildupdoesn’tnecessarilyhappenimmediatelyupon use of SVO; it typically takes place over the long term.Diesel engines with vegetable oils offer acceptable engineperformance and emissions for short-term operation. Long-term operation results in operational and durability problems[3].

Some investigators have explored modifying vehicles topreheat SVO prior to injection into the engine. Others haveexamined blends of vegetable oil with conventional diesel[4]. These techniques were mitigating the problems to somedegree but did not eliminate them entirely. Studies show thatcarbon buildup (coking) continues over time, resulting inhigher engine maintenance costs and/or shorter engine life[5]. The studies revealed that the tendency to form carbondeposits increases with increasing proportions of vegetableoil blended into the fuel [4]. The above problems can beovercomebyreducingviscosityofSVOsbyachemicalprocess called trans esterification [6 - 8], which producesbiodiesels. Biodiesel is having similar physical and chemicalpropertiesasthatofconventionaldieselandcanbesuccessfully usedinanengine eitherdirectly or blendedform [9]. The present investigation aims in production ofSRBD, RSBD and RBBD from their respective seeds[10-13]and accessibility of using in an unmodified single cylinderdiesel engine. Very few papers in the literature explain aboutuseofthesebiodieselsinadieselengine.Assuch noliteraturerevealsaboutperformance,emissionand combustion analysis of these three potential biodiesels asalternatefuels.Thismotivatedtocarryoutdetailedinvestigationstoanalyzeperformance,exhaustemissionsand combustion effect of using SRBD, RSBD and RBBD asalternatefuels.

2. BiodieselProduction

Transesterificationisachemicalprocessinwhichtriglycerides of straight vegetable oil reacts with ethanol ormethanolinthepresenceofacatalyst(acidorbase)to convert triglycerides in to monoesters of ethyl or methylesters, called as biodiesel. The byproduct will be glycerine.Biodieselswereproducedinlabscalemodel of5literscapacity consisting of a heater, reaction flask (three necks),magnetic stirrer, condenser to recover methanol. Before theprocess, free fatty acid (FFA) composition was determinedbysimpletitrationprocessbyneutralizing theacidpresentintheoiltodecide,eitherasinglestage(acidtransesterification) or two stage (acid-base trans esterification)process to produce biodiesel. As FFA was more than 4% inall fuel samples, two stage trans esterification was used toproduce biodiesel after optimizing parameters of the process(molarratio,reactiontimeandtemperature,typeofcatalyst). In two stage trans esterification process methanolor ethanol is used as reagent along with sulfuric acid andpotassium hydroxide as catalysts for acid and base reactionsrespectively. The trans esterification process with chemicalreaction is shown in Figure 1 (a) and (b). The importantproperties of SRBD, RSBD and RBBDwereevaluatedasperASTMstandardsandcomparedwithconventionaldieselsare giveninTable 1.

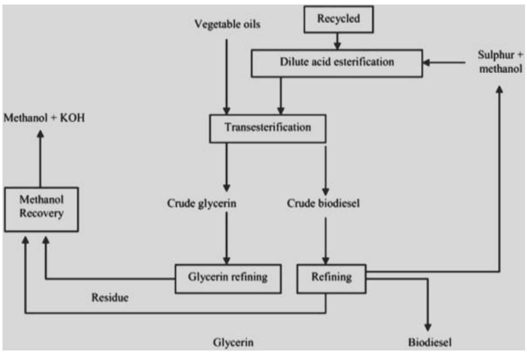

Figure1a:Blockdiagramoftransesterification

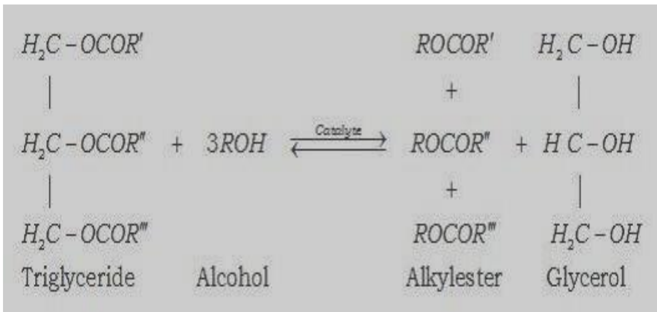

Figure1b:Chemicalreactionoftransesterificationprocess

Table1:Propertiesofsimarouba, rubberseed and ricebranbiodieselscomparedwithpetro-diesel

