EXPERIMENTAL INVESTIGATION OF USE OF CANOLA OIL AS A DIESEL FUEL

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EXPERIMENTAL INVESTIGATION OF USE OF CANOLA OIL

AS A DIESEL FUEL

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ABSTRACT

EXPERIMENTAL INVESTIGATION OF USE OF CANOLA OIL
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In this study, canola oil has been selected for the test on a diesel engine and its suitability as an alternative fuel has been examined. To decrease the high viscosity of canola oil, the effect of temperature on viscosity has been researched. Then the fuel delivery system has been modified to heat canola oil before injecting the oil into the combustion chamber. Also, ethanol has been tested as an additive by blending with canola oil. An experimental setup has been installed according to standards to carry out tests. The set up has been controlled with a computer to take measurements more precisely and to perform experiment automatically. Experimental investigations have been conducted on a four cylinder, direct injection diesel engine.

Full load-variable speed tests have been conducted to evaluate engine performance parameters. In addition 13 mode ESC test cycle has been performed to determine the exhaust emissions. Engine performance and emissions characteristics of canola oil and canola-ethanol blend containing 30% ethanol have been compared with those of baseline diesel fuel. Experimental results show that engine performance decreased for canola oil. Addition of ethanol into canola oil has been noticed to improve performance a little with respect to pure canola oil. Although, maximum

performance has been obtained with diesel fuel, minimum specifics energy cost is obtained with canola oil. It has been observed that hydrocarbon (HC) emissions decrease with canola oil, blending ethanol with canola oil increase HC emissions and maximum values are read for diesel fuel. Carbon monoxide (CO) emissions have been observed to be the highest for canola oil but blending ethanol has a decreasing effect on CO emissions. As for particulate matter (PM), use of canola oil has been seen to be more pollutant than diesel but adding ethanol in canola reduces PM emissions significantly.

ÖZ

KANOLA YAĞININ DİZEL YAKIT OLARAK KULLANILMASININ DENEYSEL OLARAK ARAŞTIRILMASI

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Bu çalışmada dizel motorda kullanılmak üzere kanola yağı seçildi ve onun alternatife bir yakıt olarak uygunluğu incelenmiştir. Kanola yağının viskozitesini düşürmek için sıcaklık ile viskozite arasındaki incelenmiştir. Sonra yakıt sistemi kanola yağın yanma odasına püskürtmeden önce ısıtmak için değiştirilmiştir. Ayrıca etil alkol katkı maddesi olarak kanola yağına eklenerek test edilmiştir. Testleri gerçekleştirebilmek için standartlara uygun bir test sistemi kurulmuştur. Bu test sistemi verilerin hassas toplanması ve otomatik olması için bir bilgisayar tarafından kontrol edilmiştir. Tüm testler direk püskürtmeli 4 silindirli bir dizel motor üstünde yapılmıştır

Motor performans değişkenleri tam yük değişken hız testleri yapılarak elde edilmiştir. Ayrıca 13 mod ESC test çevrimi yapılarak ekzost emisyonları belirlenmiştir. Motor performans değişkenleri ve emisyon değerleri kanola yağı ve %30 etil alkol karıştırılmış kanola yağı için elde edilmiştir ve referans yakıt olan dizel ile karşılaştırılmıştır. Deneysel sonuçlara göre motor performans kanola yağı kullanımı ile düşmüştür. Etil alkolün kanola yağı içine karıştırılması ile bir performans artışı gözlenmiştir. Maksimum performans dizel yakıt ile elde edimline rağmen minimum özgül enerji maliyeti kanola yağı ile yapılan deneylerde elde

edildi. Hidrokarbon emisyonları kanola yağı kullanımı ile düşmüştür. Bu emisyonlar etil alkolün kanola ile kullanılması ile artması rağmen en yüksek değerler dizel kullanımına elde edilmiştir. Karbon monoksit emisyonları ise kanola kullanımı ile artmıştır. Etil alkol karbon monoksit emisyonları ise düşürücü bir etki göstermiştir. Partikül emisyonları da kanola yağı kullanımı ile artmıştır. Fakat etil alkolün kanola yağı ile karıştırılmasıyla çok miktarda düşmüştür.

Anahtar Kelimeler: Dizel Motor, Kanola Yağı, Alternatife Yakıt, Motor Performansı, Ekzost Emisyonları

To My Beloved Parents

ACKNOWLEDGMENTS

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SYMBOL:

$\left(\dfrac{A}{F}\right)_{actual}$: Actual Air Fuel Ratio

$\left(\dfrac{A}{F}\right)_{stic}$: Stoichiometric Air Fuel Ratio

(A/F) : Air Fuel Ratio

A_p : Cross Sectional Area of the Isokinetic Sampling Probe (m^2)

A_T : Cross sectional Area of the Exhaust Pipe (m^2)

BSEC   : Brake Specific Energy Consumption (kJ/HP-h)

BSFC   : Brake Specific Fuel Consumption (kg/HP-h)

C_{air} : Air Flow Correction Factor

C_f : Correction Factor

C_{fuel} : Cost of the Fuel (YTL/kg)

C_h : Humidity Correction Factor

C_p : Pressure Correction Factor

C_T : Temperature Correction Factor

CO   : Carbon Monoxide

CO_2 : Carbon Dioxide

D   : Cylinder Bore (m)

HC   : Hydrocarbons

HC_e : HC Emission (g/HP-h)

HC_{conc} : Concentration of T-HC' (ppm)

HC_{mass} : Hydrocarbon Emission Mass Flow Rate (g/h)

$\overline{HC}$: Mean Hydrocarbon Emission (g/HP-h)

g : Gravitational Acceleration (m^2/s)

i : Number of Cylinders

j : Number of Strokes

l : The Arm length of the Dynamometer (m)

$\dot{m}_{air}$: Air Flow Rate (kg/h)

$\dot{m}_{ath}$: Theoretical Air Flow Rate (kg/h)

$\dot{m}_{fuel}$: Fuel Flow Rate (kg/h)

N_{speed} : Engine Speed (rpm)

PM : Particulate Matter

PT_e : Particulate Emission (g/HP-h)

PT_{mass} : Particulate Mass Flow Rate (g/h)

P_{atm} : Atmospheric Pressure (mm-Hg)

P_b : Corrected Brake Power (HP)

P_d : The Pressure of the Dry Air (mm-Hg)

P_{dt} : Pressure Drop at Dilution Tunnel Orifice ("WC)

P_f : Particulate Sample Mass collected (mg)

P_{std} : Standard Atmospheric Pressure (kPa)

P_v : Water Vapor Pressure (mm-Hg)

$\overline{PT}$: Mean Particulate Emission (g/HP-h)

r : Split Ratio

RH : Relative Humidity (%)

R_{air} : Air Gas Constant (kJ/kgK)

S : Piston Stroke (m)

SEC : Specific Energy Cost (YTL/HP-h)

T : Engine Torque (N-m)

T_{abm} : Ambient Temperature (^{o}C)

T_c : Corrected Engine Torque (N-m)

T_{std} : Standard Atmospheric Temperature (K)

t_f : Consumption Time of 86 ml Fuel (s)

t_p : Particulate Sampling Time (s)

q : Dilution Ratio

Q_L : Lower Heating Value of the Fuel (kJ/kg)

V_a : Voltage Output of the Air Mass Meter (Volt)

$V_{container}$: Volume among Optic Sensors (ml)

V_s : Swept Volume of One Cylinder (m^3)

V_{SAM} : Volume of the Diluted Exhaust Sample passed through the Particulate Sampling Filters (m^3)

$\dot{V}_{air}$: Air Volumetric Flow Rate on Dry Basis (m^3/h)

$\dot{V}_{dt}$: Dilution Volumetric Tunnel Flow Rate (m^3/h)

$\dot{V}_{exh}$: Exhaust Gas Volumetric Flow Rate on Wet Basis (m^3/h)

$\dot{V}_{exhd}$: Exhaust Gas Volumetric Flow Rate on Dry Basis (m^3/h)

$\dot{V}_{EDF}$: Equivalent Diluted Exhaust Gas Volumetric Flow Rate (m^3/h)

$\dot{V}_{vp}$: Vacuum Pump Flow Rate (ft^3/min)

WF_i : Weight Factors "i"

GREEK LETTERS:

ρ_{air} : Atmospheric Air Density (kg/m^3)

ρ_{fuel} : Fuel Density (kg/m^3)

ρ_{HC} : Density of Hydrocarbon (kg/m^3)

ρ_{std} : Standard Air Density (kg/m^3)

λ : Excess Air Coefficient

ϕ : Equivalence Ratio

η_v : Volumetric Efficiency (%)

η_{th} : Thermal Efficiency (%)

CHAPTER 1

INTRODUCTION

Energy is the source of life and considered as a critical factor for economic growth, social development and human welfare. However supply of energy on world is limited. With the advent of industrial revolution, the world energy consumption has been growing steadily. The world energy requirements are usually provided from conventional sources such as petroleum, natural gas and coal. According to the International Energy Agency (IEA), approximately 80 per cent of the world's energy consumption is now derived by fossil sources (Figure 1.1) [1].
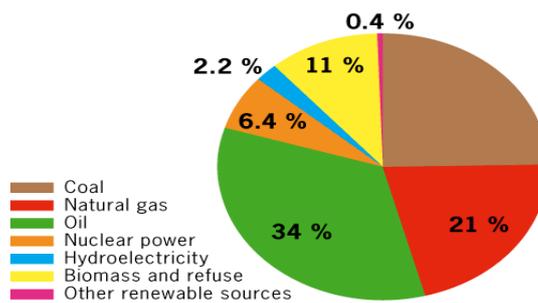
Figure 1.1: World Energy Consumption apportioned according to energy sources [1]

Petroleum consumption comprises an important place in these sources. In the world, most of the petroleum production is utilized in internal combustion engines (IC) [2]. The demand for petroleum products has been rising due to the increasing industrialization, motorization and population of the world. Petroleum based fuels are obtained from limited reserves. These finite reserves are highly concentrated in certain regions of the world. It is estimated that these reserves will run out in 65 years (Table 1) [3]. Amount consumed energy supply represents development level of country. In some developed countries such as Japan, Germany, France and Italy oil production is less than 10% of consumption [4]. Therefore, they depend upon import of crude oil and are facing economic crisis due to rising of petroleum price now.

Table 1.1: Summary of Petroleum Reserve Data as 2007 [3]

Country	Reserves [1]		Production [2]		Reserve life [3]
	10^9 bbl	10^9 m^3	10^6 bbl/d	10^3 m^3/d	years
Saudi Arabia	260	41	8.8	1,400	81
Canada	179	28.5	2.7	430	182
Iran	136	21.6	3.9	620	74
Iraq	115	18.3	3.7	590	101
Kuwait	99	15.7	2.5	400	108
United Arab Emirates	97	15.4	2.5	400	107
Venezuela	80	13	2.4	380	91
Russia	60	9.5	9.5	1,510	17
Libya	41.5	6.60	1.8	290	63
Nigeria	36.2	5.76	2.3	370	43
United States	21	3.3	4.9	780	12
Mexico	12	1.9	3.2	510	10
Total	1,137	180.8	48.2	7,660	65

Notes:

1 Claimed or estimated reserves in billions (10^9) of barrels (converted to billions of cubic metres). (Source: Oil & Gas Journal, January, 2007)

2 Production rate in millions (10^6) of barrels per day (converted to thousands of cubic metres per day) (Source: US Energy Information Authority, September, 2007)

3 Reserve life in years, calculated as reserves / annual production. (from above)

Turkey is a developing country and for this reason Turkey's energy demand has risen rapidly as a result of social and economical development in recent years [5]. Although the country's energy consumption has grown considerably since the beginning of the 1980s, while 77% of the overall primary energy consumption in 1970 was met by the domestic energy sources, this percentage decreased to 28 in 2003 [6]. In other words, Turkey is more depend on foreign country to provide its energy requirements. Therefore, those countries not having fossil reserves like Turkey are facing petroleum crisis at different times due to the import of crude oil. Hence it is necessary to look for alternative fuel, which can be produced from materials available within these countries. Another serious problem associated with the use of petroleum is the increase in emissions. These pollutant gases are badly affecting the respiratory system, the nervous system of people and producing a large number of skin diseases. The gases also damage the heating of animals and influence the plants and trees. Acid rain is also owing to these pollutants emission gases. Hence the need to search alternative fuel is inevitable.

1.1 Alternative Fuels

Alternative fuels, also known as non-conventional fuels, generally consist of gas and liquid fuel and can be used in the internal combustion engines as fuels. Well known alternative fuels include bioalcohol (ethanol, methanol), non-fossil methane, non-fossil natural gas, hydrogen, vegetable oils, biodiesel and other biomass sources. Finding alternative fuels for internal combustion engines resulted in fuels from oil shale, tar sands, as well as synthetic fuels, alcohol, biological originated fuels, natural gas, liquid petroleum gas (LPG) [7]. Spark ignition engines (SI) can be run on ethanol, methanol or blend of these with gasoline, LPG, and natural gas for the reason that they have low cetane number. Vegetable oils and methyl or ethyl ester delivered from them or blend of these fuels with diesel at any ratio are suitable for compression ignition engines (CI) since their cetane numbers are close to that of diesel fuel [8].

For using the alternative fuels, automotive industry is looking forward to the ways to lower emissions on account of environmental norms of emissions. Furthermore, many vehicles running on diesel as fuel are on the road and they are waiting for an easy-implemented alternative, environmental friendly and cheap fuel. Because of this, local and academic researchers are putting more emphasis on finding the right alternative fuel to designing a new system [9].

For those countries like Turkey with agricultural capacity, biodiesel and vegetable oils are of the most important alternative fuels. Vegetable oils used in this study refer to vegetable oils which have not been modified by transesterification or similar process to form what is called biodiesel. Biodiesel is made from oils of various types of oilseed crops like sunflower, rapeseed, soybean, peanut and palm by transesterification ways. Diesel engines can be run on vegetable oils or biodiesel without any modification of the engine, but there are many problems which have been faced during the experimental research because of their different chemical and fuel properties from diesel fuel. However, these problems may be solved with modification of oils and engines.

In next section of this chapter, historical background of vegetable oils as diesel fuels, problems about diesel engines running on neat oils as alternative and their solution and then searches on canola oil are discussed. Also, details of this study are mentioned in the last section of this chapter.

1.2 Historical Background

The diesel engine was invented by Rudolph Diesel in late 19th century. He thought up the concept of the engine that compresses only air to the resulting rise degree in temperature. At Berlin Motor Fair, the first diesel vehicles were exhibited in 1923 [14]. Diesel vehicles were started to build by automotive companies in the beginning of 20th. Diesel technology has developed during the following decades, and today approximately 95 of all transit busses and tractors on the road are diesel engine equipped vehicles [10]. Diesel engines have some advantages compared to gasoline engines; as a result their popularity has been growing steadily in heavy duty vehicles. These advantages are their durability, reliability and fuel economy. Beside the benefits, noise, low specific power output and their NO_x and particulate matter emissions and high cost are the drawbacks of compression engines, but new technologies have been minimizing these liabilities [11].

The concept of using vegetable oils as fuel for diesel engines is nothing new. This is almost as old as the diesel engine itself. Rudolph Diesel intended that an engine may be run on a variety of fuels including vegetable oils and he developed the diesel engine and then introduced it at Paris Exposition of 1900 using peanut oil as fuel. In 1911, he stated that "The diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries which use it." After one year, Diesel said "The use of vegetable oils for engine fuels may be seen insignificant today. But such oils may become in course of time as important as petroleum." [8]. Also, Charles reported that French and Belgium scientist ran compression ignition engines on palm oil in some of the African colonies in 1920. Moreover, Professor R.J. Gutierrez of Buenos Aires, Argentina, successfully tested castor oil in a diesel engine in 1916 [12]. Vegetable oils were used in diesel engines until 1920's. The engine was altered to enable it to use a residue of petroleum, which

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is known as diesel #2. However despite the technical feasibility, vegetable oil as fuel could not get acceptance, from 1930 to the energy crisis of 1974 there was no serious interest into renewable fuels such as vegetable oil. In recent years, systematic effort have been made by several researches to use biofuels, like sunflower, peanut, soybean, coconut, rapeseed, linseed oil, ethanol, methanol etc as alternative fuel for CI engines.

1.3 Why Vegetable Oil Fuel?

Although there are some problems with vegetable oils as fuel, use of them for compression ignition engine has some advantages compared to the diesel and other alternative fuels. The most important advantage is that they are renewable resources in contrast to limited petroleum resources. Moreover, it is simple to extract and process. The technology is not as sophisticated as petroleum production [3]Also, diesel engines which are on the road can be run on vegetable oils as alternative fuels directly or making some little modification. For those countries like Turkey with agricultural capacity, growing crops on the farm to produce oils that are used in internal combustion engines as fuel will make marginal lands productive. Also, this promises to keep agriculture independent and can guarantee a continued food supply in the country even during a petroleum crisis. Another positive aspect is that vegetable oils are environmentally friendly. They are non-toxic, biodegradable and do not increase the level of CO_2 at all in the atmosphere at global level [15]. Since vegetable oils do not contain any sulphur contrary to heavy diesel fuel, no sulphates are formed and the emission of particulate matter can be reduced, which would be beneficial in reducing air pollution and toxic emissions.

Reason why research has been increased on vegetable oils recently is that they have physical and chemical properties analogous to those of diesel fuel and can be a replacement for diesel fuel. For instance, the cetane numbers of vegetable oils are in the range suitable for or close to that of diesel fuel. Also, lower heating value of various vegetable oil is nearly 90% of that of diesel fuel [8].

1.4 Some Problems and Solutions with Vegetable Oil

Initially, it is believed that diesel engines run on vegetable oils directly with minimal processing and preparation. However, the results of a number of short-term engine tests have shown that vegetable oils are suitable for compression engines as an alternative fuel, but long-term endurance tests have proven that some serious problems exit in injector coking, ring sticking, gum formation, and lubricant oil thickening. High viscosity and non-volatility considerably cause these problems, which result in inadequate fuel atomization and incomplete combustion. Consequently, the engine, the fuel or both should be modified in order to make use of vegetable oils in diesel engines.

Burning in diesel engines is a very complicated process. Liquid fuel is injected into the combustion chamber in droplet form at the end of compression. There is a force against the air to inject the fuel. The air has high temperature and pressure. This is the most crucial step in the operation of a diesel engine. These droplets evaporate and are mixed with the compressed air. During injection, burning process continues and newly injected fuel mixes with burned gases and then the air [11]. If the fuel is not properly atomized, it burns slowly and unevenly, which results in reducing the engine efficiency and raising unburned pollutants in the exhaust and forming deposits of solid carbon on the piston head cylinder head, and inlet and outlet valves of the engine [12]). It is difficult to inject vegetable oils as they are more viscous then diesel fuel. The Southwest Research Institute, Reid et al. (1982) evaluated injecting behavior of 14 vegetable oils and pointed out that the oils behave very differently from petroleum-based fuel on account of their high viscosity. Also engine test showed that carbon deposits occurred on diesel engines when being fed with raw oils and carbon deposit levels differed for different oils [13].

The problems associated with a diesel engine running on vegetable oil for a long term time can be listed as below
1. During cold weather, difficult or no starting
2. Excessive carbon deposit resulting in piston ring seizure, injector coking..

3. Dilution of the lubricating oil causing thickening and sludge formation and wear of related engine parts
4. Clogging of fuel filter and decreasing of fuel supply to the engine

As it is stated above, the potential solutions for the problems are engine and fuel modification. The objective of these solutions is commonly to reduce the viscosity, which is the most important property of fuel related problems. Fuel modification involves blending (dilution), micro-emulsification, cracking/pyrolysis and transesterification, while injecting system modification and fuel line modification consist of engine modification.

1.4.1 Blending (Dilution)

Vegetable oil and diesel can be directly mixed at any ratio and they may be used for feeding a diesel engine. Blending of vegetable oils with diesel reduces high viscosity and the droplet size of the spray and improves evaporation so that this may decrease the carbon deposit buildup and the sticking of the piston rings [8].

1.4.2 Micro-emulsification

A micro emulsion is clear, stable, isotropic, liquid mixtures of oil, water, and surfactant. These can be used to solve the problem of high viscosity of vegetable oil with solvents such as methanol, ethanol, and butanol. Czerwinski prepared an emulsion of 53% of sunflower oil, 13.3% of ethanol and of 34.4% of butanol. He observed that lover viscosity and better spray patterns are obtained as increased the percentage of butanol [16].

1.4.3 Cracking (Pyrolysis)

Cracking is defined as the process of conversion of one substance into another by means of heat or with the aid of a catalyst. These materials may be vegetable oils, animal oils, natural fatty acids and methyl esters of fatty acids. Many scientists have made research on the pyrolysis of vegetable oils in order to obtain a suitable fuel [16].

1.4.4 Transesterification

Transesterification is commonly used chemical method to reduce high viscosity of vegetable oils. It is not a new process. Before World War 2, transesterified vegetable oil was first used in South Africa.

In organic chemistry, transesterification is the process of exchanging the alkoxy group of an ester compound with another alcohol. This is accomplished by mixing methanol or ethanol with sodium or potassium hydroxide to make methoxide. Methanol and ethanol are commonly used as an alcohol due to their low cost and chemical benefits. Methanol or ethanol and sodium or potassium hydroxides are mixed into vegetable oil and this mixture is heated and then maintained at 65 C. Next, the entire solution is stirred. Glycerin and ester layers are formed. The former is the lower, while the latter is the upper layer. The ester, or biodiesel, is separated and washed. Next the moisture is removed from ester [16].

1.4.5 Fuel Line Modification

As it is mentioned before, the viscosity of vegetable oils must be reduced to use it as fuel. There are two main ways to do this. The most commonly way is transesterification and converting into the biodiesel as it is explained in the previous paragraph. The second is to modify the diesel fuel line engine. Since the viscosity is very temperature sensitive, preheating the oil prior to going through the injectors is an acceptable means to solve this problem. Pre-heating before combustion may improve quality of combustion [12]. Diesel fuel line should be modified to run on engine with preheated oil as fuel.

1.4.6 Injecting System Modification

Injecting the fuel into combustion chamber is the most important process for a diesel engine. This directly affects engine performance, exhaust emissions. Diesel fuel and vegetable oil have different physical and chemical properties so they have different spray characteristic on same injector. However, to use vegetable for diesel fuel replacement, engine makers are reluctant to modify engines [12].

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1.5 Canola

Canola (Figure 1.2) is a plant that is a member of large family of plants called cruciferies. It was developed in the 1970's by Canadian plant scientists who selected rapeseed populations looking for a crop that would produce a healthy, edible product. Rapeseed is not an edible product and canola is name given to edible rapeseed. The word "canola" was derived from "**Can**adian **o**il, **l**ow **a**cid" in 1978 [17]. This oil has one of the lowest levels of saturated fat of vegetable oils and it is excellent for healthy diet. In addition, canola oil contains higher levels of the beneficial omega-3 fatty acids compared to some other vegetable oils.   Canola oil is used for cooking and baking at home and also industrial uses such as fuel, lubricants and hydraulic fluids.

a   b

Figure 1.2 a) Flower of Canola **b)** Seed of Canola

Seeds of canola include around 38% to 50% oil and produce cakes with 35% to 40% protein [17]. The cake can be used as fodder for animals. The production of canola has been increased over the years, and as can be seen from the Figure 1.3 it comprise 12% of world oil seed production in 2006 [18]. That means that rapeseed is the second largest oilseed crop in the world. The canola crop can be cultivated over all of the agricultural area of Turkey except the Black Sea region. The production of this crop has increasing since 2000. Governments are encouraging farmers to grow canola seeds and are giving some incentive pay [19].

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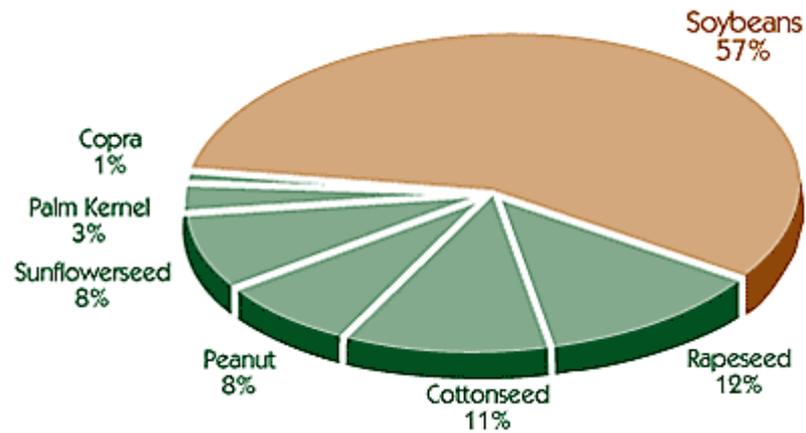
Figure 1.3: World Oil Seed Production 2006 [18]

1.6 Literature Survey

The scientists and researchers tested a number of different vegetable oils such as sunflower oil, cotton oil, rapeseed oil, soybean oil and peanut oil on different types of diesel engine to investigate the possibility of using vegetable oils as a replacement for diesel fuel. These studies may be divided in two groups. Some researchers performed experiments with neat vegetable oils and their blends with diesel or additives such as ethanol. Others studied vegetable oils esters, known as biodiesel, and their blends with diesel. In general, the objectives of these experiments are to investigate the effect of test fuels on engine performance, exhaust emissions and engine parts.

1.6.1 Neat Vegetable Oils and Their Blends

Bruweral. et al. (1980) performed experiments on sunflower seed oil as a fuel. A tractor engine operated with pure sunflower oil instead of diesel fuel without any engine modification. After 1000 hours operation, they observed an 8% power loss. To correct this power loss, the fuel injector and fuel pump were replaced, but same power loss occurred. After 1300 hours operation, they examined the injectors and reported that there were excessive carbon deposits in the injector tips when an engine fueled with 100% sunflower oil [20].

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Tahir et al. (1982) studied the use of sunflower oil as a renewable energy source. An agricultural tractor was used during the experiments. The sunflower oil viscosity was determined and it was 14% higher then diesel fuel at $37^\circ C$. They reported that there was no change engine performance but fuel economy decreased slightly. Also oxidation of sunflower oil caused gum deposits on related engine parts, which would result in engine failure [21].

Hemmerlein et. al.(1991) used rapeseed oil to study the effect of using an alternative fuel in diesel engines in Germany. Six different diesel engines were investigated with respect to performance, fuel consumption, exhaust emissions, and durability characteristic using neat (100%) rapeseed oil as fuel. A particular dilution tunnel was used to measure particulate emission. They concluded that the physical and chemical properties of rapeseed oil as a fuel were very similar to those of diesel fuel and also engine performance and energy consumption were about the same for both fuels. Also exhaust emissions were higher when operated rapeseed and they tend to be lower with direct injection (DI) engines and diesel fuel. In addition, Diesel engine with divided combustion chamber and big cylinder were more suitable for long-term operation with rapeseed oil [22].

Labeckas et al. (2006) investigated rapeseed oil flow through the fuelling system, the effect of oil as replacement for diesel fuel on high speed diesel engine performance and injector coking under various loading conditions. The diesel engine was naturally aspirated, four stroke, four cylinder and direct injection. They reported that although the brake specific fuel consumption and rated power of rapeseed oil was higher than that of diesel fuel but break thermal efficiency of both fuels was about the same. The rapeseed oil had lower smoke opacity at fully opened throttle. The effect of temperature was determined that the viscosity diminished to 19.5 mm^2s^{-1} when heated to 60^oC and smooth oil flow through the fuel filter was obtained. These reduced the brake specific energy consumption at light loads.. However heating to the temperature of 90^oC has no benefits with respect to performance. Tests conducted with modified fuel injection pump showed that the injector nozzles which operated on neat oil were more coated by carbon deposits than that operated simultaneously on diesel fuel [23]

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Kegl (2007) studied the effect of rapeseed oil as a fuel on bus engine MAN D 2566 with direct injection M system. The injection, spray and engine characteristic were determined experimentally under 13 mode ESC test. He reported that the fueling, injection duration, injecting timing and injector pressure of rapeseed oil raised under operation regimes. Rapeseed oil formed a narrower and longer spray under most tested operating conditions. The smoke, CO and HC emissions of the engine feeding with rapeseed oil were lower than those of the engine running on diesel. However, NO_x emission was higher when using the oil as fuel at all modes. The harmful emissions of rapeseed oil decreased essentially by shifting pump timing [24].

