ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc THESIS

ALİ KESKİN

PERFORMANCE AND EMISSION CHARACTERISTICS OF DIESEL ENGINES USING DIESEL FUEL, VEGETABLE OIL AND ALCOHOL BLENDS

DEPARTMENT OF MECHANICAL ENGINEERING

ADANA, 2000

ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

PERFORMANCE AND EMISSION CHARACTERISTICS OF DIESEL ENGINES USING DIESEL FUEL, VEGETABLE OIL AND ALCOHOL BLENDS

ALİ KESKİN

YÜKSEK LİSANS TEZİ

MAKİNA MÜHENDİSLİĞİ ANABİLİM DALI

Bu Tez 23 / 8 / 2000 Tarihinde Aşağıdaki Jüri Üyeleri Tarafından Oybirliği İle Kabul Edilmiştir.

İmza:	İmza:	İmza: ....
Doç. Dr. Kadir AYDIN	Doç. Dr. Osman SERİNDAĞ	Yrd. Doç. Dr. Ahmet PINARBAŞI
DANIŞMAN	ÜYE	ÜYE

Bu Tez Enstitümüz Makina Mühendisliği Anabilim Dalında Hazırlanmıştır.

Kod No: 1744

Prof. Dr. Melih BORAL
Enstitü Müdürü

Bu çalışma Çukurova Üniversitesi Araştırma Fonu tarafından desteklenmiştir.
Proje No: FBE.99.YL.31

ABSTRACT

MSc THESIS

PERFORMANCE AND EMISSION CHARACTERISTICS OF DIESEL ENGINES USING DIESEL FUEL, VEGETABLE OIL AND ALCOHOL BLENDS

ALİ KESKİN

DEPARTMENT OF MECHANICAL ENGINEERING
INSTITUTE OF NATURAL AND APPLIED SCIENCES
UNIVERSITY OF ÇUKUROVA

Supervisor : Assoc. Prof.Dr. Kadir AYDIN

Year: 2000, Pages: 83

Jury : Assoc. Prof. Dr. Kadir AYDIN

: Assoc. Prof. Dr. Osman SERİNDAĞ

: Assist. Prof. Dr. Ahmet PINARBAŞI

In this experimental study usability of cotton oil methyl ester - diesel fuel blends and cotton oil – ethyl alcohol – diesel fuel blends as an alternative fuel for diesel engine were investigated. Methyl ester was produced by reacting cotton oil with methyl alcohol. The cotton oil methyl ester – diesel fuel blends were tested in a single cylinder, direct injection diesel engine between 1500 and 3700 rpm. The Cotton oil – ethyl alcohol - diesel fuel blends were tested in three cylinder, direct injection diesel engine between 1000 and 2500. During the engine test, engines performance and emission value were measured. These results were compared with diesel fuel values. In addition, component of engine was checked at the end of the test.

Keywords: Alternative Fuel, Diesel Fuel, Cotton oil, Methyl Ester

ÖZ

YÜKSEK LİSANS TEZİ

DİZEL MOTORLARDA MOTORİN, BİTKİSEL YAĞLAR VE ALKOL KARIŞIMLARININ PERFORMANSA ETİKLERİNİN ARAŞTIRILMASI

ALİ KESKİN

ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
MAKİNA MÜHENDİSLİĞİ ANABİLİM DALI

Danışman : Doç. Dr. Kadir AYDIN
Yıl: 2000, Sayfa: 83
Jüri : Doç. Dr. Kadir AYDIN
: Doç. Dr. Osman SERİNDAĞ
: Yrd.Doç. Dr. Ahmet PINARBAŞI

Yapılan deneysel çalışmada, pamuk yağı metil esteri – dizel yakıtı karışımları ve pamuk yağı – etil alkol – dizel yakıtı karışımlarının dizel motorlarda alternatif yakıt olarak kullanılabilirliği araştırıldı. Karışımlarda alternatif yakıt olarak kullanılan metil ester pamuk yağıyla metil alkollün kimyasal tepkimeye girmesiyle elde edildi. Pamuk yağı metil esteri – dizel yakıtı karışımları tek silindirli direk püskürtmeli bir dizel motorda 1500 – 3700 d/d devirler arasında test edildi. Pamuk yağı – etil alkol – dizel yakıtı karışımları ise 3 silindirli, direk püskürtmeli bir dizel motorda 1000 – 2500 d/d devirler arasında test edildi. Test esnasında motorların performans ve emisyon değerleri ölçüldü ve bu değerler dizel yakıtı ile ölçülen değerlerle karşılaştırıldı. Ayrıca deney sonunda motor parçaları kontrol edildi.

Anahtar Kelimeler: Alternatif Yakıt, Dizel Yakıtı, Pamuk Yağı, Metil Ester

ACKNOWLEDGEMENTS

I am grateful to my supervisor Assoc. Prof. Dr. Kadir AYDIN for helping me throughout the preparation of this thesis.

I would like to thank my specialist friend, Levent KARA and technician in our laboratory Cevdet YILDIRIM.

I would like to thank my manager Uğur ALPTÜRK and my teacher friends for their support and interests.

And finally, I would like to thank my family for interest and supports.

CONTENTS Page

ABSTRACT........ I
ÖZ........ II
ACKNOWLEDGEMENT........ III
CONTENTS........ IV
NOMENCLATURE........ VI
LIST OF TABLES........ VII
LIST OF FIGURES........ IX
1. INTRODUCTION........ 1
2. LITERATURE REVIEW........ 5
3. METERIAL AND METHOD........ 13
  3.1. Chemical and Physical Properties of Vegetable Oils........ 13
    3.1.1. Chemical Properties of Vegetable Oils........ 13
    3.1.2. Physical Properties of Vegetable Oils........ 15
  3.2. Experimental Study........ 17
    3.2.1. Preparation of Alternative Fuels........ 17
      3.2.1.1. Preparation of Cotton Oil Methyl Ester........ 17
      3.2.1.2. Alternative fuels........ 20
    3.2.2. Physical and Chemical Properties of alternative fuels........ 20
  3.3 Experimental Apparatus........ 22
  3.4. Calculations........ 25
4. RESULTS AND DISCUSSION........ 29
  4.1. Presentation and Analysis of Data for Methyl Ester and Diesel Fuel Blends........ 29
    4.1.1. Torque........ 29
    4.1.2. Power........ 32
    4.1.3. Specific Fuel Consumption........ 35
    4.1.4. Exhaust Gas Temperature........ 38
    4.1.5. Heat Loss to Exhaust........ 41
    4.1.6. Exhaust Gas Emission........ 43

4.2. Presentation and Analysis of Data for Cotton Oil, Ethyl Alcohol and Diesel Fuel Blends.. 52
4.2.1. Power.. 52
4.2.2. Torque.. 54
4.2.3. Heat Loss.. 55
4.2.4. Mass of Exhaust Gasses.. 57
5. CONCLUSION... 60
REFERENCES.. 62
CIRRICULUM VITAE.. 67
APPENDIX... 68

NOMENCLATURE

T	Torque (Nm)
Pb	Brake power (Watt)
N	Engine speed (rpm)
m_a	Air consumption (kg/s)
m_f	Fuel consumption (kg/hr)
sg_f	Specific gravity for fuel (kg/m^3)
sfc	Specific fuel consumption (g/kWh)
R	Air/fuel ratio
K	Coefficient of the calibration of the dynamometer
Q	Heat loss (kj/s)
K	Opacity
2D	Diesel fuel
COME	Cotton oil methyl ester
CO	Cotton oil
A	Ethyl alcohol

LIST OF TABLES

Table 1.1. Reserve of fossil fuel for regions.. 2

Table 1.2. Production and consumption of crude between 1991 and 1994 in Turkey.. 2

Table 2.1. Advantages and disadvantages of sunflower oil and sunflower oil methyl ester.. 7

Table 2.2. Properties of the blends.. 8

Table 2.3. Diesel engine performance using sunflower oil and sunflower oil–diesel fuel mixtures as fuel.. 10

Table 3.1. Fatty acid composition of some vegetable oils.......................... 14

Table 3.2. Elemental composition of some vegetable oils and diesel fuel..... 15

Table 3.3. Physical properties of some vegetable oils................................. 16

Table 3.4. Density of experimental fuels.. 20

Table 3.5. Calorific Value of alternative fuels... 21

Table 4.3. Properties of test engine (LISTER PETER TD111).................... 22

Table A.1. Measured and Calculated values for 2D...................................... 69

Table A.2. Measured and Calculated values for 10% COME + 90% 2D........ 70

Table A.3. Measured and Calculated values for 20% COME + 80% 2D........ 71

Table A.4. Measured and Calculated values for 30% COME + 70% 2D........ 72

Table A.5. Measured and Calculated values for 40% COME + 60% 2D........ 73

Table A.6. Measured and Calculated values for %50 COME + %50 2D........ 74

Table A.7. Measured and Calculated values for %60 COME + %40 2D........ 75

Table A.8. Measured and Calculated values for %70 COME + %30 2D........ 76

Table A.9. Measured and Calculated values for 2D...................................... 77

Table A.10. Measured and Calculated values for 50% 2D – 40% CO – 10% A at 70 °C.. 78

Table A.11. Measured and Calculated values for 50% 2D – 40% CO – 10% A at 60 °C.. 79

Table A.12. Measured and Calculated values for 50% 2D – 40% CO – 10% A at 50 °C.. 80

Table A.13. Measured and Calculated values for 40% 2D – 40% CO – 20% A at 70 °C... 81
Table A.14. Measured and Calculated values for 40% 2D - %40 CO – 20% A at 60 °C... 82
Table A.15. Measured and Calculated values for 40% 2D – 40% CO – 20% A at 50 °C... 83

LIST OF FIGURE

Figure 1.1. Energy consumption of world in 1995 ... 1
Figure 3.1. Typical structure of diesel fuel and triglycerides ... 13
Figure 3.2. Fatty acid ... 14
Figure 3.3. Transesterification of vegetable oils ... 17
Figure 3.4. Distillation of vegetable oils ... 18
Figure 3.5. Kinematics viscosity of diesel fuel, cotton oil and cotton oils methyl ester at different temperatures ... 22
Figure 4.1. Torque performance curve of 2D and 10% COME + 90% 2D ... 29
Figure 4.2. Torque performance curve of 2D and 20% COME + 80% 2D ... 30
Figure 4.3. Torque performance curve of 2D and 30% COME + 70% 2D ... 30
Figure 4.4. Torque performance curve of 2D and 40% COME + 60% 2D ... 30
Figure 4.5. Torque performance curve of 2D and 50% COME + 50% 2D ... 31
Figure 4.6. Torque performance curve of 2D and 60% COME + 40% 2D ... 31
Figure 4.7. Torque performance curve of 2D and 70% COME + 30% 2D ... 31
Figure 4.8. Power performance curve of 2D and 10% COME + 90% 2D ... 32
Figure 4.9. Power performance curve of 2D and 20% COME + 80% 2D ... 33
Figure 4.10. Power performance curve of 2D and 30% COME + 70% 2D ... 33
Figure 4.11. Power performance curve of 2D and 40% COME + 60% 2D ... 33
Figure 4.12. Power performance curve of 2D and 50% COME + 50% 2D ... 34
Figure 4.13. Power performance curve of 2D and 60% COME + 40% 2D ... 34
Figure 4.14. Power performance curve of 2D and 70% COME + 30% 2D ... 34
Figure 4.15. Specific fuel consumption of 2D and 10% COME + 90% 2D ... 35
Figure 4.16. Specific fuel consumption of 2D and 20% COME + 80% 2D ... 36
Figure 4.17. Specific fuel consumption of 2D and 30% COME + 70% 2D ... 36
Figure 4.18. Specific fuel consumption of 2D and 40% COME + 60% 2D ... 36
Figure 4.19. Specific fuel consumption of 2D and 50% COME + 50% 2D ... 37
Figure 4.20. Specific fuel consumption of 2D and 60% COME + 40% 2D ... 37
Figure 4.21. Specific fuel consumption of 2D and 70% COME + 30% 2D ... 37
Figure 4.22. Exhaust temperature of 2D and 10% COME + 70% 2D ... 38

Figure 4.23. Exhaust temperature of 2D and 20% COME + 80% 2D............. 39
Figure 4.24. Exhaust temperature of 2D and 30% COME + 70% 2D............. 39
Figure 4.25. Exhaust temperature of 2D and 40% COME + 60% 2D............. 39
Figure 4.26. Exhaust temperature of 2D and 50% COME + 50% 2D............. 40
Figure 4.27. Exhaust temperature of 2D and 60% COME + 40% 2D............. 40
Figure 4.28. Exhaust temperature of 2D and 60% COME + 40% 2D............. 40
Figure 4.29. % Heat loss to Exhaust of 2D and 10% COME + 90% 2D......... 41
Figure 4.30. % Heat loss to Exhaust of 2D and 20% COME + 80% 2D......... 41
Figure 4.31. % Heat loss to Exhaust of 2D and 30% COME + 70% 2D......... 42
Figure 4.32. % Heat loss to Exhaust of 2D and 40% COME + 60% 2D......... 42
Figure 4.33. % Heat loss to Exhaust of 2D and 50% COME + 50% 2D......... 42
Figure 4.34. % Heat loss to Exhaust of 2D and 60% COME + 40% 2D......... 43
Figure 4.35. % Heat loss to Exhaust of 2D and 70% COME + 30% 2D......... 43
Figure 4.36. Opacity (k) of 2D and 10% COME + 90% 2D.............................. 44
Figure 4.37. Opacity (k) of 2D and 20% COME + 80% 2D.............................. 44
Figure 4.38. Opacity (k) of 2D and 30% COME + 70% 2D.............................. 44
Figure 4.39. Opacity (k) of 2D and 40% COME + 60% 2D.............................. 45
Figure 4.40. Opacity (k) of 2D and 50% COME + 50% 2D.............................. 45
Figure 4.41. Opacity (k) of 2D and 60% COME + 40% 2D.............................. 45
Figure 4.42. Opacity (k) of 2D and 70% COME + 30% 2D.............................. 46
Figure 4.43. Smoke (g/m^3) of 2D and 10% COME + 90% 2D.......................... 46
Figure 4.44. Smoke (g/m^3) of 2D and 20% COME + 80% 2D.......................... 46
Figure 4.45. Smoke (g/m^3) of 2D and 30% COME + 70% 2D.......................... 47
Figure 4.46. Smoke (g/m^3) of 2D and 40% COME + 60% 2D.......................... 47
Figure 4.47. Smoke (g/m^3) of 2D and 50% COME + 50% 2D.......................... 47
Figure 4.48. Smoke (g/m^3) of 2D and 60% COME + 40% 2D.......................... 48
Figure 4.49. Smoke (g/m^3) of 2D and 70% COME + 30% 2D.......................... 48
Figure 4.50. % opacity of 2D and 10% COME + 90% 2D.............................. 48
Figure 4.51. % Opacity of 2D and 20% COME + 80% 2D.............................. 49
Figure 4.52. % Opacity of 2D and 20% COME + 80% 2D.............................. 49
Figure 4.53. % Opacity of 2D and 40% COME + 60% 2D.............................. 49

Figure 4.54. % Opacity of 2D and 50% COME + 50% 2D................................ 50
Figure 4.55. % Opacity of 2D and 60% COME + 40% 2D................................ 50
Figure 4.56. % Opacity of 2D and 70% COME + 30% 2D................................ 50
Figure 4.57. Power performance curve of 2D, 50% 2D-40% CO-10% A and 40% 2D-40% CO-20% A at 70 °C.. 52
Figure 4.58. Power performance curve of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 60 °C.. 53
Figure 4.59. Power performance curve of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 50 °C.. 53
Figure 4.60. Torque performance curve of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 70 °C.. 54
Figure 4.61. Torque performance curve of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 60 °C.. 54
Figure 4.62. Torque performance curve of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 50 °C.. 55
Figure 4.63. Heat loss of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 70 °C.. 56
Figure 4.64. Heat Loss of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 60 °C.. 56
Figure 4.65. Heat loss of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 50 °C.. 57
Figure 4.66. Mass of exhaust gases for 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 70 °C.. 57
Figure 4.67. Mass of exhaust gases for 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 60 °C.. 58
Figure 4.68. Mass of exhaust gases for 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 50 °C.. 58

1. INTRODUCTION

The population of the world use many different forms of energy, but particularly the energy produced from burning fossil fuels (mainly coal, oil and natural gas), which currently provide about 62 % of the world's energy. Energy consumption of world for different energy source is shown on the figure 1.1. Today reserves of fossil fuels are currently sufficient for world's needs, but they are being used up rapidly and cannot be replaced. In addition, future demand for energy is expected to become much greater, as developing countries increase their energy consumption in line with industrialised countries.

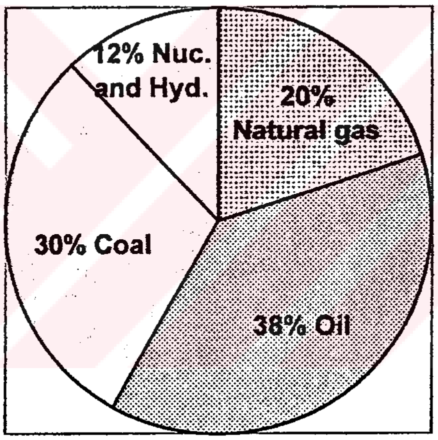

Figure 1.1. Energy consumption of world in 1995 (1995 Energy report, 1996)

However, reserves of the fossil fuel is not very much on the world. For example, oil, natural gas and coal will respectively run out in 42.8 years, 228 years, 64.7 years. Reserves of fossil fuels for regions are shown on Table 1.1. (1995 Energy Report). In addition, there is a real possibility that 80 % of these reserves will have been consumed in the brief period between 1960 and 2020. This has led to the fear of an energy crisis.

Table 1.1. Reserve of fossil fuel for regions (1995 Energy report, 1996).

REGION	PETROLEUM	NATURAL GAS	COAL
	Years	years	years
North America	18.8	12	246
Middle and South America	39.3	73.9	268
SSCB Country	22.0	80.4	500
Middle East	92.3	100	286
Africa	29.2	100	
Asia and Oceania	17.0	45.8	158
Europe	6.9	21.5	183
World	**42.8**	**64.7**	**228**

Production of fossil fuels in Turkey is insufficient and therefore the most important parts of fossil fuels are imported. The consumption of crude oil is very important factor for Turkish economy. Because, 47% of energy consumption of Turkey depends on crude oil and 87% of this is imported. Table 1.2. shows production and consumption of crude oil between 1991 and 1994 in Turkey.

Table 1.2. Production and consumption of crude oil between 1991 and 1994 in Turkey (Anonymous, 1995).

Years	Production (1000 TP)	Consumption (1000 TP)
1991	4674	23315
1992	4495	24865
1993	4087	28412
1994	3871	27198

In addition, 38.1 % of petroleum consumption in Turkey is diesel fuel. Diesel fuel is a very important energy source for economical development of Turkey, because agricultural equipment, long haul truck transportation, rail road and diesel electricity generator are predominantly operated with diesel fuel. Therefore, absence of diesel fuel affects the life of population.

Solution of the energy crisis and avoiding the dependence for petroleum is to find new alternative renewable energy resources. Today, one of the alternative energy source is vegetable oils for diesel fuel. Using of the vegetable oil as an alternative fuel for diesel engine is not new concept to the world. As early as 1900 a diesel-cycle engine was demonstrated running wholly on ground-nut oil at the Paris Exposition. In fact, activities date back to the late 70's and early 80's. As a result of the OPEC crisis, a significant amount of research on vegetable oil (biodiesel), and other domestically produced fuel, was conducted by various Universities and Government Agencies. The general conclusion at that time was that, the biodiesel was a technically acceptable substitute, replacement, or blending stock for conventional petroleum diesel, but that it's per litter costs were higher than petroleum diesel fuel.

Sunflower, soybean, cotton seed oil and peanut oil usually used as diesel fuel in the experimental studies. Studies shown that vegetable oils are too viscous for prolonged use in diesel engines. Therefore several techniques are being used to reduce viscosity of vegetable oil. One of the techniques proposed to solve the viscosity problems is the dilution technique. Use of vegetable oils blended with conventional diesel fuel as alternative compression ignition engine fuel has been investigated by many researchers during the last decade. Other technique proposed to solve the viscosity problem is transesterification of vegetable oils. The process of transesterification removes glycerol from the triglycerides and replaces it with radicals from the alcohol used for the conversion process. South Africa Republic, Australia, America, Germany, England, Holland, Belgium, Denmark, Spain and France have been investigating this subject for long years (Karaosmanoğlu, et al. 1995). Some of these countries have reduced tax for production of diesel fuel from vegetable oils.

The production of vegetable oil as an alternative fuel will provide the vegetable oil plants to enlarge. This has two advantages: the decrease in energy dependency and the effective use of the agricultural areas. In addition, as far as environmental is concerned, two important points can be mentioned in favour of vegetable oils such as olive vegetable oil. The first of these is that, unlike mineral oil, vegetable contains no sulphur, so that environmental damage due to sulphuric acid is reduced. The second is that vegetable oil takes away more CO_2 from the atmosphere in its production, than it adds by its combustion later, therefore alleviating the problem of the increasing CO_2 content of the atmosphere that keeps many scientists worried, for a number of reasons (Rakopoulos, 1992).

Production of vegetable oil plant will be increased in Turkey, when G.A.P is completely finished. Consequently, potential of vegetable oil production will be more than consumption in Turkey. This potential is used as alternative fuel in the agricultural area.

2. LITERATURE REVIEW

Rudolph Diesel used peanut oil as a fuel in one of his e ngines at the Paris Exposition of 1900 (Altın, R., 1998)

Bruwer, et al. (1980), investigated sunflower seed oil as a fuel source. They found that sunflower oil have a much higher viscosity than diesel fuel and a lower thermal efficiency in nine engines tested. Only a turbo charged engine obtained a higher thermal efficiency with sunflower oil than diesel fuel. The thermal efficiency was found to be almost 2% better while using 100 % sunflower oil than while using 100% diesel fuel. Bruwer, et al. also reported that of the nine engines tested only two experienced starting difficulties when 100 % sunflower oil was used.

Cochran, et al. (1980), Louisiana State University's Agricultural Engineering Department, looked closely at blends of diesel fuel and soybean. They determined viscosity, specific gravity, heating value, flash point and cetane number of soybean oil to diesel fuel and mixtures of the two. They found differences in all properties of each fuel. They recorded the distillation curves for mixtures of 60 %, 40 %, 20 %, 10 % and 0 % soybean oil. They also recorded higher thermal efficiencies with 40 % soybean oil than with 100 % diesel fuel.

Barsic and Humke (1981), reported that sunflower oil – No. 2 diesel fuel blends and peanut oil - No. 2 diesel fuel blends can be used as diesel fuel in diesel engine.

Goering, et al. (1982), evaluated and compared the fuel properties of eleven vegetable oils. Their results showed that all the vegetable oils were much more viscous and more reactive to oxygen than No. 2 diesel fuel. Vegetable oils with the most favourable combination of properties for fuel oils were soybean, cotton seed, corn, rape seed and sesame.

Borgelt and Harris (1982), three Onan engines were fueled with the flowing fuels; a) 100% diesel fuel, b) 25% soyoil – 75% diesel fuel and c) 50% soyoil – 50% diesel fuel. The engines were operated under 50 – 55% load for

1000 hours. The engine experienced no significant differences in measured wear, drop in power or increase in fuel consumption. As the amount of soyoil in the fuel mixture increased, fuel and injection systems experienced problems, the deposits increased and lubricating oil analysis showed changes in wear patterns (Borgelt and Harris, 1982).

Braun and Stephenson (1982), blends of 40 % diesel fuel – 40 % dewaxed soybean oil – 20 % ethanol and 30 % diesel fuel – 40 % dewaxed soybean oil – 30 % ethanol were used as diesel fuel in 4 stroke, 6 cylinder energy cell diesel engine. Engine test result showed that; at full load, fuel governor power output of engine declined about 1,5 percent for the 40:40:20 blend and 4 percent for the 30:40:30 blend. In addition viscosties of blends was determined and power, torque diagrams of blends combustion compared with diesel fuel.

Hasset and Hasan (1982), produced sunflower oil methyl ester to reduce viscosity. Usability of it as an alternative fuel in the diesel engine evaluated and compared with sunflower oil.

Preparation of sunflower oil methyl ester is as flolows ; nine liters of sunflower oil are mixed with 1456 grams of methyl alcohol and 8,4 grams of sodium has been added. The mixture is heated to 62 – 65 °C and held at this temperature with stirring for two hours. Heating and stirring are stopped and at this point glycerol, the primary reaction by product, begins to separate as a layer at the bottom of the reaction vessel. The crude methyl ester is drawn off of the top of this reaction mixture and washed with warm water to remove suspended glycerol, unreacted methanol and catalyst (Hasset and Hasan, 1982).

Sunflower oil methyl ester was tested in a single cylinder direct injection type diesel engine. Lister type LT-1 engine rate at 5,25 BHP is being used. Advantages and disadvantages of sunflower oil and sunflower oil methyl ester are shown in Table 2.1.

Table 2.1. Advantages and disadvantages of sunflower oil and sunflower oil methyl ester (Hasset and Hasan, 1982).

Sunflower oil		Methyl ester	
Advantages	Disadvantages	Advantages	Disadvantages
Low Engine Knock	High injector fouling Under Low Load	Distillation and Viscosity Curves Approximate Diesel fuel.	Polymerized oil?
Only 3% lower combustion efficiency	Polymerized oil	Low smoke	Reported Injector Sticking Problems
Easy Starting	High Engine Deposit	Better Thermal Efficiency	
		Low injector fouling	
		Easy starting	

Walter, et al. (1982), investigated twelve production tractor which were operated on North Dakota farms. The two types of fuels that were used, were blends of 50% sunflower oil – 50% diesel fuel and 25% sunflower oil – 75% diesel fuel. The handling characteristics of the blends and the durability effect on the engines were evaluated. There were no particular problems with fuel handling or engine performance while the tractors accumulated 6.300 total hours. Engine inspection did reveal excess carbon deposits on several engine components. Engine rectangular style compression rings were more prone to ring sticking problems which accelerated liner wear.

Blumberg and Fort (1982), produced experimental fuels made up of cotton seed oil (CSO), transesterified cotton seed oil (TECSO) and No. 2 diesel fuel (2D). Eight blends were evaluated: Phillips' reference diesel fuel ; 30% CSO, 70% 2D ; 50% CSO, 50% 2D ; 65% CSO, 35% 2D ; 80% CSO, 20% 2D ; 50% CSO, 50% TECSO ; 50% TECSO, 50% 2D and 100% TECSO (by volume). All blends were analysed and these fuels have been compared to baseline No. 2 diesel fuel. Properties of the blends are shown in Table 2.2.