Property	D	SRBD	RSBD	RBBD
Density(kg/m^3)	840	842	874	877
CalorificValue(MJ/kg)	42.5	38.443	34.66	33.14
Viscosity(mm^2/S)@40°C	2.54	4.87	5.81	6.21
FlashPoint(°C)	54	162	146	125

3. ExperimentalSetupandProcedure

Akirloskarmake,singlecylinder,4-stroke,aircooleddieselenginewasusedforconductingtheexperiment.Enginewascoupledtoaswingfielddynamometer for applying the electric load. Air box fittedwith a sharp edge orifice was used to determine airflow rate.Fuel consumption was measured by recording time for 20 ccof fuelflowing in totheenginethrough burette.Enginecooling water temperatures (inlet and outlet), exhaust gattemperatures were measured using thermocouples. Cylinderpressurewasrecordedusingapiezoelectricpressure transducer incorporated in an engine head. Heat release ratesand cylinder pressure variations with respect to crank anglerotation was recorded using AVL indicom mobile softwareversion V2.5 interfaced with a data acquisition system and acomputer. AVL 444 DI gas analyzer was used to measureexhaustgases-Carbonmonoxide(CO),Carbondioxide(CO_2), oxides of nitrogen (NO_x), excess oxygen (O_2) andhydrocarbon(HC). Smoke opacity was measured using AVL415 smoke meter. Schematic of engine used for conductingthe test is shown in Figure2. Test engine specifications aregiveninTable 2.

Table 2. Engine specifications

Make:-KirloskarOilengine,Singlecylinder,four stroke(TAF1)	
Ratedpower	4.4kW (6HP)
Ratedspeed	1500rpm
BorexStroke	87.5mmx110 mm
Compressionratio	17.5:1
Cubiccapacity	0.662ltr
Injectiontiming	23^{0}bTDC
Nozzleopeningpressure	200 bar
Pistonbowl	Hemispherical
Dynamometerspecification SwingingFielddynamometer(Make-powerstars)	
KVA-5,PH-1,V-240Volts,I-21Amps, RPM-1500	

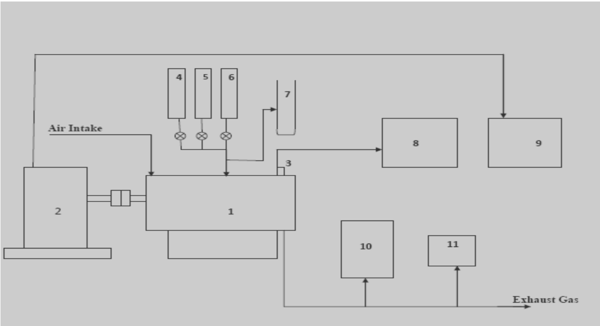

Figure2:TestEnginesetup
1.TestEngine,2. Swingingfielddynamometer,3. Pressure sensor,4. Diesel tank,5. Purebiodiesel tank, 6.Biodiesel-diesel blendstank,7.Burette,8.Dataacquisition system,9.Dynamometercontroller, 10.AVLDI Gas analyzer, 12.AVLSmokemeter.

In the beginning engine was run with conventionaldiesel with an injection pressure of 200 bars and injectiontiming of 23° before TDC by applying load ranging from noload to full load in steps of 25% of rated load in five equalparts. The base line data was collected along with exhaustgasemissions,Peakcylinderpressurerise,HRRandcalculations were made for BTE and BSFC. SubsequentlytheenginewasrunwithSRBD,RSBDandRBBDneatbiodiesels with the same operating and load conditions asthat of conventional diesel. Performance, combustion andexhaust emissions of conventional diesel and engine withneatbiodieseloperation werecompared andanalyzed.