Tadashi et al (1984) evaluated rapeseed oil and palm oil as possible sources for liquid fuels in a naturally aspirated direct injection diesel fuel. It was found that vegetable oil fuels generated acceptable engine performance and exhaust emission levels for short term operation. Nevertheless, these fuels caused carbon deposit buildups and sticking of piston rings after extended operation. They also suggested practical solutions to overcome the problems were: increasing the fuel temperature over to $200^{\circ}C$, blending the oils with diesel fuel 25% ratio, blending vegetable oils with ethanol 20% ratio, or converting the vegetable oils into methyl esters [25]

Wagner and Peterson (1982) examined rapeseed oil and diesel mixture as substitute fuel. The oil fuel mixture was heated prior to combustion and no measurable improvement in fuel injection was observed. During the short-term engine testing the diesel engine was catastrophic failure due to use of raw rapeseed oil. Nonetheless, during the durability test, signs of wear, contamination of lubricating and loss of power were not occurred when the engine operated with 70% rapeseed oil, diesel blend [26].

McCuthen (1981) evaluated the use of 30% soybean oil 70% diesel fuel blend as potential sources on direct injection (DI) and indirect injection (ID) engines. The results demonstrated that ID engines could be run on this fuel blend while DI engines could not operate with that mixture. Injector coking and piston ring sticking were observed on DI engines as a result of using soybean oil [27].

1.6.2 Biodiesels and Their Blends

Vellguth (1983) studied the use of vegetable oils and their esters as an alternative resource for diesel engines. Some problems were happened during the both short and long term engine testing. For long term tests, some engines were parts broken down. When operated with rape seed ester carbon deposits on the piston were lower compared to that rapeseed oil. He conducted that rapeseed ester can be used as diesel fuel for short-term; however, there were some problems operated long period [28].

Schumacher (1999) evaluated the effects of soybean methyl ester as a fuel on a Dodge truck. He reported that soybean methyl ester can be used in diesel engines with little difficulty. 10-20-30-40-50% soybean methyl ester diesel fuel mixture was tested. As the soybean methyl ester ratio in the diesel-biodiesel mixture increased, the power, smoke intensity, CO and HC emissions decreased while NO_x emissions and fuel consumption rose.[29]

Chio (1997) investigated the effect of rapeseed methyl ester (RME) and different diesel/RME blends on diesel engine performance and exhaust emissions on a single cylinder diesel engine. Particulate matter and CO emissions were decreased under high loads single injection. On the other hand, he observed a slight rise in NO_x as the biodiesel concentration in diesel increased. However, when using multiple injections, particulate matter decreased while NO_x emission changed little or any [30].

Makarevicience et. al. (2003) conducted exhaust emission tests on rapeseed oil methyl ester (RME), rapeseed oil ethyl ester (REE) and fossil fuel as well as on their mixtures. The tests showed that rapeseed oil ethyl ester had less negative effect on the environment compared to that of rapeseed oil methyl ester when considering emission of NO_x, CO emissions and smoke density. The emission of NO_x increased when operated with rapeseed oil ethyl ester over those of diesel fuel. However when fuelled with 25-50% bioester mixed with diesel, NO_x emission significantly decreased. In addition, when run pure rapeseed oil ester, CO, HC, CO_2 emissions and smoke decreased compared to that of fossil diesel fuel [31]

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Kwanchareon et. al (2007) studied diesel-biodiesel-ethanol blends as a fuel on diesel engine. Fuel properties such as density, heat of combustion, cetane number, flash point, and pour point of the blends and their emission characteristics in a diesel engine examined and compared to those of diesel. He reported that fuel properties are in the standard limit for diesel fuel, but the blends containing ethanol had quite different flash point from conventional fuel. The cetane number of blends could not decrease considerably due to high cetane number of biodiesel. When fueled with the blends, CO and HC emissions declined significantly under high loads condition, while NO_x emission increased compared to those diesel fuels. The most suitable ratio for diesel production was a blend of 80% diesel, 15% biodiesel and 5% ethanol [32].

1.7 Balaban Valley Project

Balaban valley project is supported by Middle East Technical University, Ankara University, Ankara Güneşi KOOP (Non Governmental Organization), Turk Traktör Company and Kırıkkale Agricultural Authority. The aim of this project is to improve the quality of life in rural area. Four villages located 60 km east of Ankara with a population of 1300 people are selected for conducting the project. A self-sustainment by using renewable energies is the expected result. One of the main operations in the project is growing crops on the farm to produce oil and substituting the fossil fuel with biofuel. Consequently, the cost of fuel used in the production of food and depending upon the fossil fuel in agricultural area should decrease. In the Balaban Valley, there is biomass energy cycling (Figure 1.4) that the canola crops is separated into oil and cake by an extraction machine, where cake is a nutritious food to animals, and oil is used as a diesel fuel in tractors to plough the fields. The cycle will go on by growing up new canola crops besides other agricultural products. This study is a part of the Balaban Valley Project which concentrates on achieving a self-sustaining village
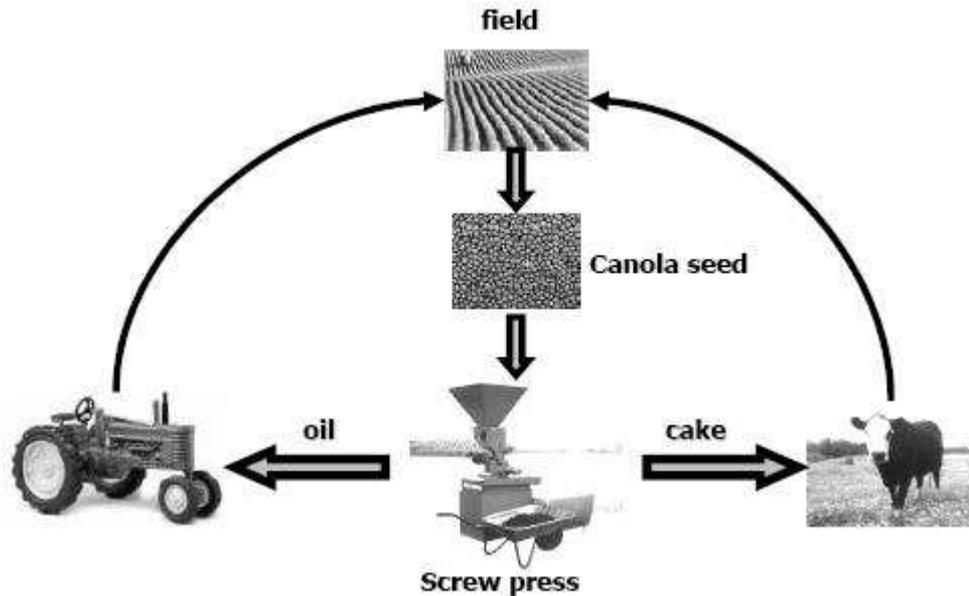
Figure 1.4: Schematic Illustration of Balaban Valley Project

1.8 Scope of the Study

The purpose of this study is, using modified fuel delivery system in diesel engine of tractor, to run the diesel engine on canola oil and blend of canola with ethanol and to compare short term engine performance and exhaust emissions to those of engine running on diesel fuel. To reduce the high viscosity, preheating the oil prior to injection and blending with ethanol are applied. These methods are simple and practical solutions. Canola oil used is not modified any chemical process; that means canola is in pure form. The hypotheses behind the this study are

1. First of all, starting the engine on diesel fuel and running on oil when coming operating temperature and purging down to diesel before shut down would cause elimination of starting problem at cold weather and provide a suitable starting fuel for the engine's next use.
2. Heating the oil or mixing it with ethanol would reduce the viscosity and get a good spray pattern and increase the combustion efficiency inside the cylinder.

For the experiment, diesel engine fuel delivery system is modified in order to heat the test fuel. For this purpose a heating system is designed and manufactured and

then mounted to test engine. The detail of this system is explained in following chapter. To perform the experiment, an experimental setup is designed according to European Union sampling and measurement procedure (Directive 1999/96/EC). Because of dimensional limits and cost, partial flow dilution system with isokinetic probe and fractional sampling methods are selected to determine effect of test fuels on exhaust emissions. Moreover, experiments are performed according to one of the European Union heavy duty diesel engines emission test cycles, European Stationary Cycle (ESC).Experimental set up is controlled with a computer to take measurements more clearly and to perform experiment automatically. For this reason electronic measurement and control apparatuses are adopted to the setup and a computer program is written to manage that system.

Details of experimental setup apparatuses, heating system, computer software, and emission test cycle are explained in the following chapter. In Chapter 3, experimental procedure is presented. In Chapter 4, the formula used in calculation of engine parameters is detailed. In Chapter 5, experimental and resulting calculated data are presented. In Chapter 6, discussion, conclusion and future work about this study are explained.

CHAPTER 2

EXPERIMENTAL SETUP AND APPARATUS

In this Chapter, the experimental setup and apparatus used in experimented system will be described. Experimental setup consists of five main systems. These are engine performance testing system, dilution tunnel, particulate and gaseous emissions sampling measurement system and electronic control and data acquisition system. Figure 2.1 gives an overview of the experimental setup and test apparatus used. In the following pages, the details of the setup will be supplied.
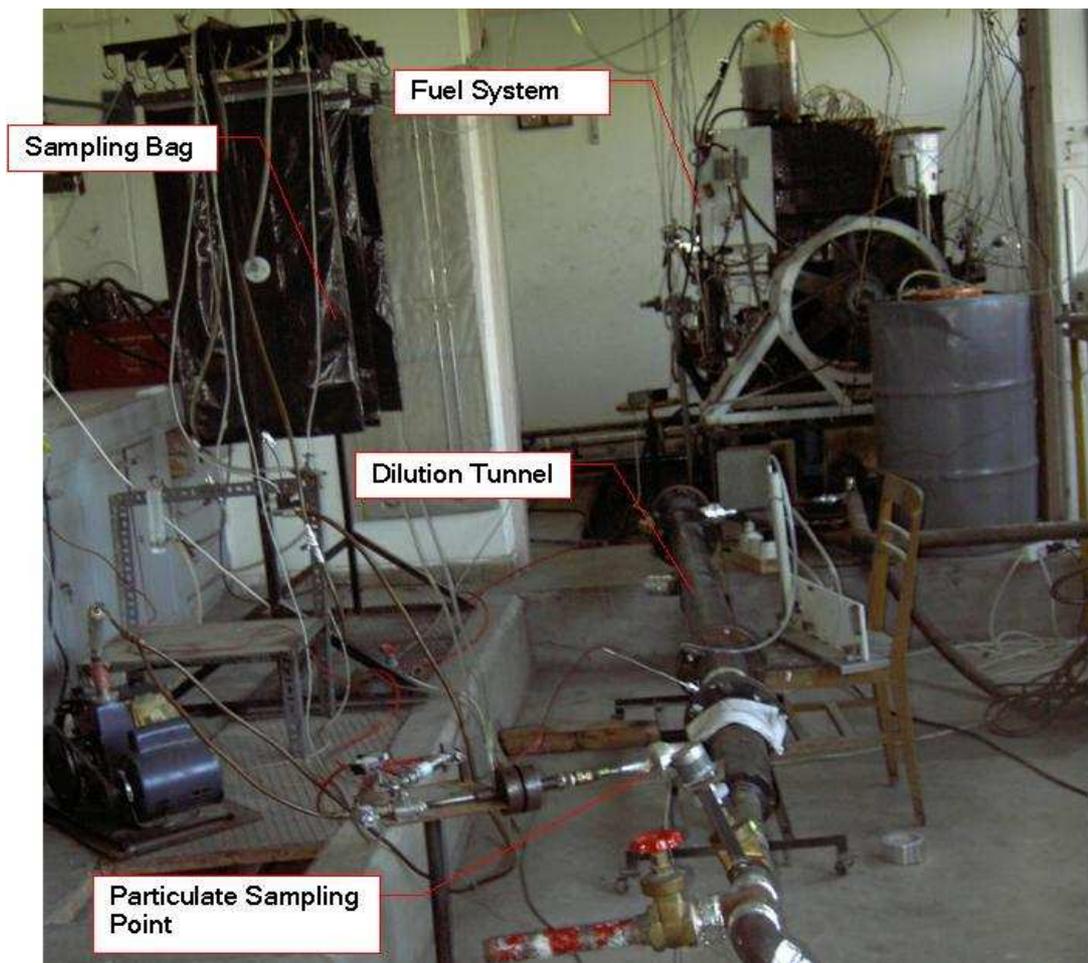
Figure 2.1: General View of Experimental Setup

2.1 Engine Performance Testing System

Engine performance testing system includes tested engine and the measuring systems; such as power, air and flow rate, speed and temperature. The electronic measuring devices mounted the setup to get more accurate data by using data acquisition card. This system is shown Figure 2.2 below.
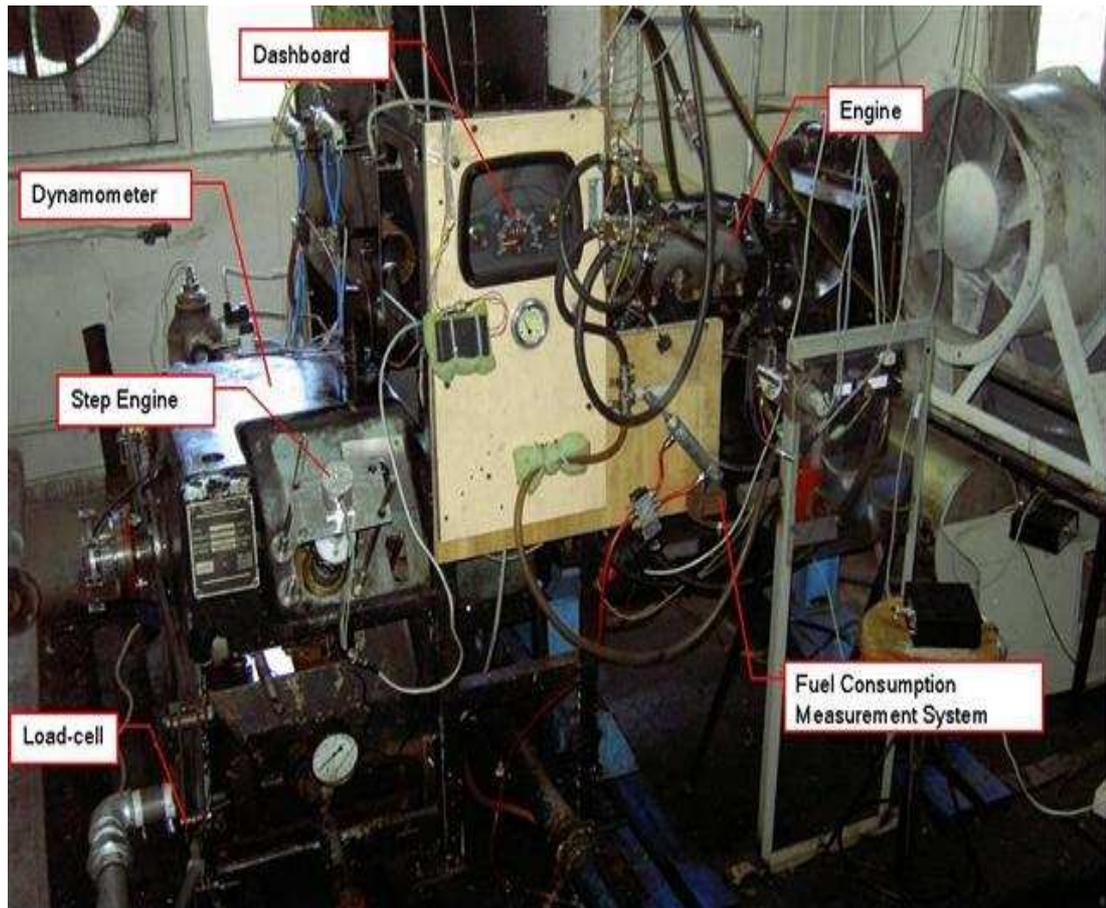
Figure 2.2: Engine Performance Testing System

2.1.1 Tested Engine

Diesel engine used the experiments was 3908 cc, four cylinders, four strokes, naturally aspirated, direct injection and water cooled. It was produced by Türk Traktör Co. and is applied in tractors. The engine and Sub-system specifications are summarized in Table 2.1.

Table 2.1: Specification of the Engine

Producer	Türk Tractor Co.
Maximum Torque	260 Nm at 1500 rpm
Maximum Power	70 Hp at 2500 rpm
Swept Volume	3908 cc
Compression Ratio	1:17
Cylinder Diameter	104 mm
Stroke	115 mm
Low Idle Speed	750 rpm
Injection System	Direct Injection (DI)

The above-specified engine was coupled to a Froude Hydraulic Dynamometer. Besides the engine itself; flywheel, starting motor, alternator, and radiator tank and dashboard assembly were mounted to required parts and places. Diesel fuel system was modified to feed canola oil and diesel fuel and to preheat the oil prior to injector.

2.1.2 Dynamometer

A dynamometer is a device for measuring torque, force, or power and rotational speed from an engine, motor or other rotating prime mover can be calculated. There are two types of dynamometers: one that is coupled directly to the engine, known as an engine dynamometer, and the other that can measure power and torque without removing the engine from the frame of the vehicle, known as a chassis dynamometer [11].

In the experiments, the test engine was loaded with the help of 350 HP loading capacity Froude Hydraulic Dynamometer, which is a sample of first type. The maximum allowable speed of the dynamometer is defined as 3500 rpm; however, in the experiments, only 2600 rpm was used for maximum speed for the reason that maximum engine speed was 2600 rpm. The dynamometer applies load onto the engine by pressurized water around the rotor of the shaft connected to the flywheel of the engine. The opposing torque occurs as soon as shaft's reaches to a required

speed. Level of the water is changed to obtain a resistance which is used to measure engine power. This is done by turning the "load control hand wheel". The load is increased or decreased by turning the load control hand wheel by hand in clockwise or counter clockwise direction. A stepper motor was attached on the load control hand wheel and it was connected to the computer. Thus, dynamometer load on the engine could be adjusted with the help of computer program that was developed for controlling the experimental setup. To attach the stepper motor, a new loading mechanism with stepper motor was designed by using ProEngineer 2001 that is a package Cad software and adaptor and rails were   manufactured and then mounted on dynamometer. This is shown in Figure 2.3. The whole layout and assembly of loading mechanism with stepper motor is also given in Appendix E.
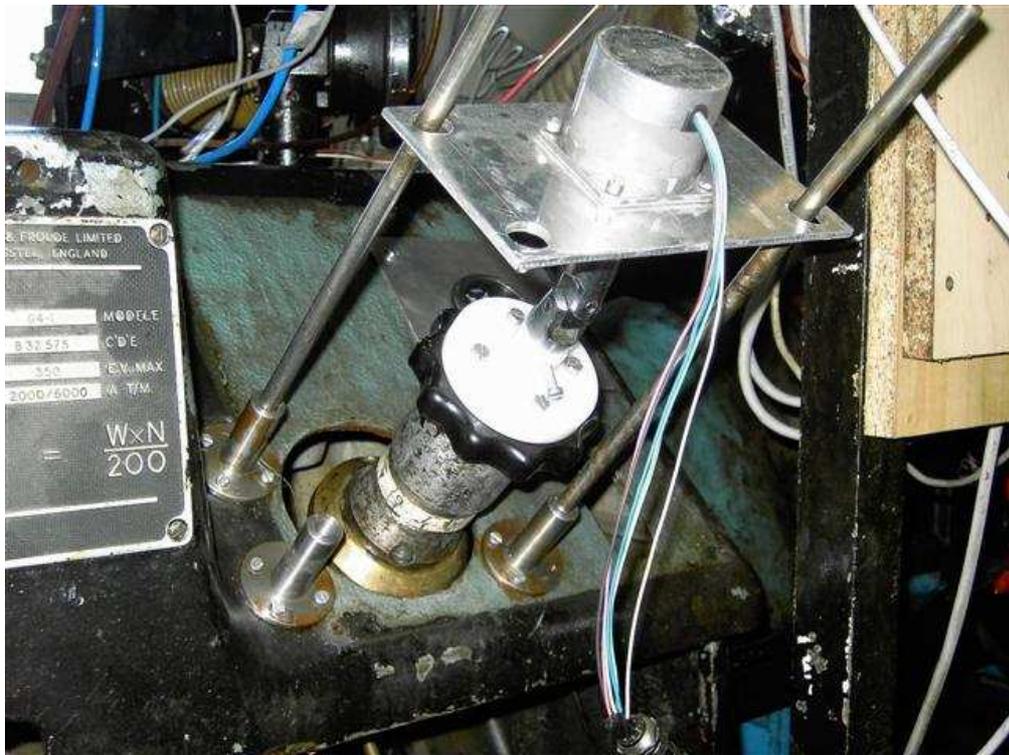
Figure 2.3: Loading Mechanism with Stepper Motor

2.1.3 Load-cell

The dynamometer was upgraded to take torque data as electronic signals instead of spring-meter read out. To upgrade the dynamometer, instead of the spring-meter

parts, a load-cell with strain gage produced by Hottinger Baldwin Messtechnik™ was implemented. First, the spring-meter parts of the dynamometer were taken down. Then, beam and fixture were designed and manufactured to fix the load-cell on the dynamometer.

The load cells of the series RSC measure tension loads in axial direction. The threaded boreholes at the top and at the bottom are used for load introduction. Loads should be introduced as close as possible to in direction of measurement. Torsion and bending moment cause measurement errors and are likely to damage the load cell. These adverse influences must be avoided by construction element such as knuckle eyes. The nuts of the knuckle eyes must be properly fastened. The fastening torque should not be applied to the load cell.

The load cell with strain gage measuring system was connecting to T7075 DC amplifier (see Appendix F) designed for strain gauge measuring systems by ELIMKO™. The connection was made as shown in Figure 2.4 below.

Figure 2.5: Load-Cell Electrical Connections

The load-cell that is connected to dynamometer is shown in Figure 2.5 and assembly and technical drawing of load-cell attachment are given in Appendix E. The installation of the load-cell resulted in more precise data and eliminated the high vibration coming from the test engine because of malfunctioning damper. Another advantage that the load-cell attached dynamometer is that the data taking was made easier, since load-cell made it possible to send the analog output to a Personal Computer (PC). The dimension and specification of the load-cell are given in Appendix F.
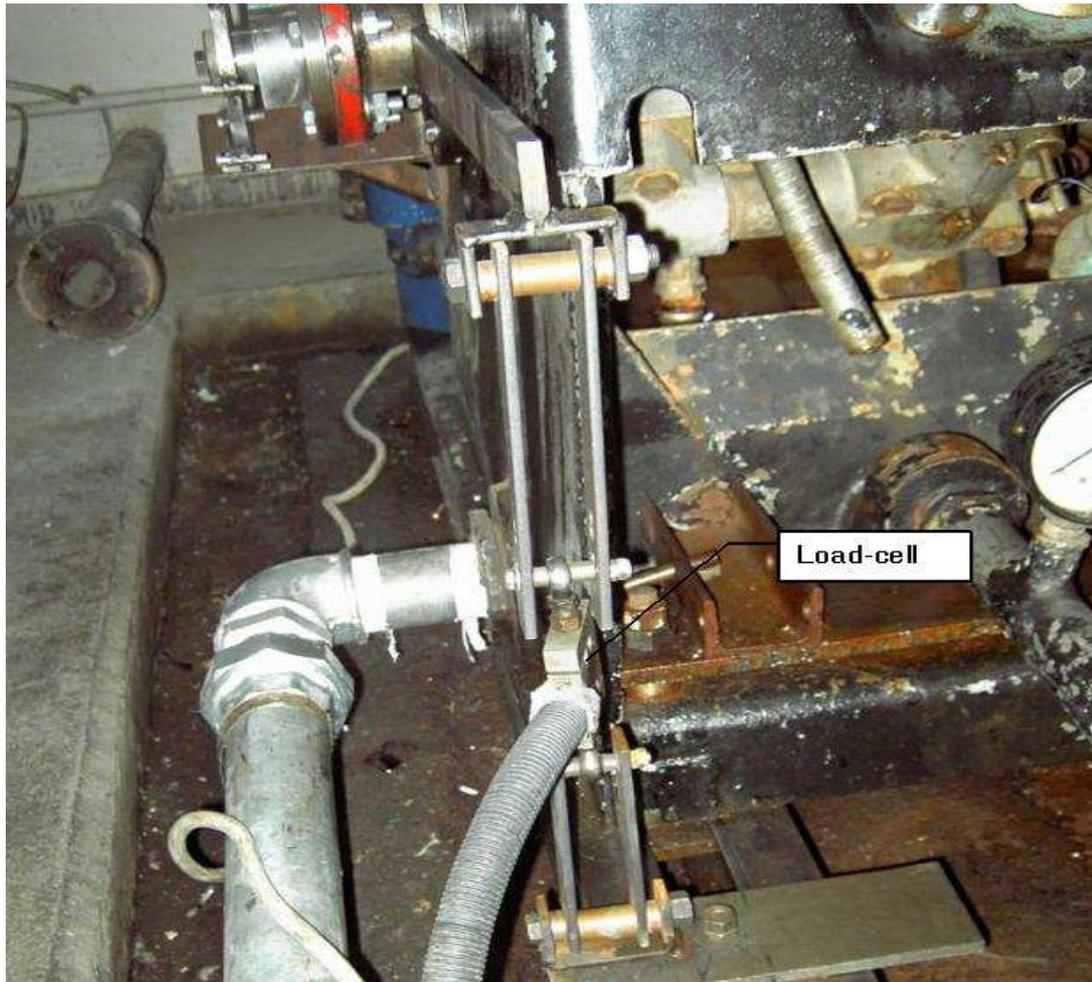
Figure 2.5: Load-Cell connected to Dynamometer

2.1.4 Speed Sensor

The dynamometer was improved to measure rotational speed data as electronic signals instead of stroboscope. To determine engine speed, instead of stroboscope, a crankshaft position sensor was implemented. This sensor measured the rotational speed of shaft of dynamometer. This speed was equal to the rotational speed of crankshaft of the engine since it coupled directly to dynamometer shaft. To connect the sensor on dynamometer first the sensor holder was designed and manufactured and then mounted. (See Figure 2.6 for the connection of the speed sensor). Detailed drawing of the speed sensor holder can be seen in Appendix E.
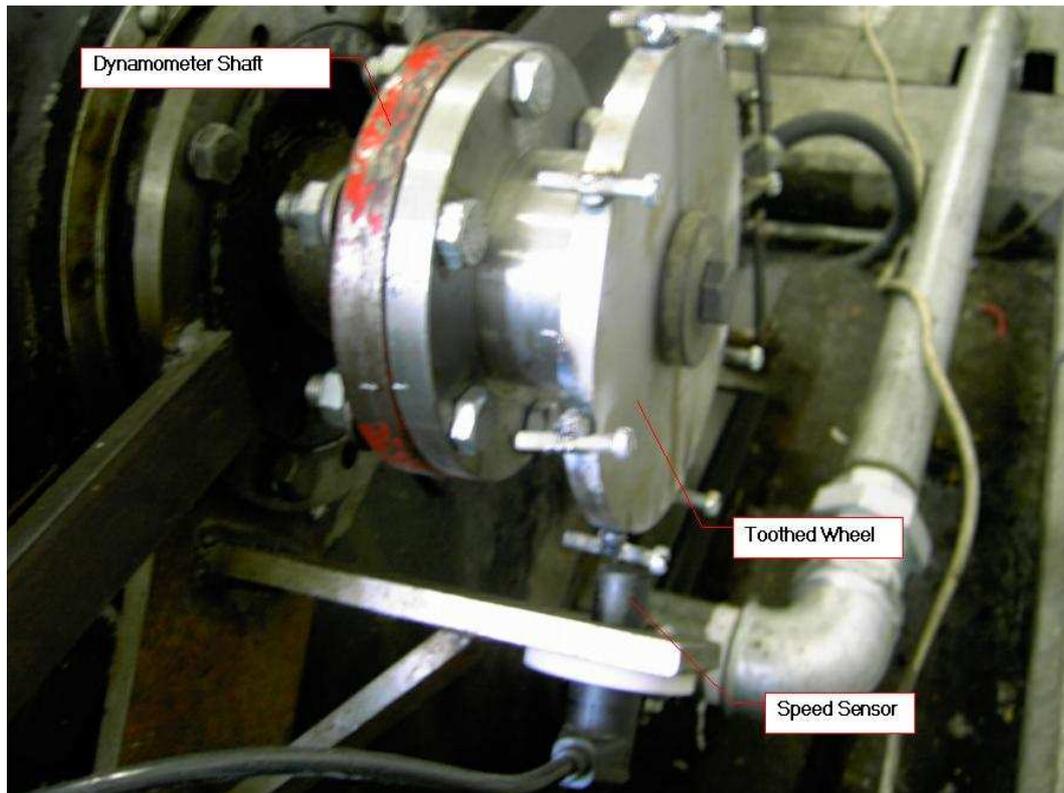
Figure 2.6: Connection of Engine Speed Sensor

Crankshaft position or vehicle speed sensor is of the pick-up coil sensor. This type of sensor consists of a permanent magnet, yoke and coil. This sensor is mounted close to toothed wheel. As each moves by the sensor, an AC voltage pulse is induced in the coil. Each tooth produces a pulse. As the wheel rotates faster more pulses are produced. The number of pulses in one second is signal frequency. To convert the frequency to analog signal, a circuit was designed and produced. It includes a LM 2907 a frequency voltage converter integrated circuit. This circuit scheme is given in Appendix F. The installation of the rpm sensor made collecting rpm data more precise and easier.