Table 2.2. Properties of the blends (Blumberg and Fort 1982).

	2D	30%CSO 70% 2D	50% CSO 50% 2D	80% CSO 20% 2D	50%TECSO 50% 2D	TECSO
API Gravity, Deg.	35.2	30.7	28.2	24.5	31.8	28.8
Density, g/ml	.8488	.8722	.8860	.9070	.8665	.8828
Viscosity, cs 40 °C	2.43	5..34	9.03	19.05	3.37	4.37
Cloud Point °C	-20	-16	-	-9	-5	-5
Pour Point °C	-24	-21	-16	-14	-6	-2
Flash Point °C	75	78	81	100	87	110
Cetane Number	47.2	45.1	48.6	32.0	48.0	51.2
Gross Heat Value, j/g	45310	43140	42230	40670	42470	40150
Net Heat Value, j/g	42620	40510	39590	38190	39990	37570
Ash %	.0022	.001	.0016	.001	.001	.001
Carbon Residue %	.18	.32	3.79	5.24	.01	.28
Sulfur %	.37	.11	.54	.61	.07	.001
Copper Corrosion	1a	1a	1a	1a	1a	1a
Color	2.0	2.5	2,5	2.5	2.0	1.0

Blends of 50% CSO – 50% 2D and 50% TECSO – 50% 2D were used as diesel fuel in 6 cylinder turbocharged, direct – injection diesel engine for a 200 hour cyclic durability test.

Results of engine testing for 50% CSO – 50% 2D blend ;

- Performance and emission are essentially the same as with the base line 2D fuel.

- It offers a reasonably high substitution of CSO for diesel fue.

- Cylinder inspection after the performance tests showed no suspicious condition.

Results of engine testing for 50% TECSO – 50% 2D blend ;

- With the exception of maximum power, performance and emission are comparable with results of diesel fuel.

- Inspection of the cylinders after performance runs did not reveal any potential problems (cylinder walls and piston tops were dry with minimal deposits).

Tahir, et al. (1982), investigated chemical and physical properties of crude – degummed sunflower oil and its methyl ester. In addition, performance characteristics of crude – degummed sunflower oil were determined with a Buda diesel engine. This test engine was a single cylinder, precombustion chamber design, stroke of 8,73 cm and maximum power of 7,5 kW. Summary of the results of this experimental study ;

- The most detrimental parameter in the use of sunflower oil is its higher viscosity which is about 14 times higher than diesel fuel at 37,75 °C
- The problem of higher viscosity can be solved by transesterification of sunflower oil to its methyl ester.
- The cetane number of sunflower oil is a little less than the minimum value of 40 for No. 2 diesel fuel. Knocking and starting problems were encountered when burnt in the compression ignition engines due to its high boiling point.
- Specific fuel consumption was higher due to its lower energy value.
- Oxidation of sunflower oil left heavy gum and wax deposits on the stationary engine parts and the test bench equipment.
- Lower levels of corrosion can be expected on metal parts due to the lower sulphur content in the sunflower oil.
- Fire hazards associated with fuel handling will be reduced because of the higher flash point of sunflower oil.

Zıejewski and Kaufman (1982), tested the blend of 25% alkali refined sunflower oil – 75% diesel fuel in a direct injection, intercooled and turbocharged, four cylinder Allis-Chalmers diesel engine. Engine testing shown that, there were no significant problems with engine operation during the baseline fuel. Moreover, problems were experieced while using the blend fuel. The major problems were; (1) abnormal buildup on the injection nozzle tips, (2) injector needle sticking, (3) secondary injection, (4) carbon buildup in the intake ports, (5) carbon deposits on the exhaust valve stems, (6) carbon filling of the compression ring grooves, and (7) abnormal lacquer and varnish buildup on the third piston land.

Peterson, et al. (1983), tested sunflower oil and blends of sunflower oil and diesel fuel in a 2.8 Liters direct injection 4 cylinder diesel engine with hole – type injectors. Results of performance test are shown in table 2.3.

Table 2.3. Diesel engine performance using sunflower oil and sunflower oil – diesel fuel mixtures as fuel (Peterson, et al., 1983).

Fuel Type	Power, kW	B.S.F.C., kg/kWh	Thermal Efficiency, %
100 % Sunflower Oil.	29,5	0,34	26,6
75 % Sunflower Oil.	29,8	0,34	25,5
50 % Sunflower Oil.	30,2	0,35	25,2
25 % Sunflower Oil.	29,4	0,32	25,6
100 % Diesel Fuel.	29,4	0,32	24,9

Geyer and et. al. (1984), tested cotton seed oil sunflower oil and methyl esters in a small single cylinder diesel engine. During the test, emission of engine investigated. Engine testing showed that, particle emission of vegetable oils is higher than particle emission of diesel fuel but particle emission of methyl esters is lower than particle emission of diesel fuel.

Apfelbeck (1986), investigated production of vegetable oil and preparation of diesel fuel from vegetable oil. Calorific value and structure of vegetable oil were determined. In addition, he reported that there are very big vegetable oil potential on the world for alternative energy.

Rakopoulos (1992), used a blend of 25 % olive oil - 75 % diesel fuel and a blend of 50 % olive oil – 50 % diesel fuel as diesel fuel in direct injection and indirect injection diesel engine. The influence of the blends, for a large range loads, has been examined on fuel consumption, maximum pressure, exhaust temperature, exhaust smokiness and exhaust-gas emission such as nitrogen oxides (NO_X), hydrocarbons (HC) and carbon monoxide (CO). Engine testing showed that results of 50 % - 50 % blend is best suitable. In addition, performance and emission characteristics of direct injection and indirection diesel engine are same.

Culshaw (1993), produced rape seed methyl ester and used as diesel fuel in diesel engine without any change. He reported that chemical and physical properties of rape seed methyl ester and diesel fuel are similar. Rape seed methyl ester can be used as diesel fuel.

Preparation of rape seed methyl esters in this experimental study was as follows ; rape seed oil was transesterified with methyl alcohol (1 ton of rape seed oil to 110 kg of methyl alcohol) at 50 °C. During the reaction of ester, sodium or potassium was used as catalyst.

Çetinkaya (1994), used sunflower oil and sunflower oil / diesel fuel mixture as alternative diesel fuel in turbulence chamber diesel engine. Before the injection, fuels were heated to 110 –120 °C. In addition, pressure of injection were increased. Results showed that from the performance viewpoint, both sunflower oil and sunflower / diesel fuel mixture are promising alternatives as diesel fuel for turbulence chamber diesel engines. However, its high viscosity, drying with time and thickening in cold condition are very important problem for flow and atomization.

Purcell, et al. (1996), ivestigated chemical and physical properties of soybean methyl ester. In short term test, methyl ester of soybean oil was used as diesel fuel in an indirect injection diesel engine. The amount of varied gasses in the exhaust was measured. Engine testing showed that emission of soybean methyl ester are lower than diesel fuel.

Cığızoğlu, et al. (1997), tested the blend of 20% sunflower oil and 80% No. 2 diesel fuel in a precombustion chamber diesel engine. Short-term engine testing showed that the fuel blends has characteristics similar to those of the baseline diesel fuel and that it displayed less smoke emission than the diesel fuel.

Batmaz and Altın (1997), tested crop oil and 50% crop oil / 50% diesel fuel blend in single cylinder, direct injection diesel engines. This experimental fuels were evaluated and compared with diesel fuel. The results showed that there is a possibility of using crop oil as an diesel fuel in the view of the engine performance, fuel economy and exhaust emission.

Altın (1998), sought possibility of industrial type oil as alternative source of fuel for diesel engines. For this reason, sunflower and soybean oils together with sunflower methyl ester and soybean methyl ester were tested in single- cylinder, four-stroke, 770 cc diesel engine at full load-different engine speeds and constant speed (1300 rpm, 1500 rpm)-different loads. Engine performance and emission values were observed. These results were compared with diesel fuel values. Moreover, the engine was subjected to 50 hours strength test and carbon residuals in exhaust.

As a result of engine performance and exhaust emission experiments, it has been determined that vegetable oils and vegetable methyl ester can be used as alternative fuels to diesel engine fuels in physical and chemical properties, it has also been determined that, methyl esters are better fuels than vegetable oils in enduring applications.

3. MATERIAL AND METHOD

3.1. Chemical and Physical Properties of Vegetable Oils

3.1.1. Chemical Properties of Vegetable Oils

Vegetable oil is produced from fruit and seed of vegetable with different method. Chemical composition of vegetable oil is different from the petroleum based fuels. For example; diesel fuel is usually composed of paraffin (C_nH_{2n+2}) and aromatic hydro carbon. Typical structure of diesel fuel is given below in figure 3.1. The molecule of a vegetable oil is usually composed of triglycerides (about 95%) and non – triglycerides (about 5%). Triglycerides are esters composed of one molecule of glycerol and tree molecules of fatty acids. The chemical composition of triglycerides is also given below in figure 3.1.

```
    H H H H H H H H H H H H H H
    | | | | | | | | | | | | | |
  H-C-C-C-C-C-C-C-C-C-C-C-C-C-C-H
    | | | | | | | | | | | | | |
    H H H H H H H H H H H H H H
```

-Diesel Fuel ($C_{16}H_{34}$)

```
CH2-OH        H-O-(CO)-R                       CH2-O-(CO)-R
|                                              |
CH2-OH   +    H-O-(CO)-R'   ------>   3HOH  +  CH2-O-(CO)-R'
|                                              |
CH2-OH        H-O-(CO)-R''                     CH2-O-(C0)-R''

Glycerol      Fatty Acids             Water    Triglycerides
```

Figure 3.1. Typical structure of diesel fuel and triglycerides (Goering et al. 1982).

Fatty acids are composed of a carboxyl group and a hydrocarbon chain (figure 3.2.). Fatty acids comprise from 94% to 96% of the total mass of a triglyceride molecule, therefore the proportion of these acids determine the physicochemical properties (e.g. viscosity, calorific value) of an oil. Fatty acid composition of some vegetable oil is shown in table 3.1.

$$\begin{array}{c} O \\ \| \\ H-O-C \end{array} \text{———} (CH_2)_n - CH_3$$

Carboxyl end Hydrocarbon chain

Figure 3.2. Fatty acid composition.

Table 3.1. Fatty acid composition of some vegetable oils (Stout, 1984).

	Vegetable Oils					
Fatty acids	Structure of Carbon	Sunflower oil	Peanut oil	Cotton seed oil	Corn oil	Soybean oil
Miristic	14	-	-	1	-	-
Palmitic	16	6	10	24	11	11
Stearic	18	5	3	2	2	4
Oleic	18:1	19	49	19	26	24
Linoleic	18:2	69	34	54	60	53
Linolenic	18:3	1	-	1	1	8
Arachidic	20	-	1	-	-	-
Behenic	22	-	3	-	-	-

Elemental composition of some vegetable oils and diesel fuel are shown in table 3.2. There is no sulphur in some vegetable oils but carbon, hydrogen, and oxygen content are as same as with diesel fuel.

Table 3.2. Elemental composition of some vegetable oils and diesel fuel (Apfelbeck, 1986).

	Diesel Fuel	Rape Seed Oil	Soybean Oil	Sunflower 0il
Carbon, C %	86	77.7	77.8	77.6
Hydrogen, H %	13	12.0	11.8	11.7
Oxygen, O %	0.4	10.9	10.7	11.1
Sulphur, S %	0.3	-	-	-

3.1.2. Physical Properties of Vegetable Oils

Kinematics Viscosity: Viscosity of vegetable oils are most important property for use of vegetable oils as an alternative fuel in diesel engine. Viscosity of vegetable oils are much more higher than diesel fuel. Viscosity of vegetable oils are 11 to 17 times higher than that of diesel fuel. Viscosity of vegetable oils usually range from 32 to 52 mm^2/sn at 38 °C. However, viscosity of diesel fuel is 2,9 mm^2/sn at 38°C. Kinematic viscosity of some vegetable oils are shown in table 3.3.

Cetane Number: The cetane number of a diesel fuel is a measure of its ignition quality. If cetane number of a fuel is high, ıt has good (high) ignition quality. During the combustion, a fuel which has a very short delay period has good (high) ignition quality. However fuel which has prolong delay period, has poor (low) ignition quality. Ignition quality of fuels is usually determined by engine bench test which measures the ignition time delay under standard carefully controlled conditions. Cetane numbers of vegetable oils range from 35 to 40. Cetane number of diesel fuel is 47.

Calorific Value: Heat of combustion or the calorific value of a fuel is an important measure since the heat energy produced by the fuel within the engine cylinder which enables the engine to do work (Tahir et al. 1982). The calorific value is measured by calorimeter. Calorific value of vegetable oils range from 39.5 to 40.5 Mj/kg. Calorific value of vegetable oils are 10-11% lower than calorific value of diesel fuel.

Cloud Point: Many vegetable oils have some triglycerides with saturated fatty acids and such triglycerides have higher melting points than the triglycerides with mostly unsaturated fatty acids. Consequently, many vegetable oils have relatively higher cloud points than diesel fuel (Pryde, 1982). Cloud point of vegetable oil usually range from -3.9 to 18.3 ^{o}C. Cloud point of diesel fuel is -15 ^{o}C.

Flash Point: The flash point of a fuel is defined as the temperature to which the fuel must be heated to produce a mixture that will ignite when exposed to a spark or flame. If the flash point of a fuel is too low, the fuel is prone to flashing, possible ignition and even explosion. Flash point of vegetable oils ranges from 240 to 277 ^{o}C. Flash point of diesel fuel is 52 ^{o}C.

Density of Vegetable Oils: Vegetable oils are not differ in specific gravity, but all vegetable oils are 7 – 9% heavier than diesel fuel. Density of vegetable oils range from 0.91 to 0.95 kg/l.

Table 3.3. Physical properties of some vegetable oils (Georing et al. 1982).

Vegetable oils	Viscosity mm^2/sn	Cetane Number	Calorific Value (Kj/kg)	Flash Point (^{o}C)	Density (kg/l)	Carbon (%)	Cloud Points (^{o}C)	Sulphur (%)	Pour Point ^{o}C
Castor	297	?	37274	260	0.9537	0.22		0.01	-31.7
Corn	34.9	37.6	39500	277	0.9095	0.24	-1.1	0.01	-40.0
Cotton	33.5	41.8	39468	234	0.9148	0.24	1.7	0.01	-15.0
Linseed	27.2	34.6	39307	241	0.9236	0.22	1.7	0.01	-15.0
Peanut	39.2	41.8	39782	271	0.9026	0.24	12.8	0.01	-6.7
Rap seed	37.0	37.6	39709	246	0.9115	0.30	-3.9	0.01	-31.7
Aspir	31.3	41.3	39519	260	0.9144	0.25	18.3	0.01	-6.7
Sesame	35.5	40.2	39349	260	0.9133	0.25	-3.9	0.01	-9.4
Soybean	32.6	37.9	39623	254	0.9138	0.27	-3.9	0.01	-12.2
Sunflower	33.9	37.1	39575	274	0.9161	0.23	7.2	0.01	-15.0
No.2 D.F.	2.7	47	45343	52	0.8400	<0.35	-15.0	<0.01	-33.0

3.2. Experimental Study

There are two phases in this experimental study. Preparation of alternative fuels from cotton seed oil and investigation of physical and chemical properties of the alternative fuels are the first phase of study. Establishment of engine test system and testing of engine with the alternative fuels are the second phase of the study.

3.2.1. Preparation of Alternative Fuels

In this experimental study, blends of cotton seed oil methyl ester – diesel fuel and cotton oil – diesel fuel – ethyl alcohol were used as alternative diesel fuel in direct injection diesel engines.

3.2.1.1. Preparation of Cotton Oil Methyl Ester

Methyl ester for the experimental purposes is prepared in the Department of Mechanical Engineering of Çukurova University. During the production of methyl ester from cotton oil, reaction vessel, cooler, heater, thermometer and chemical substances (methyl alcohol, sulphuric acid, and sodium bicarbonate) were used.

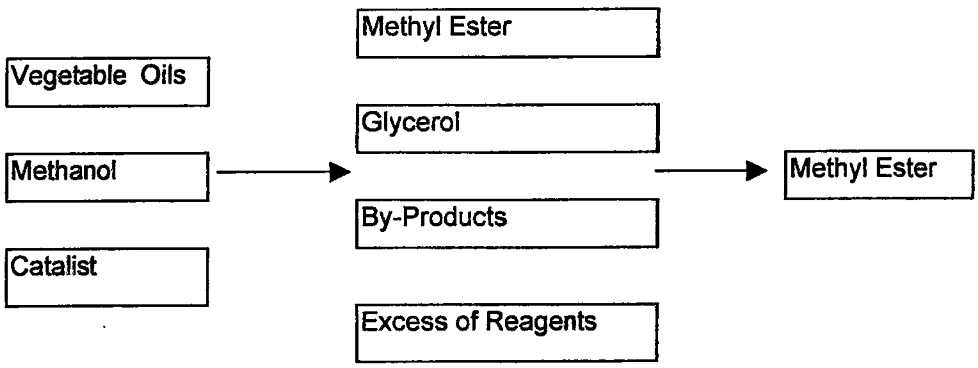

Figure 3.3. Transesterification of vegetable oils (Ramano, 1982).

Basically, the preparation of methyl ester from vegetable oil is a transesterification reaction. Transesterification of vegetable oils is shown in figure 3.3. For the transesterification to occur, there is a need for an excess amount of methyl alcohol besides the catalyst. The excess alcohol is necessary for a higher yield of ester, i.e., it is responsible for a greater percentage of broken glycerine/fatty acids (Ramano, 1982)

In this study, reaction were carried out in a 2000 ml reaction vessel equipped with a condenser and thermometer. 1000 grams of cotton oil, 200 grams of methyl alcohol and 50 grams of sulphuric acid were mixed. The mixture was heated up between 65 and 80 °C and held at this temperature with stirring for two hours. Heating and stirring are stopped and at this point glycerol, the primary reaction by product, begins to separate as layer at the bottom of the reaction vessel. The crude methyl ester was separated using separation funnel. Crude methyl ester was washed three times with solution of sodium bicarbonate to remove suspended glycerol, unreacted methanol and catalyst. Sodium bicarbonate is anti acid therefore sodium bicarbonate reduced acidity of crude methyl ester. Production of crude methyl ester is shown in figure 3.5.

1 kg of vegetable oil + 0.20 kg of methyl alcohol + 0.50 kg catalyst $\longrightarrow$ 0.85 kg methyl ester + Others

Crude methyl ester was distilled with distillation system to obtain pure methyl ester. Distillation system is shown in figure 3.4. and figure 3.6.

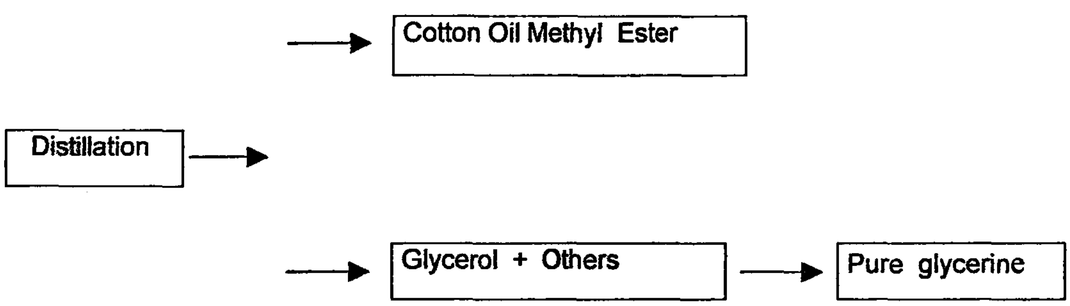

Figure 3.4. Distillation of cotton oil methyl ester.

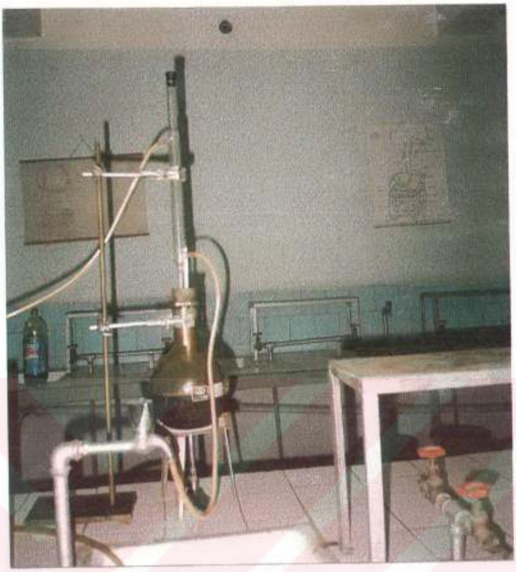

Figure 3.5. View of produced crude cotton oil methyl ester.

Figure 3.6. View of distillation system.

3.2.1.2. Alternative Fuels

In this study, blends of cotton oil – No.2 diesel fuel – ethyl alcohol and cotton oil methyl ester – No.2 diesel fuel were used as alternative diesel fuel in a direct injection diesel engine. Alternative fuels were mixed on volume basis. The volumes were measured with a graduated cylinder, calibrated in milliliters.

Three mixtures of cotton oil (CO) - No.2 diesel fuel (2D) – ethyl alcohol (EA) were evaluated. These fuels are 50% CO, 50% 2D; 50% 2D, 40% CO, 10% EA; 40% CO, 40% CO, 20% EA.

Seven mixtures of cotton oil methyl ester (COME) – No.2 diesel fuel (2D) were evaluated. These fuels are 10% COME, 90% 2D; 20% COME, 80% 2D; 30% COME, 70% 2D; 40% COME, 60%2D; 50%COME, 50% 2D; 60% COME, 40% 2D; 70% COME, 30% 2D.

3.2.2. Physical and Chemical Properties of Alternative Fuels

Density: Density of diesel fuel, cotton oil methyl ester of cotton oil and alternative fuels were measured with hydrometer at 21 °C. and 38 °C. Cotton oil and its methyl ester are respectively 8.9% and 3.8% heavier than diesel fuel. The density of alternative fuels are shown in table 3.4.

Table 3.4. Density of experimental fuels.

FUELS	DENSİTY (Kg/l)	
	21 °C	38 °C
CO	0.913	0.903
COME	0.862	0.849
10% COME + 90% 2D	0,830	0,821
20% COME + 80% 2D	0,834	0.824
30% COME + 70% 2D	0.837	0.827
40% COME + 60% 2D	0.841	0.830
50% COME + 50% 2D	0.844	0.834
60% COME + 40% 2D	0.848	0.837
70% COME + 30% 2D	0.856	0.840
50% 2D + 40% CO+10% EA	0.858	0.842
40% CO+40% CO+20% EA	0.854	0.832
2D	0.827	0.818

Calorific Value: Calorific value of a fuel is very important property. Calorific value of the experimental fuels were determined by igniting a small sample (about one gram) in oxygen bomb calorimeter. Calorific value of experimental fuels are shown in table 3.5. Heat content of cotton oil and its methyl ester are respectively 12.8% and 10.4% lower than diesel fuel. Calorific value of blends decreased depending on the amount of cotton oil, cotton oil methyl ester and ethyl alcohol.

Table 3.5. Calorific value of alternative fuels.

Experimental Fuels	**Calorific Value (kj/kg)**
CO	39,105
COME	40,597
2D	43,500
10% COME + 90% 2D	43,201
20% COME + 80% 2D	42,903
30% COME + 70% 2D	42,629
40% COME + 60% 2D	42,300
50% COME + 50% 2D	42,020
60% COME + 40% 2D	41,755
70% COME + 30% 2D	41,168
50% 2D + 40% CO+10% A	40,007
40% CO+40% CO+20% A	38,402

Viscosity: Viscosity of oils are very important property for efficiency of combustion in diesel engines. Viscosity of experimental fuels were measured with viscosimeter. Cotton oil is about 12.6 times more viscous than diesel fuel at the 38 °C. However cotton oil methyl ester is 2 times more viscous than diesel fuel at 38 °C. Viscosity of diesel fuel, cotton oil and cotton oil methyl ester for various temperature are shown in figure 3.6.

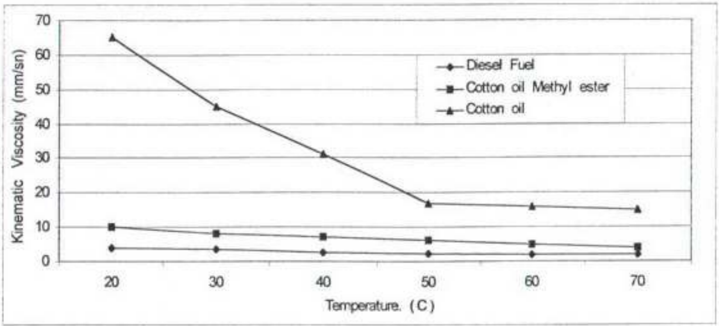

Figure 3.7. Kinematics viscosity of diesel fuel, cotton oil and cotton oils methyl ester at different temperatures.

3.3 Experimental Apparatus

Diesel Engines;

Lister Peter Diesel Engine (TD111) is four cycle, single cylinder, weather cooled. Properties of the engine is given in table 3.7.

Table 3.7. Properties of the engine (LISTER PETER TD111).

Manufacturer/Type	PETTER AA1
Valve position	Overhead
Valve rocker clearance	0.10 mm (Cold)
Swept Volume	219 cm^3
Bore	70 mm
Stroke	57 mm
Compression Ratio	17
Maximum Torque	8.2 Nm at 2700 revs / min
Maximum Brake power	2.6 Kw at 3600 revs / min
Recommend maximum speed	3600 revs / min
Fuel injection timing	24 to 33° BTDC
Dry mass	42 kg

Turk Fiat Diesel Tractor Engine is four cycle, 3 cylinder, water cooled. Bore is 100mm and stroke is 115mm. Total cylinder volume is 2710 cc. Compression ratio is 17:1 and its weight is 310 kg.

Thermocouple;

Exhaust gas temperature is measured by a chrome / alumel thermocouple conforming to BS1827. The thermocouple is located in a 1/8" BSP union brazedinto the exhaust pipe close to the cylinder block of engine. Blue and brown leads from the thermocouple are connected to similarly coloured terminals underneath the TD114 Instrumentation Unit. The temperature is indicated on a direct reading meter scaled from 0 to 1000 °C.