4. ResultsandDiscussions

BrakeThermalEfficiency

BTE variationwithpercentage loadisshowninFigure 3. BTE was increasing for fuel samples testedfromno load to 75% load (maximum) and then falls at full load.The BTE of conventional diesel operation was higher as allload conditions compared to neat biodiesels. The reason forlower BTE would be the lower heating value and higherviscosity of neat biodiesels compared to conventional diesel.Higherviscosityresultsinpooratomizationand increase average droplet size of fuel injected in to the combustionchamber undergoing partial combustion. At the same time inorder to maintain constant speed, mass of biodiesel burnt atapplied load increases as compared to conventional dieselbecause of lower heating value and hence BTE decreases.SRBD has showed improved BTE compared to RSBD andRBBDowingtoitshigherheatingvalueandlowerviscosity.BTE of D, SRBD, RSBD and RBBD were 28.2%,25.8%,25.1%and 24.2%respectivelyat75%load.

BrakeSpecificFuelConsumption

BSFC variation with percentage load is shown inFigure 4. BSFC of fuel samples tested is higher at no loadand it goes on decreasing as the load increases and reaches aminimum at 75% load and then increases at full load. BSFCis lower for diesel at all loads compared to biodiesels testedduetolowerviscosityandhigherheatingvalue.TheincreaseinBSFCvaluesofallbiodieselstestedwasinterrelatedwithdecreaseinBTE,andwasbecauseofhigherviscosityandlowerenergycontentcomparedtoconventional diesel. BSFC of D, SRBD, RSBD and RBBDwere 0.29, 0.38, 0.39 and 0.41 kg/kWh respectively at 75%load.

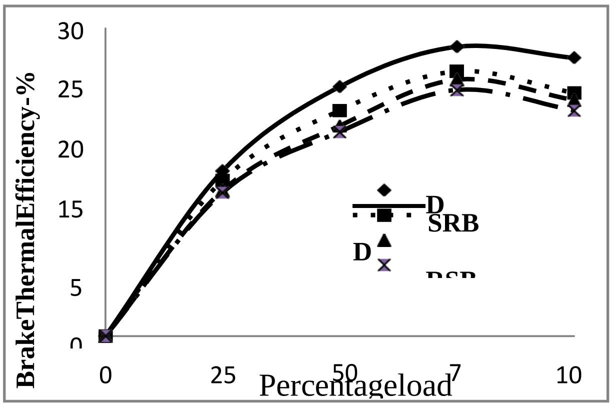

Figure3:Variationbrakethermalefficiencywithload

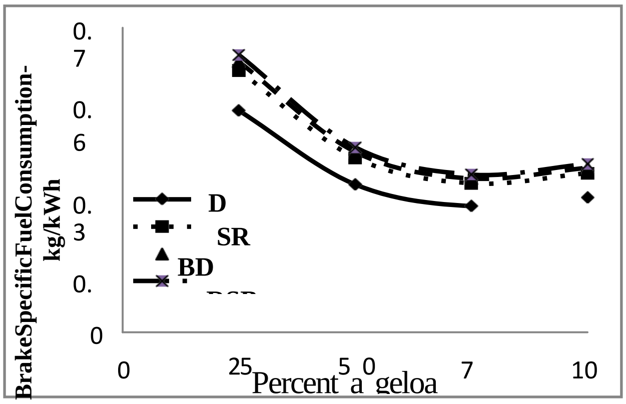

Figure4:Variationofbrakespecificfuelconsumptionwithload

CarbonMonoxideEmission

COemissionwithpercentageloadisshownin Figure 5. CO emission increases due to incomplete or partialcombustion of thefuel.COemission of biodiesels testedwas significantly reduced at all load conditions compared toconventionaldiesel.Thisisanindicationofcleanand

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completeburningofbiodiesels.Biodieselsteste dshowsreducedCObecauseofoxygenmolecul espresentinbiodiesels which helps in complete combustion of the mix atthe later part of diffusion phase. The percentage decrease inCO emission for SRBD, RSBD and RBBD was 48.23%,38.34%and23.12%respectivelyasco mparedtoconventionaldieselat 75%load.