2.1.4 Fuel Flow Measurement System

Fuel consumption was measured by newly designed optic sensor system instead of standard and most known stopwatch method. An electronic signal outputting system composed of two optic sensors designed by Prof Dr. A. Demir Bayka since the standard stopwatch method causes the flow rate to be read wrongly. Beside the optic

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sensors, fuel flow measurement system (see Figure 2.7) includes 3-way solenoid valve, piston, glass-buoy in the bulb structure, a new small fuel container, flag and holder of optic sensors. The small fuel container and aluminum part that holds the optic sensors were designed and produced for Ms Study of Cerit (2006). Flag, black colored plastic thin sheet, was glued on the glass-buoy, which floats on fuel in container. Also, a hole drilled to the flag so that when that hole faces the sensors, the sensor would produce a digital signal. This digital signal was sent to a PC data acquisition card. The fuel return line was also connected to the fuel container.
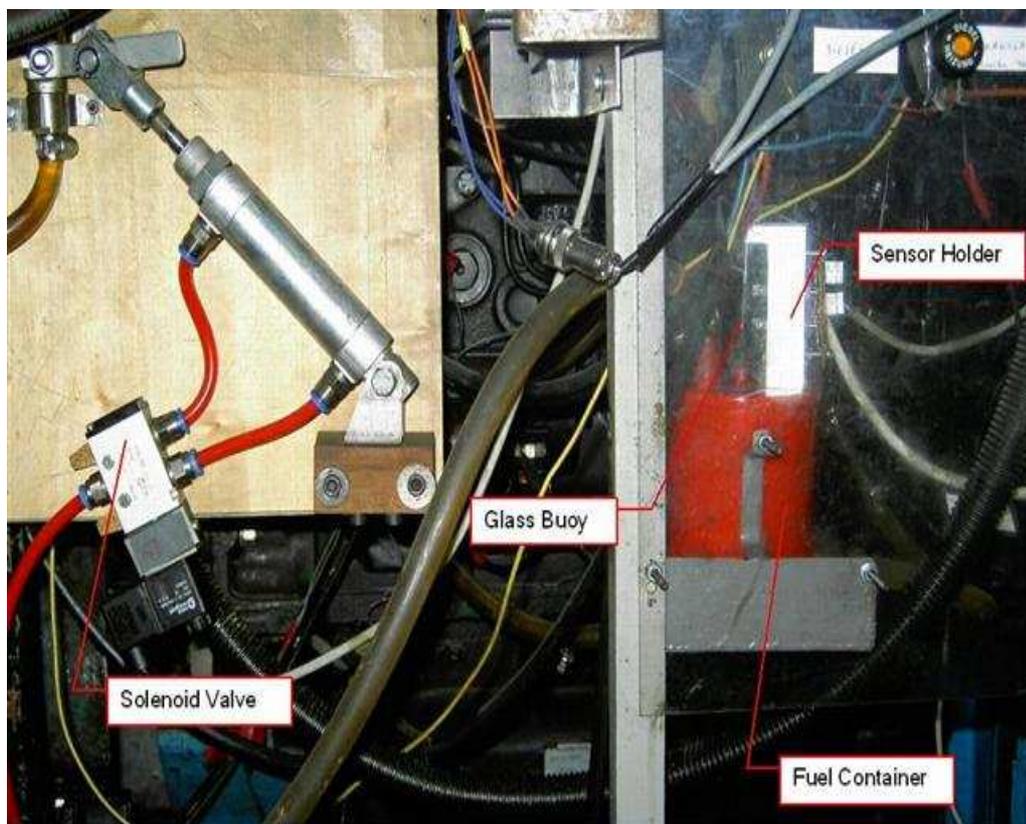
Figure 2.7: Fuel Consumption Measurement System

The logic of the flow rate measurements have been made as follows. When fuel amount increases buoy and flag on it ascends. Two optic sensor installed such a way that flag can pass inside them. As the hole on the flag goes in front of the sensor installed above, a signal is send to the computer and the computer send a signal to activate solenoid valve in which fuel comes with the help of the computer program

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developed for the experiment. Then the solenoid valve directs the pressurized air to close fuel line and the fuel in the container decreases and the buoy descends. When the hole on the flag goes in front of the sensor installed below. After the sensor installed below is passed another signal is send to computer and solenoid valve to close the fuel line. Since the volume difference of the container is known (area is constant and the volume area is multiplied by the distance between the sensors) and the time difference is known, therefore volumetric flow rate can be calculated. The installation of new fuel flow measurement system resulted in more accurate fuel consumption data collection.

2.1.5 Air Consumption Measurement System

Air consumption was measured an air mass meter with hot film element instead of Go-Power air flow meter. Hot film air mass meter consists of   plug-in sensor and measurement venturi. The details and all of the specifications of air mass meter used can be viewed in Appendix F. The micromechanical sensor is located in the plug-in sensor's flow passage. The micromechanical measuring system uses a hybrid circuit, and by evaluating the measuring data is able to detect when flow takes place during air-flow pulsation.

The heated sensor element in the air-mass meter dissipates heat to the incoming air. The higher the air flow the more heat is dissipated. The resulting temperature differential is a measure for the air mass flowing past the sensor. An electronic hybrid circuit evaluates this measuring data so that the air-flow quantity can be measured precisely, and its direction of flow. Only part of the air-mass flow is registered by the sensor element. The total air mass flowing through the measuring tube is determined by means of calibration [33]. For this reason, an air-mass meter was taken and calibrated by using Go-Power air flow meter and air blower. The air blower sucked the air passing through the air-mass meter and simulated an engine. The air mass-meter is attached between air blower and an air filter tank. To change air quantity, there was a valve between air-meter and air blower. After calibration, it was mounted to experimental setup (before induction manifold, after air filter tank). It is shown in Figure 2.9. The calibration curve of the air meter done is presented in Appendix C.

Figure 2.8: Air-Mass Meter

2.1.6 Temperature Measuring Devices

In the experimental setup, K type thermocouples were used to measure temperatures and to take the data as electrical output to the PC. Thermocouples produce low voltage output signal varying with temperature. For that reason amplifiers are necessary to amplify the signal produced from thermocouples. For this purpose amplifiers used in test setup were designed by Prof. Dr. A. Demir Bayka and produced. Signals of thermocouples were amplified to -10/+10 V range with the help of these amplifiers. Then the signals send to one of the analog input ports of the data acquisition card. Calibration of these amplifiers were made using thermometer and calibration curves are given in Figure C.3, C.4, C.5 and C.6 at Appendix C. To measure fuel temperature prior injection pump, exhaust temperature, sampling point of exhaust temperature and diluted mixture temperature at particulate sampling point, this temperature measuring devices were utilized.

2.1.7 Fuel Pump Control System

The fuel pump of the engine was controlled by the computer automatically to change engine speed instead of manual control. For this purpose a direct current (DC) electric motor with reduction gearing was used. The electric motor could be rotated in clockwise or counter clockwise with the help of computer program and input/output (I/O) interface board. Therefore the pump can be adjusted continuously. The circular motion of the electric motor is converted to linear motion using a screw mechanism and a cable attached to this mechanism. Moreover, the position of fuel pump was determined with the help of linear potentiometer. 12 V was send to the potentiometer. When the electric motor rotated, the adjustable arm of the potentiometer moved linearly and an analog signal was sent to one of the analog input channels of the data acquisition card. The signals that were produced when the fuel pump was entirely open and closed were determined and entered in the computer program. The fuel pump control system is shown in Figure 2.9.
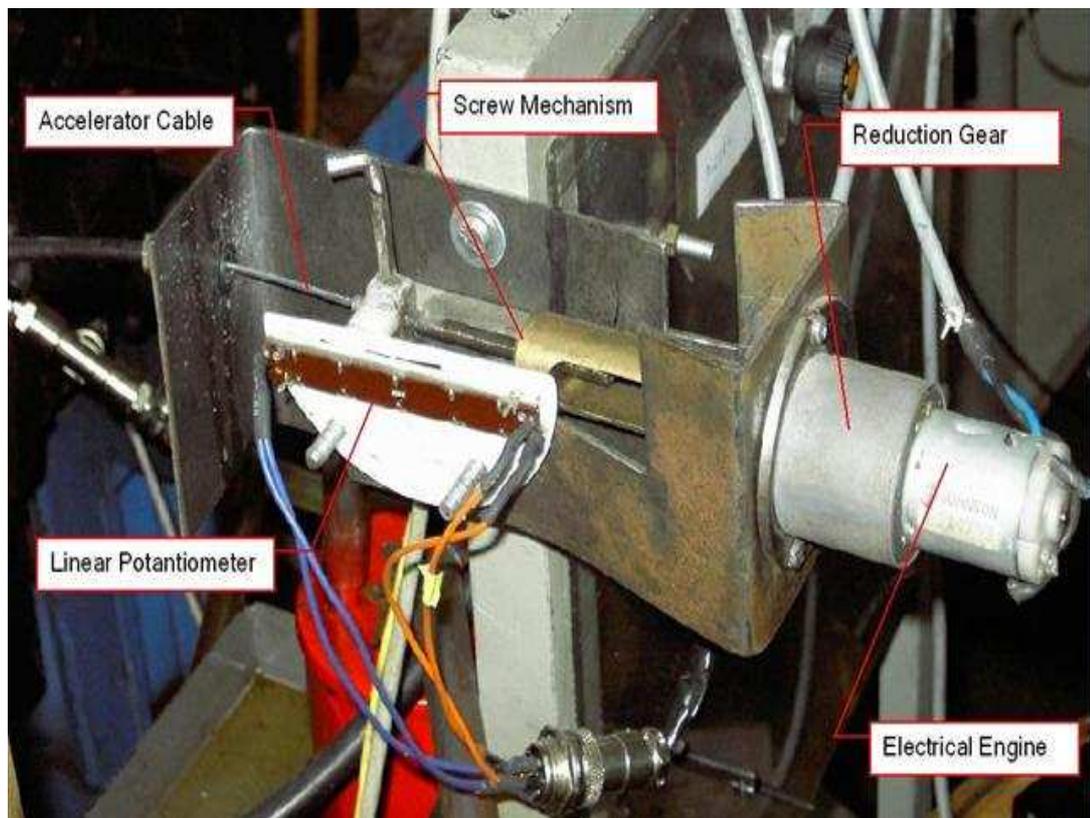
Figure 2.9: Fuel Pump Control System

2.2 Dilution Tunnel

Dilution tunnel is used to determine particulate and exhaust emissions of the internal combustion engine. It is defined as channel system where the engine exhaust gas is diluted with air from the environment [34]. Dilution air is obtained from an air blower. All or some portion of exhaust gas is taken from the exhaust tail pipe and is given to the dilution tunnel and then mixed with the air that is given to tunnel with other pipe in the mixing chamber. The air and the exhaust should be mixed homogeneously in a short time. Avoiding instantaneous temperature decreases where two gases come into the mixing chamber is the most important point about that mixing process [11] In tunnel system, sampling is performed at constant flow condition; called Constant Volume Sampling (CVS)[37]. Some measurement devices such as temperature, pressure and flow rate must be installed to control flow condition in the tunnel. Full exhaust flow dilution tunnels and partial exhaust dilution tunnels are the types of dilution tunnels that the frequently   used. In the full exhaust dilution tunnel systems, the entire exhaust gas is diluted with air. They have to operate at very high flow rates especially when large engines are tested. Thus, these dilution systems are very large and their installation is vey expensive [37]. As for partial dilution tunnels, only a portion of the exhaust gases is sampled. Therefore system dimensions and installation cost can be reduced.

In this study, because of dimensional limits and cost, partial flow dilution system with isokinetic probe and fractional sampling was used to determine particulate matter (PM) and exhaust emissions. Mini dilution tunnel used for the experiments was firstly designed and produced for PhD study of Karel (1996). The dilution tunnel is described in Figure 2.10.

With that system, raw exhaust gas is taken from exhaust pipe (EP) and is transferred to dilution tunnel (DT) through the transfer tube (TT) by the isokinetic sampling probe (ISP). To draw exhaust sample into transfer tube, an air blower is used (Figure 2.11). The blower is connected to dilution tunnel and supplied dilute air. Sampling probe with open tube facing upstream was inserted on the exhaust pipe centerline.
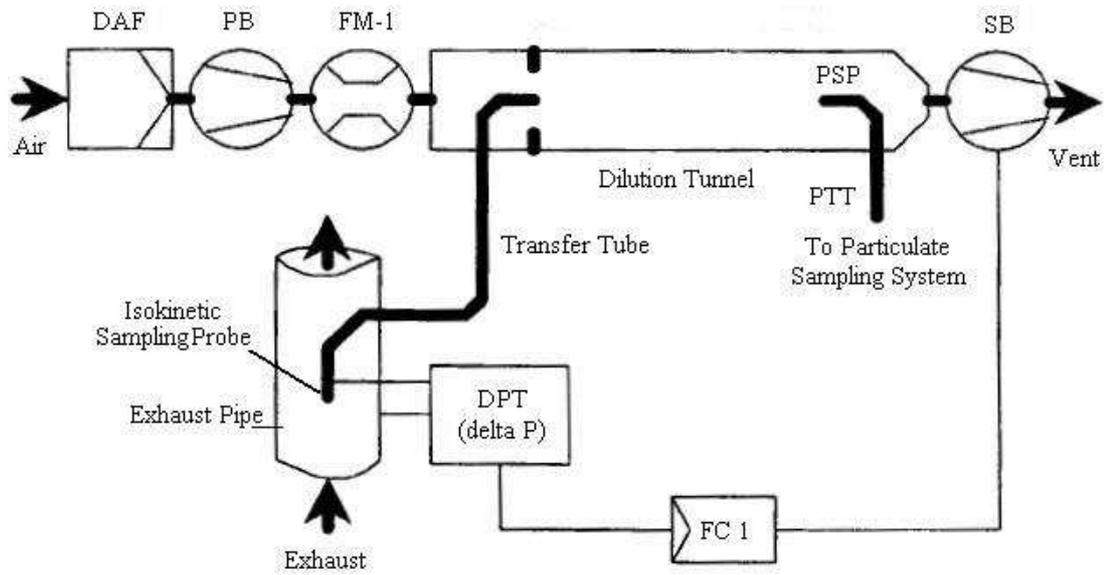
Figure 2.10: Partial Flow Dilution System with Isokinetic Sampling and Fractional s

Sampling (SB Control) [35]

Figure 2.11: Air Blower connected to Dilution Tunnel (DT)

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Isokinetic sampling probe is used to get sample of gaseous with same concentration as exhaust pipe. The pressure equations of exhaust gas between exhaust pipe and the probe inlet shall be achieved with that sampling method. For that reason, pressure difference of exhaust gas between sampling probe tip and exhaust pipe near the sampling probe was measured by using u-tube manometer equipment with capacitive sensors produced by Mefa (see Appendix F) instead of differential pressure transducer (DPT) (Figure 2.12). To do this, a small hole was drilled to the points. Cupper pipes were installed and connected on U manometer. It was filled with water. The capacitive sensors were mounted on U manometer pipe but there was a small distance between water inside U manometer and them (Figure 2.13). These sensors can sense water. When water increases in one direction, the capacitive sensor sends a signal to the computer. The program written for this study activates the step engine mounted on a valve at the end of tunnel and adjusts the pressure difference and dilution tunnel flow rate. If there is no signal produced by capacitive sensors, the pressure difference is not zero but it is nearly zero and changing 0 to 250 Pa. This is the allowable differential pressure range in Directive 96/EC/1999.
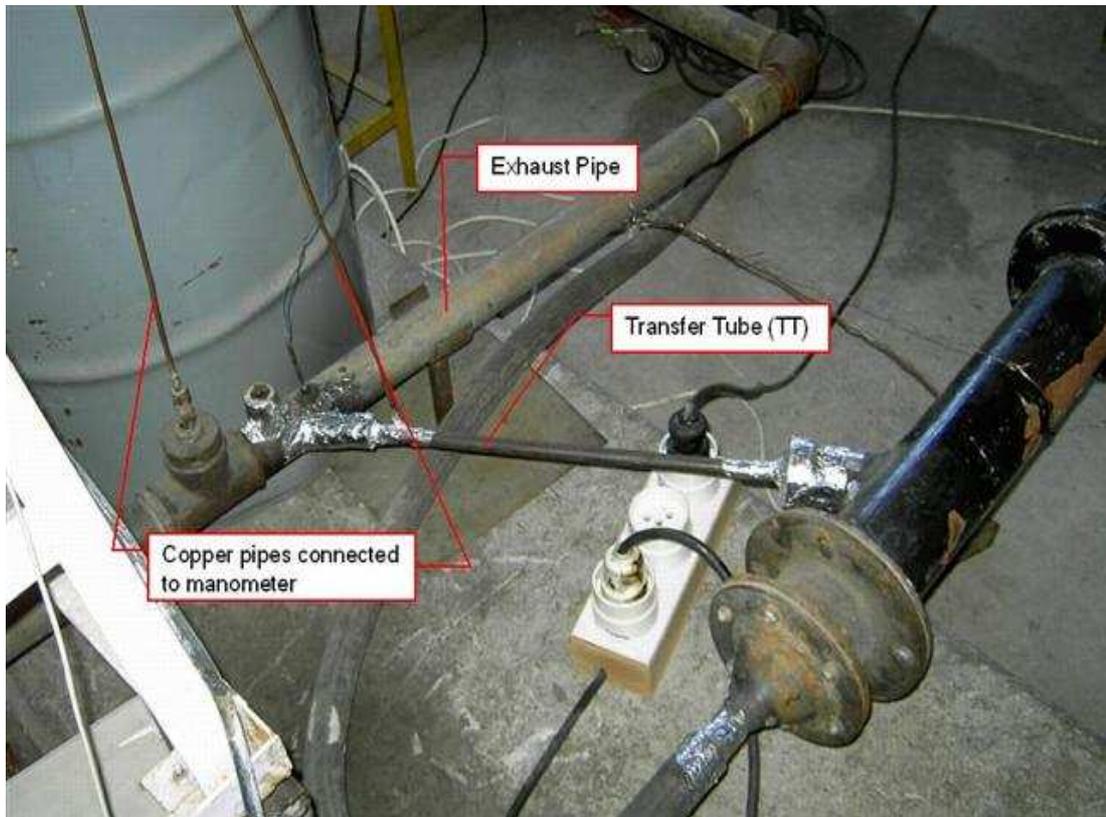
Figure 2.12: Isokinetic Sampling Point (ISP) and Transfer Tube (TT)

When exhaust gas pressure in exhaust pipe and isokinetic sampling point are equal, velocities are assumed to be identical. Hence, flow rate of exhaust gas and flow rate through ISP and TT have a constant ratio and that ratio is called as split ratio. It can be determined by the cross sectional area of EP and ISP and is used with the dilution air flow rate to calculate dilution ratio. The detail of this calculation is explained in Chapter 4.

As stated above, a homogeneous mixture of air and exhaust gas should be achieved. The most important factor to get it is flow condition through the dilution tunnel. Where exhaust gas sampled and dilute air come in contact in first part, there is a turbulence flow. This flow condition increases the mixing rate. Flow condition reach to laminar flow through the tunnel. In order to measure flow rate of diluted exhaust through the tunnel, an orifice was used (Figure 2.14). The orifice also increases the mixing rate since it results in narrowing and expansion in flow. The flow rate is calculated by the pressure drop in the orifice. This pressure was measured using a manometer and calibration curves are evaluated by Karel for PhD study (1996) and presented in Appendix C.
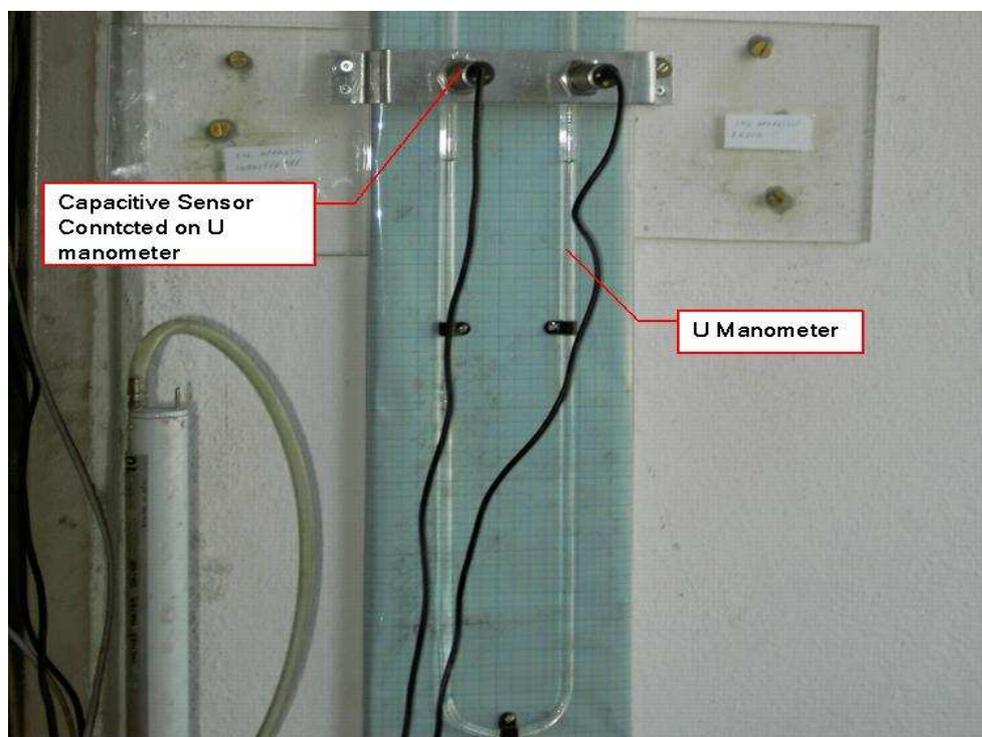
Figure 2.13: Capacitive Sensor connected on Manometer

Dilution tunnel length is important to take accurate sammples. In dilution tunnel designed by Karel, pipe length between the orifice and sampling point is 16 times of the pipe diameter. This distance is determined as minimum 10 times of the tunnel diameter in BS 1042 (British Standard).

Another important point about the tunnel flow, the maximum mixture temperature of diluted gas at particulate sampling point should be $52^{o}C$. To measure this temperature, a thermocouple was inserted to dilution tunnel at sampling point. The mixture temperature stayed that critic temperature during the experiment for dilution tunnel used.

Figure 2.14: Manometer connected to Orifice on Dilution Tunnel

In the partial flow dilution tunnel systems, some particulate loss in the transfer tube and following steps. This is an important problem and is taken into account carefully [11]. For that reason, dilution tunnel consisted of pipes with smooth inside surfaces. A section of pipe was cleaned before the experiment to determine soot amount adhered inside the pipes. Then it was removed with linen fabric and solvent material

and total particulate mass inside the pipes was calculated. The ratio between adhered soot inside pipes and total soot of exhaust gas is 1.12% according to this test [37].

As mentioned above, tunnel flow rate is adjusted by the valve at the end of the tunnel. When the valve is turned to reduce cross section area of tunnel pipe, pressure inside the dilution tunnel increased. As a result, transfer tube velocity and amount of sample taken decreases. It is obvious that as the valve is opened, exhaust gas taken from exhaust pipe increases. To control this operation with the computer during the experiment automatically a stepper motor was attached on the valve.

The exhaust gaseous sampling system from exhaust pipe to dilution tunnel was designed and produced for Ms Study of Cerit (2006) (Figure 2.12). The design is based on Directive 96/EC/1999. The inside diameter of sampling probe should be minimum 12 mm and the minimum ratio between exhaust pipe and isokinetic sampling probe should be 4 according to Directive 96/EC/1999. Because of these requirements, sampling probe with 13 mm inside diameter and exhaust pipe with 60 mm inside diameter were used. In addition, the maximum length of pipes from engine to dilution tunnel should be 10 m according to Directive 96/EC/1999. In the system used, a muffler, isokinetic sampling probe, transfer tube and exhaust pipe were installed and total length of them was about 2 m. As for an isokinetic system, the exhaust pipe must be free, bends and sudden changes at least 6 pipe diameters upstream and 3 pipe diameter downstream of the tip of the probe. The exhaust pipe had 60 mm inside diameter and the distance between the muffler and sampling probe upstream was 430 mm, greater than 360 mm. Moreover, transfer tube should be as short as, but not more than 5 mm in length and the diameter should be equal or greater than isokinetic sampling probe, but not more than 25 mm in diameter. Transfer tube used in the experiment has 13 mm in diameter from tip of sampling probe to exit of the tube and located on the center line of the tunnel.

2.3 Particulate Sampling System

Particulate matter (PM) sampling and mass measurement procedures are defined in the standards such as European Union Legislation (Directive 96/EC/1999), US 2007

Regulation and ISO 16183 Standard. Main points about sampling and measurement methods are transportation of exhaust gas to dilution tunnel, design of dilution tunnel, flow conditions in the tunnel, whose details are explained in previous section, particulate sampling filter and passing of diluted exhaust gas through the filter, whose details are explained in this section. Particulate sampling system is required for collecting the particulates on the particulate filter. Total sampling and fractional sampling may be used. In the case of total sampling partial flow dilution, the entire diluted exhaust passes through the filter and dilution tunnel and sampling system is usually an integrated unit. In the case of fractional sampling partial flow dilution or full flow dilution only a portion of the diluted exhaust passes through the filter and sampling system is usually a different unit from the dilution tunnel.