Airmeter;

Air consumption was measured by a viscous flowmeter and in addition, there are a large damping volume (airbox). The large damping volume is installed between the viscous flowmeter and engine.

Chronometer;

It is used to measure the time of fuel consumption for the volume of 8ml.

Dynamometer;

Engine toque is measured by the Hydraulic Dynamometer and transmitted to a torquemeter located on the Instrumentation Unit.

Thermometer;

They are used to measure the temperature in calorimeter and measured water temperature of engine at inlet and outlet.

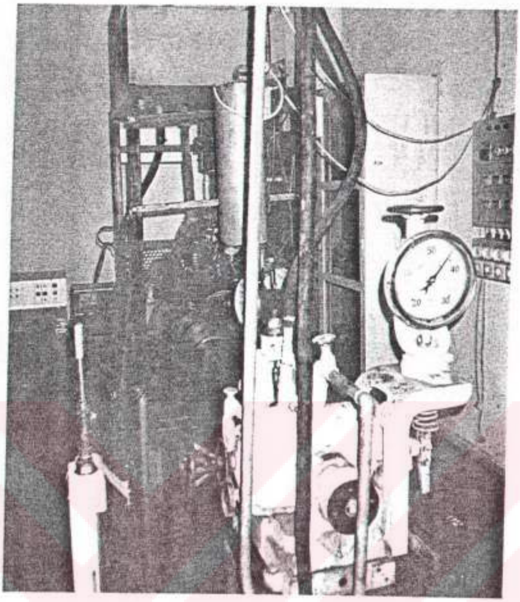

Figure 3.8. View of Türk Fiat diesel engine and dinamometer.

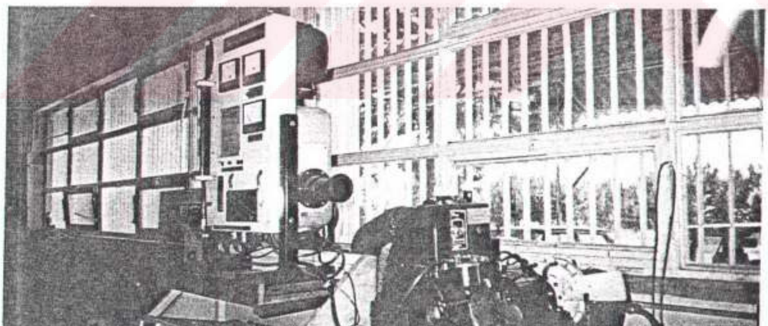

Figure 3.9. View of Lister Peter diesel engine and other test equipment.

Diesel Exhaust Gas Analyse Equipment;

Exhaust emissions of diesel engine were measured by MOD-2100 exhaust gas analyse equipment. Opacity (k), % opacity and smoke value can be measured with the diesel exhaust gas analyse equipment.

Calorimeter :

Calorific value of the experimental fuel were measured with Cussons Bomb Calorimeter.

Viscosimeter:

Viscosity of experimental fuels were measured with Rotorymeter Viscosimeter.

Hydrometer:

Density of experimental fuels were measured with hydrometers.

3.4. Calculations

Calculation for Lister Peter diesel engine;

Engine torque is measured directly using a dynamometer coupled to the engine output shaft.

Calculation of brake power is given by:

$$Pb = \frac{2\pi N}{60} xT \qquad (3.1)$$

T = Torque (Nm)

N = Speed (rpm)

Pb= Power (Watt)

The air consumption is calculated as:

$$m_a = \text{Value of Manometer} \times 1.1 \tag{3.2}$$

m_a = Air consumption (kg/s)

Calculation of fuel consumption is given in equation 3.3 for volumes of 8ml.

$$m_f = \frac{sg_f \times (8) \times 10^{-3}}{t} \times 3600 \tag{3.3}$$

t = Time of fuel consumption

m_f = Fuel consumption, (kg/hr)

sg_f = Specific gravity for fuel, (kg/m^3)

The specific fuel consumption is calculated as:

$$sfc = \frac{m_f \times 10^3}{P_b} \tag{3.4}$$

sfc = Specific fuel consumption (g/kWh)

Air / fuel ratio(R):

$$R = \frac{m_a}{m_f} \tag{3.5}$$

Ideally, R has the “stoichiometric” value of about 14.8.

The heat carried away by the exhaust, expressed as a percentage of the heat input, is

$$\%\ \text{Heat Loss in Exhaust} = \frac{(m_a + m_f)\, l \times \Delta t \times 100}{m_f \times H} \tag{3.6}$$

H = Heat content of fuel

Calculations for Türk fiat diesel engines;

The break power is calculated as:

$$Pb = \frac{W \times N}{K} \tag{3.7}$$

Pb = Power (Hp)

W = Force is measured by dynamometer (kg)

K = The coefficient of the calibration of the dynamometer (K=4500)

Torque is calculated as:

$$T = \frac{60 \times Pb}{2\pi N} 0.75x1000 \tag{3.8}$$

Heat Energy:

$$Q = \dot{m}_w \times Cp_w\,(T_3 - T_4)/60 \tag{3.9}$$

Q = Heat loss (kj/s)

$\dot{m}_w$ = Water flow rate (L/min)

T_3 = Water exiting temperature (°C)

T_4 = Water entering temperature (°C)

Cp_w = Specific heat of water 4.184 (kj/kg.K)

Mass of the Exhaust Gases

$$M_{exh} = \frac{Q}{Cp_{exh} \times (T_1 - T_2)} \tag{3.10}$$

M_{exh} = Mass of the exhaust gases (kg/s)

T_1 = Exhaust gases entering temperature (°C)

T_2 = Exhaust gases exit temperature (°C)

Cp_{exh} = Specific heat of exhaust gases 1.7 (kj / kg. K)

4. RESULTS AND DISCUSSION

4.1. Presentation and Analysis of Data for Methyl Ester and Diesel Fuel Blends

Blends of cotton oil methyl ester and diesel fuel were tried at full load-different engine speeds in a single cylinder diesel engine. Before each test, the engine was warmed up with the diesel fuel about 15 minutes until the engine temperatures are stabilised. During the engine test, power, torque, fuel consumption, air consumption, exhaust temperature and exhaust emissions were measured for different engine speeds and load condition. Power – speed, toque – speed, specific fuel consumption – speed, air consumption – speed, exhaust temperature – speed, % exhaust heat loss – speed and emission – speed graphs are plotted from the experimental results.

4.1.1. Torque

Torque of engine with blends of cotton oil methyl ester – diesel fuel were measured in between 1500 and 3700 rpm. Engine torque is measured directly using a dynamometer coupled to the engine output shaft. Toque versus speed changes are given in figures 4.1. – 4.7.

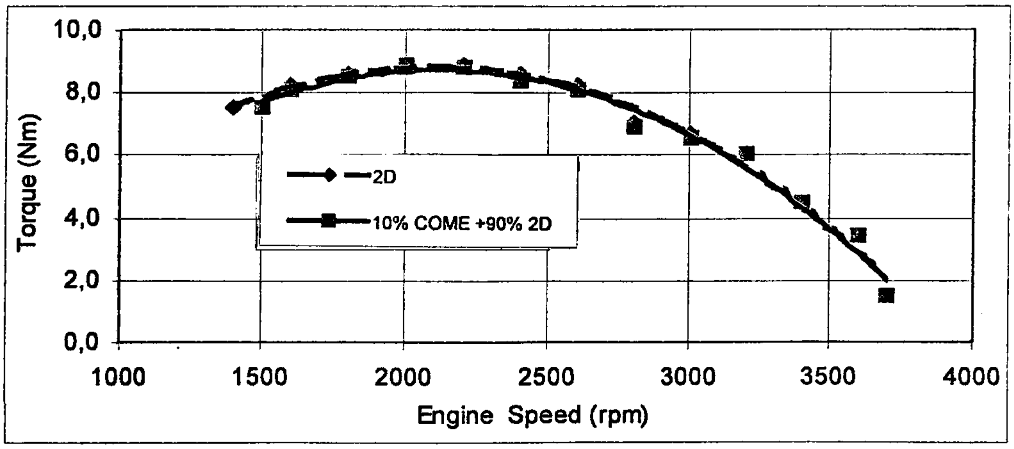

Figure 4.1. Torque – engine speed curve of 2D and 10% COME + 90% 2D.

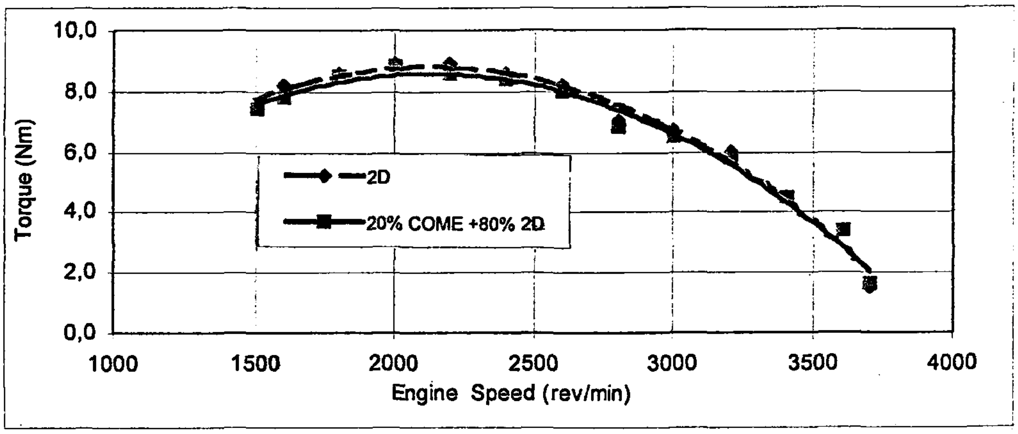

Figure 4.2. Torque – engine speed curve of 2D and 20% COME + 80% 2D.

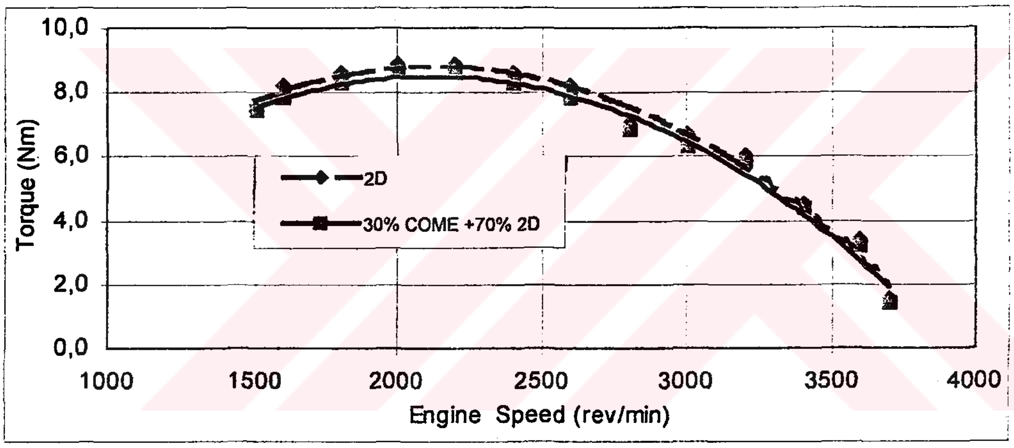

Figure 4.3. Torque – engine speed curve of 2D and 30% COME + 70% 2D.

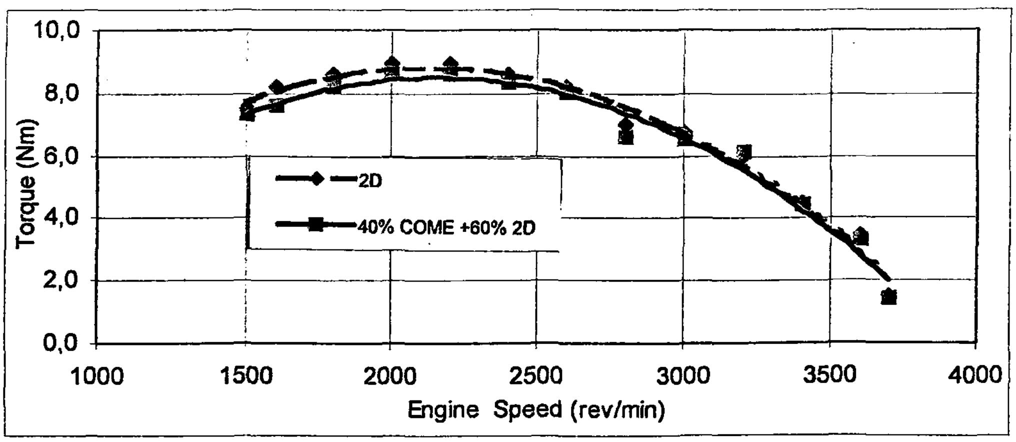

Figure 4.4. Torque – engine speed curve of 2D and 40% COME + 60% 2D.

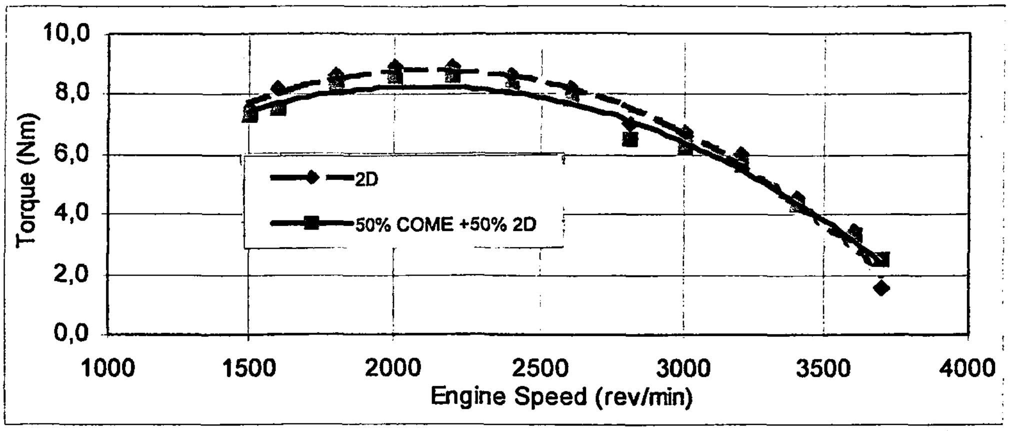

Figure 4.5. Torque – engine speed curve of 2D and 50% COME + 50% 2D.

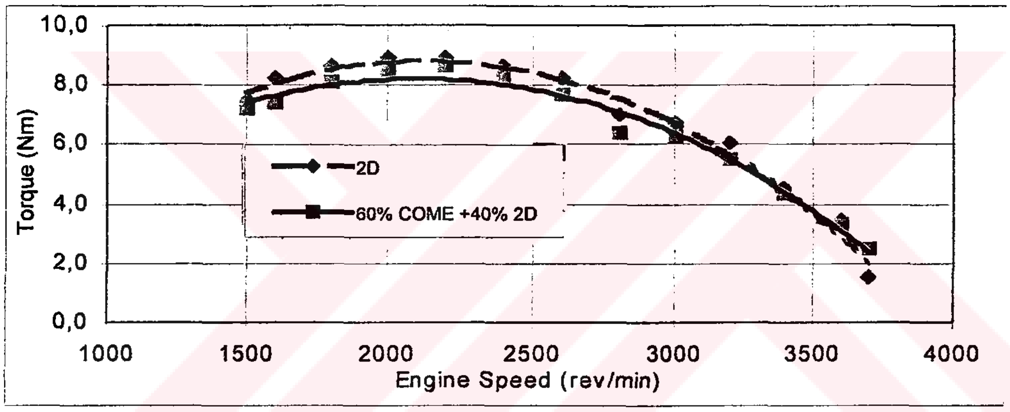

Figure 4.6. Torque – engine speed curve of 2D and 60% COME + 40% 2D.

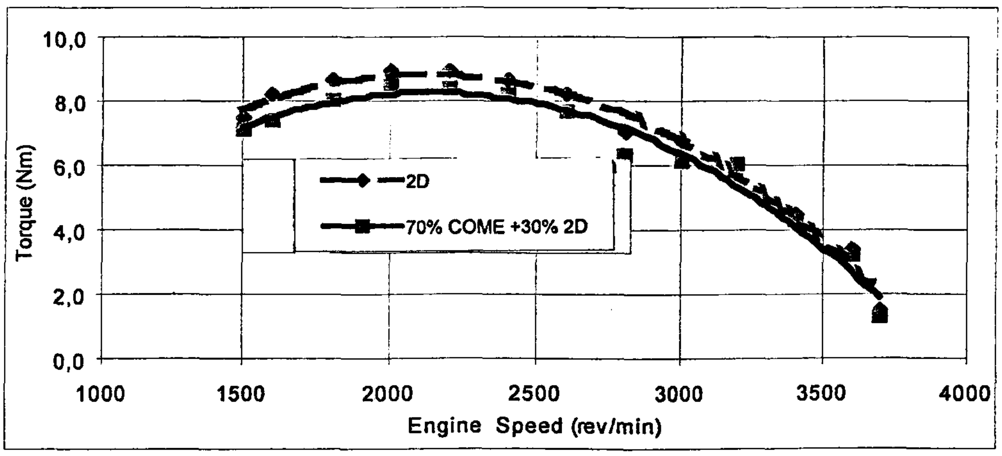

Figure 4.7. Torque – engine speed curve of 2D and 70% COME + 30% 2D.

Torque of engine did not vary significantly for blends at all engine speeds. Decreasing of engine torque ranged between 0 and 5 % depending on the amount of COME (Cotton Oil Methyl Ester) at the maximum torque. Maximum torque point of engine with seven blends and diesel fuel riched at 2100 rpm. Torque reduction was lower at high speed of engine.

Torque of 10% COME – 90% 2D blend and diesel fuel was same at all engine speed. Maximum torque of the engine were 8.7 Nm for 20% COME – 80% 2D and 30% COME –70% 2D blend, 8.6 Nm for 40% COME – 60% 2D blend, 8.55 Nm for 50% COME – 50% 2D blend, 8.5 Nm for 60 COME – 40% 2D and 70% COME – 30% 2D blend.

4.1.2. Power

Power of engine for blend fuels and diesel fuel were calculated from engine torque and speed. Results of blend fuels were compared with diesel fuels. Power versus engine speed changes of different fuel mixtures are shown in figures 4.8. – 4.14.

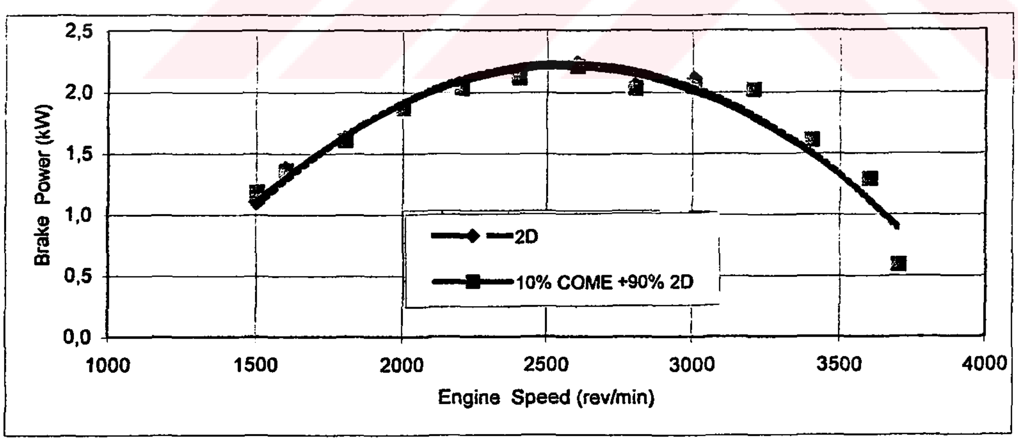

Figure 4.8. Power – engine speed curve of 2D and 10% COME + 90% 2D.

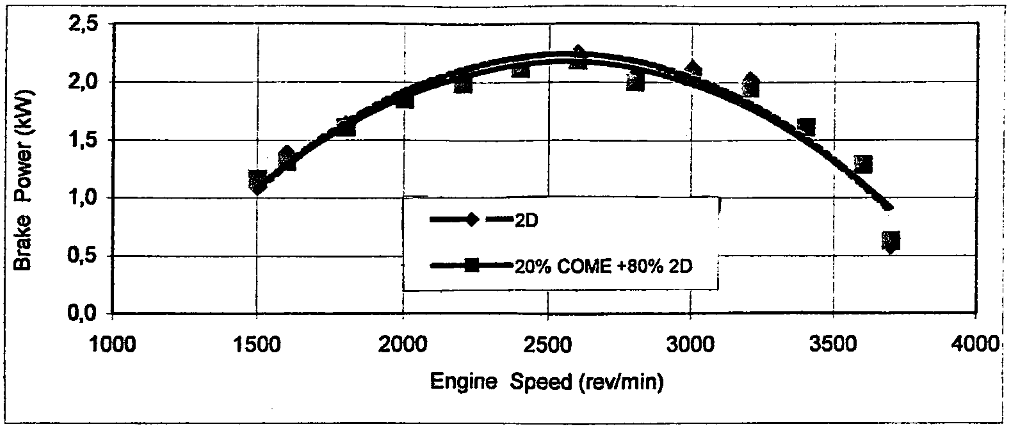

Figure 4.9. Power – engine speed curve of 2D and 20% COME + 80% 2D

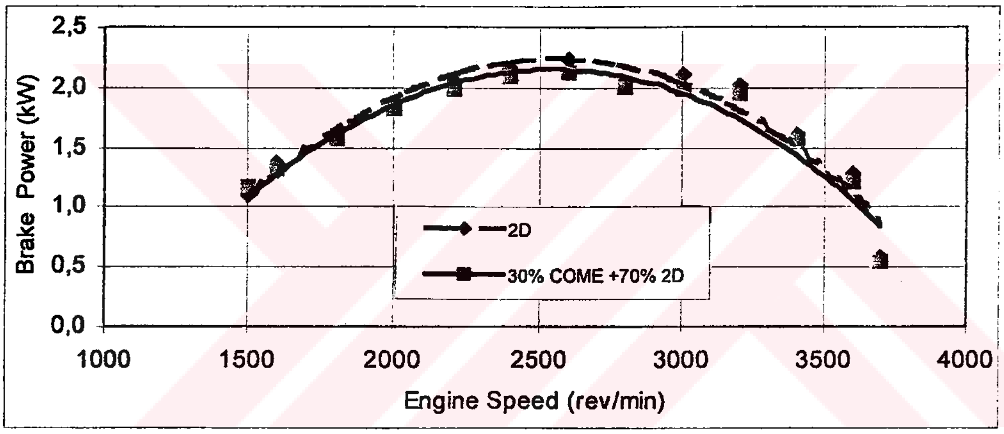

Figure 4.10. Power – engine speed curve of 2D and 30% COME + 70% 2D.

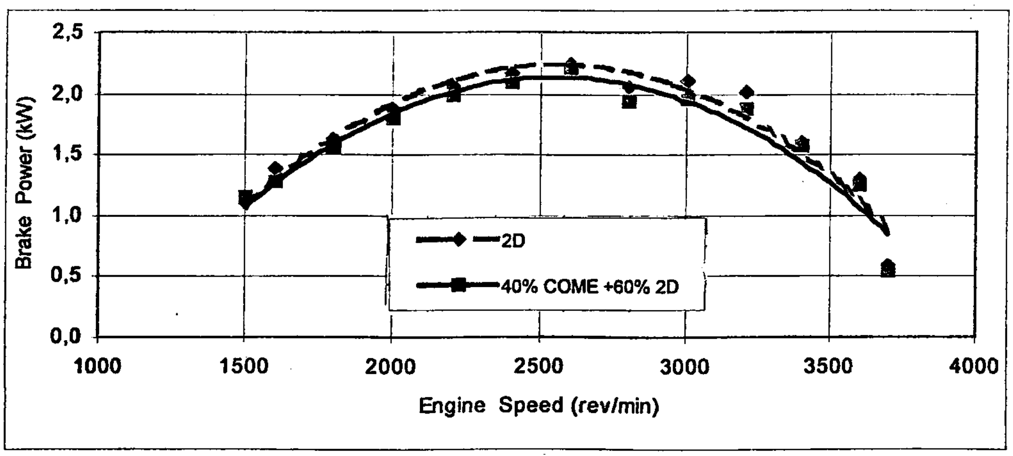

Figure 4.11. Power – engine speed curve of 2D and 40% COME + 60% 2D.

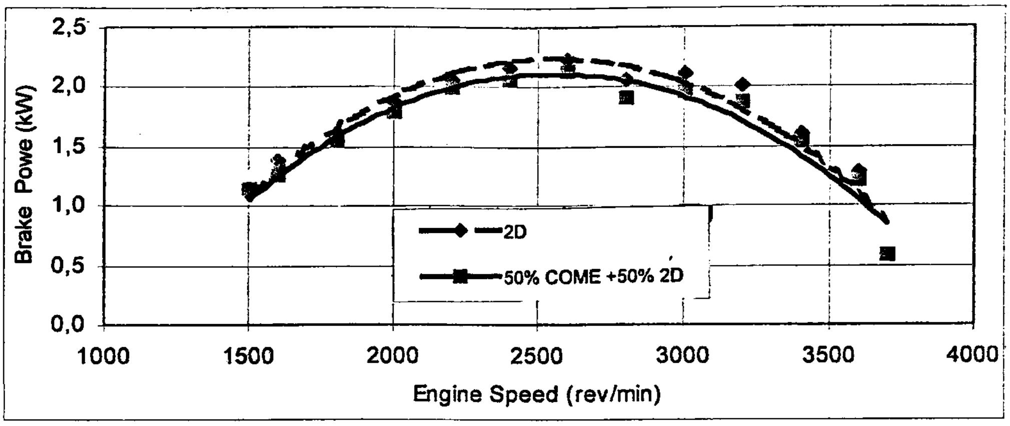

Figure 4.12. Power – engine speed curve of 2D and 50% COME + 50% 2D.