HydroCarbonEmission

HCemissionwithpercentageloadisshownin Figure6.EmissionofHCincreaseswithloadforfuelsamples tested. As the load increases, more mass of fuel isadded and burnt to achieve the constant speed and this mayresultsinpartialcombustionandhenceincreases HC emission. HC emission with biodiesels was greatly reducedatallload conditions comparedto conventionaldiesel forthereasonmentionedincaseofCOemission.Thepercentage reduction in HC emission of SRBD, RSBD andRBBDwas46.43%,35.71%and28.57%respectively ascompared toconventionaldiesel at 75%load.

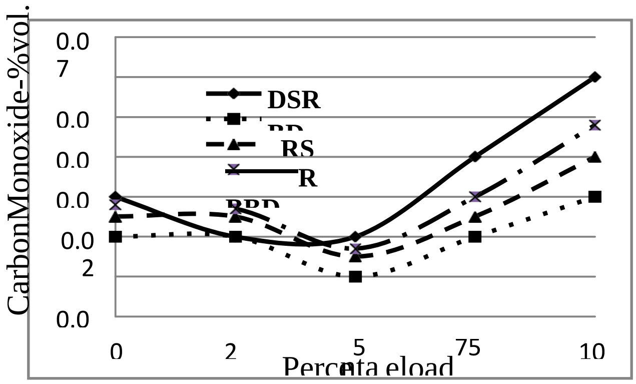

Figure5:Variationofcarbonmonoxidewithload

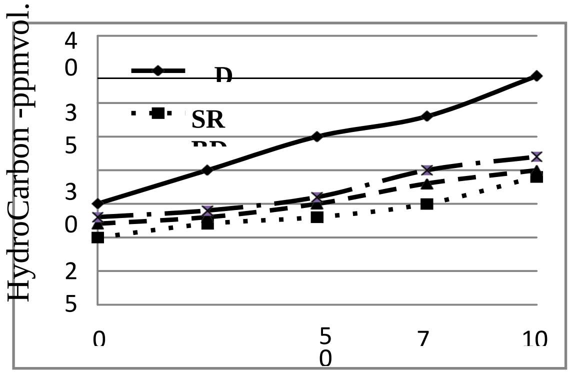

Figure6:Variationofhydrocarbonemission withload

CarbonDioxideEmission

CO_2emissionwithpercentageloadisshownin Figure7.Emission ofCO_2 increases as the loadincreasesfor fuel samples tested. CO_2 emission is higher as a result ofcomplete combustion of the mix. The trend of more CO_2emission with biodiesels tested at all load conditions is anindicationofcompletecombustioncomparedtoconventional diesel. Oxidation reaction of CO enhance duetotheoxygenmoleculepresentinthebiodieselandresultsin higher CO_2.Emission of CO_2 by biodiesels was absorbedby crops and maintains balance of it on the earth surface andhencenoriskofglobalwarming.

OxidesofNitrogen

NO_xemissionincreaseswithloadasshowninFigure 8 for fuel samples tested. Biodiesels tested shownhigher NO_x at all load conditions compared to conventionaldiesel. SRBD has shown highest NO_x at all loads comparedto other two biodiesels tested, indicating that it undergoesclean and complete combustion due to lower viscosity andhigher heating value. Other possible reason for higher NO_xwithbiodieselsasfuelispresenceofoxygenmoleculewhichsupportsincombustion.No_xemissioncanbe controlled by many modern techniques such as exhaust gasrecirculation, advancing injection timing, water injection onto combustionchamberheadetc.