In this study, partial flow dilution system and fractional sampling was used for measuring PM and exhaust emissions as mentioned before. The sampling system was designed and produced for PhD study of Karel (1996). It is shown in Figure 2.15.
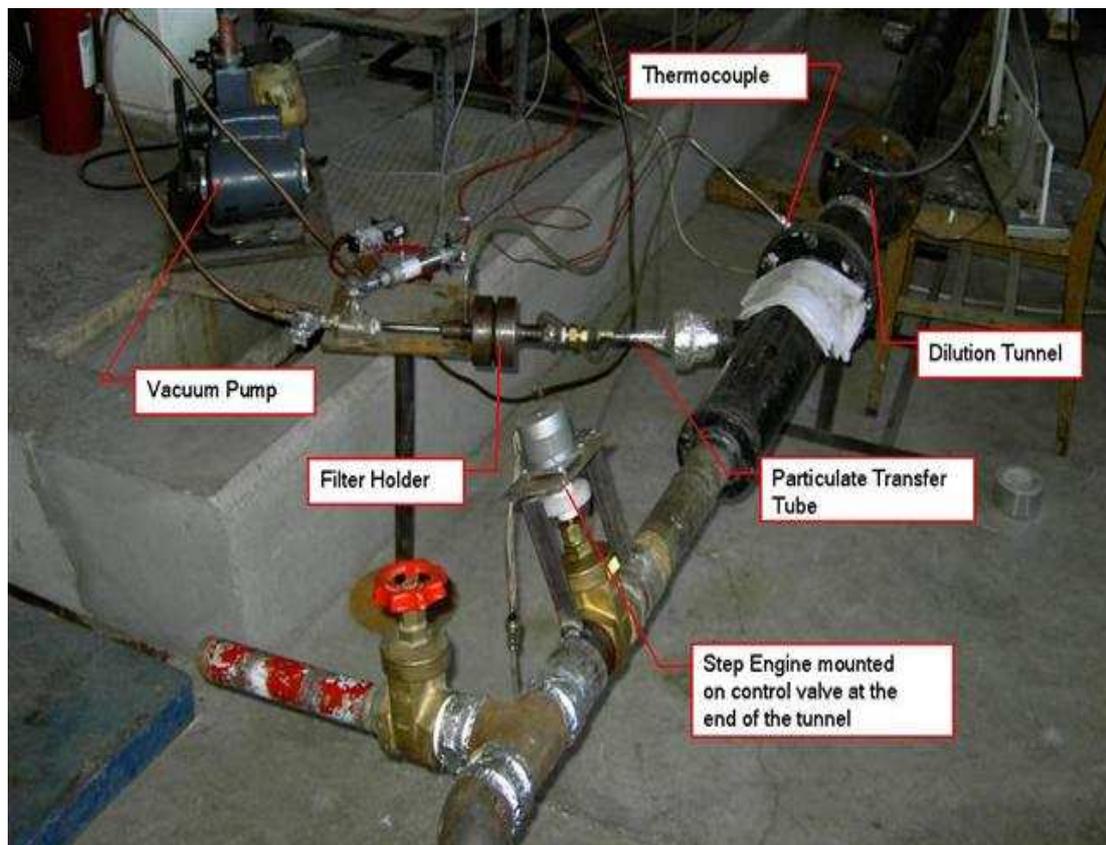
Figure 2.15: General View of Fractional Particulate Sampling

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Fractional sampling system consists of a particulate sampling probe (PSP), a particulate transfer tube (PTT), a particulate filter, a filter holder, a vacuum pump, a control valve and a rotameter. A sample of the diluted exhaust gas is taken from the dilution tunnel through the particulate sampling probe and particulate transfer tube by the means of vacuum pump. Then the sample is passed through the filter holder that contains the particulate sampling filter. The sample flow rate is measured using a rotameter (Figure 2.16). During the sampling, the velocity of diluted exhaust in the tunnel and the velocity of the sampled exhaust in the particular sampling probe should be equal. Therefore, there is a control valve on the sampling system to adjust the sampling flow rate. To start the particulate sampling when the flow reached to required condition a solenoid-piston-valve system was used (Figure 2.17). The system was inserted on particulate sampling line and was controlled by the computer. The computer sends signals to open or close the solenoid valve when the particulate sampling starts or finishes respectively. The solenoid valve activates the piston and then it turned the spherical valve to open or close the particulate sampling line.
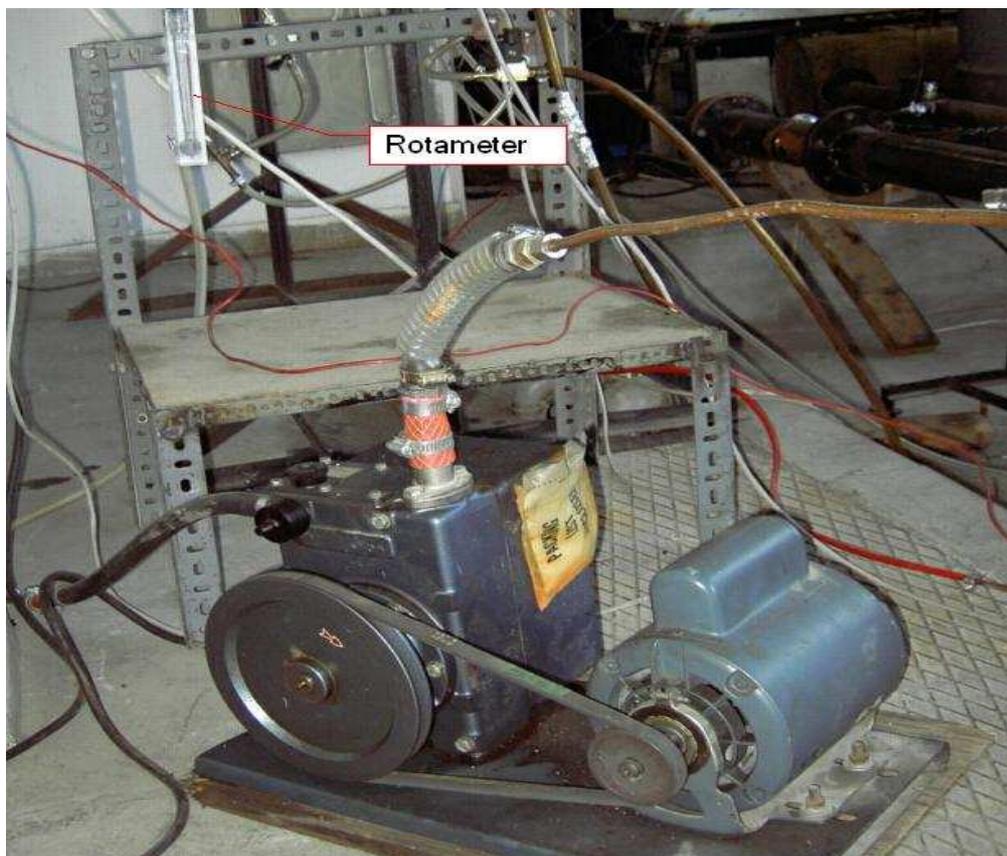
Figure 2.16: Particulate Sampling with Vacuum Pump and Rotameter

In the system used, particulate sampling probe was inserted facing upstream on the dilution tunnel pipe centerline where the dilution air and exhaust gas are well mixed according to Directive 96/EC/1999. That point is at the distance 16 times of pipe inside diameter from exhaust entrance in dilution tunnel. Moreover, sampling probe should be 12 mm in minimum diameter and opening of the probe should have sharp edges, and wall thickness less than 1 mm. Thus, the diameter of the probe was 12 mm. As for particulate transfer tube, it was connected to a filter holder. The maximum length of the transfer tube from the tip of the probe to filter holder should be 1020 mm. As a result, transfer tube used was 430 mm in length. Also, a thermocouple was attached to sampling point since the diluted exhaust gas temperature must not exceed $52^{\circ}C$ as stated previous section.
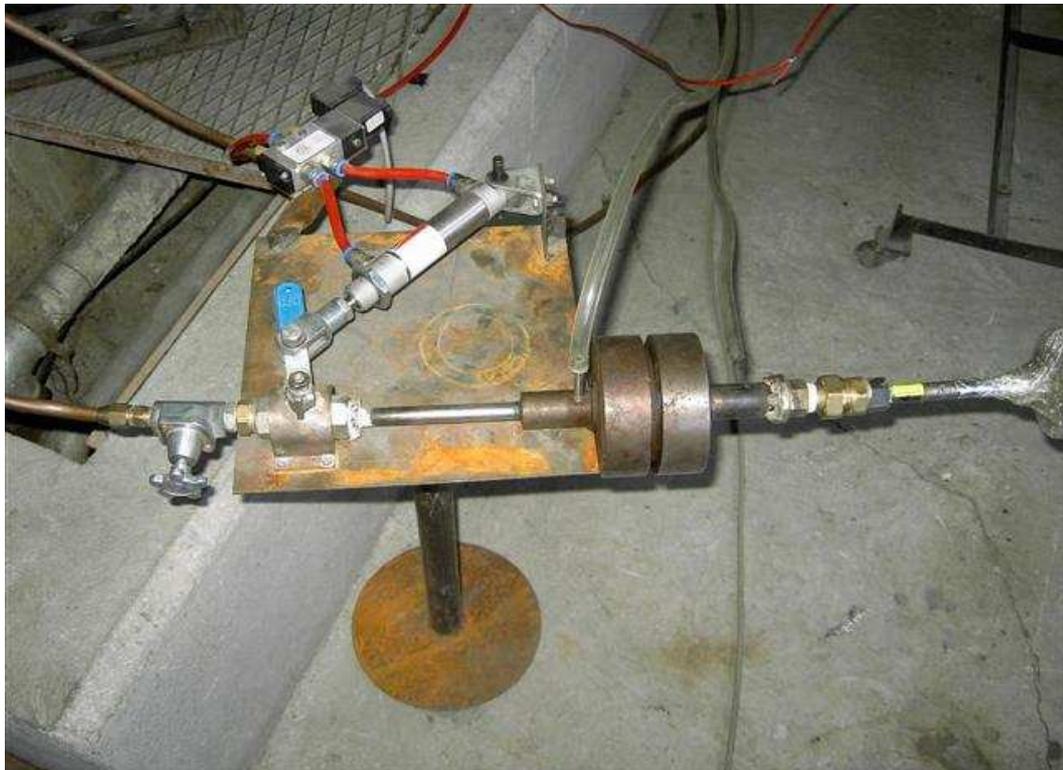
Figure 2.17: Solenoid-Piston-Valve system on Particulate Sampling Line

Filter holder used was connected to between particulate transfer tube and vacuum pump. The holder material was a kind of material that does not react with exhaust gases. Filters are positioned in the filter holder so that the sampled exhaust does not pass from outside of them. A ring was used to hold the fiberglass filters in the filter

holder. The holder, the filter and the ring is shown in Figure 2.18. Particulate filters should have a minimum of 47 mm and stain diameter of filter should be 10 mm smaller than that of the filter. In addition, they should have minimum efficiency of 95% for particles 0.3 μm and above. In the experiments, fiberglass filters with 65 mm in diameter was used.

Figure 2.18: Filter Holder and Fiberglass Filter in it

To determine the mass of the particulates, the filter must be prepared according to standards. For this reason, a preparation process in parallel with the standards stated before was applied to make the filters ready. To begin with, the filters were kept in an oven for 3 hours at $80^{\circ}C$, and then they were put in a desiccators and waiting for 24 hours to remove the humidity. Afterwards, the filters were pre-weighted using an analytical balance in a weighting chamber to determine the tare. At the end of sampling, the filter was taken back to the laboratory (Chemistry Laboratory of MKE Small Arms Ammunition Factory) and reweighted after humidity equilibrium again to determine the mass of the particular matter collected on the filter. During this

process the filter was not touched by hands, they were taken using pincers. The analytical balance used was 1/10000 g sensitivity (see Figure 2.19). The temperature and humidity of the weighting room was controlled and they were maintained to within $24C \pm 2^{o}C$ and $40 \pm 8\%$ during the filter weighting respectively.

Figure 2.19: Analytical Balance with 1/10000 g Sensitivity

During the particulate sampling, the blockage of the filter may be happened and it is an important risk considered. The blockage may tear the filter. Therefore, tips of a manometer were connected to the front and the back of the filter holder to determine whether there was a pressure drop on the filter.

2.4 Sampling of Gaseous Emissions

There are several methods which can be utilized to determine concentration of gaseous emissions and is defined in the standards stated. In this study, sampling of gaseous emissions was performed by using nylon bags which do not have any

reaction with exhaust gasses (see Figure 2.20). The nylon bags were placed in particulate sampling line after vacuum pump pipe. Diluted and sampled exhaust gas pass through the particulate sampling filter and then are collected in the bags. Therefore, the exhaust gas is purified. This method is called as grab sampling.

Figure 2.20: Nylon Gags and Solenoid Valves on Them

Sampled gas is channelized by using solenoid valves and is drawn by the pressure of vacuum pump. As a result, seven 12v solenoid valves were connected and were controlled by the computer automatically. Leakages of the bags were checked in order to prevent the contact of exhaust gases with air or other gases. Nylon bags have only a port for entering and exiting the gases. For this reason, a pipe frame and port were designed and manufactured (see Appendix E for technical Drawings). The frame was inserted from the top edge of the bag and it was seamed. Sampled exhaust gases in the bags were vacuumed by the AVL DiaGas 465 gas analyzer device   to measure the total percentages of CO, CO_2 and total Hydrocarbons. After analyzing,

the gases remained discharged from the bags using vacuum pump again. AVL gas analyzer device has two probes; one is used for the measurement of opacity, and other is used for measurements of gaseous emissions. For the measurements of the opacity an auxiliary device must be necessary with AVL gas analyzer (see Figure 2.21).
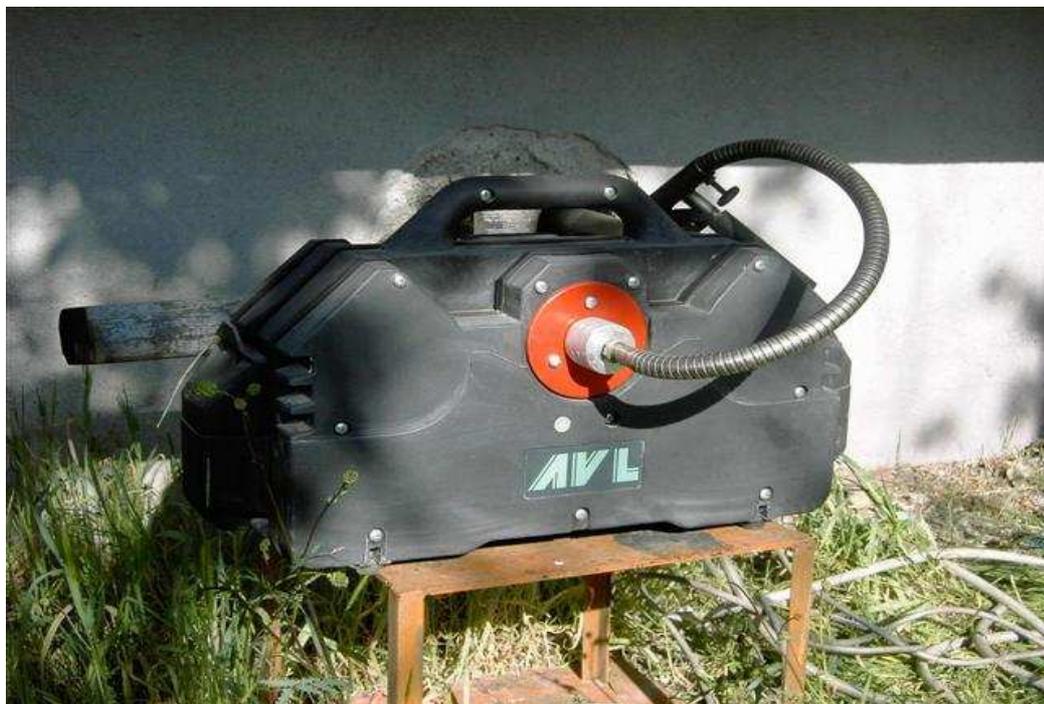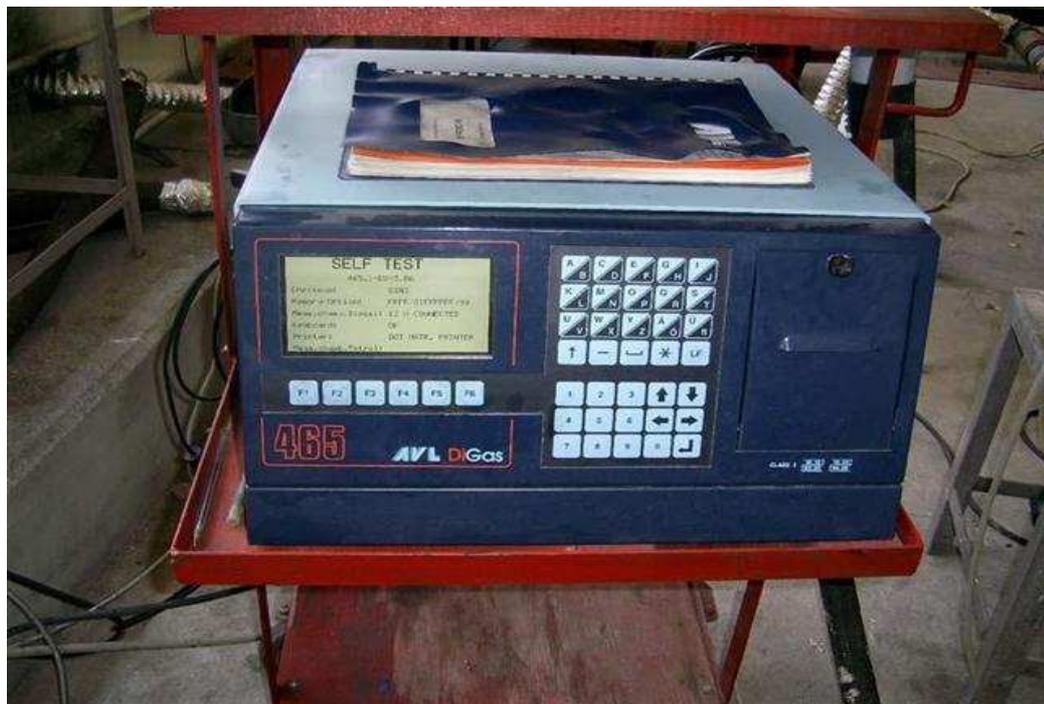
Figure 2.21: AVL DiaGas 465 Gas Analyzer and Opacity Measurement Device

2.5 Data Acquisition and Control System

For collecting data and the control of the experiments, data acquisition and control system was build and used (Figure 2.22). This system is made of hardware and software. The hardware part is made of a personal computer (PC), a data acquisition card, an Input/Output Interface Board and stepper motor drive box. The software part is made up of analysis software. Electronic control and data acquisition system takes the outputs of the previously mentioned measuring devices as an experimental data with the help of the data acquisition card. Then the data is processed with the computer and several output signals are sent to manage the experiments.

Figure 2.22: General View of the Control Panel.

2.5.1 Data Acquisition Card

In this study, a plug-in board was used. Therefore, a data acquisition card was placed internally and installed to a personal computer for collection of the data and sending necessary signals to direct the devices stated before with the help of software

developed for this study. The card used was an Advantech brand PCI-1710 coded multifunction analog and digital I/O card. It has 16-channel digital input and output, 16-channel single-ended or 8 differential A/D input, 2-channel D/A output and programmable counter/timer. In addition to data acquisition card, Advantech PLC-10168 wiring cable and PLCD-8710 wiring terminal board were used as accessories.

Temperature data collection was low voltage outputs of the thermocouples. This low voltage should be amplified to measure temperature precisely. Therefore, the previously mentioned amplifiers have been used. They supplied to the analog inputs of the terminal of data acquisition card. Other analog outputs were sent to the analog inputs of the card without being amplified. In addition, the optic sensors used for measuring the fuel consumption were sent signal to the input-output interface board to be converted to digital signal. Then, this digital signal supplied to the digital inputs of the terminal of the data acquisition card. Also, the control of the solenoid valves and fuel pump position were performed with the help of this card. The digital output channel of the data acquisition card was used for this purpose. Digital signal was sent to input/output interface box to activate relays and voltages were sent to solenoid valves and fuel pump electrical motor.
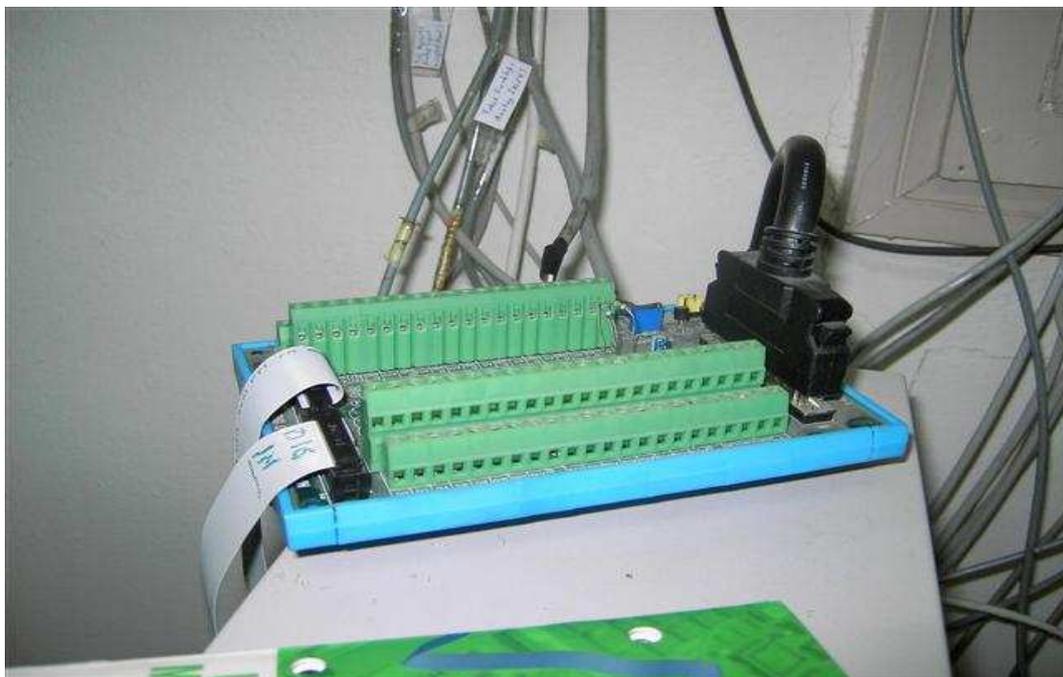
Figure 2.23: PLCD-8710 Wiring Terminal Board

2.5.2 Input/Output Interface Board

An Input/Output interface board was designed and manufactured for communicating with PC based the data acquisition board with flexible coupling of relays for Ms Study of Cerit (2006). It can permit the computer to communicate with peripheral devices such as solenoid valves, fuel pump electrical motor through a data acquisition card. For this purpose, there are 16 relays on the board. They can enable a digital signal to open or close a device as a switch. The digital signal of the data acquisition card switches the relays. Then, this relays complete voltage circuit of peripheral devices.

The box has nine sockets, on the front of the box, and nine output sockets, on the back of the box. The eight front sockets are used for inputs; the eight back sockets are used for outputs. The sockets remaining were used for voltage connection. In this study, two kinds of solenoid valves were used. Solenoids at the entrance of the nylon sampling bags work with 12V. Other solenoids which control the piston motion work with 24V. In addition, relays in the I/O control board and throttle control engine work with 12V. Therefore two voltage sources 12 and 24 volts were connected to the board. 24V and 12V that is used for relays cables were attached on the front socket and other 12V cable was mounted on back socket.

Figure 2.24: Input/Output Interface Board (front side)

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2.5.3 Computer Software

Computer software used during the experiments has been developed using Delphi 4 to control function of data acquisition card. The software can perform real time data collection and control of the experiments. The output of measuring devices is analyzed and stored as data in the software and output signals are send the devices used. The program has a suitable graphical user interface (GUI), which is user-friendly and able to cover all the related data.

First of all, data acquisition card installed the computer should be selected from the data acquisition selection window (Figure2.25).
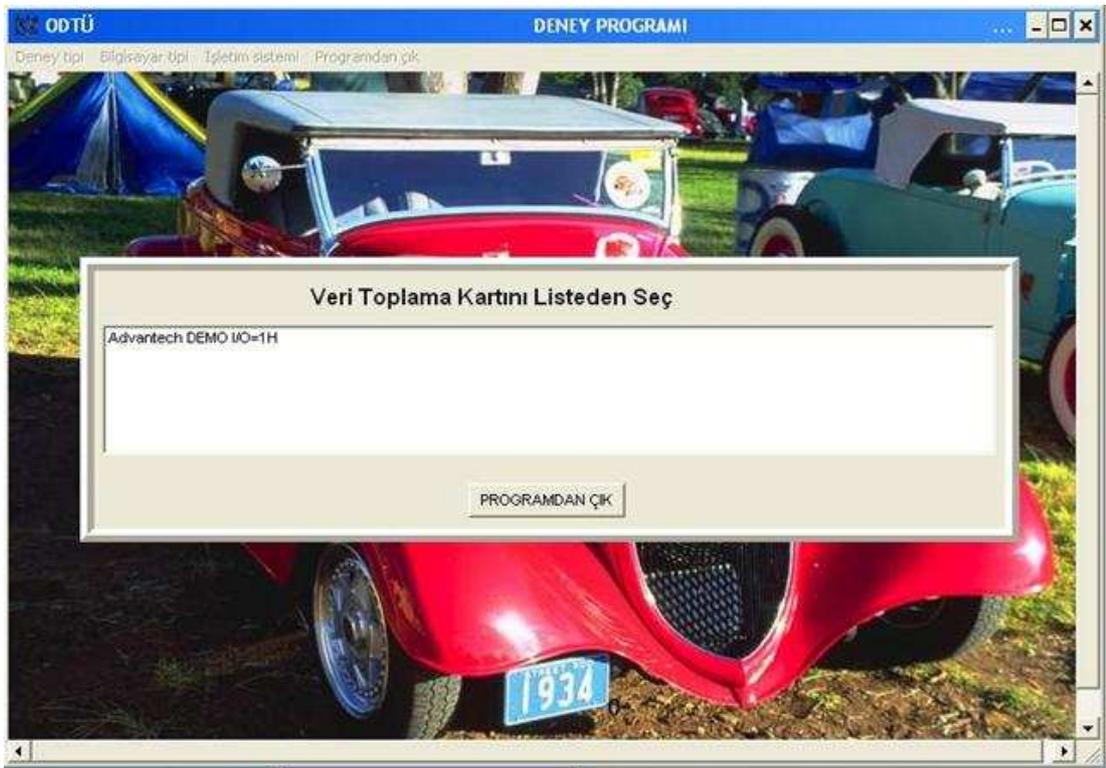
Figure 2.25: Screen Shot of Data Acquisition Card Selection Window

Because the software written for this study was integrated METU Engine Experiments Software developed by Prof Dr. A. Demir Bayka, after selection of the card, Canola oil test type should be selected from experiment type pull-down menu. Before starting the experiments, data acquisition card options should be adjust. User

should select channels where input signals come and output signals send. For this experimental setup, there are 11 analog inputs come to terminal box and also 11 digital outputs send to the devices. In addition voltage ranges for the analog inputs data should be selected (Figure 2.26). The voltage ranges used for this experiment can be viewed in Appendix F. Moreover, sampling period is determined. Data was collected in every 100 msec. here. Afterwards, fuel used to feed the engine was selected and clicked on START button to activate the program.
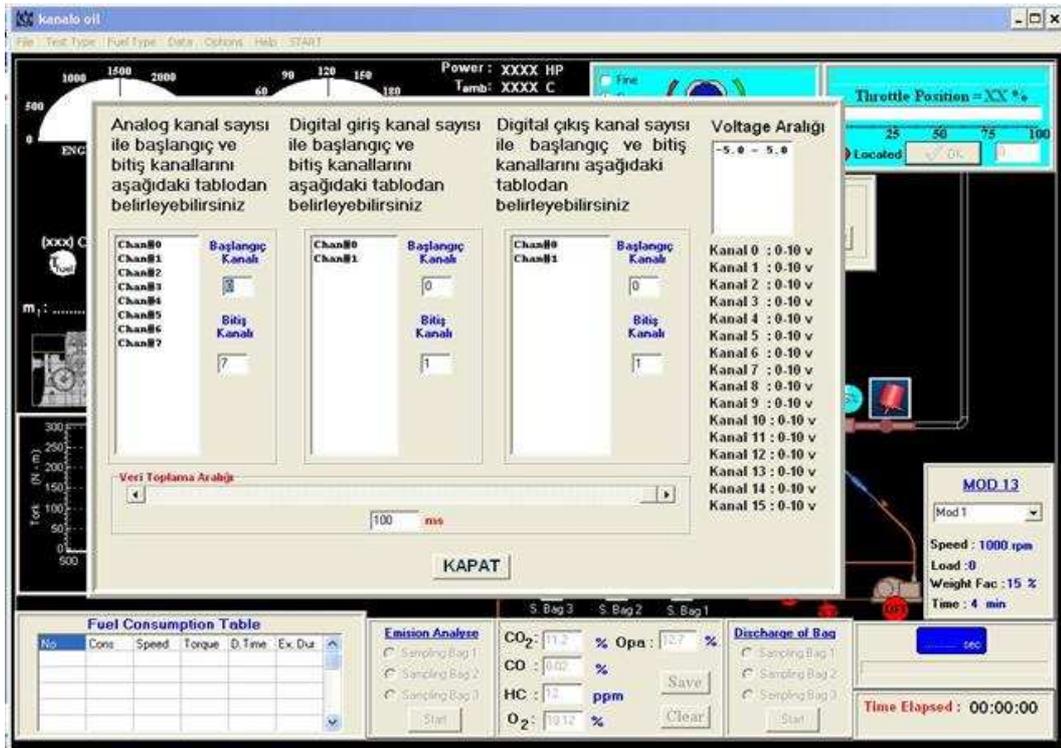
Figure 2.26: Screen shot of Input-Output Channel Selection Window

During the experiments, interface of the software shows engine parameters which is calculated from the inputs such as engine speed, torque, fuel and air consumption, temperatures, and throttle position. Some graphs is drawn automatically, hence; the user can see variation of engine power and torque with engine speed etc. The position of the solenoid, throttle can also be monitored in the software. Engine performance and emission cycles were controlled by the computer automatically. Computer program set dynamometer at specified load and speed and open the solenoid valves in the dilution tunnel and sampling system according to ESC MOD 13 test cycle. However the user can control the engine test bench manually.