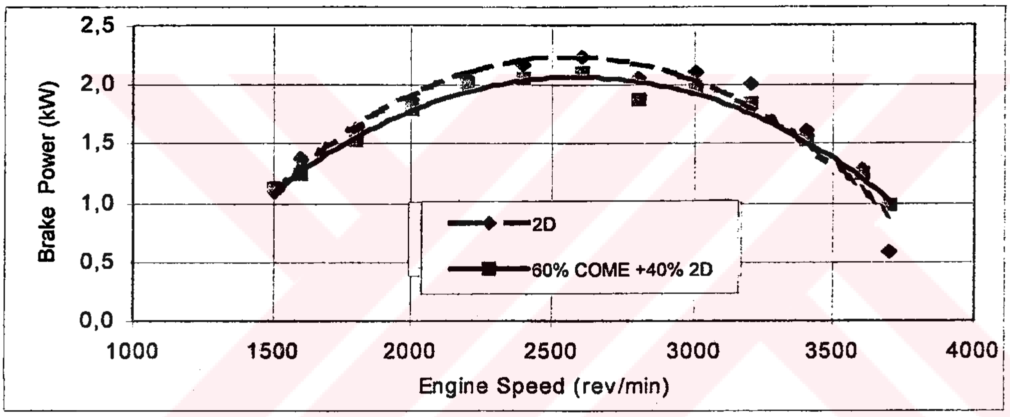

Figure 4.13. Power – engine speed curve of 2D and 60% COME + 40% 2D.

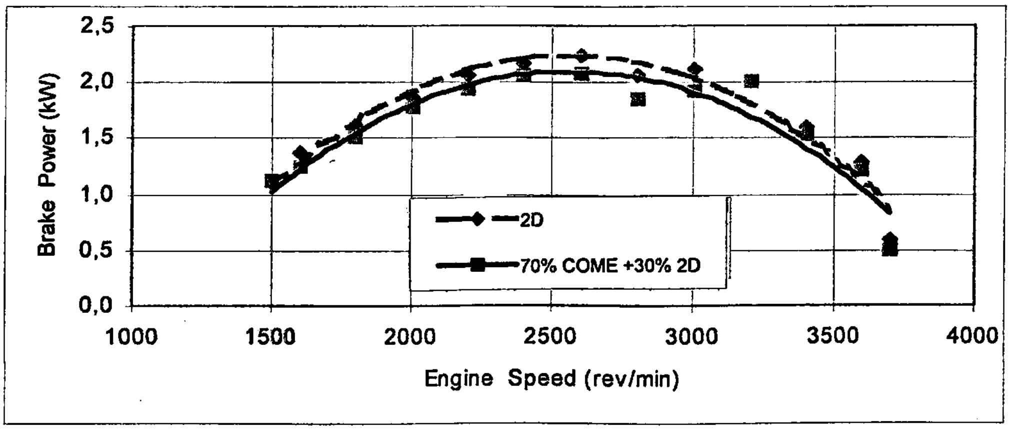

Figure 4.14. Power – engine speed curve of 2D and 70% COME + 30% 2D

Power of engine for all blend fuels were usually lower than diesel fuel at all engine speed. Maximum power of engine speed was at 2500 rpm for all blend fuels and diesel fuel. Maximum power of diesel fuel was 2.23 kW. Decreasing of maximum power for blend fuels ranged from 0% to 5 % depending on the amount of COME. However power of engine did not vary significantly with blend fuels at higher and lower engine speed. In addition, power of 60/40% blend was higher than diesel fuel between 3400 rpm and 3700 rpm.

4.1.3. Specific Fuel Consumption

Specific fuel consumption of blend fuels and diesel fuel were measured. Specific fuel consumption is very important engine performance characteristics. Specific fuel consumption results are shown in figures 4.15 – 4.21.

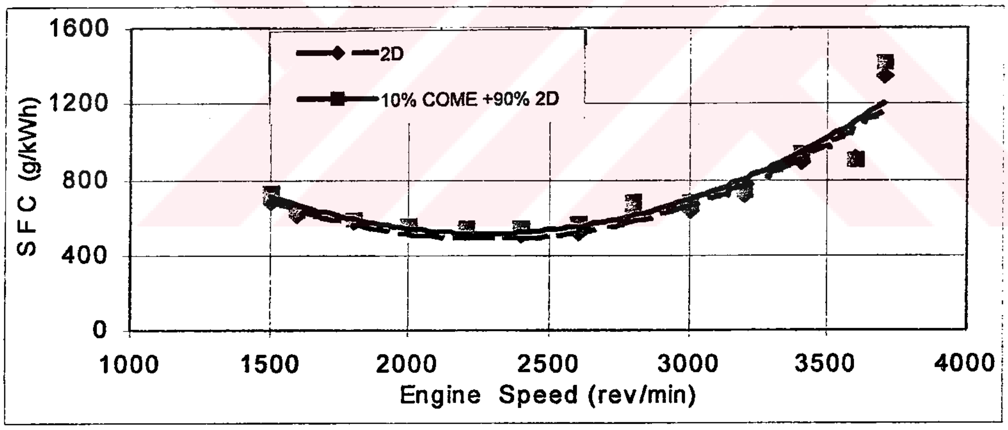

Figure 4.15. Specific fuel consumption of 2D and 10% COME + 90% 2D.

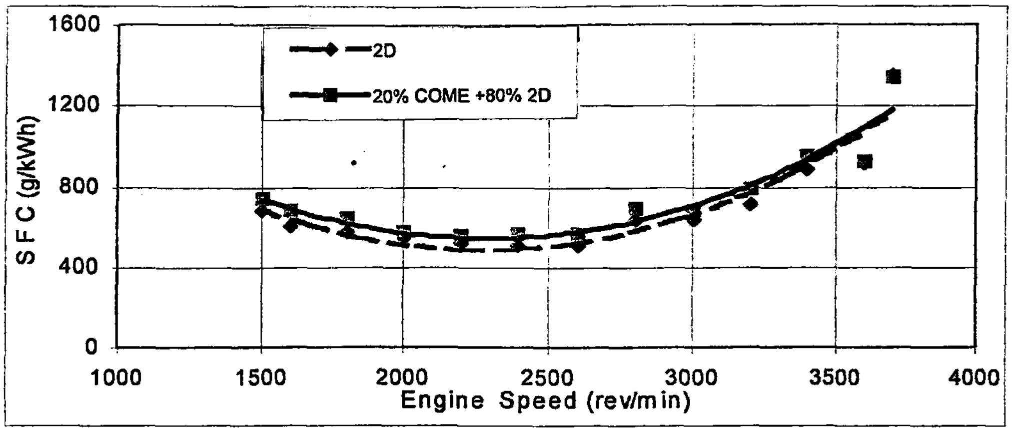

Figure 4.16. Specific fuel consumption of 2D and 20% COME + 80% 2D.

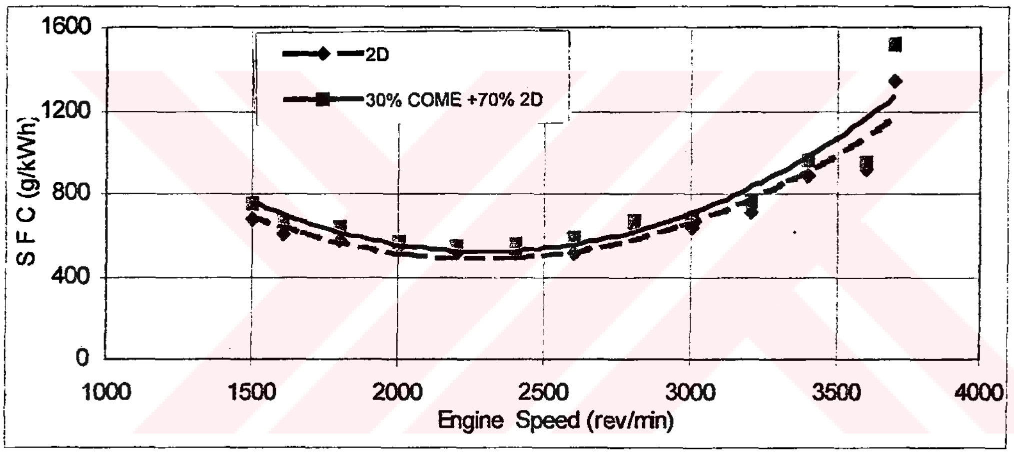

Figure 4.17. Specific fuel consumption of 2D and 30% COME + 70% 2D.

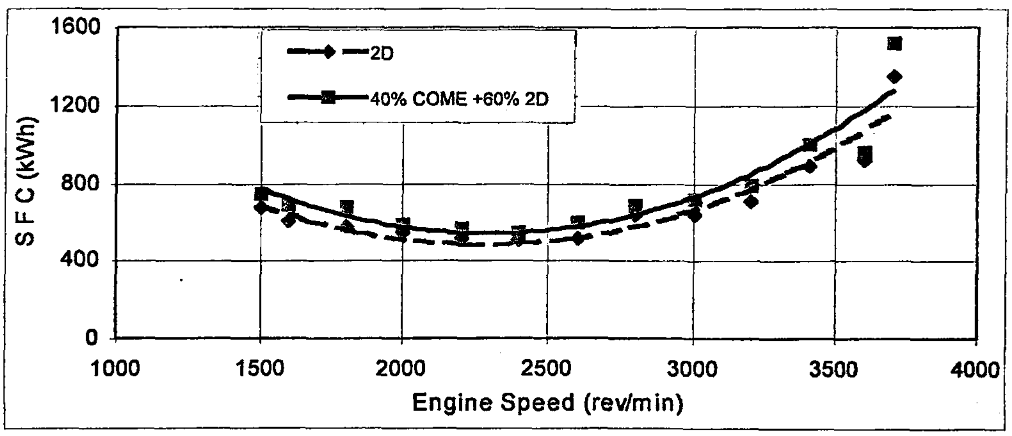

Figure 4.18. Specific fuel consumption of 2D and 40% COME + 60% 2D.

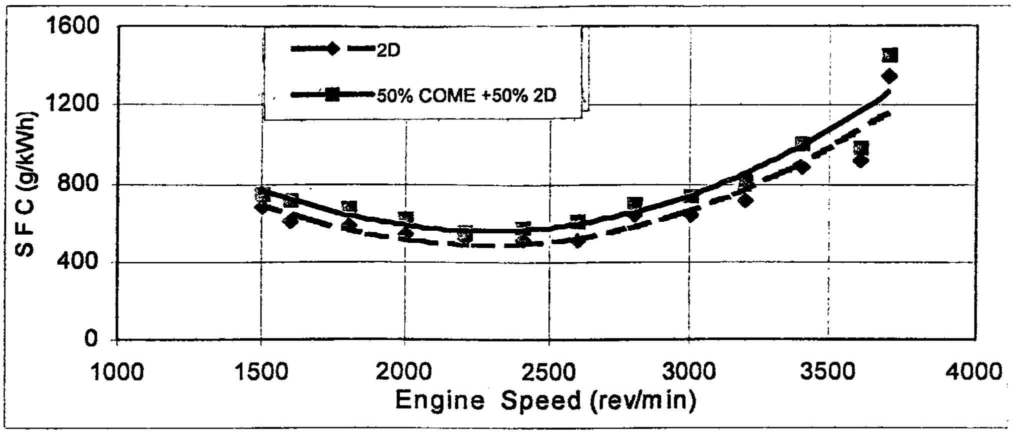

Figure 4.19. Specific fuel consumption of 2D and 50% COME + 50% 2D.

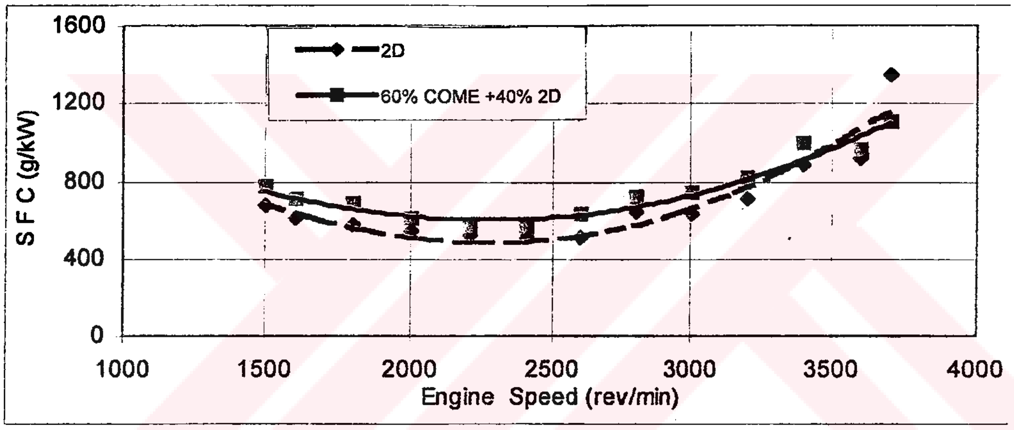

Figure 4.20. Specific fuel consumption of 2D and 60% COME + 40% 2D.

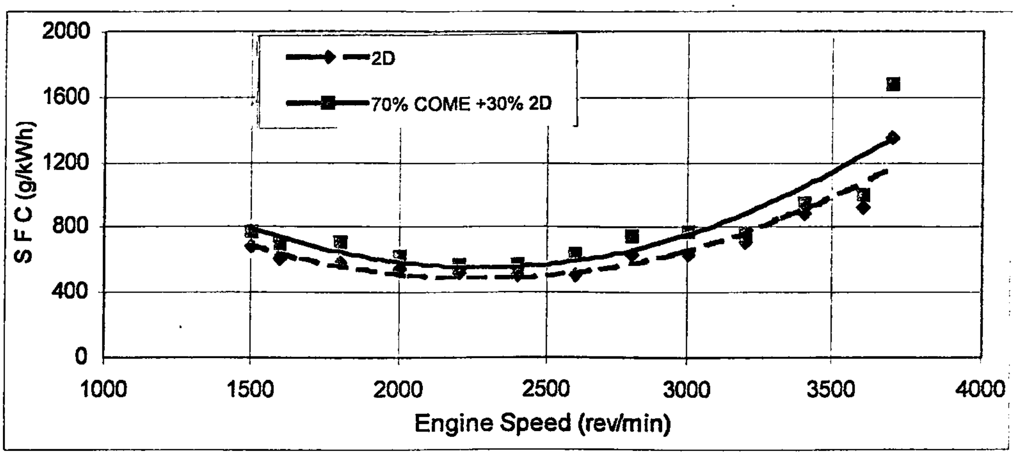

Figure 4.21. Specific fuel consumption of 2D and 70% COME + 30% 2D.

There was a interaction between specific fuel consumption and test fuel. Because specific fuel consumption increased between 2.3 percent and 12.4 percent depending on the amount of COME. Specific fuel consumption varied with energy content and viscosity of blend fuels. Only, 60% COME – 40% 2D blend had lower specific fuel consumption than diesel fuel between 3400 and 3700rpm. At maximum torque speed, specific fuel consumption increased about 2.3 percent for 10-90 blend, 6 percent for 20-80% and 30-70% blends, 8.5 percent for 40-60% blend, 9.5 percent for 50-50% blend, 11.4 percent for 60-40% blend and 12.4 percent for 70-30% blend.

4.1.4. Exhaust Gas Temperature

Exhaust gas temperatures of engine for blend fuels and diesel fuel were measured by a chrome / alumel thermocouple. The thermocouple is located in exhaust pipe. The temperature is indicated on a direct reading meter scaled from 0 to 1000 °C. Measured exhaust gas temperatures are given figures 4.22.- 4.28.

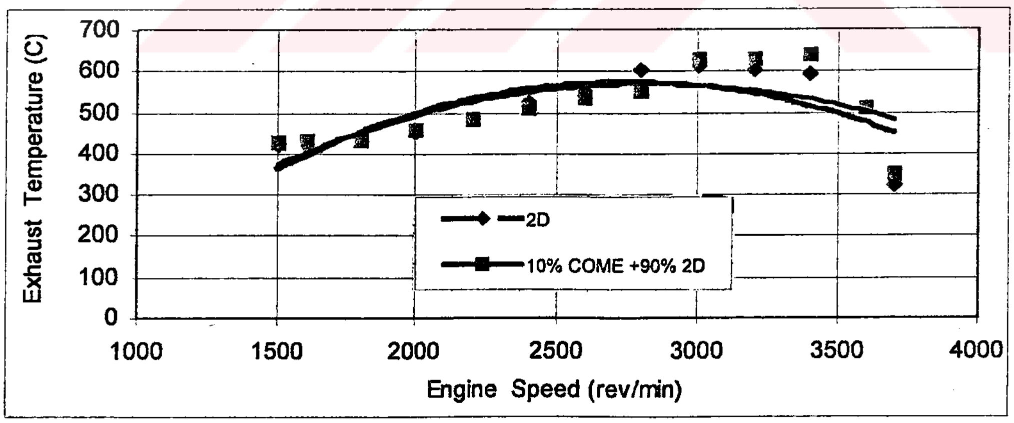

Figure 4.22. Exhaust temperature of 2D and 10% COME + 70% 2D.

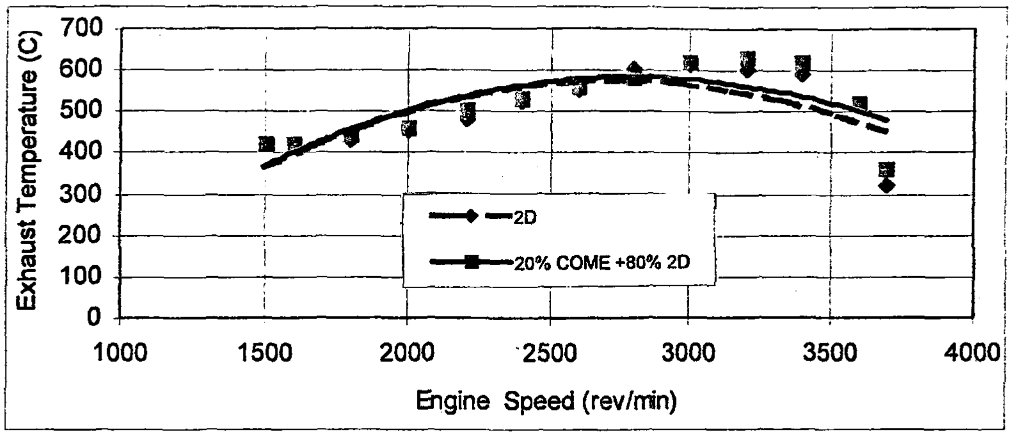

Figure 4.23. Exhaust temperature of 2D and 20% COME + 80% 2D.

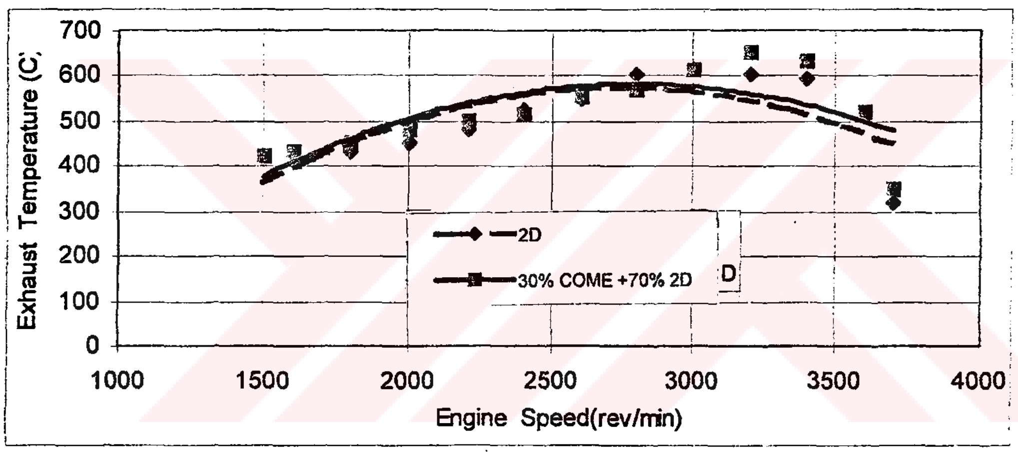

Figure 4.24. Exhaust temperature of 2D and 30% COME + 70% 2D.

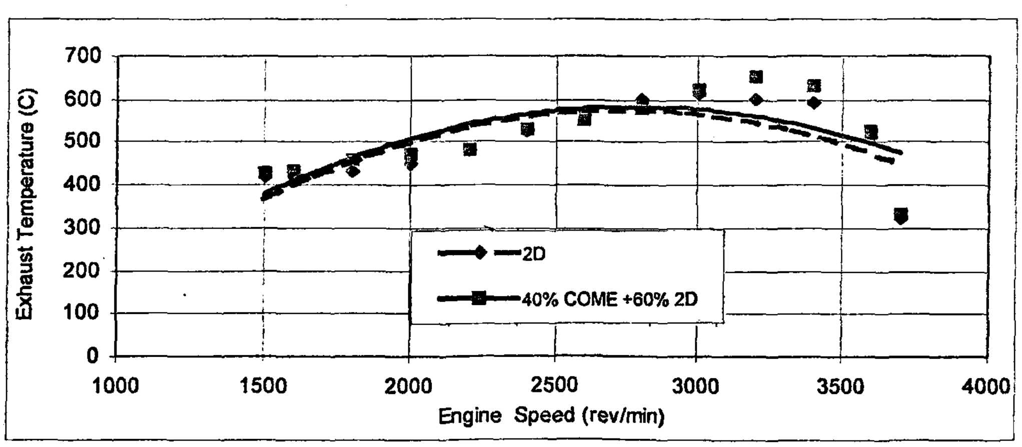

Figure 4.25. Exhaust temperature of 2D and 40% COME + 60% 2D.

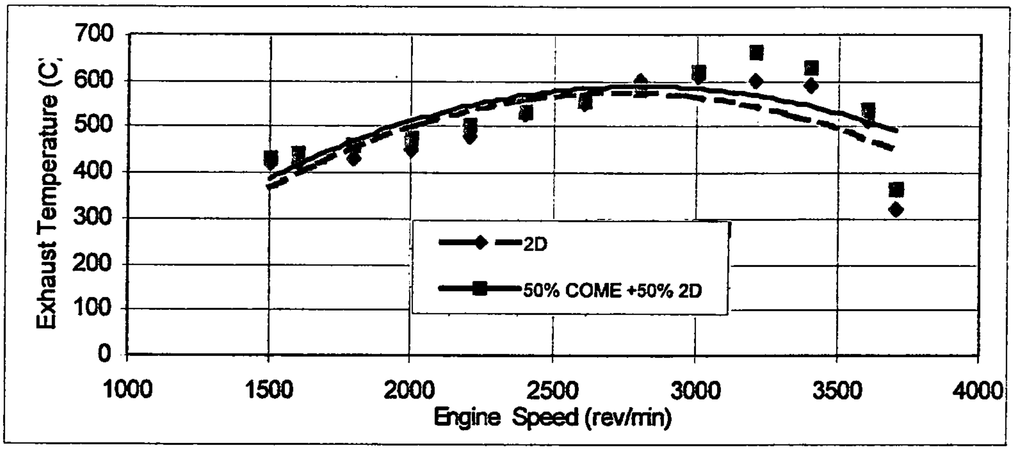

Figure 4.26. Exhaust temperature of 2D and 50% COME + 50% 2D.

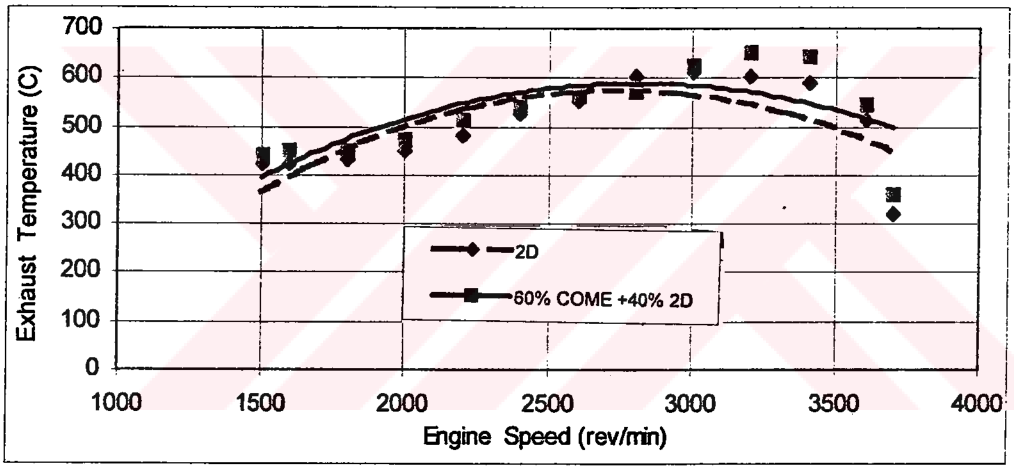

Figure 4.27. Exhaust temperature of 2D and 60% COME + 40% 2D.

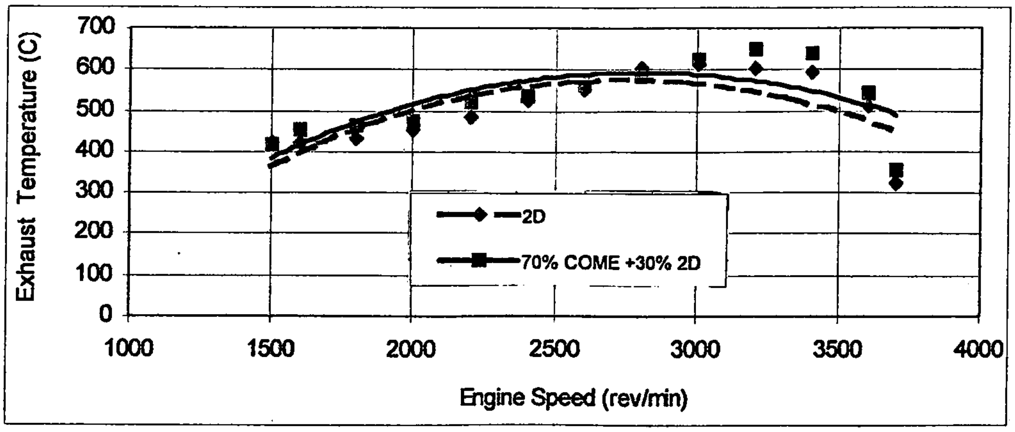

Figure 4.28. Exhaust temperature of 2D and 60% COME + 40% 2D.

Exhaust temperature of all blends fuel were usually higher than diesel fuel at all engine speed. Maximum exhaust temperature of blends and diesel fuel was riched at 3200 rpm. Exhaust temperature of diesel fuel was 600 ^{O}C at 3200 rpm, however exhaust temperature of blends ranged from 600 ^{O}C to 650 ^{O}C at 3200 rpm depending amount of COME. Exhaust temperatures were inclined between 3200 and 3700 rpm.