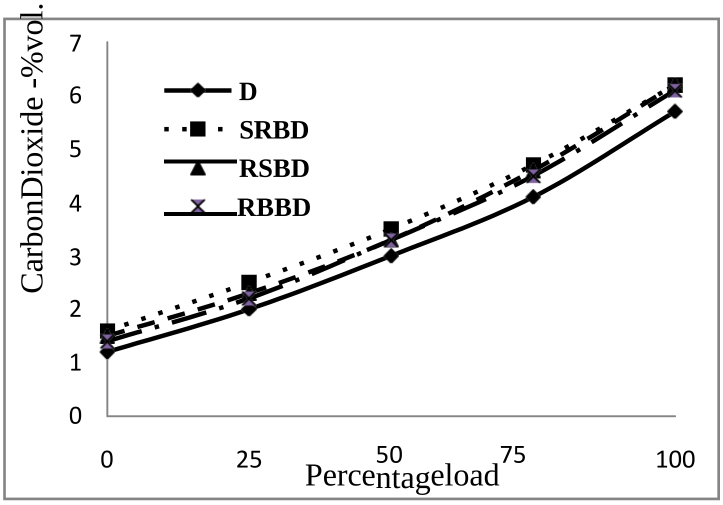

Figure7: Variationofcarbondioxidewithload

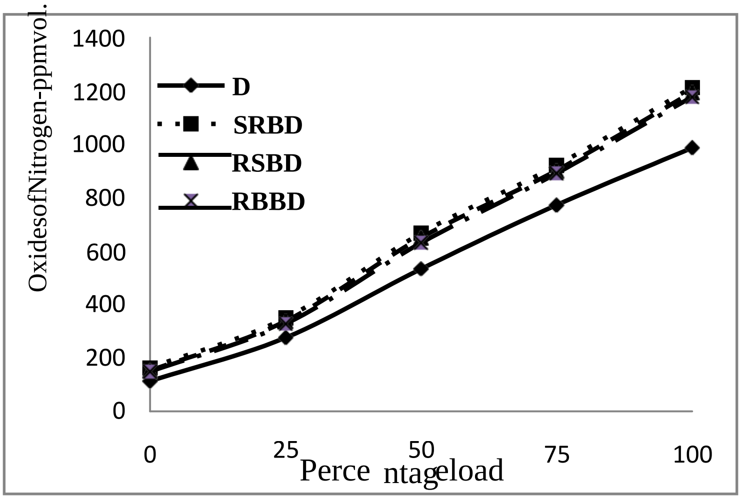

Figure8:Variationofoxidesofnitrogenwithload

SmokeOpacity

Smokeopacity(inpercentage)increaseswithincrease in load is shown in Figure 9. A Lower CO and HCemission tends to reduce smoke opacity. As biodiesels testedundergo complete combustion due to the presence of oxygenmolecule, smoke opacity was considerably reducedat allloadconditionscomparedtoconventionaldiesel.Thepercentage decrease in smoke opacity of SRBD, RSBD andRBBD was 33.62%, 22.5% and 17.1% respectively at 75%load.

EffectofIgnitionDelay

Figure10showsvariationofignitiondelaywithpercentage load.Ignitiondelayislongeratno loadcondition and goes on decreasing for fuel samples tested as the loadincreases. Diesel is having longer ignition delay at all loadconditions as compared with neat biodiesels tested. Delayperiodofneatbiodieselsisshorter,aschemicaldelayreducesduetothepresenceofoxygenmoleculewhichprepares the mixture well before piston reaches top deadcenterandcombustionstarts.Theotherfactoron whichdelay period depends is cetane number. As cetane number ofbiodiesels tested is more that diesel and hence delay periodreduces. The total ignition delay period for D, SRBD, RSBDand RBBD was 8, 4, 5 and 4 degrees of CA respectively at75% load. The overall decrease in delay for biodiesels was2-6 degreesofCAascompared to conventionaldiesel.