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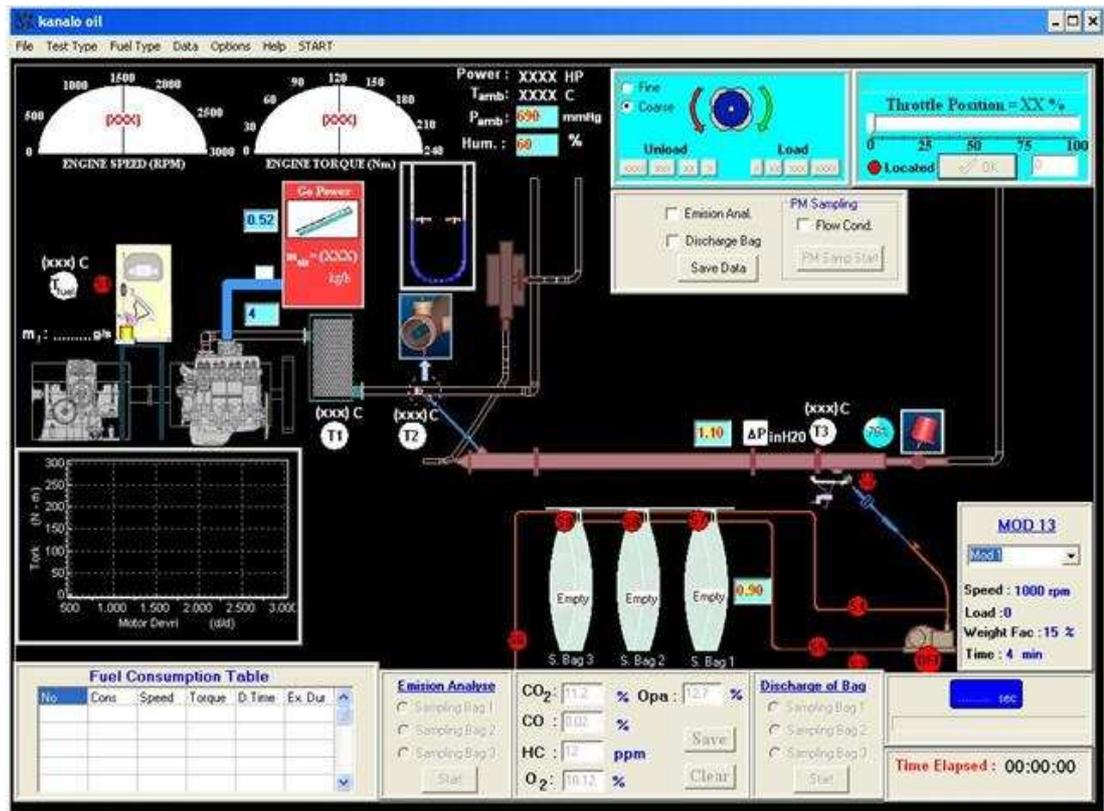
Figure 2.27: Screen Shot of Computer Software

2.5.4 Stepper Motor Drive Box

A stepper motor interface board was designed by Utku Avgan and produced to drive stepper motors. The communication between stepper motors and computer was made by means of serial port. Therefore, stepper motor interface board was connected to the computer by a serial port cable. The board used can drive 4 stepper motors simultaneously, but two stepper motors were used in experiment test bench. The one mounted on dynamometer loading arm, the other connected on diluted tunnel flow rate control valve as mentioned before. The 5V cable was connected the box to supply necessary voltage.

Figure 2.28: Stepper Motor Drive Box

CHAPTER 3

EXPERIMENTAL METHOD AND TEST PROCEDURE

The experiments are done according to some standards and regulations where the experimental apparatus are applicable for such standards. Before the experiments, the engine fuel delivery system is modified to run on canola oil. In this chapter, the properties of fuels used, the modification of fuel delivery system and the procedure applied during the experiments are explained.

3.1 Properties of Tested Fuels

Diesel fuel, canola oil and ethanol are selected and used as test fuels. The diesel fuel is commercially available and is obtained from the commercial market. The canola oil is refined produced by Aymar Company. The ethanol is absolute ethyl alcohol (99.5%). The ethanol is used as a solvent and is blended with canola in 30/70% on volume basis. The properties of the diesel, canola oil and ethanol are summarized in Table 3.1.

Table 3.1: Properties of the Diesel fuel, Canola Oil and Ethanol

		Diesel	**Canola Oil**	**Ethanol**
Chemical Formula	-	$C_{10.8}H_{18.7}$	$C_{57}H_{105}O_6$	C_2H_5OH
Carbon Content	(wt%)	84	77.2	52
Hydrogen Content	(wt%)	14	11.8	13
Oxygen Content	(wt%)	-	10.8	35
Cetane Number	-	55	41-43	7
Heating Value	kJ/kg	42000	37000	28000
Density	g/cc (20 C)	0.82	0.916	0.79
Viscosity	cSt (20 C)	4,50	78,2	1,52
Flash Point	C	58	275 - 290	9 - 11
Boiling Point	C	180-330	-	78.5
Cloud Point	C	-10	-4	-

As diesel fuel and canola oil are compared, the canola oil has some advantages on diesel fuel. The flash point of canola oil is around $280^{o}C$. This improves fire security during fuel transportation and storage. Also there is considerably higher oxygen content in canola oil (10.8%). As a result of this, a more complete combustion can be achieved to reduce emissions. However, besides advantages, some properties of diesel fuel are better than that of canola oil. It can be seen that calorific value of canola oil is 11.9% lower than that of diesel fuel. The density of diesel fuel at $20^{o}C$ is 11.7% higher than that of diesel fuel. At a temperature of $20^{o}C$ the viscosity of canola oil is seventeen times as high as with diesel fuel. The high viscosity of canola oil is the main problem when the oil is used. Therefore, to make use of canola oil in diesel engine, the high viscosity should be reduced. As a result, because the viscosity of the vegetable oil is very dependent on temperature, the effect of temperature on viscosity of canola oil is researched by Levent Semiz at the Department of Chemistry of Middle East Technical University. The viscosity is measured using an Ubbelohde viscometer. The results of the experiments are shown in Figure 3.1.
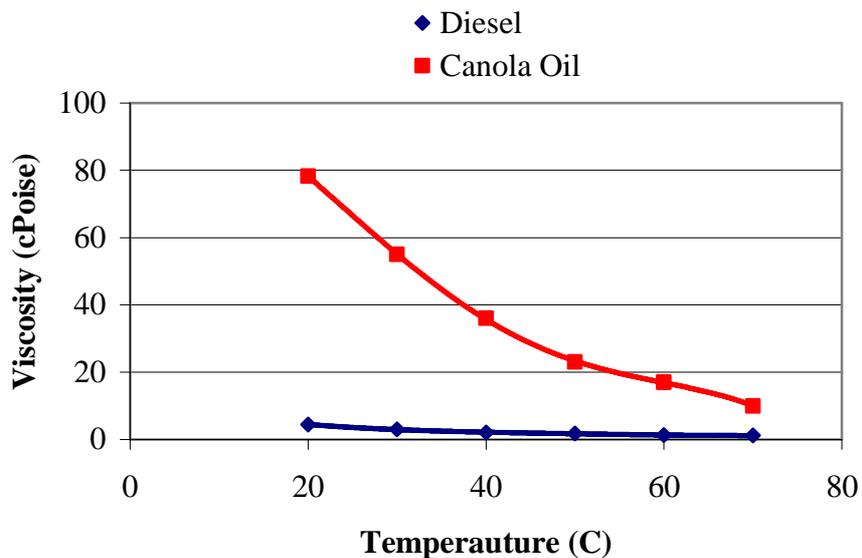
Figure 3.1: Variation of Viscosity with Temperature [43]

As seen in the figure, the viscosity of canola oil decreases rapidly as temperature is increased. At a temperature of $70^{o}C$, the viscosity of canola oil is only two times as high as with diesel fuel. Therefore, the canola oil is preheated before the fuel pump and before the injectors to minimize its resistance to flow. In addition to preheating, in order to decrease the viscosity, canola oil is also mixed with ethanol. Since the

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ethanol is a polar substance, it does not give a homogenous solution with canola oil. However, when the mixture is heated, it becomes homogenous [43]. Hence, the critical temperature where the mixture becomes homogenous and its relation with of the volumes of ethanol and the oil and viscosity adjustment of oil with ethanol were found by Levent Semiz. The temperature at which the ethanol-canola mixture becomes homogenous are tabulated in Table 3.2

Table 3.2 The critical temperature of ethanol-canola mixture [43]

Percent (V/V) Ethanol in the mixture	Mole Fraction of Ethanol in the mixture	Temperature
20	0,815	42
30	0,883	58
40	0,922	68
50	0,946	73
60	0,964	75
70	0,976	72
80	0,986	69
90	0,994	66

Moreover, the viscosity of the mixtures was determined. According to this study, the viscosity of the mixture of ethanol-canola oil having 30% ethanol on volume basis is 4.2 cPoise at $60^{\circ}C$. This is nearly equal to the viscosity of diesel fuel at $20^{\circ}C$. This viscosity value can be acceptable. Therefore, canola oil and ethanol are blended in 70/30% on volume basis and tested. To heat the blend a thermostatically controlled electrical heater is used.

3.2 Fuel Delivery System

The diesel engines are fitted with injection systems designed to deliver and properly atomize diesel fuel. However, because canola oil is sixteen times more viscous than diesel fuel, trying to spray it through to an injector designed for less viscous fluid does not give a better spray characteristic. An improper spray pattern will result in incomplete combustion and some problems such as carbon deposits, injector coking and piston ring seizure. There are several ways to reduce vegetable oil viscosity; the simplest is heating it up as mentioned before. As can be seen from the Figure 3.1 when canola oil is heated to $70^{\circ}C$ its viscosity is close to that of petroleum diesel.

As a result fuel delivery system was modified to heat canola oil to $70^{\circ}C$ before being injected so that it can be atomized properly by the injector.

The engine is cooled with coolant (water) and there is ample coolant which is up to $80^{\circ}C$ by the time the engine is up to operating temperature. Therefore, a heat source is ready. By using coolant and a heat exchanger, it is possible to heat canola oil up to $70^{\circ}C$ when the engine has an operating temperature of $80^{\circ}C$. According to this principle, a fuel preheating system was adapted on diesel fuel delivery system.

The fuel preheating system consists of a canola oil tank, a switching valve, a purging valve, a heat exchanger and a control switch. It is presented in Figure 3.3. There are two independent fuel systems, one for diesel fuel and one for the canola oil. The engine starts on diesel fuel and runs on that fuel until operating temperature. After this point, the canola oil is supplied and diesel fuel is closed by using a switching valve. Before shutting down the engine while the engine is running on canola oil, the oil is purged in the fuel system with diesel by a using purging valve. In this study, switching and purging between two fuel systems was made manually using a control switch, there is no control unit to do this automatically. To control the efficiency of the heat exchanger, the temperature of fuel is measured before the injector pump (Figure 3.2).
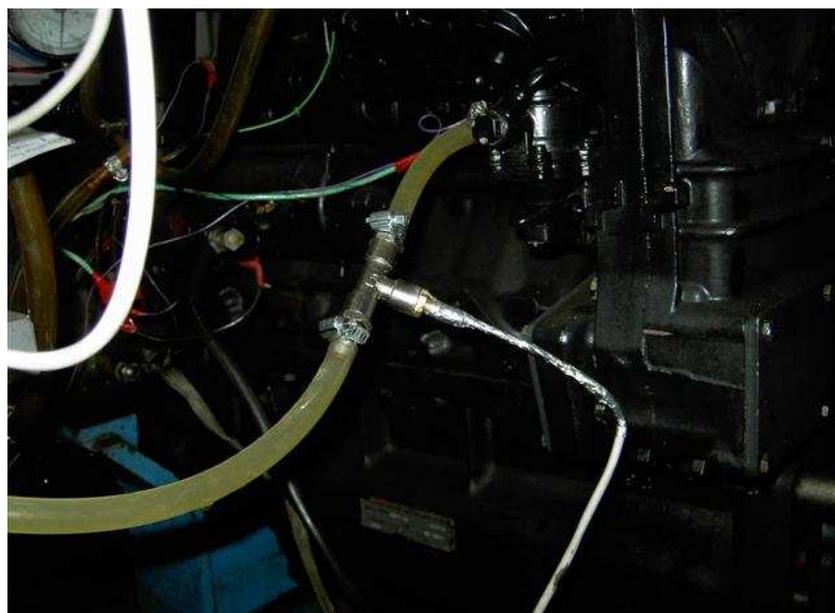
Figure 3.2: Thermocouple to Measure Fuel Temperature

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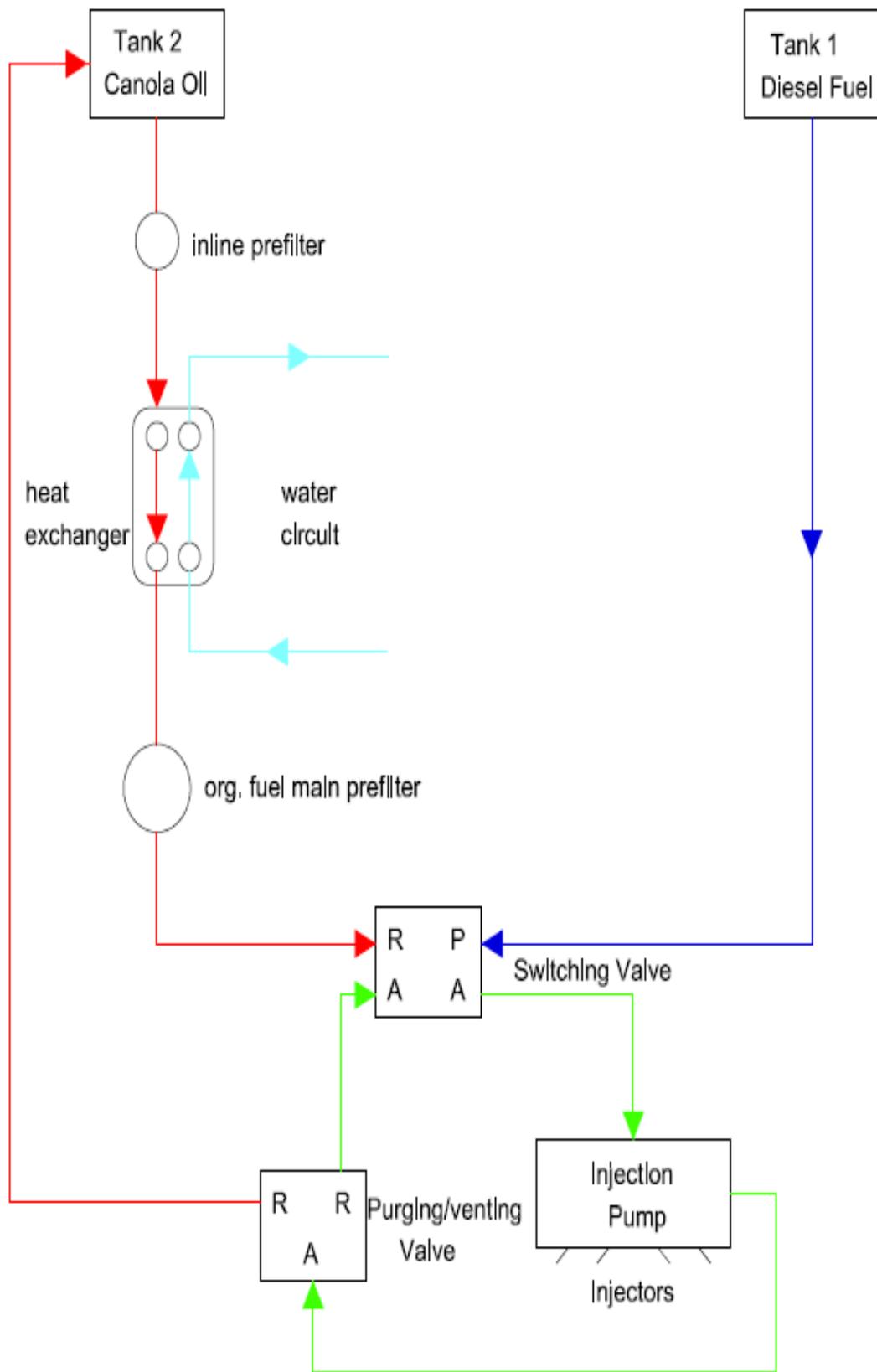
Figure 3.3: The Layout of Modified Fuel Delivery System

3.3 European Stationary Test Cycle (ESC)

The ESC test cycle (also known as OICA/ACEA cycle) has been introduced together with the ETC (European Transient Cycle) and the ELR (European Load Response) tests, for emission certification of heavy-duty diesel engines in Europe starting in the year 2000 (directive 1999/96/EC of December 13 1999) The ESC is a 13-mode, steady-state procedure that replaces the R-49 test.

The engine is tested on an engine dynamometer over a sequence of steady-state modes (Table 3.3, Figure 3.4). The engine must be operated for the prescribed time in each mode, completing engine speed and load changes in the first 20 seconds. The specified speed shall be held to within ±50 rpm and the specified torque shall be held to within ±2% of the maximum torque at the test speed. Emissions are measured during each mode and averaged over the cycle using a set of weighting factors. Particulate matter emissions are sampled on one filter over the 13 modes. The final emission results are expressed in g/kWh.

Table 3.3: ESC Test Modes

Mode	Engine Speed	% Load	Weighting Factor%	Duration
1	Low Idle	0	15	4 minutes
2	A	100	8	2 minutes
3	B	50	10	2 minutes
4	B	75	10	2 minutes
5	A	50	5	2 minutes
6	A	75	5	2 minutes
7	A	25	5	2 minutes
8	B	100	9	2 minutes
9	B	25	10	2 minutes
10	C	100	8	2 minutes
11	C	25	5	2 minutes
12	C	75	5	2 minutes
13	C	50	5	2 minutes
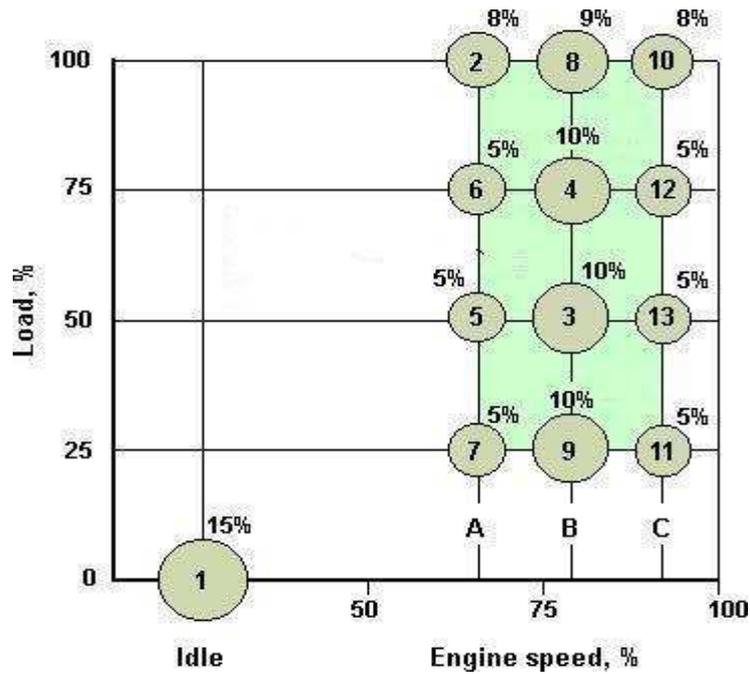
Figure 3.4: ESC 13 Mode Cycle

3.4 Experimental Plan and Procedure

The experiments are performed at full load-variable speed and at 13 modes of ESC test to determine the effect of canola oil on engine performance and emissions. First of all, full load-variable speed tests at full throttle are conducted then ESC mod 13 test cycle is applied. The engine is operated on diesel fuel first and then on canola oil and canola-ethanol blend. All experiments are performed by setting a throttle position and varying the load on the engine with the help of the dynamometer. Experimental set up is controlled with the help of the program as mentioned previous chapter.

3.4.1 Full Load Variable Speed Performance Test

The step by step procedures followed in the diesel fuel experiments are

1. Check fuel level in the diesel fuel tank and open the fuel tank and fill the fuel container.
2. Check water level in the radiator.

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3. Start air compressor.

4. Start the water pump on the water tank of dynamometer.

5. Turn on the water vane of dynamometer, then discharge the air left in the dynamometer by turning small vane arm until the water comes out having pressure little or more than atmospheric pressure.

6. Turn the PC on and have the test software ready

7. Turn the adapters on (5,12 and 24 Volts)

8. Start the engine and let it run at 1000-1200 rpm until the cooling water temperature reaches $70^{o}C$

9. Turn the cooling fan on to simulate that the engine surface is cooled with convection

10. Run the controlling and monitoring software

11. Set the throttle to wide open throttle position

12. Set the loading handle so that engine speed is about 1400 rpm. Wait for 2-3 minutes until the engine is steady.

13. Measure fuel flow rate at least 3 times.

14. Take engine speed, torque, air flow rate and temperatures.

15. Repeat steps 12, 13, 14 for engine speed 1500, 1700, 1900, 2100, 2300 and 2500 rpm

16. Set the throttle and the loading handle to fully closed

For canola oil and canola-ethanol blend performance tests similar procedure is used with the following differences.

Steps 1 through 9 are followed exactly, after 10th step the fuel in the small container is discharged and the control switch of fuel is set from "Diesel" to "Canola" and then the container is filled with the test fuel and the engine is ran on canola oil and its blend at idle speed for 10 minutes to replace the diesel fuel in the system with canola oil. Then steps 10 through 16 are followed after that the steps below are performed.

17. Set control switch of fuel form "Canola" to "Diesel"

18. Run the engine on diesel fuel at idle speed for 10 minutes to replace the test fuel in the system with diesel fuel

3.4.2 ESC Test Cycle

According to ESC test, the engine speeds to be test in this study are $n_A = 1500 \, rpm$, $n_B = 1900 \, rpm$ and $n_C = 2300 \, rpm$. The engine speed at idle is 1000 rpm. The procedures used throughout the ESC test cycle for diesel fuel are

1. Start AVL Gas Analyzer 15 minutes prior to tests to heat it self up and for automatic self calibration
2. Make AVL Gas Analyzer leakage test.
3. Check fuel level in the diesel fuel tank and open the fuel tank and fill the fuel container
4. Check water level in the radiator
5. Place the particulate filter (preparation process applied and weighted) in filter holder.
6. Check the sampling bag and discharge if necessary
7. Check the water levels of the manometers on dilution tunnel.
8. Start air compressor
9. Start the water pump on the water tank of dynamometer
10. Turn on the water vane of dynamometer, then discharge the air left in the dynamometer by turning small vane arm until the water comes out having pressure little or more than atmospheric pressure
11. Start the air blower.
12. Turn the PC on and have the test software ready
13. Turn the adapters on (5,12 and 24 Volts)
14. Start the engine and let it run at 1000-1200 rpm until the cooling water temperature reaches $70^{\circ}C$
15. Run the controlling and monitoring software.
16. Set engine speed and load according applied mode. Wait for 2-3 minutes until the engine is steady from computer program.
17. Adjust the valve position to make isokinetic sampling point pressure difference to zero from computer program.
18. Start the vacuum pump from computer program.
19. Start the particulate sampling from computer program

20. Take manometer reading of dilution tunnel.
21. Take rotameter reading.
22. Check the manometer on filter for blockage.
23. Take the fuel flow rate during the particulate sampling.
24. Take engine speed, torque, air flow rate and temperatures.
25. Place the opacity apertures of probe of AVL Gas Analyzer Device in exhaust pipe, and take opacity data.
26. Change the particulate filter and place dirty filter in glass container.
27. If all sampling bags are used, stop the engine and air blower
28. Place the probe of AVL Gas Analyzer device in sampling pipe and analyze the emission gas in the sampling bag respectively.
29. Discharges the emission gases remain in the bags using vacuum pump
30. Repeat steps 16 through 29 for other ESC modes.
31. After the 13 test modes performed the particulate filters was reweighted as mentioned previous chapter.

For canola oil and canola-ethanol blend performance tests similar procedure is used with the following differences.

Steps 1 through 15 are followed exactly, after 16th step the fuel in the small container is discharged and the control switch of fuel is set from "Diesel" to "Canola" and then the container is filled with the test fuel and the engine is ran on canola oil and its blend at idle speed for 10 minutes to replace the diesel fuel in the system with canola oil. Then steps 15 through 31 are followed after that the steps below are performed.

32. Set control switch of fuel form "Canola" to "Diesel"
33. Run the engine on diesel fuel at idle speed for 10 minutes to replace the test fuel in the system with diesel fuel.

CHAPTER 4

CALCULATION PROCEDURE

In this chapter, the Formulae used in calculation of engine parameters' and exhaust emissions' will be supplied. In the calculations, each parameter is explained separately. The calculations have been made by using Microsoft Excel.

4.1 Performance Parameter Calculations

These parameters are used to determine the performance evaluation of the test engine. These parameters are power output, torque output, fuel consumption, and brake specific fuel consumption, volumetric and thermal efficiency. Air flow rate, Air Fuel ratio (A/F) and excess air coefficient have also been calculated in order to evaluate above mentioned parameters. The data is taken at 10 Hz for the setup by using data acquisition card and system. Therefore, the average of the collected data is used.