4.1.5. Heat Loss to Exhaust

Heat loss in exhaust of engine with blend fuels and diesel fuel were calculated, which depends on exhaust gas temperature. Exhaust heat loss of experiments are given in figures 4.29.- 4.35.

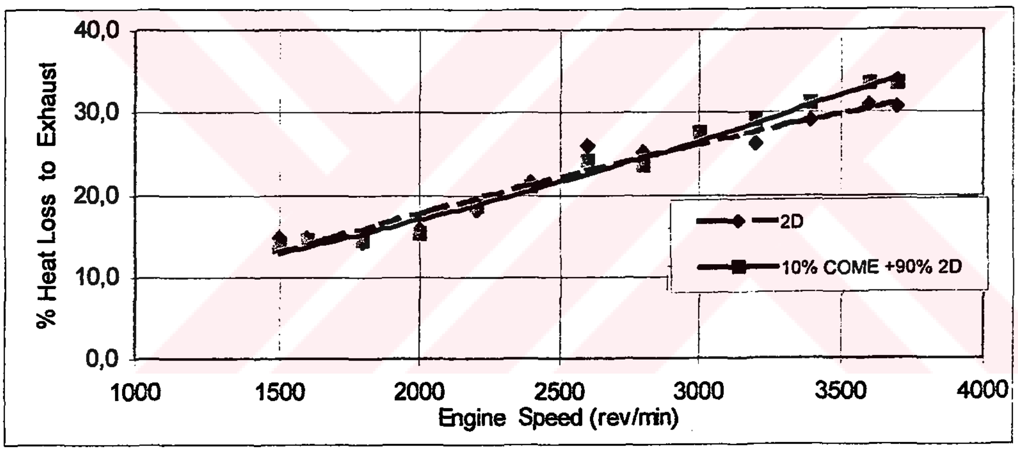

Figure 4.29. % Heat loss to Exhaust of 2D and 10% COME + 90% 2D

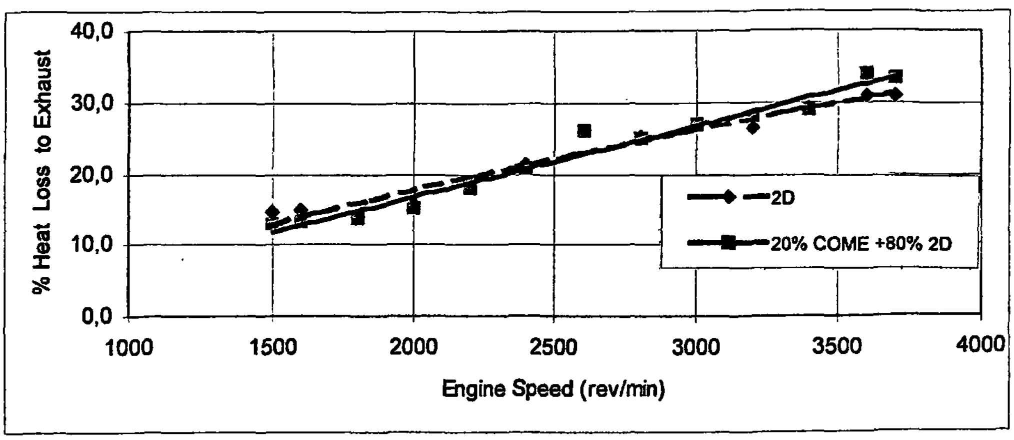

Figure 4.30. % Heat loss to Exhaust of 2D and 20% COME + 80% 2D

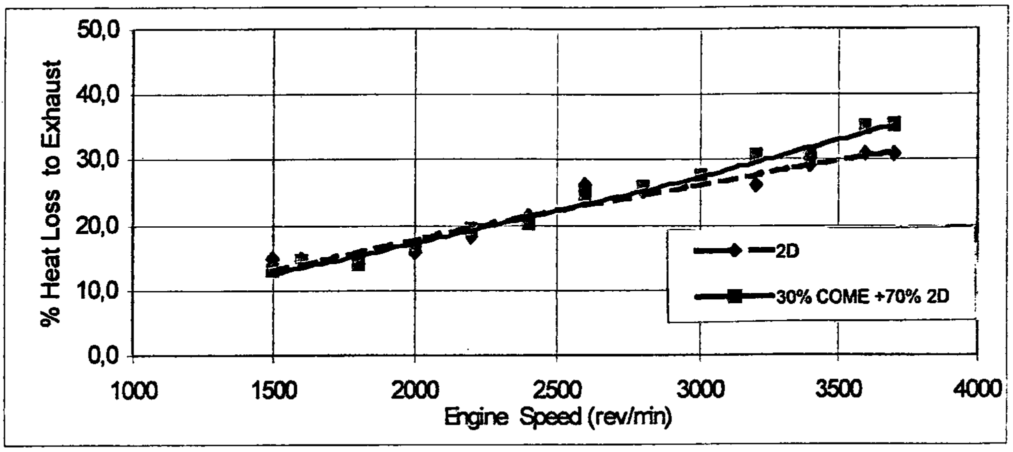

Figure 4.31. % Heat loss to Exhaust of 2D and 30% COME + 70% 2D.

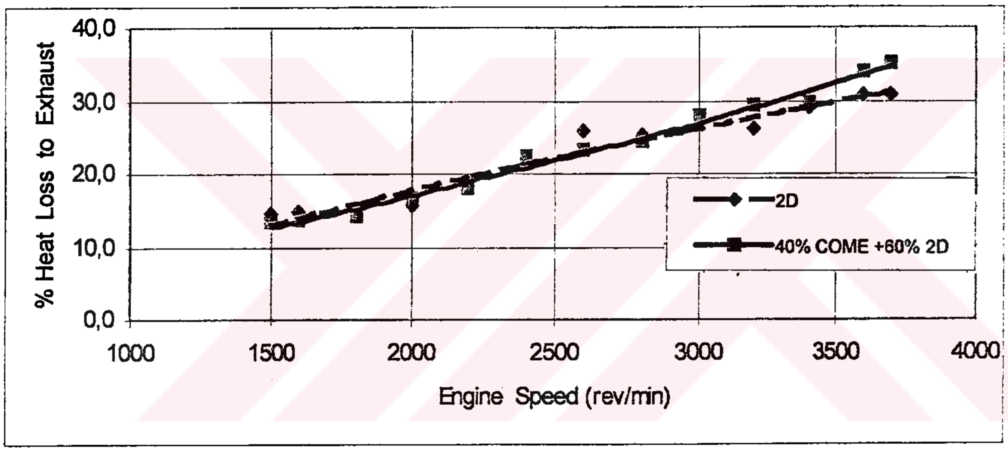

Figure 4.32. % Heat loss to Exhaust of 2D and 40% COME + 60% 2D

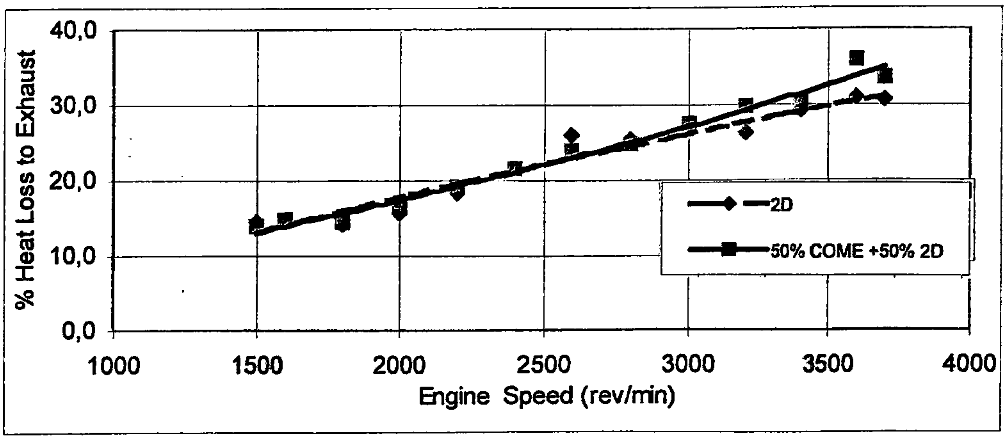

Figure 4.33. % Heat loss to Exhaust of 2D and 50% COME + 50% 2D.

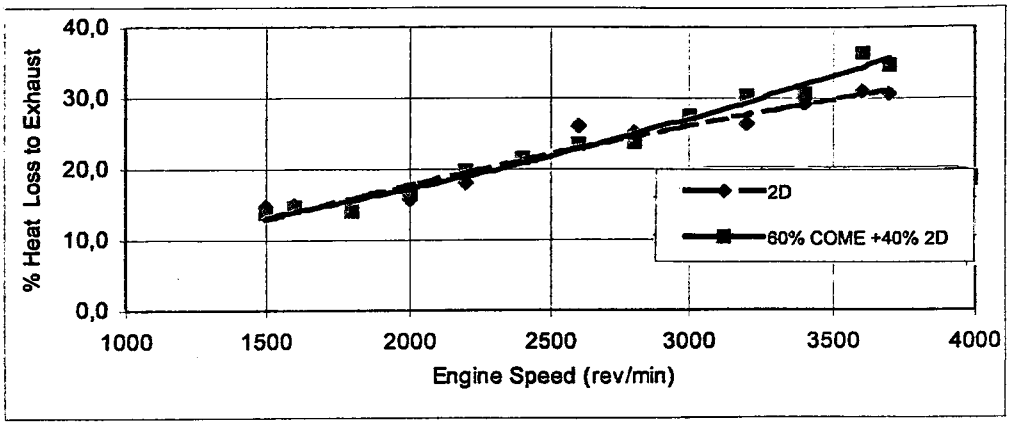

Figure 4.34. % Heat loss to Exhaust of 2D and 60% COME + 40% 2D.

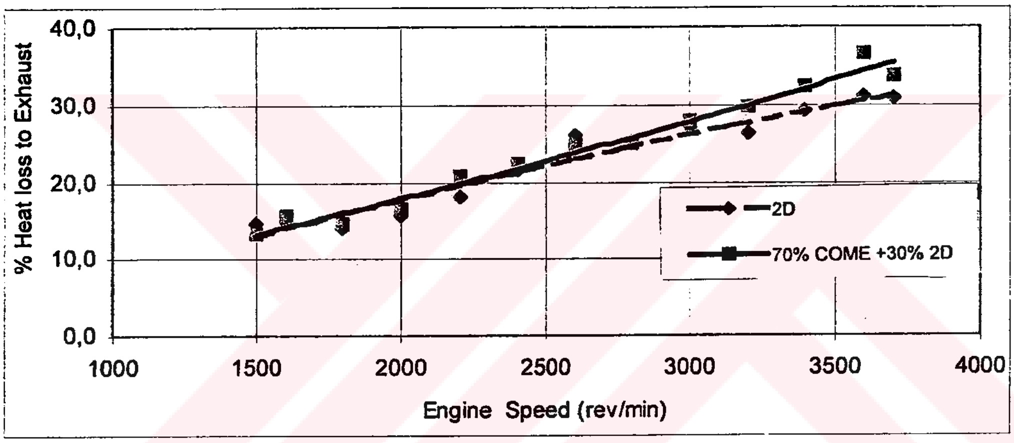

Figure 5.35. % Heat loss to Exhaust of 2D and 70% COME + 30% 2D

According to diesel fuel, % heat loss to exhaust of blends did not vary significantly between 1500 and 3000 rpm. % heat loss to exhaust of all blend fuels were higher than diesel fuel at high speed of engine. It increased depending on exhaust temperature. % heat loss to exhaust of 50%-50%, 60%-40% and 70%-30% blends was same between 3000 and 3700 rpm.

4.1.6. Exhaust Gas Emission

Exhaust emissions of diesel engine were measured with MOD-2100 exhaust gas analyse equipment between 1500 and 3500 rpm. Opacity (k), % opacity and smoke value were measured with the diesel exhaust gas analysing equipment. Measured exhaust emissions are illustrated in figures 4.36 – 4.56.

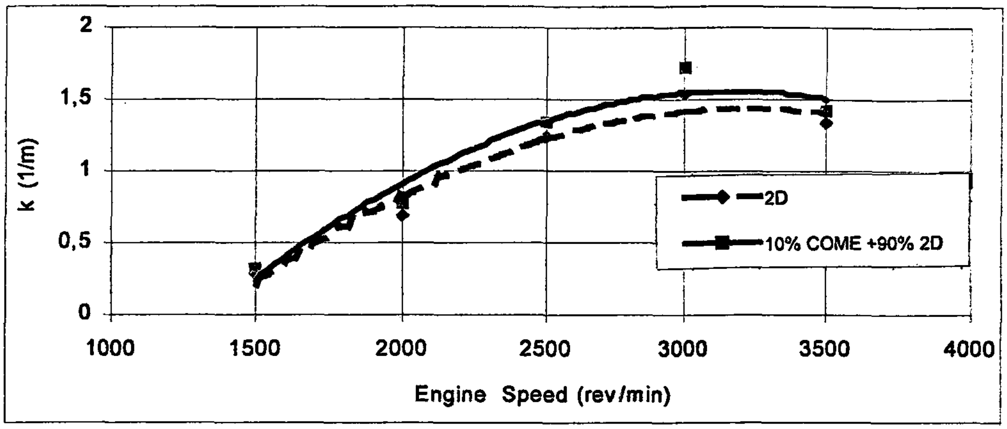

Figure 4.36. Opacity (k) to Exhaust of 2D and 10% COME + 90% 2D.

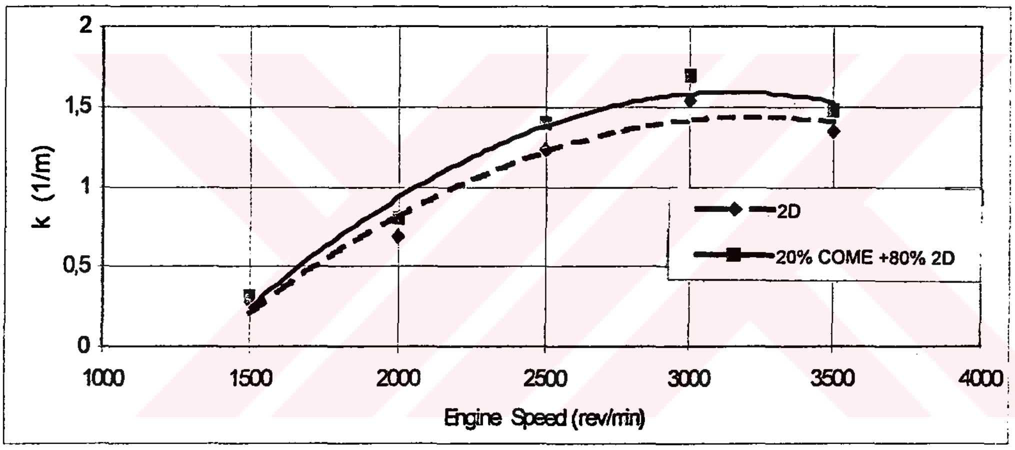

Figure 4.37. Opacity (k) of 2D and 20% COME + 80% 2D

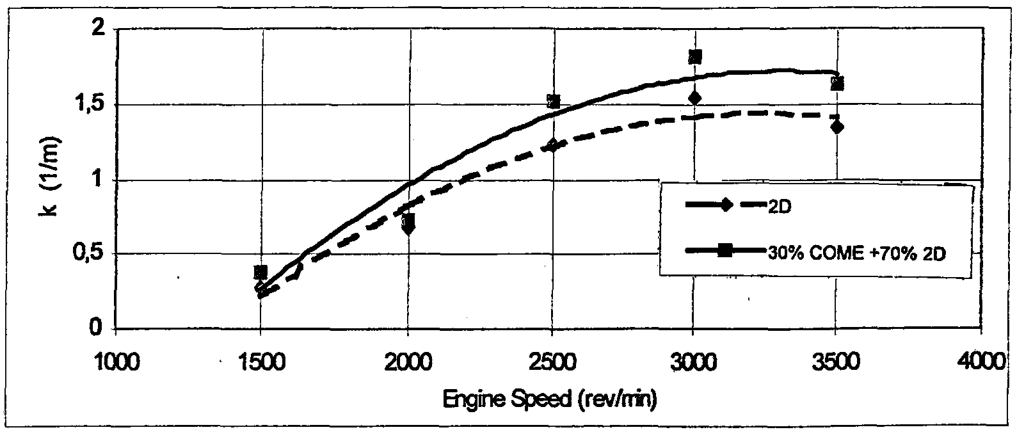

Figure 4.38. Opacity (k) of 2D and 30% COME + 70% 2D.

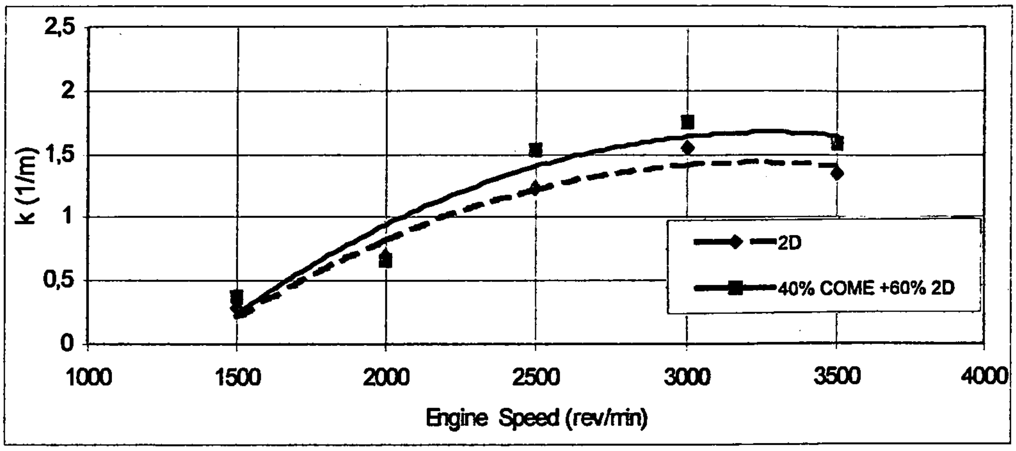

Figure 4.39. Opacity (k) of 2D and 40% COME + 60% 2D.

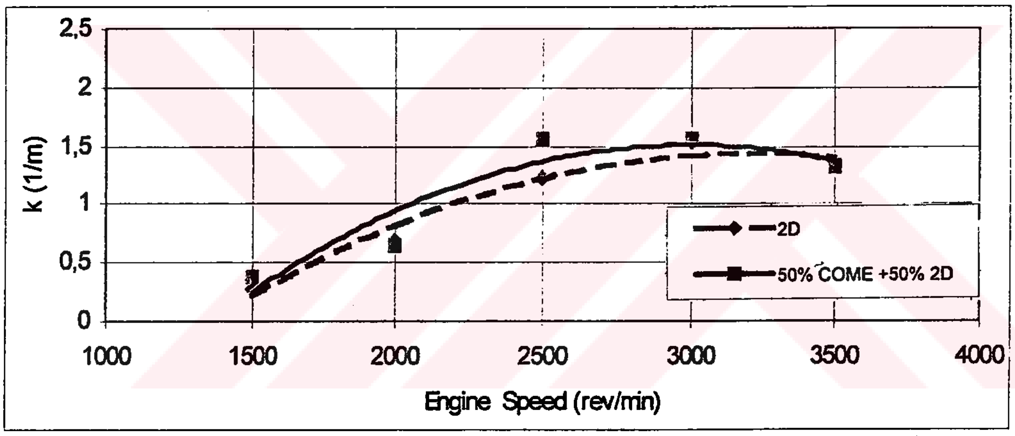

Figure 4.40. Opacity (k) of 2D and 50% COME + 50% 2D

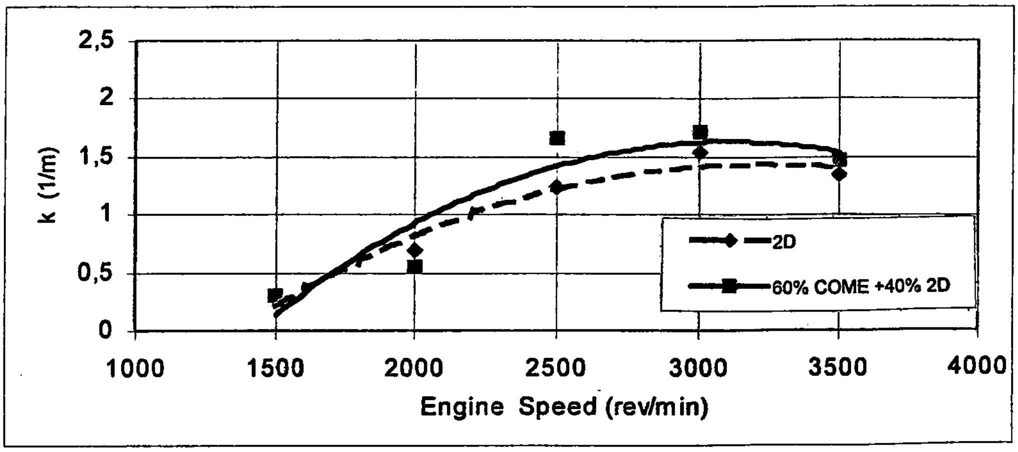

Figure 5.41. Opacity (k) of 2D and 60% COME + 40% 2D.

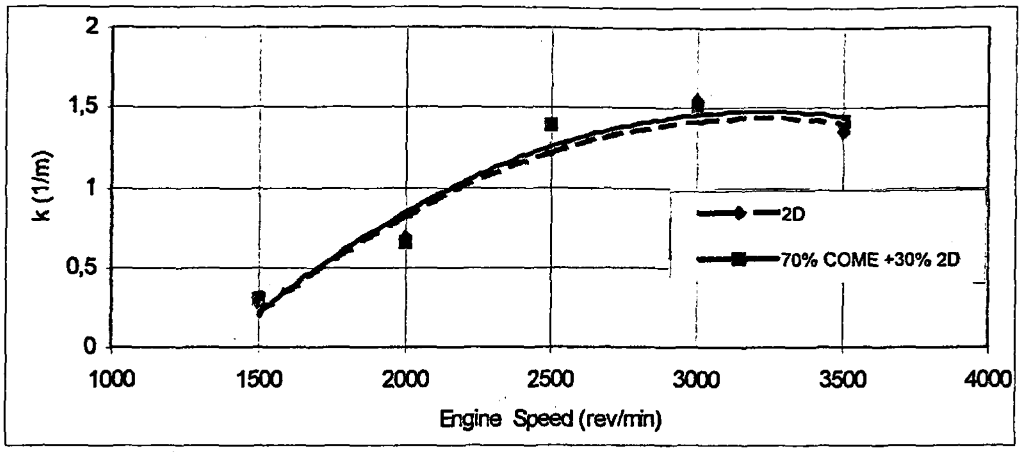

Figure 4.42. Opacity (k) of 2D and 70% COME + 30% 2D.

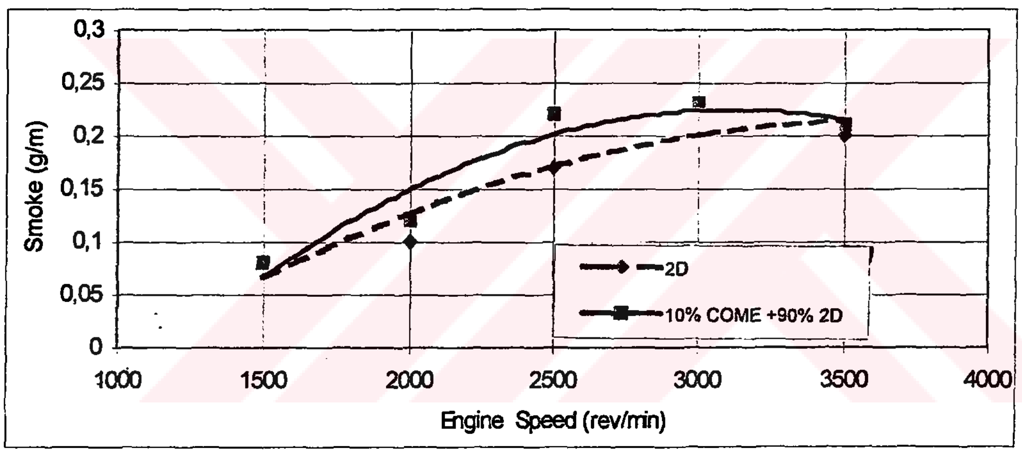

Figure 4.43. Smoke (g/m^3) of 2D and 10% COME + 90% 2D.

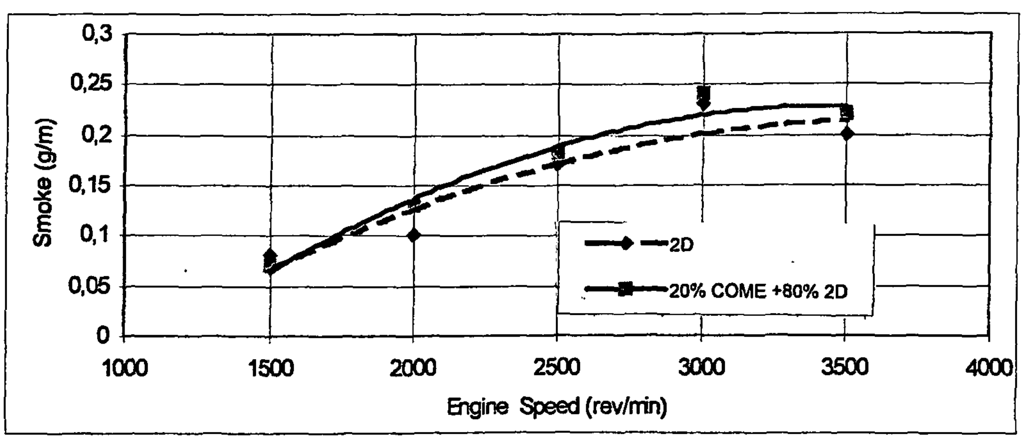

Figure 4.44. Smoke (g/m^3) of 2D and 20% COME + 80% 2D.