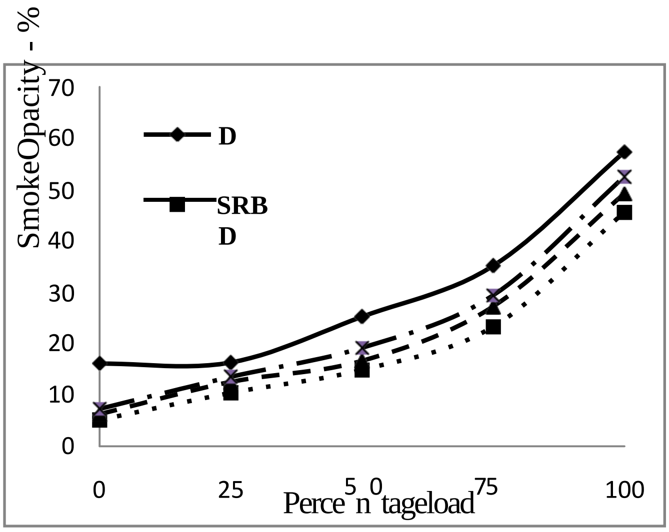

Figure9: Variationofsmokeopacitywithload

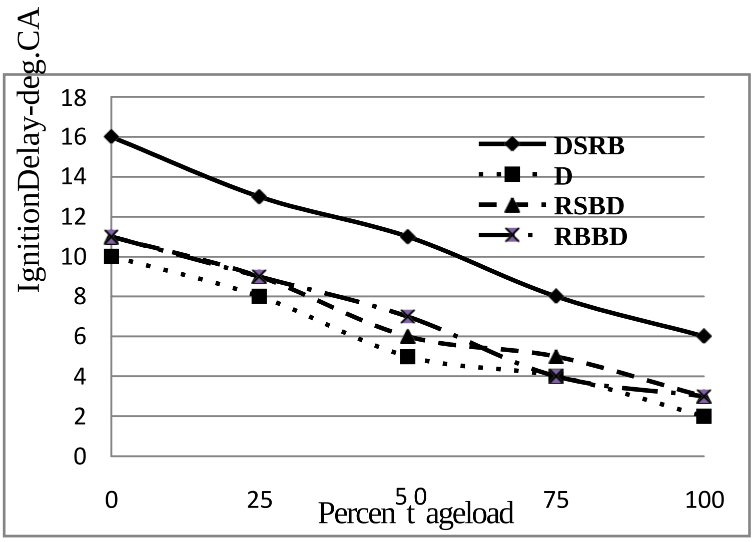

Figure 10:Variationofignitiondelay(°CA)withload

HeatReleaseRate

Figure11showsvariationofHRRwithdegrees of CA for fuel samples tested at 75% load. PeakHRRforconventionaldieselwashighestbecause ofitshigher heating value and lower viscosity. As calorific valueof biodiesels was lower than diesel and delay periods wereshorter, peak HRR gets reduced and shifts away from TDC.The values of peak HRR for D, SRBD, RSBD and RBBDwas 89.89, 80.53, 75.69 and 71.91 kJ/m^3 before 2-4 degreesofCAbefore TDC.

CylinderPressureRise

Variation of cylinder pressure rise with degrees ofCA for fuel samples tested is shown in Figure 12 at 75%load. Conventional diesel releases higher peak pressure at allload conditions as compared to neat biodiesels because of itshigher heating value and lower viscosity It is observed fromthe graph that, the peak cylinderpressurefor D, SRBD,RSBDandRBBDwas65.19,63.65,61.76and 60.52bar respectivelyafter TDCby6-8degreesofCA.