4.1.1 Engine Torque

Torque produced is measured as voltage signals by using a load-cell. Engine torque produced at the measure engine speed is a product of the load on the load-cell and the arm length of the dynamometer. It can be found from the following relation.

$$\mathbf{Load(kg)} = (5\frac{\mathbf{kg}}{\mathbf{volt}})\mathbf{xV_{load\text{-}cell}(Volt)} \qquad (4.1)$$

$$\mathbf{T = Loadxlxg} \qquad (4.2)$$

$$\mathbf{T_c = TxC_f} \qquad (4.3)$$

Where: $"l"$ = The arm length of the dynamometer (l=0.56 m)

"g" = Gravitational acceleration (g=9.81 m^2/s)

"T" = Engine torque (N-m)

"T_c" = Corrected Engine Torque (N-m)

"5 kg/Volt" = The load-cell voltage output per kg (10 Volts for 50 kg)

The brake power and torque available from a normally aspirated internal combustion engine are dependent on the density of the air. However, the measurements have not been made at sea level, 99 kPa dry pressure and 25^oC (reference atmospheric conditions) [38]. Therefore, found torque is multiplied with correction factor (C_f) to be able to make comparisons between different engines. The equation for correction factor is given below.

$$C_f = \left(\frac{742.56107}{P_d}\right)^{0.65} \left(\frac{T_{amb} + 273.15}{298.15}\right)^{0.5}$$ (4.4)

Where: "C_f" = Correction factor

"P_d" = The pressure of the dry air (mm-Hg)

"T_{abm}" = Ambient temperature (^oC)

The pressure of the dry air is found by subtracting the vapor pressure from actual air pressure

$$P_d = P_{atm} - RHxP_v$$ (4.5)

Where: "P_{atm}" = Atmospheric pressure (mm-Hg)

"RH" = Relative humidity (%)

"P_v" = Water vapor pressure (mm-Hg)

Water vapor pressure can be evaluated as follow [39].

$$P_v = \left(6.10708x10^{\frac{7.5xT_{amb}}{237.3+T_{amb}}}\right)0.75$$ (4.6)

4.1.2 Brake Power

The brake power produced at measured engine speed by the engine is found by multiplying the torque on crankshaft with rotational engine speed. The brake power is measured generally in terms of horsepower. It can be found from the following relation.

$$P_b = T_c x N_{speed} x \frac{\pi}{30000} x 1.36 \tag{4.7}$$

Where: $"P_b" =$ Corrected brake power (HP)

$"N_{speed}" =$ Engine speed (rpm)

$"1.36" =$ Conversion constant from kW to HP

$"1/30000" =$ Conversion constant (W rev/sec to kW rad/s)

4.1.3 Fuel Consumption

Fuel consumed by the engine is calculated using volumetric fuel flow rate. Volumetric flow rate is measured with fuel consumption system discussed in Chapter 2. In this system, the volume change of the container has been measured with respect to time. The volume among optic sensors is also constant and known. Thus, volumetric flow rate can be calculated. Consequently, fuel consumption is evaluated as follows.

$$\dot{m}_{fuel} = \frac{V_{container} x \rho_{fuel} x 3.6}{t_f x 1000} \tag{4.8}$$

Where: $"\dot{m}_{fuel}" =$ Fuel flow rate (kg/h)

$"V_{container}" =$ Volume among optic sensors ($V_{container}$ = 86 ml)

$"\rho_{fuel}" =$ Fuel density (kg/m^3)

$"t_f" =$ The consumption time of 86 ml fuel (s)

"3.6/1000" $=$ Conversion constant (ml/s to m^3/h)

$\rho_{fuel} = 820$ kg/m^3 for diesel at 25°C, $\rho_{fuel} = 875$ kg/m^3 for canola oil at 70°C and $\rho_{fuel} = 862$ kg/m^3 for canola-ethanol mixture at 70°C were used as fuel density. This calculation is performed by the computer software during the experiment automatically

4.1.4 Brake Specific Fuel Consumption

The brake specific fuel consumption is a measure of an engine's efficiency. It is the rate of fuel consumption divided by the power produced. It is calculated as follows.

$$\mathbf{BSFC} = \frac{\dot{\mathbf{m}}_{\mathbf{fuel}}}{\mathbf{P}_{\mathbf{b}}} \qquad\qquad (4.9)$$

Where: "BSFC" $=$ Brake specific fuel consumption (kg/HP-h)

4.1.5 Brake Specific Energy Consumption

Brake specific energy consumption is the energy consumed per unit time per unit power. It is calculated as follows.

$$\mathbf{BSEC} = \mathbf{BSFCxQ_L} \qquad\qquad (4.10)$$

Where: "BSEC"$=$ Brake specific energy consumption (kJ/HP-h)

"Q_L"$=$ Lower heating value of the fuel (kJ/kg)

$Q_L = 42000$ kJ/kg for diesel, $Q_L = 37000$ kJ/kg for canola oil and $Q_L = 34300$ kJ/kg are used as lower heating value of the fuel.

4.1.6 Specific Energy Cost

Specific energy cost is the energy cost consumed per unit time per unit power. It is evaluated as follows.

$$SEC = BSFCxC_{fuel} \qquad (4.11)$$

Where: "SEC"= Specific energy cost (YTL/HP-h)

"C_{fuel}"= Cost of the fuel (YTL/kg)

C_{fuel} = 3.41 YTL/kg for diesel, C_{fuel} = 1.34 YTL/kg for canola oil and C_{fuel} = 2.14 YTL/kg for canola-ethanol mixture are used as fuel cost. Detail of cost analysis is given in Appendix H.

4.1.7 Air Flow Rate

The voltage outputs of the air-mass meter are converted to air flow rate by using the calibration data given in Appendix C and the equation is stated below.

$$\dot{m}_{air} = (-11.971831V_a^2 + 237.02446V_a - 491.8309)C_{air} \qquad (4.12)$$

Where: "$\dot{m}_{air}$"= Air flow rate (kg/h)

"V_a"= Voltage output of the air mass meter (Volt)

"C_{air}"= Air flow correction factor

Air flow correction factor is evaluated as follows.

$$C_{air} = C_p x C_t x C_h \qquad (4.13)$$

$$C_p = 0.066428571 + 0.011238095\left(\frac{P_{atm}}{25.4}\right) + 0.00066666667\left(\frac{P_{atm}}{25.4}\right)^2 \qquad (4.14)$$

$$C_T = 1.0954518 - 0.0016846296(1.8T_{amb} + 32) + 1.5872009E - 06(1.8T_{amb} + 32)^2 \ (4.12)$$

$$C_h = \left(\frac{0.733826288((0.62198P_v)/P_d)}{0.733726456}\right) \qquad (4.15)$$

Where: "C_p"= Pressure correction factor

"C_T"= Temperature correction factor

"C_h"= Humidity correction factor

4.1.8 Air/ Fuel Ratio

Air/fuel ratio is defined as the ratio of air sucked by the engine to fuel consumed by the engine. It is calculated as given in the below formula

$$\left(\frac{A}{F}\right)_{actual} = \frac{\dot{m}_{air}}{\dot{m}_{fuel}}$$
(4.16)

4.1.9 Excess Air Coefficient

Excess air coefficient is the ratio of actual and stoichiometric Air/Fuel ratios. It is evaluated as follows.

$$\lambda = \frac{\left(\frac{A}{F}\right)_{actual}}{\left(\frac{A}{F}\right)_{stoic}}$$
(4.17)

Where "λ" = Excess air coefficient

Here, stoichiometric ratio is taken as 14.389 for diesel, 12.481 for canola oil and 12.567 for canola-ethanol mixture. Equivalence ratio related to this coefficient is calculated as follows.

$$\phi = \frac{1}{\lambda}$$
(4.18)

Where: "ϕ" = Equivalence ratio

4.1.10 Volumetric Efficiency

Volumetric efficiency is the ratio between air mass charge induced at atmospheric conditions and total air mass charge induced under standard atmospheric conditions. It is calculated by the following formulas.

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$$\eta_v = \frac{\overset{.}{m}_{air}}{\overset{.}{m}_{ath}} \qquad\qquad (4.19)$$

Where: "η_v"= Volumetric efficiency (%)

"$\overset{.}{m}_{ath}$"= Theoretical air flow rate (kg/h)

Theoretical air flow rate is found as follows.

$$\overset{.}{m}_{ath} = \frac{\rho_{std}.V_s.N_{speed}.i.2.60}{j} \qquad\qquad (4.20)$$

$$V_s = \frac{\pi.D^2.S}{4} \qquad\qquad (4.21)$$

$$\rho_{std} = \frac{P_{std}}{R_{air}.T_{std}} \qquad\qquad (4.22)$$

Where: "V_s"= Swept Volume of one cylinder (m^3)

"i"= Number of cylinders

"j"= Number of strokes

"D"= Cylinder bore (m)

"S"= Piston stroke (m)

"ρ_{std}"= Standard air density

"P_{std}"= Standard atmospheric pressure $(P_{std}=101.325 \text{ kPa})$

"T_{std}"= Standard atmospheric temperature $(T_{std}=293 \text{ K})$

"R_{air}"= Air gas constant $(R_{air}=0.287 \text{ kJ/kgK})$

4.1.11 Thermal Efficiency

Thermal efficiency of an engine is the ratio of the brake power to the energy available in the fuel to produce this power. It is calculated by means of the following equation.

$$\eta_{th} = \frac{P_b \, x \, 3600}{Q_L \, x \, \dot{m}_{fuel} \, x \, 1.341} \tag{4.23}$$

Where: "η_{th}" = Thermal efficiency (%)

4.2 Exhaust Emission Calculation

Exhaust emissions are made up of gaseous emissions and particulate emissions. The gaseous emissions are made up of carbon monoxide (CO), hydrocarbons (HC), nitric oxides (NO_x) and carbon dioxide (CO_2).The particulate emission is made up of particulate matter (PM). NO_x emissions were not measured because the AVL DiGas 465 did not measure NO_x emissions. To calculate these mentioned emissions, diluted ratio, diluted exhaust flow rate, drawn exhaust flow rate and total exhaust flow rate have also been evaluated.

4.2.1 Dilution Tunnel Flow Rate

Diluted tunnel flow rate was measured by using an orifice plate on the dilution tunnel. The manometer reading indicates the pressure difference through the nozzle. This manometer reading is converted into tunnel flow rate using the calibration data given in Appendix C and the equation is given below.

$$\dot{V}_{dt} = (639.784 + 84.8454 P_{dt} - 0.802568 P_{dt}^2)0.06 \tag{4.24}$$

Where: "$\dot{V}_{dt}$" = Dilution volumetric tunnel flow rate (m^3/h)

"P_{dt}" = Pressure drop at dilution tunnel orifice ("WC)

4.2.2 Exhaust Gas Flow Rate

For calculation of the emissions, it is necessary to know the exhaust gas flow. It can be determined by measuring air flow and fuel flow rate [40]. The equations are given below.

$$\dot{V}_{exh} = \dot{V}_{air} + 0.77\,\dot{m}_{fuel} \qquad\qquad (4.25)$$

$$\dot{V}_{exhd} = \dot{V}_{air} - 0.75\,\dot{m}_{fuel} \qquad\qquad (4.26)$$

$$\dot{V}_{air} = \frac{\dot{m}_{air}}{\rho_{air}} \qquad\qquad (4.27)$$

$$\rho_{air} = \frac{P_{atm}\,x\,0.1333224}{R_{air}\,x\,(T_{abm} + 273.15)} \qquad\qquad (4.28)$$

Where: $"\dot{V}_{exh}"$ = Exhaust gas volumetric flow rate on wet basis (m^3/h)

$\quad "\dot{V}_{exhd}"$ = Exhaust gas volumetric flow rate on dry basis (m^3/h)

$\quad "\dot{V}_{air}"$ = Air volumetric flow rate on dry basis (m^3/h)

$\quad "\rho_{air}"$ = Atmospheric air density (kg/m^3)

$"0.1333224"$ = Conversion constant (mmHg to kPa)

4.2.3 Dilution Ratio

Dilution ratio is the ratio of diluted exhaust flow rate in dilution tunnel to the drawn exhaust flow rate through the tunnel. It is evaluated as follows.

$$q = \frac{\dot{V}_{dt}}{\dot{V}_{exh}\,.\,r} \qquad\qquad (4.29)$$

$$r = \frac{A_p}{A_t} \qquad\qquad (4.30)$$

Where: $"q"$ = Dilution ratio

$\quad "r"$ = Split ratio

$\quad "A_p"$ = Cross sectional area of the isokinetic sampling probe (m^2)

$\quad "A_T"$ = Cross sectional area of the exhaust pipe (m^2)

4.2.4 Equivalent Diluted Exhaust Gas Flow Rate

Equivalent diluted exhaust gas flow rate can be found from following relation in the isokinetic sampling system.

$$\dot{V}_{EDF} = \dot{V}_{exh} \, x q \qquad (4.31)$$

Where: "$\dot{V}_{EDF}$"= Equivalent diluted exhaust gas volumetric flow rate (m^3/h)

4.2.5 Particulate Mass Flow Rate (g/h)

The particulate mass flow rate is calculated as follows

$$PT_{mass} = \frac{P_f \, x \, \dot{V}_{EDF}}{V_{SAM} \, x 1000} \qquad (4.32)$$

$$V_{SAM} = \frac{V_{vp} \, x t_s \, x 1.69906}{3600} \qquad (4.33)$$

Where: "PT_{mass}"= Particulate mass flow rate (g/h)

"P_f"= Particulate sample mass collected (mg)

"V_{SAM}"= Volume of the diluted exhaust sample passed through the particulate

sampling filters (m^3)

"$\dot{V}_{vp}$"= Vacuum pump flow rate (ft^3/min)

"t_f"= Particulate sampling time (s)

"1.69906"= Conversion constant (from ft^3/min to m^3/h)

4.2.6 Particulate Emission (g/HP-h)

Particulate emission is defined as amount of particulate matter formed per unit time and power. It is calculated in the following way.

$$PT_e = \frac{PT_{mass}}{P_b} \qquad (4.34)$$

Where: "PT_e"= Particulate emission (g/HP-h)

4.2.7 Gas Emissions Mass Flow Rate (g/h)

The gas emission mass flow rate is evaluated for each mode as follows.

$$HC_{mass} = \frac{\rho_{HC} x HC_{conc} x \dot{V}_{EDF}}{1000} \qquad (4.35)$$

Where: "HC_{mass}"= Hydrocarbon emission mass flow rate (g/h)

"ρ_{HC}"= Density of hydrocarbon (ρ_{HC}=0.619 kg/m^3)

"HC_{conc}"= Concentration of T-HC' (ppm)

4.2.8 Gas Emissions (g/HP-h)

Total hydrocarbon emission is evaluated as follows.

$$HC_e = \frac{HC_{mass}}{P_b} \qquad (4.36)$$

Where: "HC_e"= HC emission (g/HP-h)

4.2.9 MOD 13 Test Calculation

In ESC MOD 13 test, particulate and gas emission are calculated as explained above. All these calculated amounts are also averaged using the weighting factors defined below.

$$\overline{PT} = \frac{\sum PT_{mass} x WF_i}{\sum P_b x WF_i} \qquad (4.37)$$

$$\overline{HC} = \frac{\sum HC_{mass} \times WF_i}{\sum P_b \times WF_i}$$

<div align="right">(4.38)</div>

Where: "$\overline{PT}$"= Mean particulate emission (g/HP-h)

"$\overline{HC}$"= Mean hydrocarbon emission (g/HP-h)

"WF_i"= Weight factors "i"

Table 4.1: Weighting Factor

Mode	Weighting Factor,%
1	15
2	8
3	10
4	10
5	5
6	5
7	5
8	9
9	10
10	8
11	5
12	5
13	5

CHAPTER 5

EXPERIMENTAL RESULTS

In this chapter, the experimental data of the performance and exhaust emissions tests for each test fuel are presented with the help of the figures and analyzed in detail. The data that has been obtained by measurements and calculations are presented in plots and analyzed accordingly. All of the experimental results for each test fuel are explained in comparing manner. The measured and calculated data are tabulated and can be viewed in Appendix A.

Results of engine performance for each test fuel are reported first. Afterwards, results of gaseous emissions are presented. Finally, exhaust emissions of particulate matter and opacity for each fuel are compared.

5.1 Engine Performance Results

Full load-variable speed tests at full throttle are conducted to evaluate engine performance parameters. The performance characteristics of the engine are evaluated in terms of brake power and torque, brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC), specific energy cost (SEC) and thermal efficiency. These performance characteristics are compared with the results of baseline diesel fuel. All the parameters mentioned above are graphed from the data of Appendix A.

5.1.1 Brake Power and Torque

 Most important performance parameters that are torque and power produced by the engine with respect to engine speed are given in this section. All the data are fit 3rd degree polynomials. Figure 5.1 shows the engine torque curves at different speeds at

full load for three kinds of fuel. Brake torque values of engine for diesel are greater than that of canola oil and mixture of canola and ethanol for entire range of operation. Maximum torque is obtained at 1500 rpm for each test fuel. As seen in Figure 5.1, the maximum torque of diesel, canola oil and canola-ethanol mixture are 189.41 Nm at 1500 rpm, 182.5 Nm at 1500 rpm and 186.6 Nm at 1500 rpm respectively. The maximum engine torque of canola and canola-ethanol is lower by 3.6% and 1.48% than that of diesel. Although the canola-ethanol blend gives higher torque than canola at low speed, after 2100 rpm the torque of canola-ethanol is lower than of canola
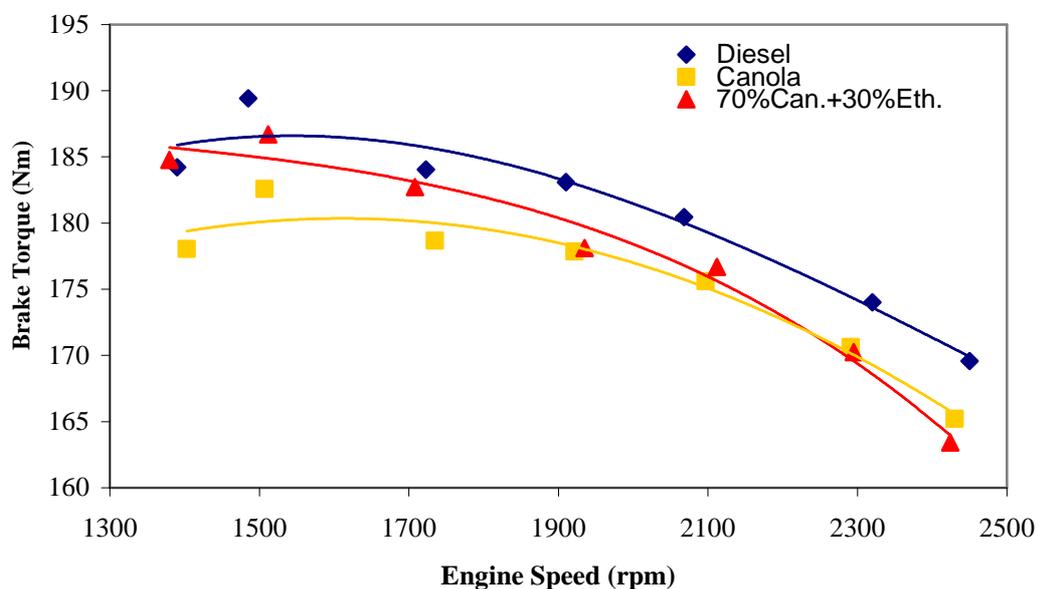
Figure 5.1: Variation of Brake Torque with Engine Speed at Full Load

The variation of engine power with respect to engine speed at full load is illustrated in Figure 5.2. The engine power is directly proportional to the torque at certain speed. Thus, brake power of diesel is greater than that of alternative fuels used during the full load-variable speed experiments as simulated from the torque of the engine. The maximum brake power of diesel, canola and canola-ethanol mixture are 58.54 HP at 2450 rpm, 56.38 HP at 2450 rpm and 55.63 at 2450 rpm respectively, which are lower by 3.68% and 4.9%. Since the torque produced by the engine when running on canola-ethanol blend decreases sharply after 2100 rpm, the engine produced higher power when operated with canola oil as compared to canola-ethanol blend operation.

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It is well known that the heating value of the fuel affects the power of an engine. The heating values of canola and canola-ethanol blend are approximately 12% and 18% less than that of diesel. Therefore some reduction in engine power and torque is expected. The lower heating value is not only responsible for this reduction. The canola oil and ethanol also have lower cetane number as compared with diesel. Hence, combustion process may be affected and may lead to reduction of torque output. In addition, the viscosity of canola oil is reduced by preheating or blending with ethanol is not equal to that of diesel. This affects fuel injection characteristic and causes incomplete combustion, hence; reducing power output.
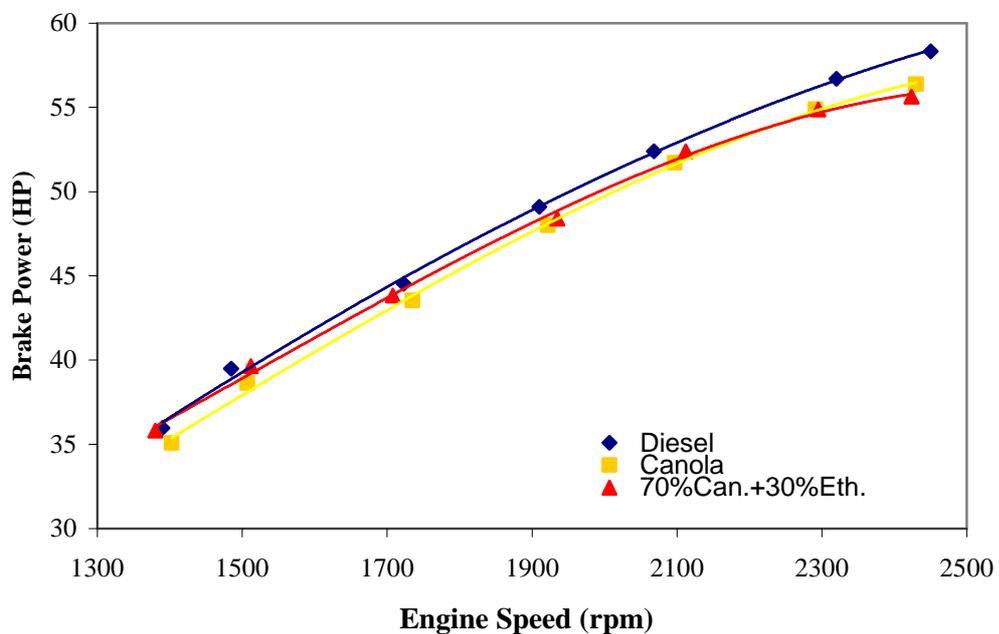
Figure 5.2: Variation of Brake Power with Engine Speed at Full Load

The power reduction due to the lower energy content of canola and ethanol may be improved by some modifications to the engine operating conditions. The compression ratio, the fuel injecting time may be optimized to increase the engine power output.

5.1.2 Brake Specific Fuel Consumption (BSFC)

Brake specific fuel consumption is one of the most important parameters of an engine and is defined as the fuel consumed by the engine to produce unit power per unit time.
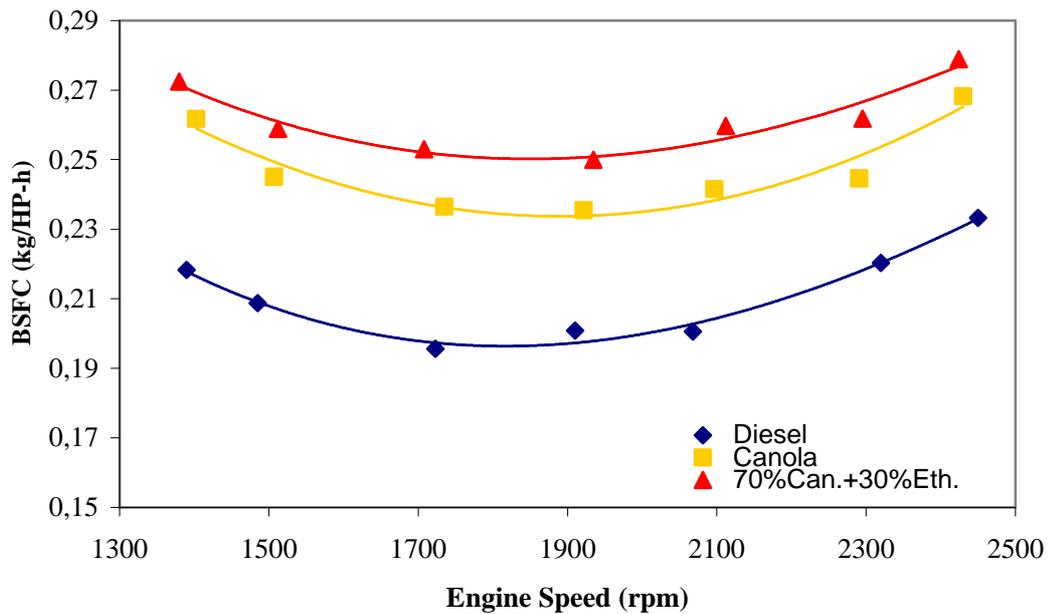
Figure 5.3: Variation of BSFC with Engine Speed at Full Load.

Figure 5.3 shows the brake specific fuel consumption (BSCF) curves under different speeds at full load for diesel, canola oil and canola-ethanol blend. BSFC of diesel is lower than that of other fuels for the entire range of operations. As seen Figure 5.3, BSFC of canola-ethanol blend is the highest. Minimum BSFC of canola – ethanol blend and canola oil are 0.25 kg/h at 1900 rpm and 0.24 kg/h at 1900 rpm against 0.20 kg/h of diesel at 1900 rpm. The higher specific fuel consumption values in the case of canola and ethanol are due to their lower energy content mentioned above. Therefore if nearly same power output from the engine, more fuels which has lowers heating value needs to be consumed.

5.1.3 Brake Specific Energy Consumption (BSEC)

The BSFC is not a very reliable parameter in order to compare fuels with different calorific values and density. Hence, brake specific energy consumption (BSEC) is a more reliable parameter for comparison of three kinds of fuel. It is energy consumed per unit power per unit time. Figure 5.4 shows the variation of brake specific energy consumption with engine speed for diesel; canola oil and canola-ethanol blend in the

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test engine. As seen in Figure 5.4, since the brake specific fuel consumption of the engine is lower with diesel and the power produced is higher with diesel, it is expected that the result of brake energy consumption is the lowest with diesel. Minimum BSEC of canola and canola – ethanol blend are 8712 kJ/HP-h at 1900 rpm and 8571 kJ/HP-h at 1900 rpm against 8216 kJ/HP-h of diesel at 1850 rpm. BSEC of canola is grater than that of other test fuels for whole operation speed regime while BSFC of canola-ethanol blend is grater than that of diesel and canola. The reason for this might be that combustion characteristic of canola oil is poor.
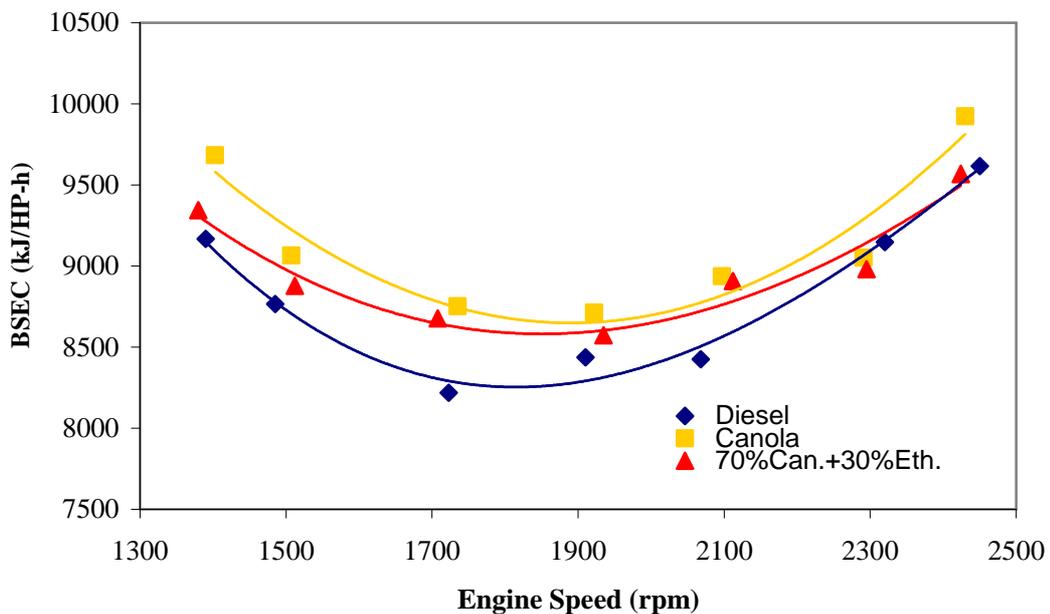
Figure 5.4: Variation of BSEC with Engine Speed at Full Load.