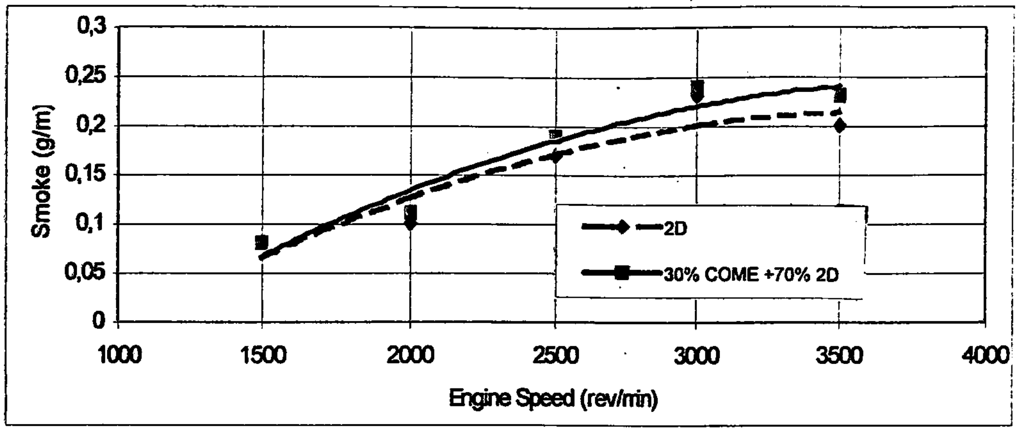

Figure 4.45. Smoke (g/m^3) of 2D and 30% COME + 70% 2D.

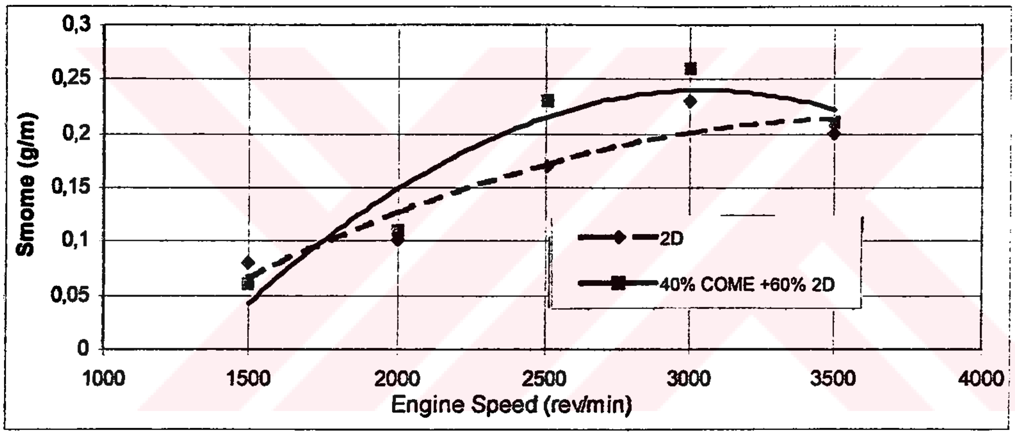

Figure 4.46. Smoke (g/m^3) of 2D and 40% COME + 60% 2D.

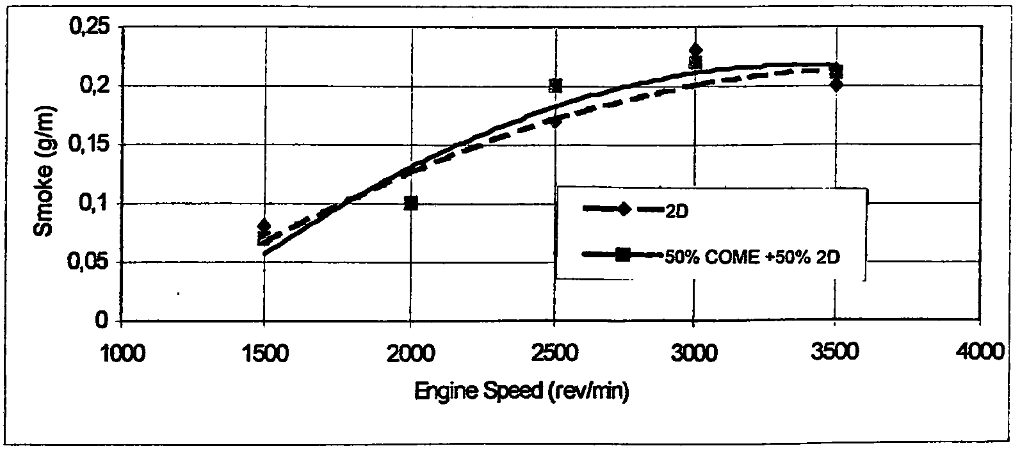

Figure 4.47. Smoke (g/m^3) of 2D and 50% COME + 50% 2D.

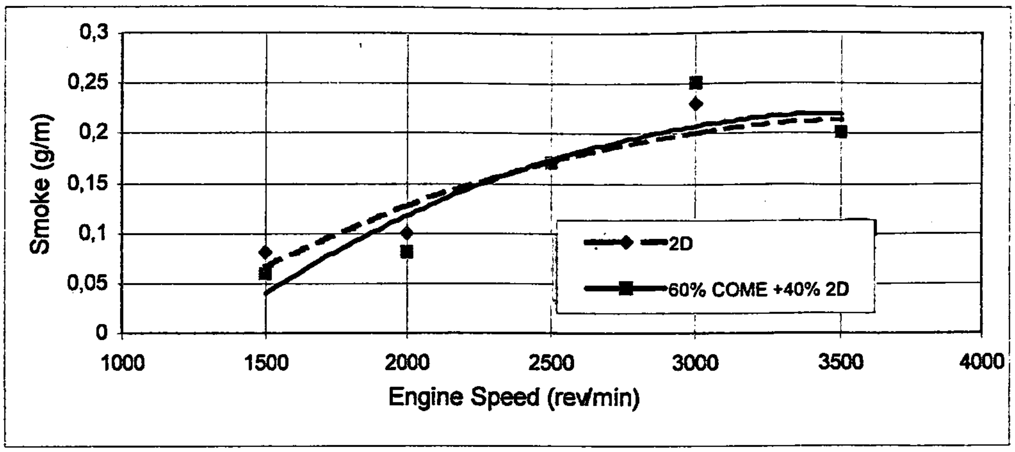

Figure 4.48. Smoke (g/m^3) of 2D and 60% COME + 40% 2D.

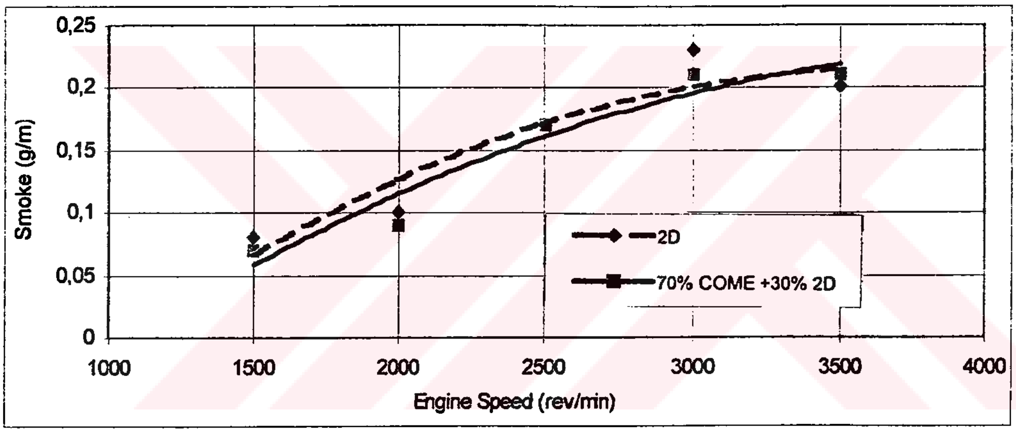

Figure 4.49. Smoke (g/m^3) of 2D and 70% COME + 30% 2D.

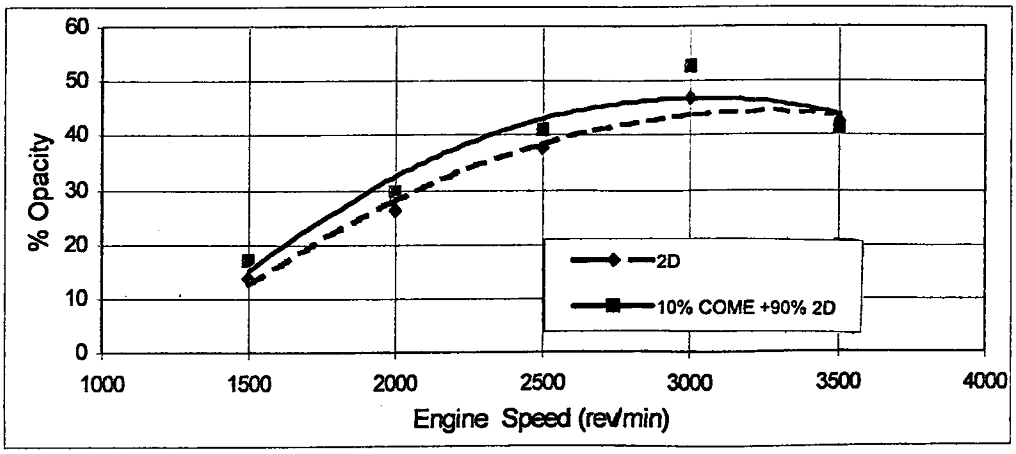

Figure 4.50. % opacity of 2D and 10% COME + 90% 2D.

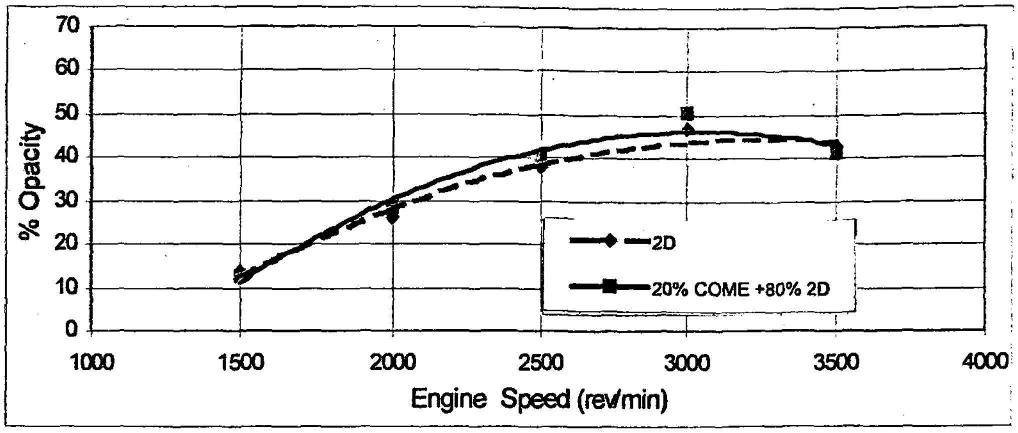

Figure 4.51. % Opacity of 2D and 20% COME + 80% 2D.

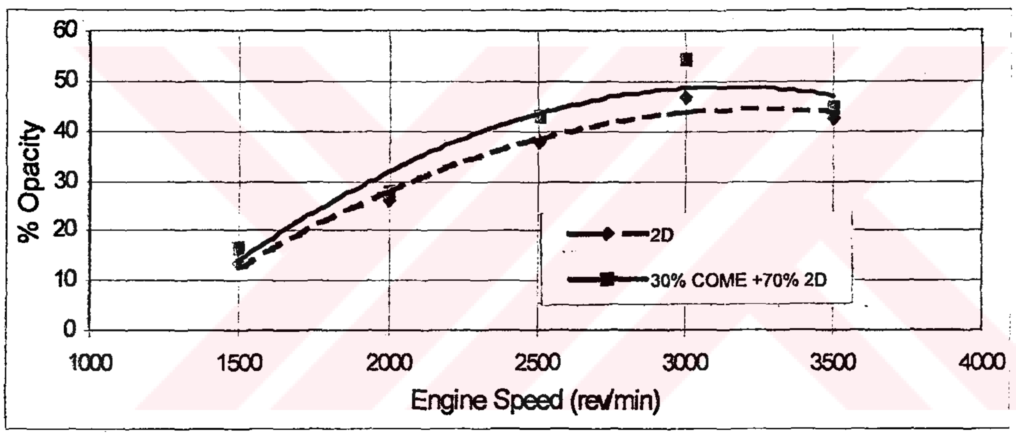

Figure 4.52. % Opacity of 2D and 20% COME + 80% 2D.

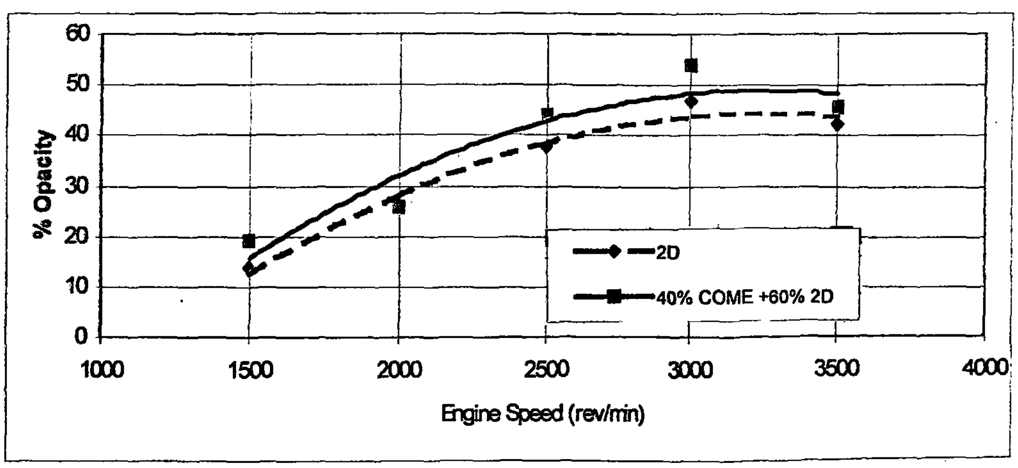

Figure 4.53. % Opacity of 2D and 40% COME + 60% 2D.

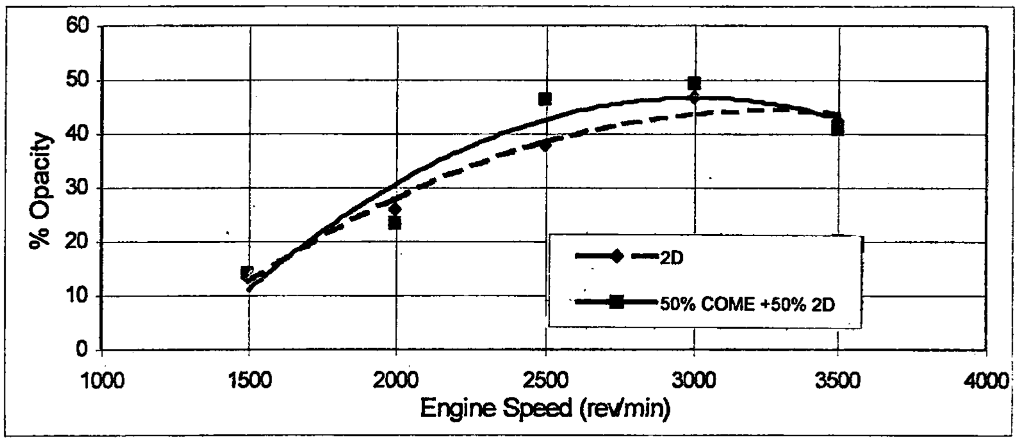

Figure 4.54. % Opacity of 2D and 50% COME + 50% 2D.

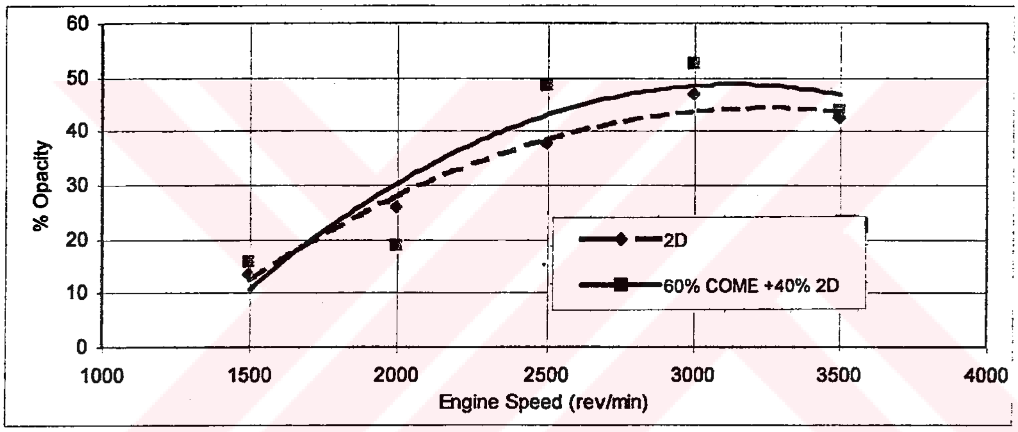

Figure 4.55. % Opacity of 2D and 60% COME + 40% 2D.

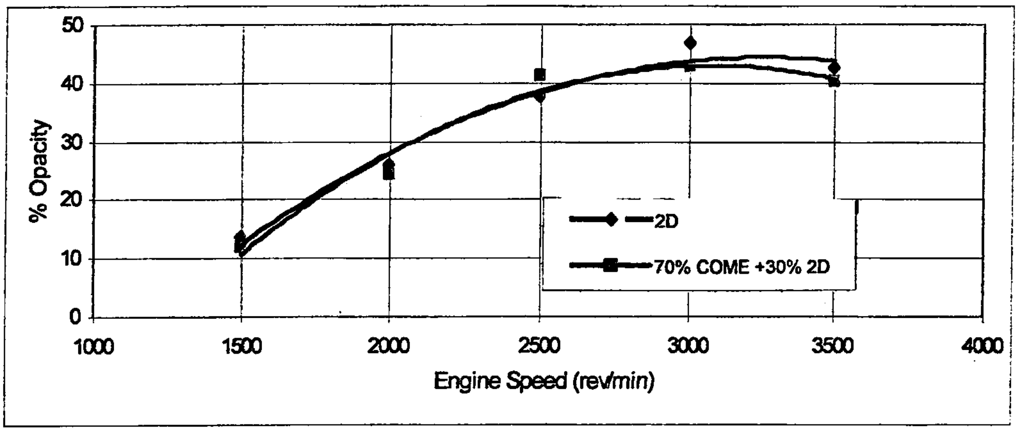

Figure 4.56. % Opacity of 2D and 70% COME + 30% 2D.

Emission of engine with all blend fuels values didn't vary significantly for all engine speed. However, emission values of blend fuels were usually a little higher than diesel fuel. Only, emission values of 70%-30% blend were slightly lower than diesel fuel. Emission values of blend fuels decreased depending amount of COME. In addition, emission value of some blend fuels were lower than diesel fuels at lower and higher engine speeds.

4.2. Presentation and Analysis of Data for Cotton Oil, Ethyl Alcohol and Diesel Fuel Blends

Blends of cotton oil, ethyl alcohol and diesel fuel were tried at full load-different engine speeds in three cylinder, direct injection diesel engine. Before each test, the engine was warmed up with the diesel fuel until the engine temperatures stabilised. During the engine test, blend fuels were heated and stirred in engine fuel tank. Power, torque, heat loss and mass of exhaust gases were measured for 50, 60 and 70 °C fuel temperatures at different engine speeds and load condition. Experimental results of power – speed, Toque – speed, heat loss– speed and mass of exhaust gas – speed graphs are plotted in following figures.

4.2.1. Power

Power of engine for blend fuels and diesel fuel were calculated from engine speed and force. Results of blend fuels were compared with diesel fuels. Toque versus speed changes are given in figures 4.57. – 4.59.

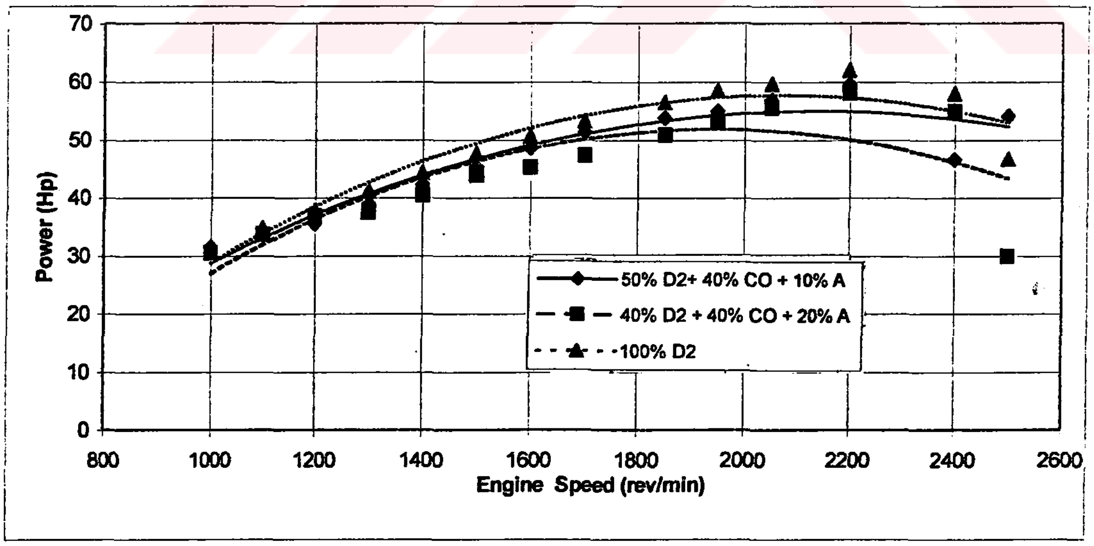

Figure 4.57. Power – engine speed curve of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 70 °C.

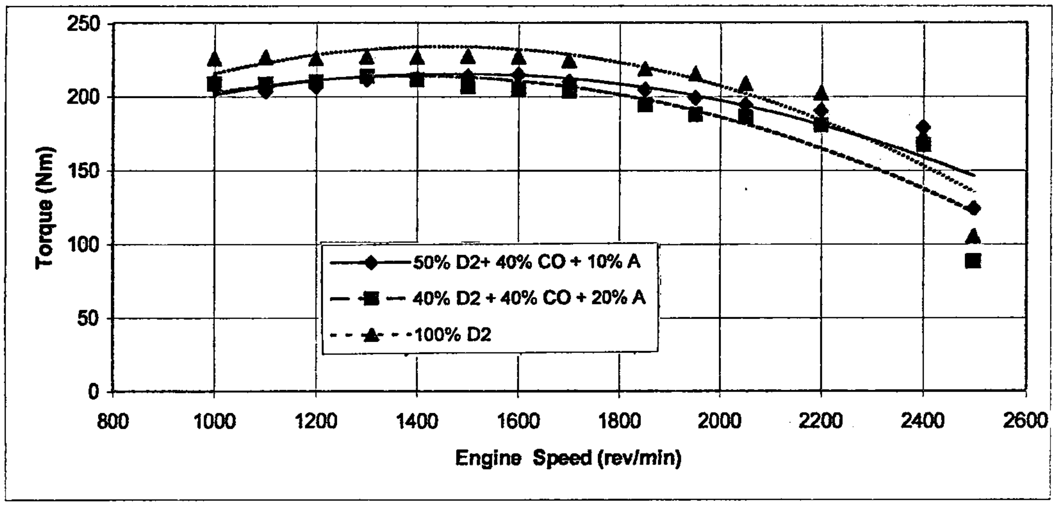

Figure 4.58. Power – engine speed curve of 2D, 50% 2D-40% CO-10%A and 40% 2D - 40% CO-20% A at 60 °C.

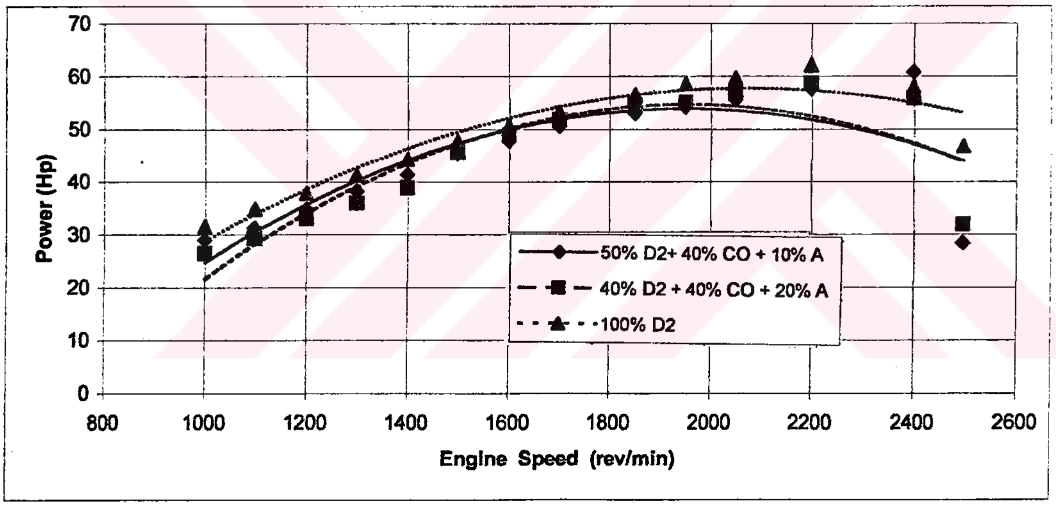

Figure 4.59. Power – engine speed curve of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 50 °C

Maximum power of engine was measured between 2200 and 2500 rpm for all blend fuels and diesel fuel at every fuel temperature. Maximum power of blend fuels ranged from 60 to 56 Hp. After 1700 rpm, power of engine declined significantly with all blend fuels at 50 and 70 °C fuel temperatures. In addition, decreasing of power values were lower between 1000 and 1700 rpm for 70 °C and 50 °C constant temperature. At 60 °C constant temperature, power of blend fuels were higher than others at higher engine speeds.

4.2.2. Torque

Torque of engine for blend fuels and diesel fuel were calculated from power and engine speed. Torque versus engine speeds changes of different fuel mixtures and diesel fuel are shown in figures 4.60. – 4.62.