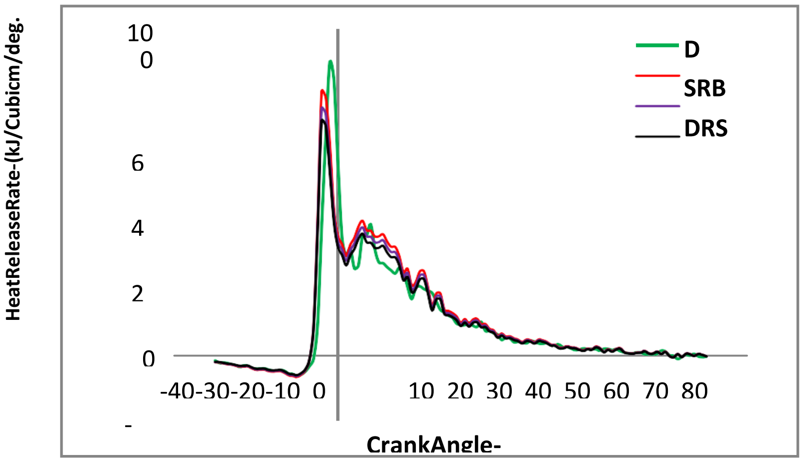

Figure11: Heatreleaseratewithcrankangleindegreesat75%load

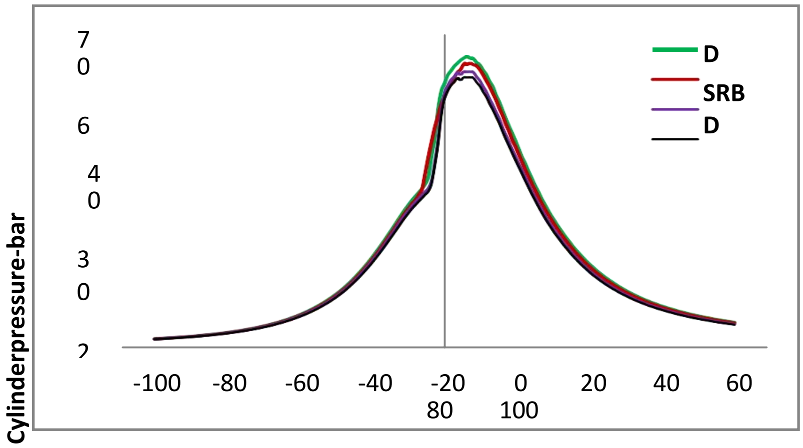

Figure12:Cylinderpressurerisewithcrankangleindegreesat75% load

Conclusions

Experiments were conducted on single cylinder,4-stroke air cooled diesel engine, at an injection pressure of200 bar and injection timing of 23°before TDC with diesel,SRBD,RSBDandRBBDasfuels.Theperformance,exhaust emissions and combustion parameters for biodieselstested were analyzed and were compared with conventionaldiesel.Afterdetailedanalysisoftheresultsfollowingconclusionsweredrawn.

1. TheneatbiodieselsofSRBD,RSBDandRBBDcanbe successfully used in a diesel enginewithout anymodifications of base engine design as an alternate todiesel.
2. Theperformanceofenginewasdroppedwithbiodiesels operation due to their higher viscosityandlowerheatingvalueascompared toconventional diesel. The BTE was lower and BSFCwashigherforbiodieselstestedatallloadconditionsascompared to
3. conventionaldiesel.
4. Exhaust emissions i.e. CO, HC and smoke opacityforbiodieselstestedweresignificantlyreduced(except NO_x) at all load conditions as compared toconventional dieseland is mentioned below (75%load)
    - The percentage decrease in CO emissionforSRBD,RSBDandRBBDwas48.23%,38.34%and23.12%respectively.

- The percentage decrease in HC emissionforSRBD,RSBDandRBBDwas46.43%,35.71%and28.57%respectively
- The percentage decrease in smoke opacityforSRBD,RSBDandRBBD was33.62%,22.5%and 17.1%respectively

5. Thecylinderpeakpressureriseandheatreleaserate were reduced with biodiesel operations at allload conditions as compared to conventional diesel.The higher viscosity and lower heating values arethereasonfor this.
6. Combustionanalysisrevealedthat,ignitiondelayofbiodieselstestedwasshorteratallloadconditions as compared to conventional diesel andwasshorter intherangeof3-6 degreesofCA.
7. Among three biodiesels tested, SRBD has showedbetterresults in terms of improvedperformance,significant reduction in exhaust emissions (exceptNO_x),and higher peak cylinder pressure and heatrelease rate. Thus we can conclude that SRBD canbeabetter choiceasapotentialalternateto diesel.

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