5.1.4 Specific Energy Cost (SEC)

Specific energy cost (SEC) is a parameter that is used in order to compare fuels with different price. It is defined as cost of energy consumed per unit power per unit time. Figure 5.5 illustrates the variation of specific energy cost with engine speed for diesel; canola oil and canola-ethanol blend in the test engine. SEC of canola oil is lower than that of other test fuels for entire range of operation. As seen in Figure 5.5, SEC of diesel is the highest. Minimum SEC of diesel and canola-ethanol blend is 0.685 YTL/HP-h at 1900 rpm and 0.535 YTL/HP-h at 1900 rpm against 0.316 YTL/HP-h of canola oil at 1900 rpm.
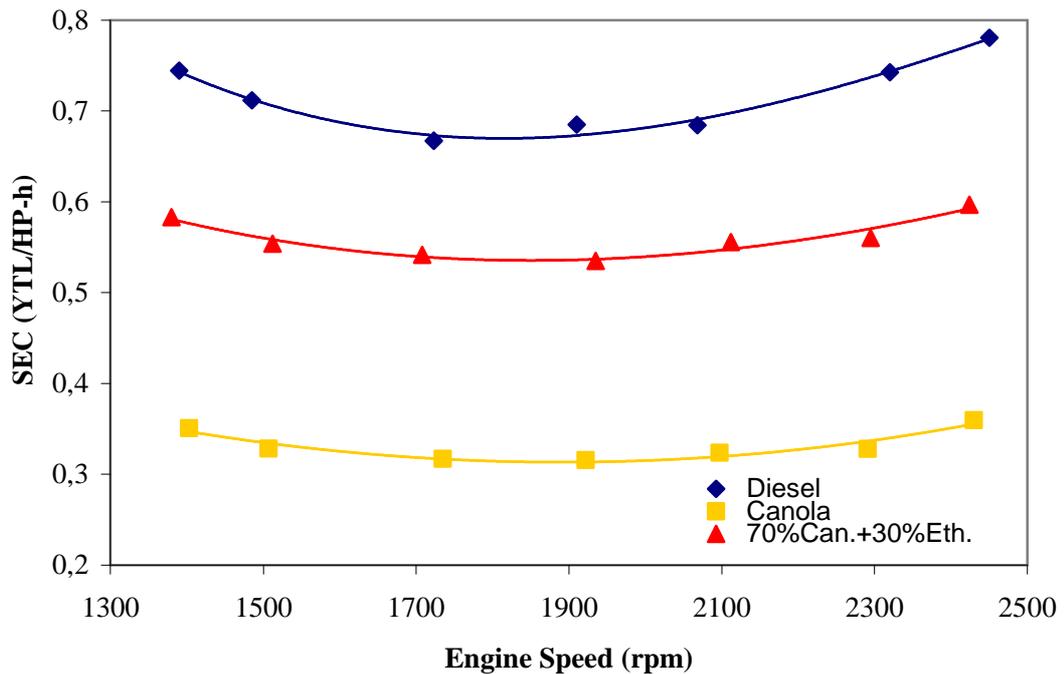
Figure 5.5: Variation of SEC with Engine Speed at Full Load.

5.1.5 Brake Thermal Efficiency

Thermal efficiency shows how much of fuel is converted to power. It is defined as the actual effective power divided by the amount of fuel chemical energy. In order to compare fuels with different calorific values, the brake thermal efficiency is commonly used. The results of the brake thermal efficiency of the test engine for diesel, canola and canola-ethanol blend are supplied in Figure 5.6 As seen in the figure, thermal efficiency of the engine operating on diesel is better than that operating on canola or its blend with ethanol. The maximum thermal efficiency of diesel, canola-ethanol blend and canola are 32.67%, 31.32% and 30.82% at 1800 rpm respectively.

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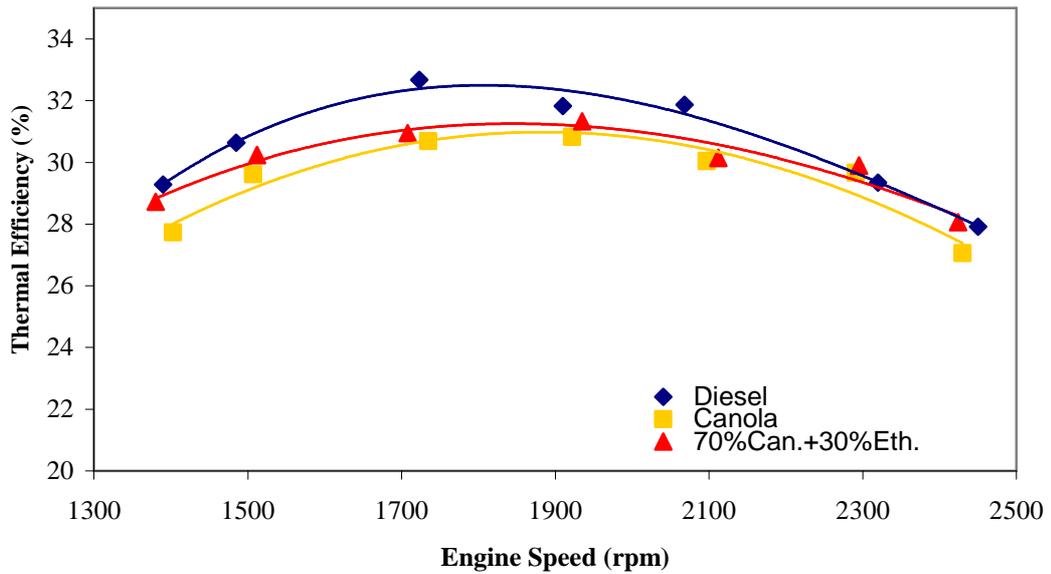
Figure 5.6: Variation of Thermal Efficiency with Engine Speed at Full Load.

The efficiency of canola-ethanol blend is higher than that of canola oil as can be seen BSEC. This shows to use canola oil as an alternative fuel in compression ignition engine, the oil should be modified. As the speed is increased up to 1800 rpm, thermal efficiency also increased. However, after 1800 rpm the efficiency decreased with increasing load. The ideal operating speed at full load for this engine in terms of thermal efficiency and brake specific fuel consumption is around 1850 rpm. The drop thermal efficiency and increase in BSFC and BSEC might be attributed to the poor combustion characteristic of canola oil.

5.2 Gaseous Exhaust Emissions Results

13 mode ESC test cycle is performed to determine the effect of canola oil on exhaust emissions. The gaseous emission of hydrocarbon (HC), carbon monoxide (CO), and carbon dioxide (CO_2) are measured by using AVL DiGas 465 gas analyzer. These exhaust characteristics are compared with the results of baseline diesel fuel. All the parameters stated above are plotted from the data tabulated in Appendix A. Also, the mean results of Mod 13 for each fuel are given in Table 5.1. The table shows mean performance and emission results calculated by using weighting factor and enable to compare the effect of test fuel.

Table 5.1: Mean Performance and Emission Parameters during the Total ESC Cycle.

		Diesel	Canola	70%Kanola+ %30Ethanol
Brake Power	HP	26,61	25,75	25,88
Torque	Nm	100,60	97,11	97,54
Fuel Cons.	kg/h	6,43	7,59	8,16
BSFC	kg/HP-h	0,42	0,63	0,68
BSEC	kJ/HP-h	17643	23224	23265
Volumetric Ef.	%	57,32	53,84	50,31
Thermal Ef.	%	22,51	20,84	21,14
HC Flow Rate	g/h	5,08	4,05	4,56
HC	g/HP-h	0,1948	0,1573	0,1762
CO	%	0,238	0,291	0,255
CO2	%	6,67	5,62	5,98
PT Flow Rate	g/h	11,98	12,20	11,29
Particulate	g/HP-h	0,45	0,47	0,44

5.2.1 HC Emissions

Mean HC emissions of canola, canola-ethanol blend and diesel fuel operation during total ESC cycle are shown in Figure 5.7 As seen in the figure, the operation with both canola and canola-ethanol decreases specific HC emission and canola oil is the best in HC emission. When operated with canola HC emission decreases by 21% of while its blend with ethanol reduces by 7.4%.
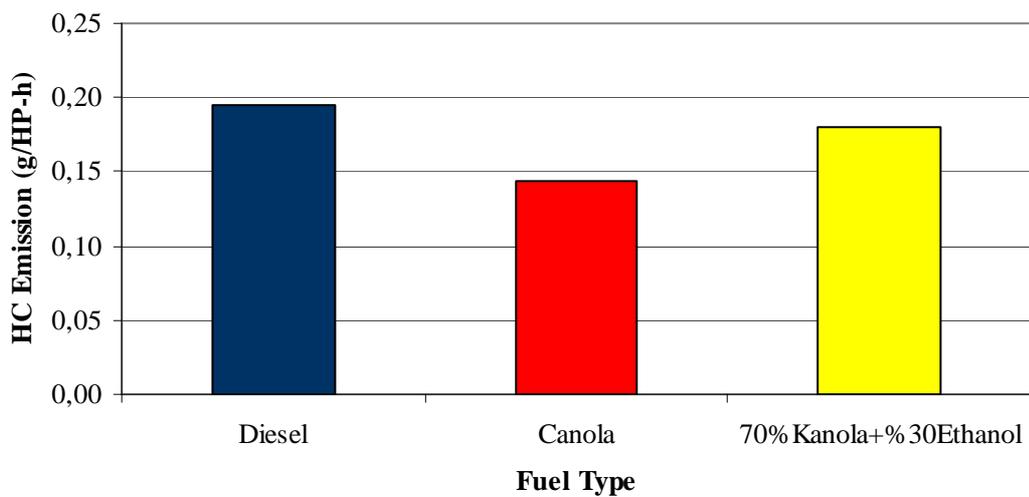
Figure 5.7: Mean HC Emissions during the Total ESC Cycle (g/HP-h)

Figure 5.8illustrates mean HC emission rate of canola, canola-ethanol blend and diesel fuel operation during total MOD 13 test cycle. HC emission rate is noted to decrease when feeding with canola and its blend with ethanol. The reduction rates of HC emission rate for these fuels are 20.2% and 9.2% respectively. This is similar mean specific HC emissions (g/HP-h) since the power produced is nearly same for three kinds of fuel.
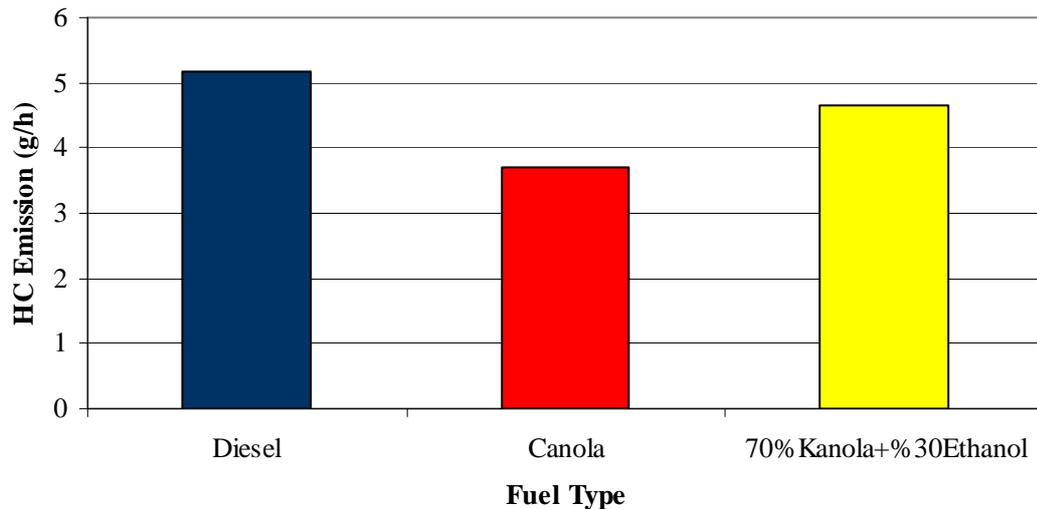
Figure 5.8: Mean HC Emissions Rate during the Total ESC Cycle (g/h)

The plot of specific HC emissions of canola and canola-ethanol blend and diesel fuel operation at the speed of 1500 rpm at different loading conditions is given in Figure 5.9 the plot shows a decrease in specific HC emissions as the load is increased. The HC emissions are usually lower when running on Canola instead of other fuel. A similar trend is observed at all experiment speeds. This trend is perhaps due to late burning of canola oil at low loads. There is a large difference in HC emissions of the test fuels. However, at high load levels, diesel, canola and its blend with ethanol do not show any marked difference in HC emissions. Also the canola-ethanol blend operation produces low HC emissions when compared with the test results on diesel fuel.
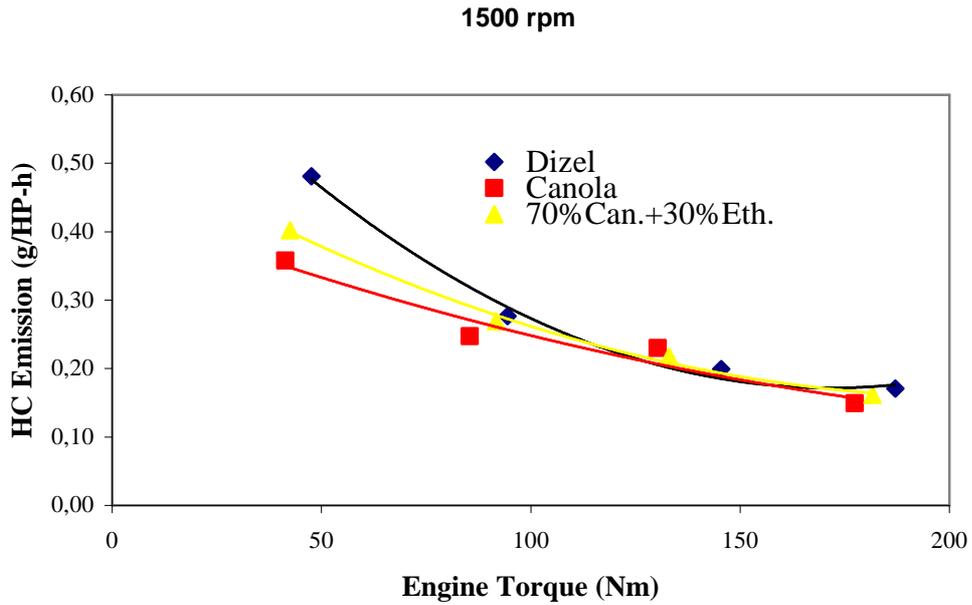
1500 rpm

Figure 5.9: Variation of HC Emissions with Load at 1500 rpm

Figure 5.10 shows the plot of specific hydrocarbon emission of canola, canola-ethanol blend and diesel fuel operation at full load at different speeds.
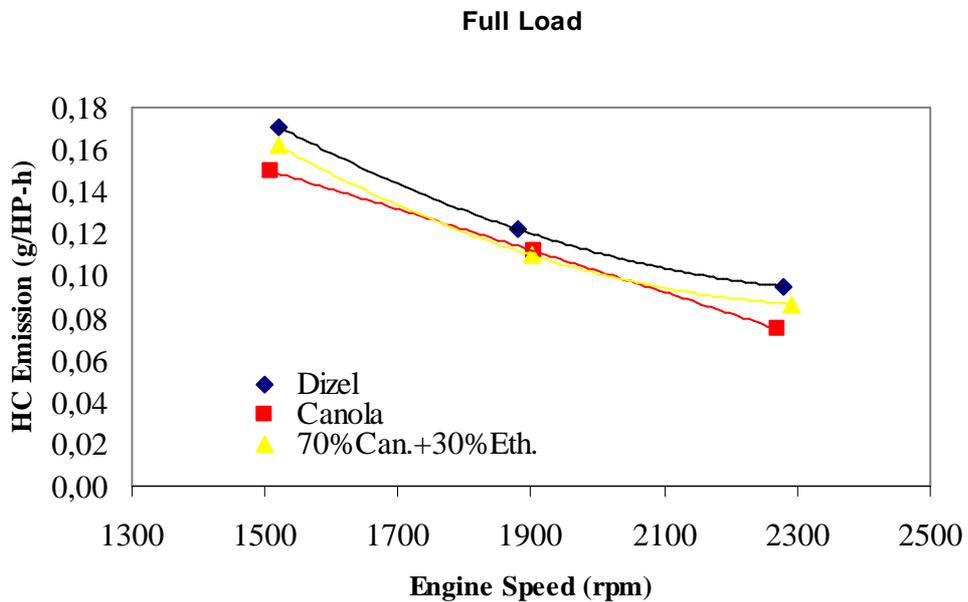
Full Load

Figure 5.10: Variation of HC Emissions with Speed at Full Load.

As seen in the figure above, the trends of graph shows a decrease in HC emissions with increasing speed. The canola operation produces the lowest HC emissions

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during the 13-mode tests. A similar trend is observed for other loading conditions. In addition the canola-ethanol blend operation produces low HC emissions when compared with the test results on diesel fuel at variation of speed. Also, HC emission rate is decreased with increased engine speed and load.

5.2.2 CO Emissions

Mean CO emissions of canola, canola-ethanol blend and diesel fuel during total ESC cycle are shown in Figure 5.11. As seen in the figure, the operation with both canola and canola-ethanol increase CO emissions. The engine proves to emit the most carbon monoxide when operated with canola oil. Relative compression of CO emissions (Figure 5.11) shows that when pure canola oil is used, the emission of CO increases by 20% when compared with the case of diesel fuel. An increase by 7.2 is determined when the engine is operated on canola-ethanol blend.
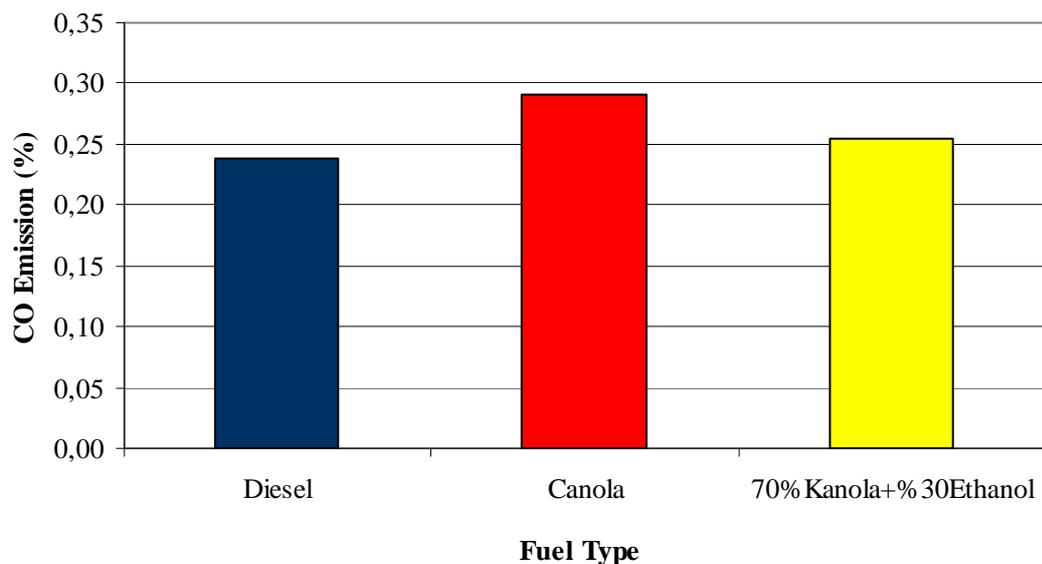
Figure 5.11: Mean CO Emissions during the Total ESC Cycle (%)

The plot of CO emissions of canola and canola-ethanol blend and diesel fuel operation at the speed of 1500 rpm at different loading conditions is shown in Figure 5.12. As seen in the plot, CO emission decreases at low loads, while it increases at high loads. At low loads, there is a little difference in CO emissions of the test fuels. However, at high load levels, diesel, canola and its blend shows large difference. In the medium-load range, the CO emissions are almost equal with each test fuels. CO

emissions are usually higher when running on Canola instead of other fuels. A similar trend is observed at all experiment speeds. In addition, the canola-ethanol blend operation causes high CO emissions when compared with the test results on diesel fuel.
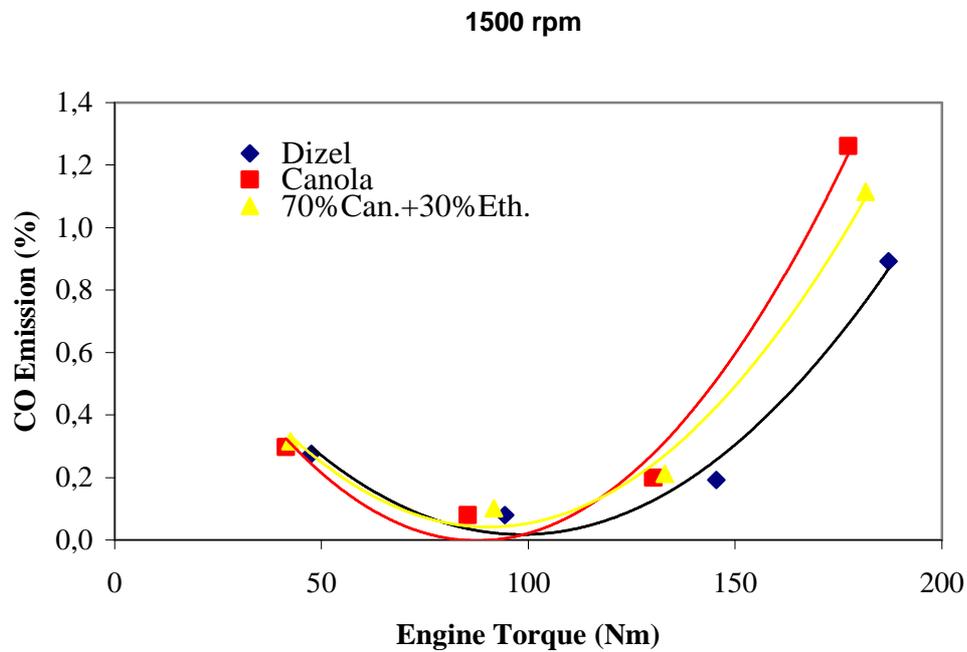
1500 rpm

Figure 5.12: Variation of CO Emissions with Load at 1500 rpm

The variations of CO emission with respect to three kinds of fuels at various speeds at full load are presented in Figure 5.13. The plot shows that CO emission is in a decreasing trend with increased speed. Feeding with canola and the blend causes the engine to emit the most carbon monoxide. A similar trend is noticed for other loading conditions in entire 13 modes. At low speeds, the difference in the emissions is great, but at high speeds the CO emissions are almost equal for the fuels.
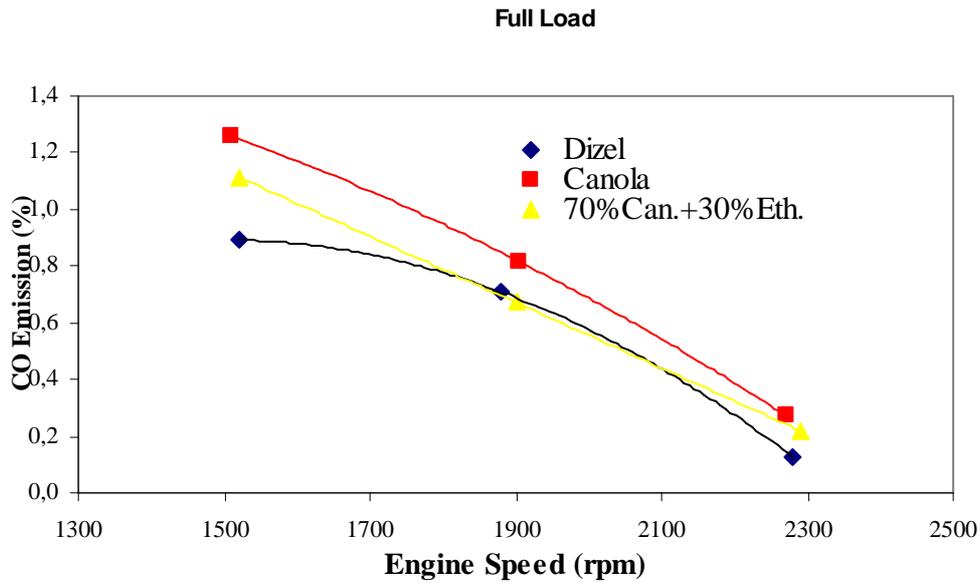
Figure 5.13: Variation of CO Emissions with Speed at Full Load.

5.2.3 CO_2 Emissions

Figure 5.14 shows mean CO_2 emissions when fuelled with diesel, canola and its mixture with ethanol during total ESC cycle. Comparison of results shows that usage of canola and canola-ethanol blend leads to a decrease of CO_2 emissions. When fueled with pure canola oil, the emission of CO_2 decreases by 15.8% when compared with use of baseline diesel fuel. In the case of canola-ethanol blend, decrease of CO_2 emission by 10.3% is observed when compared with use of baseline diesel fuel.
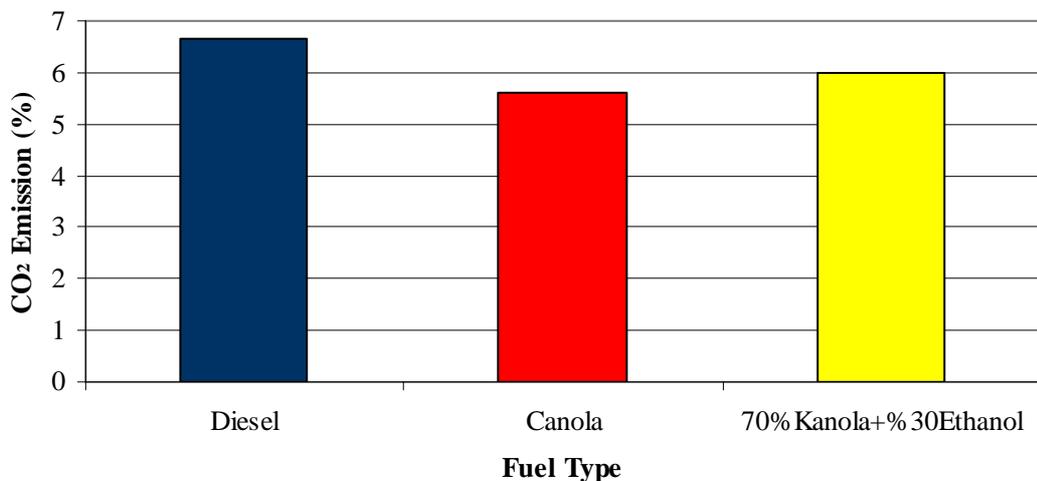
Figure 5.14: Mean CO_2 Emissions during the Total ESC Cycle (%)

The CO_2 emissions of canola, canola-ethanol blend and diesel fuel operation under different loads and speeds are shown in Figure 5.15 and 5.16 respectively. As seen figures, the percentage of CO_2 emissions increases with increased engine speed and load. A similar trend is observed at all experiment speeds and loads. Generally, the CO_2 emission of diesel operation is higher than that of other test fuels. Also, canola oil usually causes less CO_2 emission during the 13-mode test.
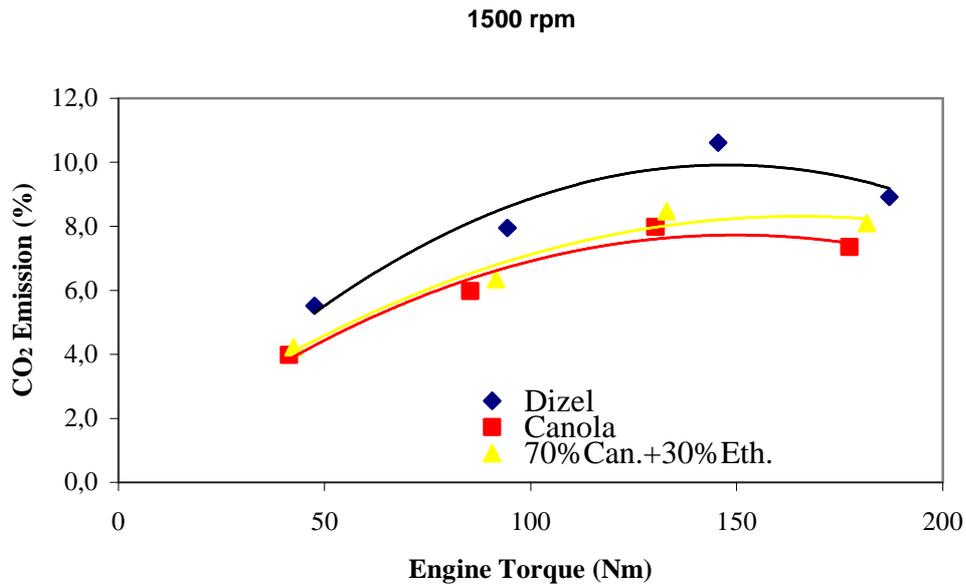
1500 rpm

Figure 5.15: Variation of CO_2 Emissions with Load at 1500 rpm
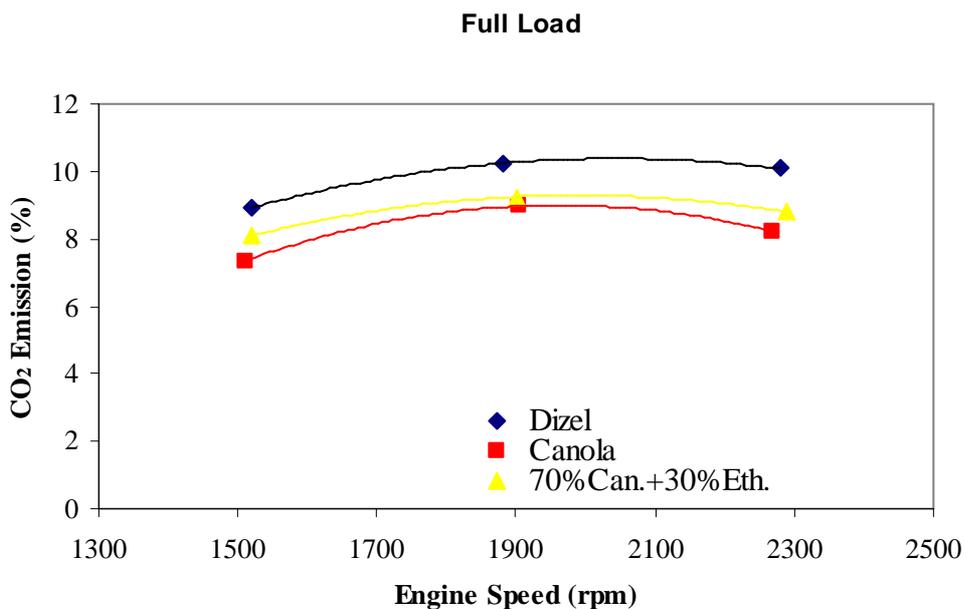
Full Load

Figure 5.16: Variation of CO_2 Emissions with Speed at Full Load.