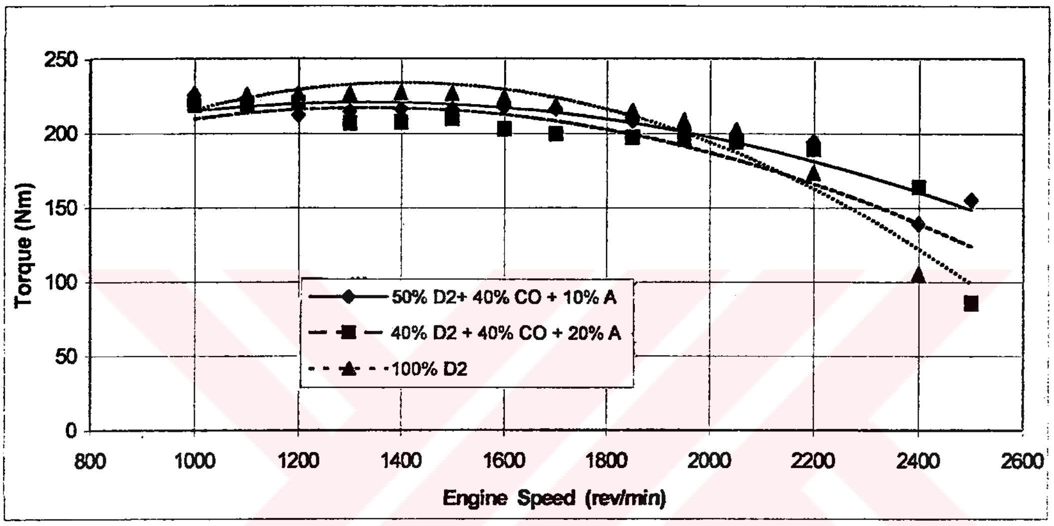

Figure 4.60. Torque – engine speed curve of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 70 °C.

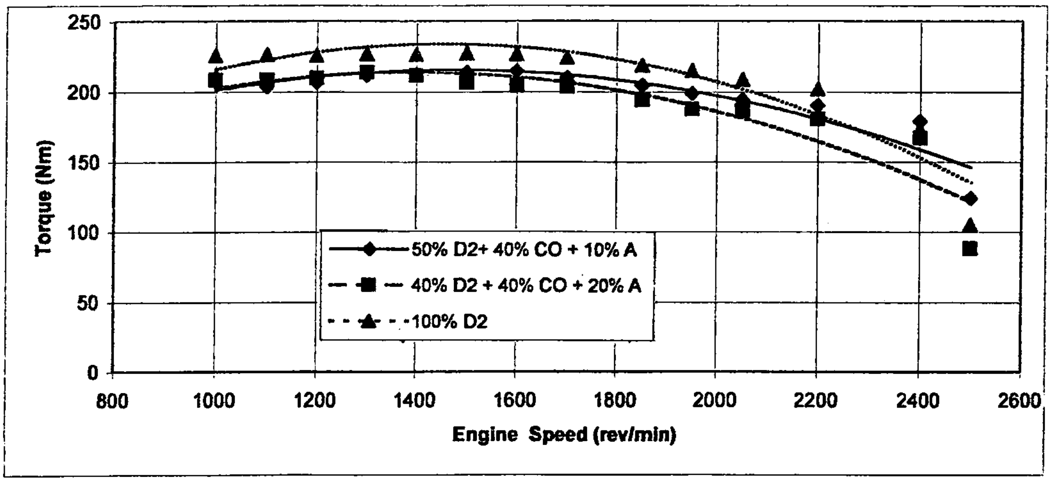

Figure 4.61. Torque – engine speed curve of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 60 °C.

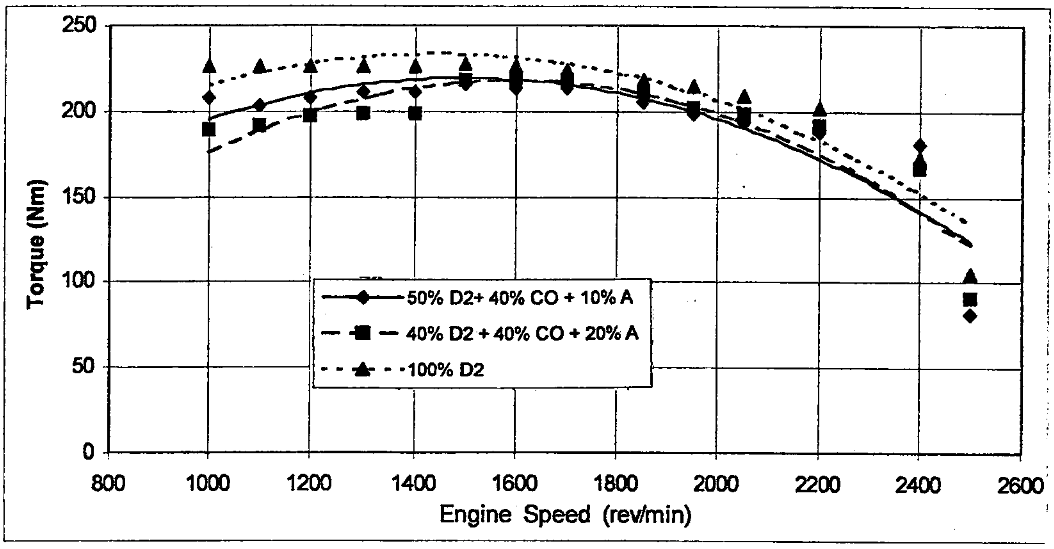

Figure 4.62. Torque – engine speed curve of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 50 °C.

Maximum torque for every blend fuels and diesel fuel was measured between 1300 - 1600 rpm at all measured fuel temperature. Maximum torque of all blend fuels didn't reach maximum torque of diesel fuel. Torque of engine decreased depending on the amount of cotton oil and ethyl alcohol at all measured fuel temperature. However, higher toque values are measured for blend fuels between 2100 and 2500rpm at 70 °C constant temperatures.

4.2.3. Heat Loss

At 60 °C and 50°C constant temperature, Heat losses of blend fuels didn't vary significantly between 1000 -1800 rpm. In addition, at 70 °C constant temperature, 40-40-20 blend had lower heat loss than diesel fuel between 1000 – 1800 rpm. After 1800 rpm, all blend fuels had higher heat loss than diesel fuel for every fuel temperature. At 50 °C constant temperature, heat losses of 50-40-10 blend was higher than other fuels between 2000 – 2500 rpm.

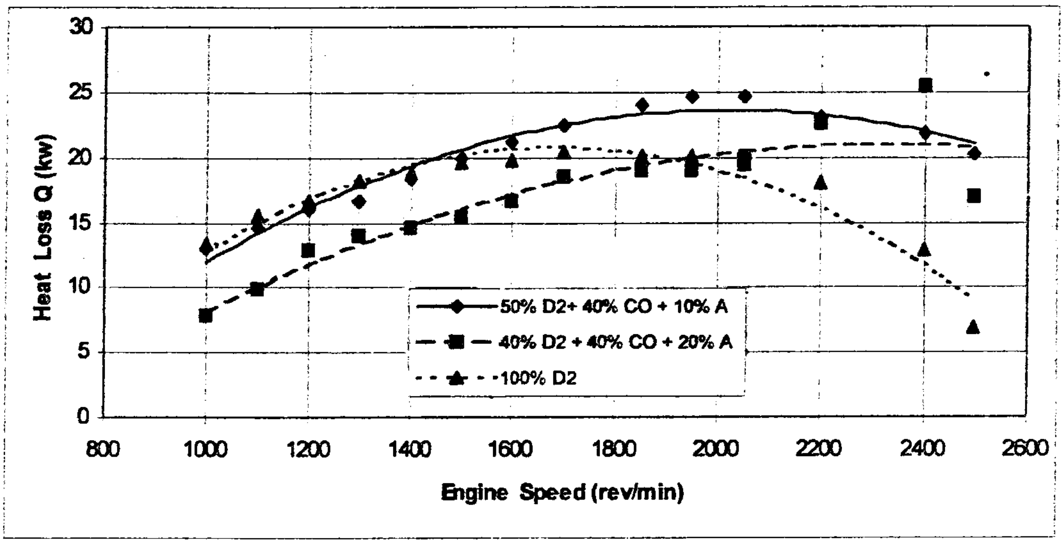

Figure 4.63. Heat loss of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 70 °C.

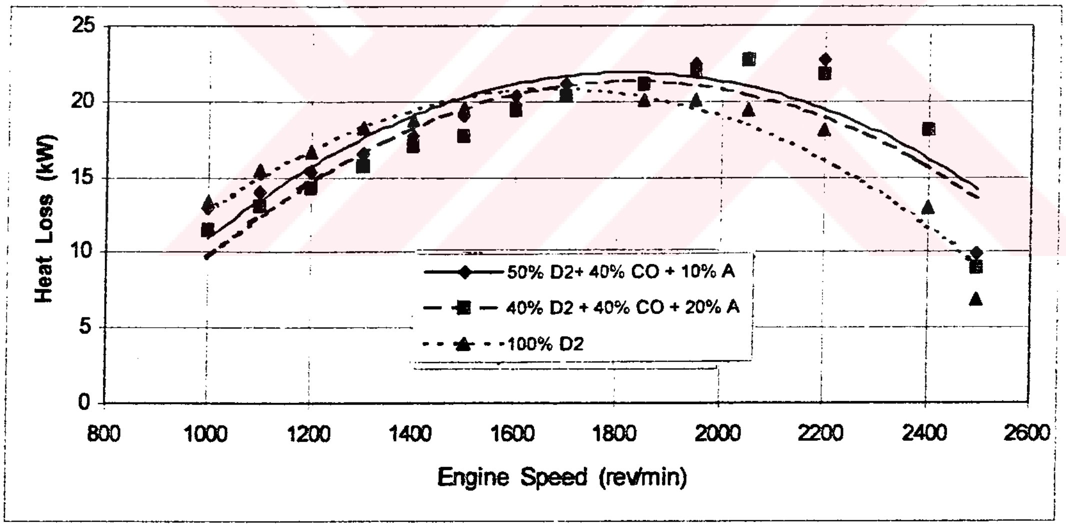

Figure 4.64. Heat Loss of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 60 °C.

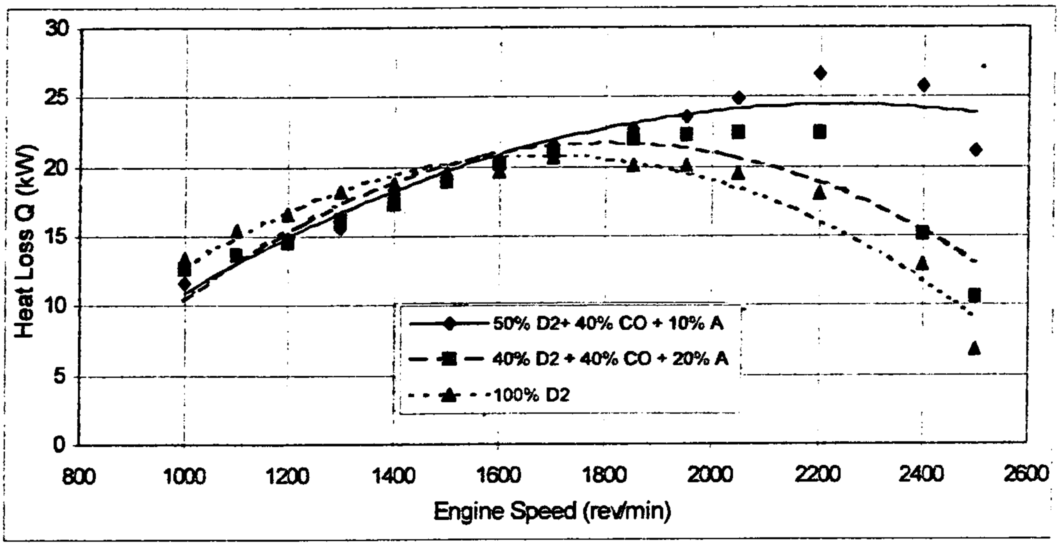

Figure 4.65. Heat loss of 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 50 °C.

4.2.4. Mass of Exhaust Gasses

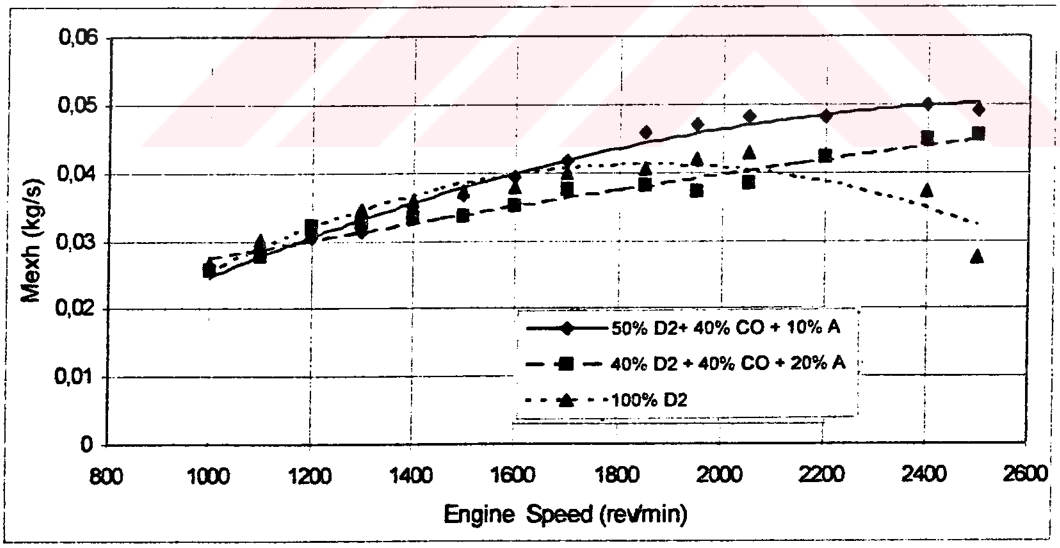

Figure 4.66. Mass of exhaust gases for 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 70 °C.

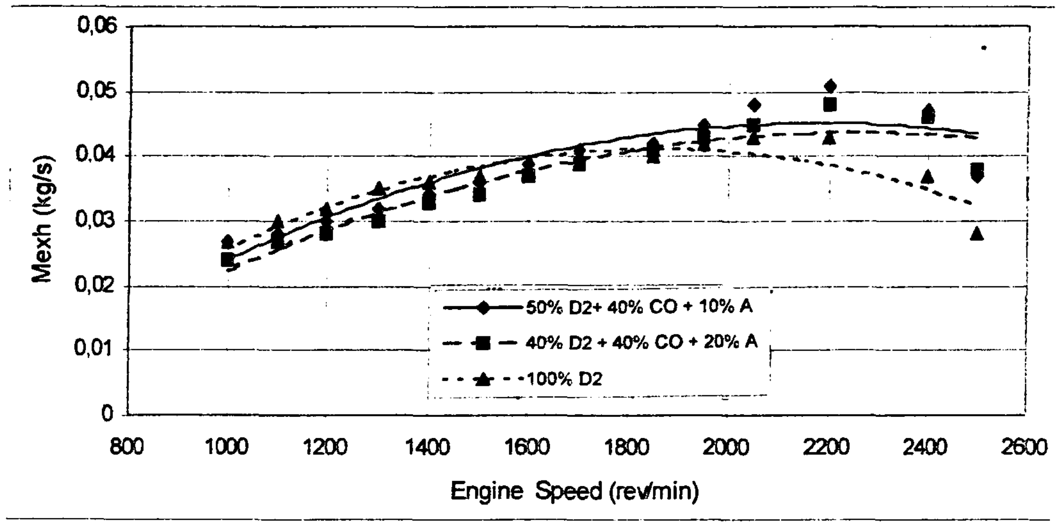

Figure 4.67. Mass of exhaust gases for 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 60 °C.

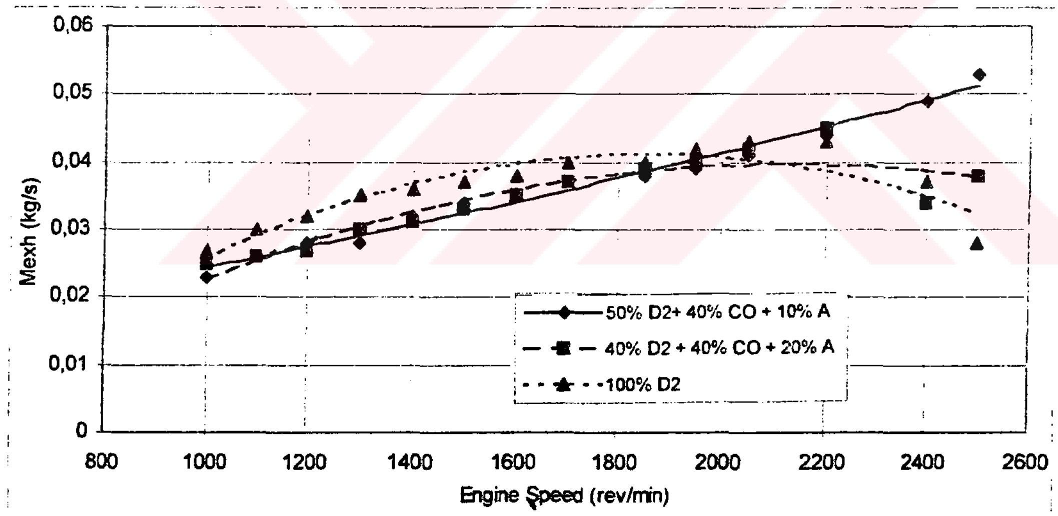

Figure 4.68. Mass of exhaust gases for 2D, 50% 2D-40% CO-10%A and 40% 2D-40% CO-20% A at 50 °C.

Mass of exhaust gas for diesel fuel was higher than blend fuels between 1000-1600 rpm. However, at higher engine speeds, diesel fuel usually had lower mass of exhaust gas than all blend fuels at all measured fuel temperature. After 1800 rpm, two blend fuels of exhaust gas mass were higher than diesel fuel at 60 °C constant temperature. In addition, 50-40-10 blend fuel had higher mass of exhaust gas than other blend fuels for all engine speed at 70 °C constant temperature.

5. CONCLUSION

Low viscosity, high calorific value, low sulfur content and similar characteristics were advantageous of all mixtures for alternative or emergency fuel for diesel engines.

Low viscosity of blends fuels solved a lot of problem by using of vegetable oil as alternative fuel in diesel engines. These problems are block of injectors and filters, poor atomization and contamination of lubrication oil.

The calorific values of cotton oil – ethyl alcohol – diesel fuel blends are 8-11.7% lower than diesel fuel. Calorific values of cotton oil methyl ester – diesel fuel blends are 0.6-5.3% lower than diesel fuel. Calorific values of the blend fuels decreased depending on the amount of cotton oil methyl ester, cotton oil and ethyl alcohol.

Torque, power and specific fuel consumption value of engines did not vary significantly with all blend fuels at all engine performance test. Torque, power and specific fuel consumption of engines were largely dependent on calorific value and viscosity of blend fuels.

Maximum torque of engine with cotton oil methyl ester – diesel fuel blends were decreased between 0% and 5%. However, maximum torque of engine with cotton oil - diesel fuel - ethyl alcohol blends were decreased between 2.6% and 5.7%.

Decreasing of maximum engine power ranged between 0 and 4.5% with cotton oil methyl ester - diesel fuel blends. After 1700 rpm, power of engine with cotton oil - diesel fuel - ethyl alcohol blends declined significantly at measured fuel temperatures. In addition, decreasing of maximum engine power with cotton oil - diesel fuel - methyl alcohol blend ranged between 0 and 6%.

Specific fuel consumption of engine with cotton oil methyl alcohol – diesel fuel blend increased between 2.3% and 12.4%.

Cotton oil methyl ester – diesel fuel blends and diesel fuel have approximately same emission value at all engine test. Only, emission values of 70% cotton oil methyl ester -30% diesel fuel blend were slightly lower than diesel fuel at some engine speed.

Using of vegetable oil as alternative fuel in diesel engine has two advantages: the decrease in energy dependency and the effective use of the agricultural areas. In addition, unlike mineral oil, vegetable oil contains no sulphur, so that environmental damage due to sulphuric acid is reduced.

Solution of the energy crisis and dependence for petroleum in our country is new alternative renewable energy resources. Therefore, using of vegetable oil as alternative fuel in diesel engine is very important.

REFERENCES

ALTIN, R., 1998, Bitkisel Yağların Dizel Motorlarında Yakıt Olarak Kullanılmasının Deneysel Olarak İncelenmesi, Doktora Tezi, Gazi Üniversitesi, Ankara.

ANONYMOUS., 1995. Enerji raporu, Dünya eneji konseyi Türk milli komitesi yayını, s. 69, Ankara.

APFELBECK, R., 1986. Production and processing of plant oil and by-proucts to fuels. Paper No.83, Biomass Conversion For Energy Thermochemical Conversion, Procedings of The First Technical Consultation of CNRE. Freising, F. R. Of Germany, October 14-17.

BATMAZ, İ. and ALTIN, R., 1997. Dizel motorlarında alternatif yakıt olarak mısır yağının kullanılması, Poli Teknik Dergisi, sayı 7 G.Ü.T.E.F. Ankara.

BARSIC, N. J. and HUMKE, A.L., 1981. Performance and Emissions characteristics of a Naturally Aspirated Diesel Engine with Vegetable oil fuels (Part 2), SAE 810955, Transaction of SAE, p. 2925-2935.

BLUMBERG, P. N. and FORT, E. F., 1982. Performance and durability of a turbocharger diesel fueled with cotton seed oil blends, Vegetable oils Fuels Procedings Of The International Conference on Plant And Vegetable Oils As Fuels. ASAE August 82.

BORGELT, S. C. and HARRIS, F. D., 1982. Endurance Tests Using Soybean Oil-Diesel Fuel Mixture to Fuel Small Pre-Combustion Chamber Engines, Vegetable oils Fuels Procedings Of The International Conference on Plant And Vegetable Oils As Fuels. ASAE August 82.

BRAUN, D. E. and STEPHENSON, K. Q., 1982. Alternative Fuel Blends and Diesel Engine Tests, Vegetable Oils Fuels Proceeding Of The International Conference On Plant And Vegetable Oils As Fuels, ASAE.

BRUWER, J. J., et al. 1980. Sunflower seed oil as an extender for diesel fuel in agricultural tractors. Department of Agriculture and Fisheries, Silverton, Republic of South Africa.

BUCKINGHAM, F., 1982. Vegetable Oil Fuels- Not Quite Yet. **ASAE.** Vol. 63, NO:10, p.27-29.

CIĞIZOĞLU, K. B., ÖZAKTAŞ, T. and KARAOSMANOĞLU, F., 1997. Used sunflower oil as an alternative fuel for diesel engines. Paper No. 559, 19th Energy Sources.

COCHRAN, B. J., DANIEL, L. B., and BALDWIN, J. C., 1980. Diesol – an alternative fuel for compression ignition engines. Paper presented at the National Energy Symposium of the American Society of Agricultural Engineers, Kansas City, Missouri.

CULSHAW, F. A., 1993. The potential of 'biodiesel' from oilseed rape: Proceeding of the Institution of Mechanical Eng. Part A, Journal of Power Eng. V 207, No:A3, p 73-77, Hatwell, Oxfordshire, England.

ÇETINKAYA, S., 1994. Ayçiçek yağının dizel motoru yakıtı olrak kullanılabilme potansiyeli, Gazi Üniversitesi Tek. Egt. Fak., Doçentlik Tez Taktimi, Ankara.

DEMIRSOY, M. and KINDIROĞLU, K., 1997, Dizel motorlarında alternatif yakıt olarak değişik yağların kullanılması, 1. Uluslararası Katılımlı Otomotiv Teknolojisi Kongresi Bildiriler Kitabı, p. 107-115, Adana.

GOERING, C. E., SCHWAP, A. W., CAMPLON, R. M. and PRYDE, E. F., 1982. Fuel Properties of Eleven Vegetable Oils. Transactions of ASAE.

GEYER, S. M., JACOBUS, M. J. and LESTZ, S. S., 1984. Comparison of diesel engine performance and emission from neat and transesterified vegetable oils. Paper No. 375, Vol.27 Transactions of the ASAE.

HASSETT, D. J., and HASAN, R. A., 1982. Sunflower oil methyl ester as diesel fuel, Vegetable Oils Fuels Proceding Of The International Conference on Plant And Vegetable Oils As Fuels, ASAE.

İLKILIÇ, C., BAYINDIR, H. and ÖNER, C., 1997. Dizel Motorlarda Alternatif Yakıt Olarak Ayçiçek Yağının Kullanılması, 1.Uluslararası Katılımlı Otomotiv Teknolojisi Kongresi Bildiriler Kitabı, p. 116-123.

KNOTHE, G., BAGBY, M. O. and RYAN, T. W., 1992, Vegetable oils as alternative diesel fuel: dedradation of pure triglycerides during the precombustion phase in a reactor simulating a diesel engine, SAE Tech. Paper, 920194, p 1-12, USA.

KARAOSMANOĞLU, F., CIĞIZOĞLU, K. B. and TÜTER, M., 1995. Biyomotorin uygulamaları. Mühendis ve Makine Dergisi. Sayı 431.

MENDILCIOĞLU, M., 1996, Enerji politikalarımız ve enerji sektörümüzdeki gelişmeler, Türkiye Enerji Sempozyumu, p 203-209, TMMOB, Ankara.

PETERSON, C. L., WAGNER, G. L. and AULD, D. L., 1983. Vegetable Oil Substitutes for Diesel Fuel. Transaction of ASAE.

PRYDE, E. H., 1982. Vegetable Oil as Diesel Fuel: Overview. JAOCS, Vol.60, No:8

QUICK, G.R., WILSON, B.T. and WOODMORE, P. J., 1982. Injector – fouling propensity of certain vegetable oils and derivatives as fuels for diesel engines, Vegetable Oils Fuels Proceedings of the Internal Conference on Plant and Vegetable Oils as Fuels, ASAE.

RAKOPOULOS, C. D., 1992. Comparitive performance and emission studies when using olive oil as a fuel supplement in DI and IDI diesel engines, Renewable Energy, V.2, No:33, Pergamon Press. Ltd.

RAMDEEN, P., BACKER, L.F., KAUFMAN, K.R., KUCERA, H.L. and MOILANEN C.W., 1982. Some Physiochemical Tests of Sunflower Oil and No: 2 Diesel Oil as Fuels, The Rise of Sunpower, North Dakota Farm Research Biomonthly Bulletin, Vol. 39, No: 6, p. 12-14.

ROMANO, S., 1982. Vegetable oils – a new alternative, Vegetable Oils Fuels Procedings Of The International Conference on Plant And Vegetable Oils As Fuels, ASAE.

SARAÇOĞLU, N., 1996. Enerji projelerinin Türkiye'nin enerji potansiyeline katkı olanakları, Türkiye Enerji Sempozyumu, TMMOB, Ankara.

SCHMIDT, A., STAETTER, W., et al., 1992. Rape seed oil as a source of energy (2): rape seed oil as a diesel oil extender - results of laboratory and test stand experience, Erdoel Erdgas Kohle, V 108, p 415-418, Germany.

SCHOLL, K. W., SERENSON, S. C., 1992. Combustion of oil methyl ester in di engine, SAE Special Publ., 920934, 950, p 211-223. Detroit, USA.

STOUT, B. A.,1984. Energy Use And Manegement In Agriculture, Texas

TAHİR, A. R., LAPP, H. M. and BUCHANAN L. C., 1982. Laboratory Endurance Test of a Sunflower Oil Blend in a Diesel Engine, Vegetable Oils Fuels Proceding Of The International Conference on Plant And Vegetable Oils As Fuels, ASAE.

ZIEJEWSKI, M. and KAUFMAN, K. R., 1982. Laboratory Endurance Test of a Sunflower Oil Blend in a Diesel Engine, Vegetable Oils Fuels Proceeding Of The International Conference on Plant And Vegetable Oils As Fuels, ASAE.

VELLGUTH. G., (1983). Performance of Vegetable Oils and Their Monoesters as Fuels for Diesel Engines, SAE 831358, Transaction of SAE. p. 3.1098-3.1107.

WALTER, J., AAKRE, P. and DERRY, J., 1982. The 1981 "Flower Power" Field Testing Program, Vegetable Oils Fuels Proceding Of The International Conference on Plant And Vegetable Oils As Fuels, ASAE.

1995 Enerji Raporu, 1996. Dünya Enerji Konseyi Türk Milli Komitesi, Ankara.

CURRICULUM VITAE

Ali KESKİN was born in Karaisalı/ADANA 1975. He enrolled in the Automotive Department of Gazi University. He graduated from Gazi University as a Technical teacher on June 1997. He started Master of Science education in the Çukurova University Department of Mechanical Engineering in 1998.

APPENDIX

Table A.1. Measured and Calculated values for 2D

Test Number	Torque (Nm)	Speed (rpm)	Exhaust Tem. (C)	Time (m)	Manometer mm (H_2O)	Power (Pb) (kW)	Air/Fuel Ratio	S F C (g/kWh)	M_a (kg/s)	M_f (kg/s)	% Heat Loss Exhaust
1	1.5	3700	320	30.96	33.00	0.6	43.5	1344	34	0.78	30.7
2	3.4	3600	510	20.60	30.00	1.3	26.4	916	31	1.17	30.9
3	4.5	3400	590	17.11	29.00	1.6	21.2	882	30	1.41	29.1
4	6.0	3200	600	17.02	25.50	2.0	18.6	707	27	1.42	26.2
5	6.7	3000	610	18.24	24.00	2.1	18.8	630	25	1.33	26.9
6	7.0	2800	600	18.56	22.30	2.1	17.9	635	23	1.30	25.2
7	8.2	2600	550	21.30	22.00	2.2	20.3	509	23	1.14	25.9
8	8.6	2400	525	22.13	18.00	2.2	17.4	506	19	1.09	21,3
9	8.9	2200	480	22.97	16.00	2.1	16.1	514	17	1.05	18.1
10	8.9	2000	450	24.06	14.00	1.9	14.9	539	15	1.01	15.7
11	8.6	1800	430	25.93	12.00	1.6	13.9	576	13	0.93	14.1
12	8.2	1600	420	29.11	11.50	1.4	15.0	605	13	0.83	14.8
13	7.5	1500	420	32.62	10.00	1.1	14.8	674	11	0.74	14.6

Table A.2. Measured and Calculated values for 10% COME + 90% 2D.

Test Number	Torque (Nm)	Speed (rpm)	Exhaust Tem. (C)	Time (m)	Manometer mm (H2O)	Power (Pb) (kW)	Air/Fuel Ratio	S F C (g/kWh)	M_a (kg/s)	M_f (kg/s)	% Heat Loss Exhaust
1	1.5	3700	350	30.12	32.0	0.6	42.8	1415	35.20	0.82	33.6
2	3.4	3600	510	21.40	30.0	1.3	28.5	903	33.00	1.16	33.6
3	4.5	3400	640	16.51	28.0	1.6	20.5	936	30.80	1.50	31.0
4	6.0	3200	625	16.65	26.5	2.0	19.6	740	29.15	1.49	28.9
5	6.5	3000	630	18	23.0	2.0	18.4	674	25.30	1.38	27.5
6	6.9	2800	550	18.12	22.5	2.0	18.1	676	24.75	1.37	23.5
7	8.1	2600	535	20.10	21.5	2.2	19.2	559	23.65	1.23	24.1
8	8.4	2400	510	21.66	18.0	2.1	17.3	542	19.80	1.14	20.8
9	8.8	2200	480	22.88	16.0	2.0	16.3	534	17.60	1.08	18.4
10	8.9	2000	455	24.21	13.0	1.9	14.0	549	14.30	1.02	15.1
11	8.5	1800	430	26.41	12.0	1.6	14.1	585	13.20	0.94	14.4
12	8.1	1600	430	28.82	11.0	1.4	14.1	633	12.10	0.86	14.4
13	7.5	1500	425	29.14	10.5	1.2	13.6	721	11.55	0.85	13.7

Table A.3. Measured and Calculated values for 20% COME + 80% 2D.

Test Number	Torque (Nm)	Speed (rpm)	Exhaust Tem. (C)	Time (m)	Manometer mm (H2O)	Power (Pb) (kW)	Air/Fuel Ratio	S F C (g/kWh)	M_a (kg/s)	M_f (kg/s)	% Heat Loss Exhaust
1	1.6	3700	360	29.84	31.0	0.6	41.1	1339	34.10	0.83	33.4
2	3.4	3600	520	21.08	30.0	1.3	28.1	917	33.00	1.17	33.9
3	4.5	3400	620	16.30	27.0	1.6	19.5	948	29.70	1.52	28.7
4	5.8	3200	630	16.22	26.0	1.9	18.7	786	28.60	1.53	28.1
5	6.5	3000	620	17.83	23.0	2.0	18.2	680	25.30	1.39	26.9
6	6.8	2800	580	18.05	22.5	2.0	18.0	688	24.75	1.37	24.8
7	8.0	2600	557	20.22	22.0	2.2	19.8	562	24.20	1.22	26.0
8	8.4	2400	530	21.04	17.5	2.1	16.4	558	19.25	1.18	20.6
9	8.6	2200	500	22.68	15.0	2.0	15.1	551	16.50	1.09	18.0
10	8.6	2000	460	23.64	13.0	1.8	13.6	568	14.30	1.05	15.0
11	8.5	1800	440	24.33	12.0	1.6	13.0	635	13.20	1.02	13.7
12	7.8	1600	420	28.10	10.5	1.3	13.1	674	11.55	0.88	13.1
13	7.4	1500	420	28,90	10.0	1.2	12.8	737	11.00	0.86	12.9

Table A.4. Measured and Calculated values for 30% COME + 70% 2D.

Test Number	Torque (Nm)	Speed (rpm)	Exhaust Tem. (C)	Time (m)	Manometer mm (H2O)	Power (Pb) (kW)	Air/Fuel Ratio	S F C (g/kWh)	M_a (kg/s)	M_f (kg/s)	% Heat Loss Exhaust
1	1.4	3700	350	29.49	31.0	0.5	41.6	1512	34.10	0.82	35.2
2	3.2	3600	520	21.30	29.5	1.2	28.6	941	32.45	1.14	34.8
3	4.4	3400	630	16.12	27.5	1.6	20.2	958	30.25	1.50	30.3
4	5.8	3200	650	16.51	26.0	1.9	19.5	754	28.60	1.47	30.4
5	6.3	3000	610	18.03	23.0	2.0	18.9	678	25.30	1.34	27.5
6	6.8	2800	570	18.32	22.5	2.0	18.7	662	24.75	1.32	25.5
7	7.8	2600	555	19.45	21.0	2.1	18.6	586	23.10	1.24	24.6
8	8.3	2400	515	21.15	17.0	2.1	16.3	548	18.70	1.14	20.2
9	8.6	2200	500	22.66	15.5	2.0	16.0	539	17.05	1.07	19.2
10	8.7	2000	480	23.50	13.5	1.8	14.4	565	14.85	1.03	16.7
11	8.3	1800	450	24.42	11.5	1.6	12.8	633	12.65	0.99	13.9
12	7.8	1600	430	27.95	11.0	1.3	14.0	662	12.10	0.87	14.4
13	7.4	1500	420	27.88	10.0	1.2	12.7	746	11.00	0.87	12.9

Table A.5. Measured and Calculated values for 40% COME + 60% 2D.

Test Number	Torque (Nm)	Speed (rpm)	Exhaust Tem. (C)	Time (m)	Manometer mm (H2O)	Power (Pb) (kW)	Air/Fuel Ratio	S F C (g/kWh)	M_a (kg/s)	M_f (kg/s)	% Heat Loss Exhaust
1	1.4	3700	330	30.06	32.0	0.5	42.7	1519	35.20	0.82	35.0
2	3.3	3600	525	20.90	28.0	1.2	26.0	953	30.80	1.19	34.0
3	4.4	3400	630	15.95	27.6	1.6	19.6	991	30.36	1.55	29.6
4	6.1	3200	650	16.78	25.0	1.9	18.6	787	27.50	1.48	29.2
5	6.5	3000	620	17.84	23.5	1.9	18.6	713	25.85	1.39	27.8
6	6.6	2800	575	18.75	21.0	1.9	17.5	683	23.10	1.32	24.3
7	8.0	2600	550	19.25	20.5	2.2	17.5	591	22.55	1.29	23.2
8	8.3	2400	530	21.84	18.0	2.1	17.5	544	19.80	1.13	22.3
9	8.6	2200	480	22.02	16.0	2.0	15.6	568	17.60	1.12	18.1
10	8.6	2000	470	23.36	14.0	1.8	14.5	589	15.40	1.06	16.5
11	8.2	1800	460	23.64	12.0	1.5	12.6	678	13.20	1.05	14.1
12	7.6	1600	430	28,22	10.5	1.3	13.2	689	11.55	0.88	13.7
13	7.3	1500	425	29.02	10.0	1.1	12.9	744	11.00	0.85	13.3

Table A.6. Measured and Calculated values for %50 COME + %50 2D.

Test Number	Torque (Nm)	Speed (rpm)	Exhaust Tem. (C)	Time (m)	Manometer mm (H2O)	Power (Pb) (kW)	Air/Fuel Ratio	S F C (g/kWh)	M_a (kg/s)	M_f (kg/s)	% Heat Loss Exhaust
1	2.5	3700	360	29.46	31.0	0.6	40.6	1447	34.10	0.84	33.7
2	3.3	3600	535	20.90	30.5	1.2	28.3	982	33.55	1.19	36.0
3	4.3	3400	630	16.25	27.5	1.5	19.8	996	30.25	1.52	30.3
4	5.6	3200	660	16.36	25.5	1.9	18.5	807	28.05	1.51	29.8
5	6.2	3000	620	17.40	23.5	1.9	18.2	731	25.85	1.42	27.4
6	6.5	2800	580	18.85	21.0	1.9	17.6	689	23.10	1.31	24.8
7	7.8	2600	557	19.30	20.5	2.1	17.6	604	22.55	1.28	23.8
9	8.2	2400	530	21.30	17.5	2.1	16.6	564	19.25	1.16	21,3
10	8.6	2200	500	22.87	15.5	2.0	15.7	547	17.05	1.08	19.1
11	8.5	2000	475	22.93	14.0	1.8	14.3	607	15.40	1.08	16.5
12	8.2	1800	460	24.02	12.0	1.5	12.8	667	13.20	1.03	14.5
13	7.5	1600	440	27.80	11.0	1.3	13.6	709	12.10	0.89	14.6
14	7.3	1500	430	29.33	10.0	1.1	13.0	736	11.00	0.84	13.7

Table A.7. Measured and Calculated values for %60 COME + %40 2D

Test Number	Torque (Nm)	Speed (rpm)	Exhaust Tem. (C)	Time (m)	Manometer mm (H2O)	Power (Pb) (kW)	Air/Fuel Ratio	S F C (g/kWh)	M_a (kg/s)	M_f (kg/s)	% Heat Loss Exhaust
1	2.5	3700	360	30.16	31.0	1.0	41.5	1100	34.10	0.82	34.6
2	3.3	3600	545	20.85	30.0	1.2	27.8	955	33.00	1.19	36.2
3	4.3	3400	640	16.30	27.0	1.5	19.5	992	29.70	1.52	30.5
4	5.5	3200	650	16.52	26.0	1.8	19.1	813	28.60	1.50	30.3
5	6.2	3000	625	17.26	23.5	1.9	18.0	737	25.85	1.43	27.5
6	6.4	2800	570	18.33	21.0	1.9	17.1	720	23.10	1.35	23.8
7	7.7	2600	560	18.90	20.5	2.1	17.2	625	22.55	1.31	23.5
8	8.2	2400	540	21.40	17.0	2.1	16.2	562	18.70	1.16	21.4
9	8.6	2200	510	22.10	16.0	2.0	15.7	566	17.60	1.12	19.6
10	8.5	2000	470	23.09	14.0	1.8	14.4	603	15.40	1.07	16.6
11	8.1	1800	450	23.81	12.0	1.5	12.7	681	13.20	1.04	14.1
12	7.4	1600	450	28.22	10.5	1.2	13.2	708	11.55	0.88	14.6
13	7.2	1500	440	28.54	10.0	1.1	12.7	767	11.00	0.87	13.8

Table A.8. Measured and Calculated values for %70 COME + %30 2D.

Test Number	Torque (Nm)	Speed (rpm)	Exhaust Tem. (C)	Time (m)	Manometer mm (H2O)	Power (Pb) (kW)	Air/Fuel Ratio	S F C (g/kWh)	M_a (kg/s)	M_f (kg/s)	% Heat Loss Exhaust
1	1.3	3700	355	29.30	31.0	0.5	40.3	1678	34.10	0.85	33.6
2	3.2	3600	540	20.61	30.5	1.2	27.9	996	33.55	1.20	36.5
3	4.3	3400	640	17.05	27.0	1.5	20.4	949	29.70	1.45	32.3
4	6.0	3200	650	16.29	25.5	2.0	18.4	756	28.05	1.52	29.8
5	6.1	3000	620	16.90	24.0	1.9	18.0	765	26.40	1.47	27.7
6	6.3	2800	580	18.16	21.5	1.8	17.3	738	23.65	1.36	24.9
7	7.6	2600	560	19.10	21.0	2.1	17.8	627	23.10	1.30	24.7
8	8.2	2400	535	21.09	18.0	2.1	16.9	570	19.80	1.17	22.3
9	8.4	2200	520	22.50	16.0	1.9	16.0	569	17.60	1.10	20.6
10	8.5	2000	470	22.67	14.0	1.8	14.1	614	15.40	1.09	16.5
11	8.0	1800	460	23.50	12.0	1.5	12.5	699	13.20	1.05	14.5
12	7.4	1600	450	28.84	11.0	1.2	14.1	693	12.10	0.86	15.8
13	7.1	1500	415	29.11	10.0	1.1	12.9	763	11.00	0.85	13.4

Table A.9. Measured and Calculated values for 2D.

Speed (rpm)	Weight (kg)	Air Pressure (kpa)	Water flow rate (lt/min)	T1 (^oC)	T2 (^oC)	T3 (^oC)	T4 (^oC)	Power Pb (hp)	Torque T (Nm)	Heat loss Q(Kw)	Mexh (kg/s)
1000	142	2.15	7.7	331	34	45	20	31.56	226.11	13.42	0.027
1100	142.4	2.35	7.8	338	35	48.5	20	34.81	226.75	15.5	0.03
1200	142	2.6	7.7	342	34	51	20	37.87	226.11	16.65	0.032
1300	142.6	3	7.7	344	34.5	54	20	41.2	227.07	18.26	0.035
1400	142.5	3.1	7.3	345	34.5	57	20	44.33	226.91	18.83	0.036
1500	143	3.15	7.2	344	34.5	59	20	47.67	227.71	19.58	0.037
1600	142.6	3.2	6.9	341	34.5	61	20	50.7	227.07	19.73	0.038
1700	141	3.25	6.8	335	34.5	63	20	53.27	224.52	20.63	0.04
1850	137.5	3.28	6.4	328	35.5	65	20	56.53	218.95	20.08	0.04
1950	135.2	3.3	6.4	316	34	65	20	58.59	215.29	20.08	0.042
2050	131	3.35	6.5	302	34	63	20	59.68	208.6	19.49	0.043
2200	127	3.38	6.5	284	33.5	60	20	62.09	202.23	18.13	0.043
2400	108.8	3.46	7.4	236	32	45	20	58.03	173.25	12.9	0.037
2500	66.2	3.4	7.6	178	31	33	20	46.78	105.41	6.89	0.028

Table A.10. Measured and Calculated values for 50% 2D – 40% CO – 10% A at 70 °C.

Speed (rpm)	Weight (kg)	Air Pressure (kpa)	Water flow rate (lt/min)	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)	Power Pb (hp)	Torque T (Nm)	Heat loss Q(Kw)	Mexh (kg/s)
1000	142.00	2.10	11.00	328	34	35	18	31.56	226.11	13.04	0.026
1100	137.00	2.25	11.00	337	34	37	18	33.49	218.15	14.57	0.028
1200	133.50	2.55	10.90	343	34	39	18	35.60	212.58	15.96	0.030
1300	135.00	2.80	10.90	347	34	40	18	39.00	214.97	16.72	0.031
1400	136.00	3.00	11.00	351	34	42	18	42.31	216.56	18.41	0.034
1500	136.00	3.10	11.00	353	34	44	18	45.33	216.56	19.94	0.037
1600	137.00	3.15	10.90	353	34	46	18	48.71	218.15	21.28	0.039
1700	136.00	3.20	10.70	349	33.5	48	18	51.38	216.16	22.38	0.042
1850	131.00	3.25	10.80	345	34	50	18	53.86	208.60	24.10	0.046
1950	127.00	3.30	10.70	341	33.5	51	18	55.03	202.23	24.62	0.047
2050	125.00	3.35	10.70	334	34	51	18	56.84	199.04	24.62	0.048
2200	122.00	3.40	10.70	316	33	49	18	59.64	194.27	23.13	0.048
2400	87.50	3.45	10.80	290	33	47	18	46.67	139.33	21.84	0.050
2500	97.50	3.50	10.80	276	32	45	18	54.17	155.25	20.33	0.049

Table A.11. Measured and Calculated values for 50% 2D – 40% CO – 10% A at 60 °C.

Speed (rpm)	Weight (kg)	Air Pressure (kpa)	Water flow rate (lt/min)	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)	Power Pb (hp)	Torque T (Nm)	Heat loss Q(Kw)	Mexh (kg/s)
1000	132.00	2.40	9.50	314	33	37,5	18	29.33	210.19	12.92	0.027
1100	128.00	2.65	9.10	322	33	40	18	31.29	203.82	13.96	0.028
1200	130.00	3.00	9.00	330	33	42.5	18	34.67	207.01	15.38	0.030
1300	133.00	3.15	8.80	335	33	45	18	38.42	211.78	16.57	0.032
1400	133.50	3.20	8.90	338	33	46.5	18	41.53	212.58	17.69	0.034
1500	134.50	3.25	9.10	340	33	48	18	44.83	214.17	19.04	0.036
1600	135.00	3.30	9.40	339	33	49	18	48.00	214.97	20.32	0.039
1700	132.00	3.35	9.20	337	33	51	18	49.87	210.19	21.17	0.041
1850	128.50	3.45	9.20	330	33	52	19	52.83	204.62	21.17	0.042
1950	125.00	3.50	9.50	324	32	53	19	54.17	199.04	22.52	0.045
2050	122.00	3.80	9.50	310	31,5	53.5	19	55.58	194.27	22.86	0.048
2200	119.50	4.05	9.60	293	31	53	19	58.42	190.29	22.76	0.051
2400	112.50	4.20	10.00	255	29	45	19	60.00	179.14	18.13	0.047
2500	78.00	3.80	9.50	185	27	34	19	43.33	124.20	9.94	0.037

Table A.12. Measured and Calculated values for 50% 2D – 40% CO – 10% A at 50 °C.

Speed (rpm)	Weight (kg)	Air Pressure (kpa)	Water flow rate (lt/min)	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)	Power Pb (hp)	Torque T (Nm)	Heat loss Q(Kw)	Mexh (kg/s)
1000	130.50	2.35	9.00	329	33.5	37.5	19	29.00	207.80	11.61	0,023
1100	128.00	2.65	890	341	34	41	19	31.29	203.82	13.65	0.026
1200	130.00	3.00	8.90	350	35	43	19	34.80	207.80	14.90	0.028
1300	132.50	3.15	860	360	34.5	45	19	38.28	210.99	15.59	0.028
1400	133.00	3.20	8.90	367	34	48	19	41.38	211.78	18.00	0.032
1500	136.00	3.25	8.70	374	34	51	19	45.33	216.56	19.41	0.034
1600	134.50	3.30	8.70	377	34	52.5	19	47.82	214.17	20.32	0.035
1700	134.00	3.35	8.70	380	34	54.5	19	50.62	213.38	21.54	0.037
1850	129.00	3.40	8.70	384	34	56.5	19	53.03	205.41	22.75	0.038
1950	125.00	3.55	8.70	388	34	58	19	54.17	199.04	23.66	0.039
2050	122.00	3.75	8.80	389	34	59.5	19	55.58	194.27	24.85	0.041
2200	118.00	3.45	8.70	388	33.5	63	19	57.69	187.90	26.69	0.044
2400	114.00	4.40	9.00	342	31	60	19	60.80	181.53	25.73	0.049
2500	51.20	4.30	9.20	365	31	52	19	28.44	81.53	21.17	0.053

Table A.13. Measured and Calculated values for 40% 2D – 40% CO – 20% A at 70 °C

Speed (rpm)	Weight (kg)	Air Pressure (kpa)	Water flow rate (lt/min)	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)	Power Pb (hp)	Torque T (Nm)	Heat loss Q(Kw)	Mexh (kg/s)
1000	137.50	2.56	10.20	200	21	31	20	3056	218.95	7.82	0.03
1100	138.00	2.80	10.20	234	23	33	19,5	33.73	219.75	9.60	0.03
1250	138.50	3.15	10.20	258	25	37	19	3847	220.54	12.80	0.03
1350	130.00	3.20	10.50	275	25	38	19	39.00	207.01	13.91	0.03
1450	130.40	3.25	10.50	285	26	39	19	42.02	207.64	14.64	0.03
1550	132.00	3.30	10.50	295	26	40	19	45.47	210.19	15.38	0.03
1650	127.50	3.35	10.40	306	27	42	19	46.75	203.03	16.68	0.04
1750	125.50	3.38	10.60	316	27	44	19	48.81	199.84	18.48	0.04
1950	123.00	3.40	10.50	327	27	45	19	53.30	195.86	19.04	0.04
2100	122.00	3.45	10.50	341	30	47	19	56.93	194.27	20.50	0.04
2250	119.00	3.47	11.20	362	31	49	19	59.50	189.49	23.43	0.04
2350	103.00	3.55	11.20	365	32	51	19	53.79	164.01	25.38	0.04

Table A.14. Measured and Calculated values for 40% 2D - %40 CO – 20% A at 60 °C.

Speed (rpm)	Weight (kg)	Air Pressure (kpa)	Water flow rate (lt/min)	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)	Power Pb (hp)	Torque T (Nm)	Heat loss Q(Kw)	Mexh (kg/s)
1000	131.00	2.60	9.70	311.5	31	36	19	29.11	208.60	11.50	0.024
1100	131.00	3.00	9.90	321	31	38	19	32.02	208.60	13.12	0.027
1200	132.00	3.15	9.80	328	31.5	40	19	35.20	210.19	14.35	0.028
1300	134.50	3.25	9.80	335.5	32	42	19	38.86	214.17	15.72	0.030
1400	133.00	3.30	9.80	339	31	44	19	41.38	211.78	17.08	0.033
1500	130.00	3.35	9.40	340	31	46	19	43.33	207.01	17.70	0.034
1600	128.50	3.40	9.60	341	31	48	19	45.69	204.62	19.41	0.037
1700	128.00	4.35	9.40	340	31	50	19	48.36	203.82	20.32	0.039
1850	122.00	4.50	9.50	338	32	51	19	50.16	194.27	21.20	0.041
1950	118.00	4.55	9.60	335	30	52	19	51.13	187.90	22.09	0.043
2050	117.00	4.60	9.60	327	29.5	53	19	53.30	186.31	22.76	0.045
2200	113.50	4.70	9.80	298	28.5	51	19	55.49	180.73	21.87	0.048
2400	105.00	4.40	10.00	257	27.5	45	19	56.00	167.20	18.13	0.046
2500	55.50	4.00	9.90	165	25	32	19	30.83	88.38	8.97	0.038

Table A.15. Measured and Calculated values for 40% 2D – 40% CO – 20% A at 50 °C

Speed (rpm)	Weight (kg)	Air Pressure (kpa)	Water flow rate (lt/min)	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)	Power Pb (hp)	Torque T (Nm)	Heat loss Q(Kw)	Mexh (kg/s)
1000	119.00	3.00	9.10	326	28	38	18	26.44	189.49	12.69	0.025
1100	120.00	3.10	8.90	334	28	40	18	29.33	191.8	13.65	0.026
1200	124.00	3.10	8.70	342	28	42	18	33.07	197.45	14.56	0.027
1300	124.50	3.20	8.90	348	28	44	18	35.97	198.25	16.14	0.030
1400	125.00	3.25	8.60	358	28	47	18	38.89	199.04	17.39	0.031
1500	137.00	3.35	8.60	363	28	49.5	18	45.67	218.15	18.89	0.033
1600	137.50	3.40	8.80	365	28	51	18	48.89	218.95	20.25	0.035
1700	137.00	3.50	8.90	365	28	52	18	51.76	218.15	21.10	0.037
1850	133.00	3.75	9.00	362	29	53	18	54.68	211.78	21.97	0.039
1950	127.00	3.65	9.00	352	28	53.5	18	55.03	202.23	22.28	0.040
2050	124.50	3.60	9.20	338	26.5	53	18	56.72	198.25	22.45	0.042
2200	120.00	3.55	9.30	320	26	52.5	18	58.67	191.08	22.37	0.045
2400	104.70	3.50	9.40	282	24	41	18	55.84	166.72	15.08	0.034
2500	57.50	3.40	9.50	186	22	34	18	31.94	91.56	10.60	0.038