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5.3 Particulate Matter (PM) and Opacity Results

Particulate emissions are measured by means of a dilution tunnel. In this study, a partial flow dilution tunnel with fractional sampling is used in order to determine the mass of particulate matter. The amount of soot collected on the filters is measured by an analytical balance with 1/10000 g sensitivity as mentioned in section 2. In addition, the opacity is measured from exhaust pipe using AVL DiGas 465 opacity meter. These PM and opacity characteristics are compared with the results of baseline diesel fuel. All the parameters stated above are plotted from the data tabulated in Appendix A.

5.3.1 PM Emissions

Mean PM emissions of canola; canola-ethanol blend and diesel fuel operation during total ESC test cycle are presented in Figure 5.17. As observed in the figure, the operation with canola oil increases PM emissions while the operation with canola-ethanol blend decreases PM emissions as compared with baseline diesel fuel. The 13-mode test result shows that at pure canola oil operation, the PM emissions increase by 5.3%. When fueled with canola-ethanol blend, PM emissions decrease by 3.2%.
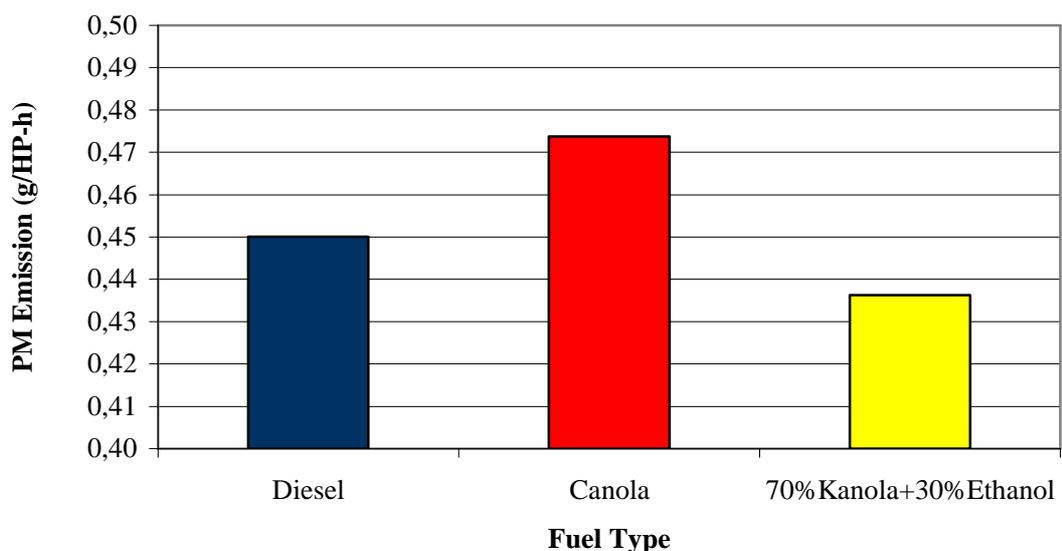
Figure 5.17: Mean PM Emissions during the Total ESC Cycle (g/HP-h)

Figure 5.18 shows mean PM emissions rate of canola, canola-ethanol blend and diesel fuel operation during total ESC test cycle. It is observed that, PM emissions rate increases by 2% when feeding with canola oil, whereas PM emissions rate of canola-ethanol blend decreases by 5% when compared with those where diesel is used. This is similar mean specific CO emissions (g/HP-h) since the power produced is nearly same for test fuels.
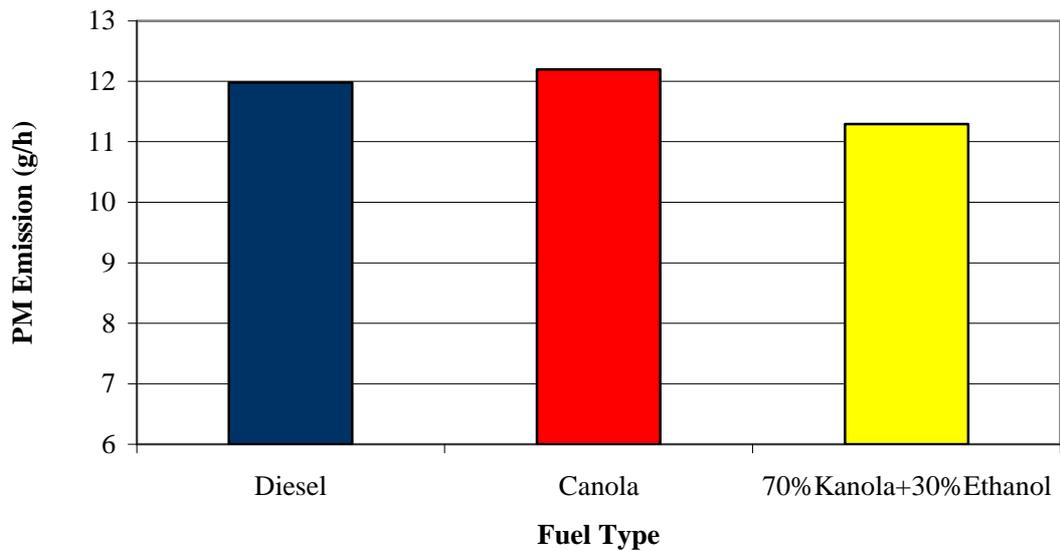
Figure 5.18: Mean PM Emissions Rate during the Total ESC Cycle (g/h)

The plot of specific PM emissions of canola and canola-ethanol blend and diesel fuel operation at the speed of 1500 rpm at different loading conditions is shown in Figure 5.19. The plot shows an increase in specific PM emissions as engine load is increased. In general, the PM emissions are higher when feeding with canola oil. At the low loads, PM emissions of canola-ethanol blend is higher than that of diesel, while at the high load levels, the engine running on diesel leads to more particulate emissions than the blend of canola with ethanol. A similar trend is observed for particulate emission rate.
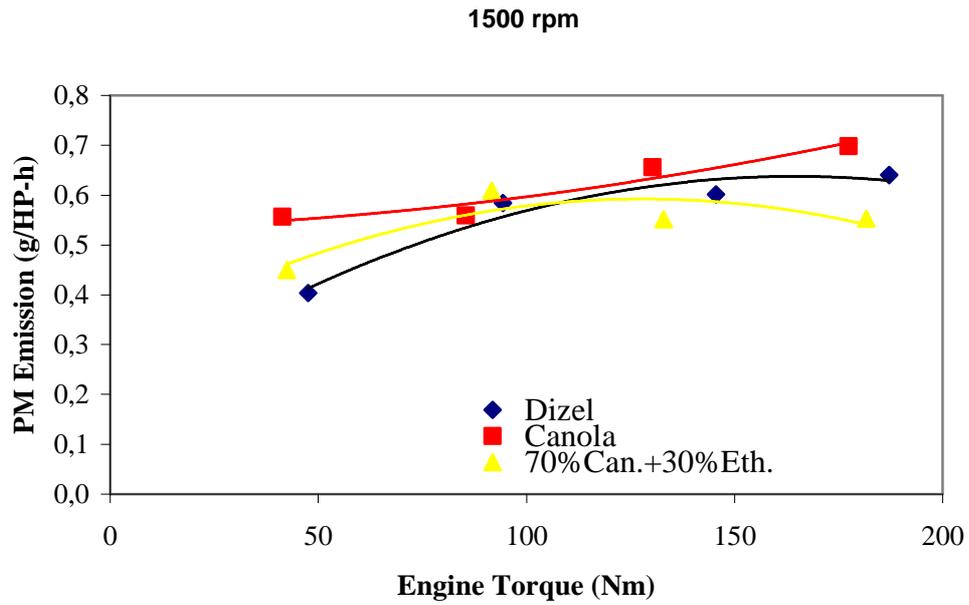
Figure 5.19: Variation of PM Emissions with Load at 1500 rpm

Figure 5.20 illustrates the plot of specific particulate emissions of canola, canola-ethanol blend and diesel fuel operation at full load at different speeds. As seen in the figure, PM emissions decrease as engine load is increased. Generally, the PM emission of canola oil operation is higher than that of other test fuels. With the increased speed, the differences of PM emissions are reduced.
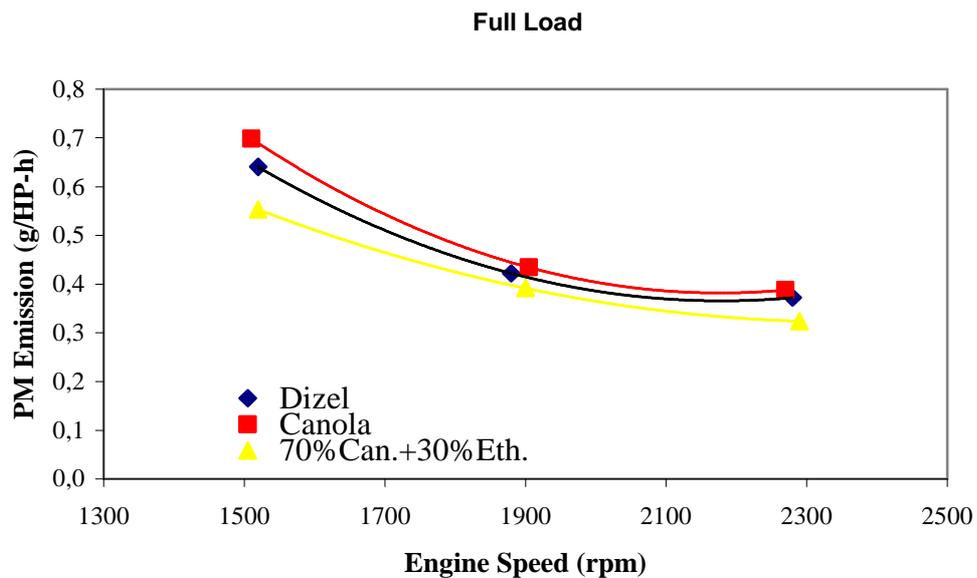
Figure 5.20: Variation of PM Emissions with Speed at Full Load.

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5.3.2 Opacity

Opacity is a measurement of the amount of light that is obscured by smoke. When there is no visible smoke, the opacity measures 0% meaning all of the light is able to pass through the smoke. Very dark smoke reach 100% opacity meaning none of the light is able to pass through the smoke. Mean opacity of canola, canola-ethanol blend and diesel fuel operation during the entire ESC test cycle are shown in Figure 5.21. The data shows that opacity level increases by 8% when fuelled with canola. However, an opacity level decrease of 5% is observed as operated with canola-ethanol blend.
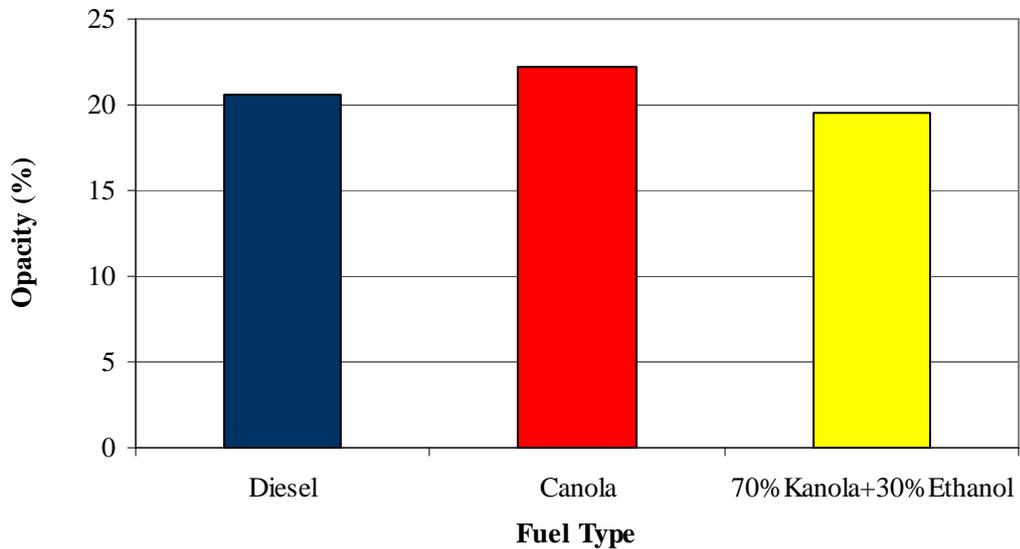
Figure 5.21: Mean Opacity during the Total ESC Cycle (%)

Figure 5.22 shows the plot of opacity of canola and canola-ethanol blend and diesel fuel operation at the speed of 1500 rpm at different loading conditions. As seen in the figure, an increase in opacity levels when engine load is increased. After medium loads the opacity is sharply increased. Opacity of the canola is higher as compared with baseline diesel fuel in all loads. When adding ethanol in canola oil, the opacity level is decreased and it is lower as compared to diesel. However, Opacity relation of diesel and canola-ethanol blend is changing according loading conditions. A similar behavior is observed other speeds.
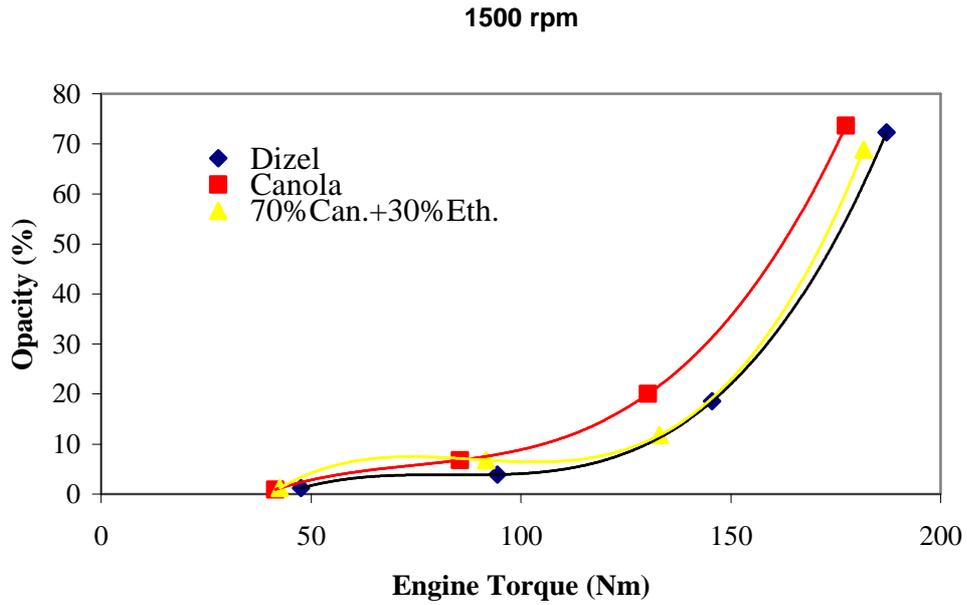
1500 rpm

Figure 5.22: Variation of Opacity with Load at 1500 rpm

The plot of opacity of canola, canola-ethanol blend and diesel fuel operation at full load at different speeds is shown in Figure 5.23. As seen in the figure, opacity decreases as engine load is increased. Opacity is usually the highest when fueled with canola oil.
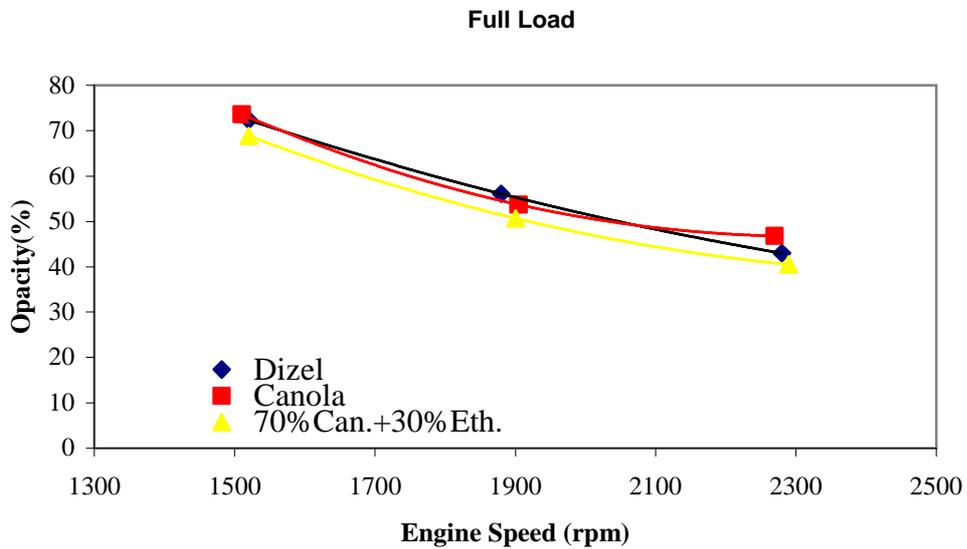
Full Load

Figure 5.23: Variation of PM Emissions with speed at Full Load.

The figures about PM emissions and opacity show that, smoke and PM have similar emission characteristics.

CHAPTER 6

DISCUSSIONS AND CONCLUSIONS

In this experimental investigation, canola oil is selected for the test on a diesel engine and its suitability as an alternative fuel is examined. Experimental investigations are carried out on a four cylinder diesel engine. At the beginning, the fuel delivery system is modified to heat the canola oil before the injectors. To perform the experiments an experimental setup is installed. Then the performance and emission characteristics of canola oil and its blend with ethanol are evaluated and compared with diesel fuel. In this final chapter of this study, use of canola oil as an alternative fuel for CI engines is discussed about their problems at the usage, main advantages and disadvantages. Also, some of noticed problems about the parts of experimental setup installed at the time of experiments are explained.

The performance tests show that the engine produces maximum power output with diesel fuel. The engine power decreases when feeding with canola oil. However, the engine power increases a little as blending ethanol in canola as an additive. This result was expected because the heating value of canola and its blend with ethanol are lower than that of diesel fuel. This increment with addition of ethanol is due to lower viscosity of the blend than that of canola, hence better atomization occurs at injector nozzle and improves power output.

Brake specific fuel consumption values show that the lowest values are obtained for diesel. Brake specific fuel consumption of canola is higher than diesel, and the highest values are read for ethanol canola blend. These results are expected due to lower heating values of canola oil and ethanol. As ethanol has lower heating value than canola oil, its blend with canola oil will be less than 100 percent canola.

Brake specific energy consumption is calculated to compare efficiencies of test fuel. Results show that diesel has lowest BSEC, hence has higher thermal efficiency than other test fuel. On the contrary, the highest BSEC and lowest thermal efficiency are recorded for pure canola oil. This shows that blending ethanol in canola improves thermal efficiency and reduces BSEC. This result can be reasoned as improvement in combustion efficiency due to better atomization of the blend compared to pure canola oil.

Specific energy cost results show that the cost for diesel is twice as much as canola oil. Addition of ethanol increases specific energy cost but the values of energy cost for ethanol are still cheaper than that of diesel. The reason of this situation is the fact that the canola oil is produced by farmer and so the cost is reduced. However, the ethanol and diesel fuel are still commercial.

As for HC emissions, canola has significant effect on reduction of emission values compared to diesel. Addition of ethanol has adverse effects on emissions, where HC content of exhaust gases are close to that of diesel. The reason of this situation may be evaporation of ethanol inside combustion chamber and removal of heat yielding temperature drop at combustion chamber walls. This results an increase of HC emissions.

CO emissions are the lowest for diesel and highest for canola but the situation is the opposite when CO_2 emissions are considered. Addition of ethanol reduces CO emissions and causes an increment on CO_2 emissions. Canola is deposited on cylinder and piston walls, and it can not evaporate as rapidly as diesel does. As a result, carbon atoms partially react with oxygen and form CO. Addition of ethanol is expected to increase the rate of evaporation of fuel inside the combustion chamber.

Particulate matters are observed to be higher for canola oil than PM emission of diesel. Using canola-ethanol blend, a significant decrease of PM emission is observed.

To obtain the engine performance and emission characteristics data, previously mentioned data measurement devices is designed and manufactured in the Mechanical Engineering Laboratories of the Middle East Technical University. In design stage, ProEnginner 2001 software is used. Hence, some problems that would occur at the manufacturing stage are eliminated. Problems were still faced in engine speed measurement device and fuel flow measurement device. In fuel flow measurement device, unexpected signals come from optic sensors. Optic sensor light passes through the hole on the flag due to vibration of dynamometer. This problem was solved by moving fuel container away from dynamometer. For engine speed measuring device, the problem is vibration damaging the circuitry. This was solved by placing rubber between the circuit and holder.

These results indicate that pure canola oil may be an alternative fuel for unmodified diesel engine. Although engine power output and thermal efficiency is decreases when operated on canola oil, specific energy cost decreases slightly feeding with canola oil. These drawbacks can be reverted by modification of oil, such as using proper additive. Blending canola oil with ethanol improves engine performance, thermal efficiency and slightly reduces particulate matter additions. However, the conditions required to obtain a homogenous mixture may not be practical for some additives. It can be seen from the previous chapters, maintaining homogeneity of the canola-ethanol blend requires heating and mixing and this situation may not be practical in some applications. In addition, use of ethanol-canola blend may be improving several modifications on the engine to obtain suitable conditions for running the engine with remarkable engine performance and exhaust emissions. Finally, there is an engine startup problem occurred sometimes when operated on canola oil. In order to solve this problem, it should be ensured that fuel line will feed the engine with diesel at startup phases.

The experimental setup installed can be utilized to perform different experiments. Therefore as a future work

➢ In this study canola oil is refined and commercial. But the neat canola oil should be obtained by extracting canola oil and tested on diesel engine to

investigate whether there is a different with difference between refined canola oil and neat canola oil.

➢ The effect of temperature on use of canola oil as fuel should be investigated. For this purpose, an adjustable electrical heater should be mounted on preheating system and experiments can be performed

➢ Optimization of ratio of ethanol in canola oil should be studied in order to use ethanol as an additive in more efficient way.

➢ Before practical use of canola oil as an alternative fuel for diesel engines, long-term endurance tests should be performed on various diesel engines and engine parts should be analyzed in order to understand effects of use of canola oil on long term use.

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APPENDIX A

EXPERIMENTAL DATA

Table A1: Full Load-Variable Speed Tests Measured Data for Diesel Fuel

		1	2	3	4	5	6	7
Speed	(rpm)	1390	1485	1723	1910	2068	2320	2450
Engine Torque	Nm	182,3	187,1	182	180,5	177,9	171,6	167,2
Fuel Flow Rate	g/s	2,18	2,29	2,42	2,74	2,92	3,43	3,71
Air Consumption	kg/h	118,7	126,5	142	158,9	170	193,8	203,3
Fuel Temperature	C	23,4	25,1	24,3	21,2	27,8	29,3	30,4
Exhaust Temperature	C	412,3	486,3	490,3	513,2	532,7	555,5	590,8
Engine Oil Temperature	C	83	84	87	85	89	90	94
Ambient Temperature	C	25	25,4	25,3	26,2	26,2	26,1	26,1
Ambient Pressure	mm-Hg	745	744	745	744	744	744	744
Relatıve Humidity	%	60	60	60	60	60	60	60
Load	%	100%	100%	100%	100%	100%	100%	100%
Density of Fuel	g/cc	0,82	0,82	0,82	0,82	0,82	0,82	0,82
Heating Value of Fuel	kj/kg	42000	42000	42000	42000	42000	42000	42000
Fuel Cost	YTL/kg	3,41	3,41	3,41	3,41	3,41	3,41	3,41
(A/F) stiometric		14,389	14,389	14,389	14,389	14,389	14,389	14,389
Fuel Type		Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel

Table A2: Full Load-Variable Speed Tests Calculated Data for Diesel Fuel

		1	2	3	4	5	6	7
Water Vapor Pressure	mm-Hg	23,76	24,33	24,18	25,51	25,51	25,36	25,36
Dry Air Pressure	mm-Hg	730,75	729,40	730,49	728,70	728,70	728,79	728,79
Break Pow. Cor. Factor		1,01	1,01	1,01	1,01	1,01	1,01	1,01
Corrected Break Torque	Nm	184,21	189,41	184,04	183,09	180,46	174,02	169,56
Corrected Break Power	HP	35,96	39,50	44,53	49,11	52,41	56,70	58,34
BSFC	kg/HP-h	0,218	0,209	0,196	0,201	0,201	0,218	0,229
BSEC	kJ/HP-h	9166,74	8765,66	8216,76	8435,95	8424,62	9147,25	9615,53
SEC	YTL/HP-h	0,744	0,712	0,667	0,685	0,684	0,743	0,781
Cp(For Air Con. Cor.)		0,97	0,97	0,97	0,97	0,97	0,97	0,97
Ct(For Air Con. Cor.)		0,98	0,97	0,97	0,97	0,97	0,97	0,97
w(For Air Con. Cor.)		0,02	0,02	0,02	0,02	0,02	0,02	0,02
Chr(For Air Con)		0,97	0,97	0,97	0,97	0,97	0,97	0,97
Air Con. Cor. Factor		0,92	0,92	0,92	0,91	0,91	0,91	0,91
Corrected Air Con.	kg/h	109,08	115,80	130,32	144,95	155,07	176,86	185,53
Air /Fuel Ratio		13,90	14,05	14,96	14,69	14,75	14,32	13,89
Excess Air Coefficient		0,97	0,98	1,04	1,02	1,03	1,00	0,97
Equivalence Ratio		1,04	1,02	0,96	0,98	0,98	1,00	1,04
Teorik Air Consumption	kg/h	196,37	209,79	243,42	269,83	292,16	327,76	346,12
Volumetric Efficiency	%	55,55	55,20	53,54	53,72	53,08	53,96	53,60
Thermal Efficiency	%	29,29	30,63	32,67	31,82	31,87	29,35	27,92

Table A3: Full Load-Variable Speed Tests Measured Data for Canola Oil

		1	2	3	4	5	6	7
Speed	(rpm)	1403	1507	1735	1922	2097	2291	2430
Engine Torque	Nm	176,2	180,4	176,2	175,1	173,3	167,9	163,2
Fuel Flow Rate	g/s	2,55	2,63	2,86	3,14	3,47	3,73	4,2
Air Consumption	kg/h	114,2	117,7	139,5	153,1	165,7	183,9	193,3
Fuel Temperature	C	63,4	72,3	67,4	69,7	67,2	73,5	76,7
Exhaust Temperature	C	412,3	486,4	521,3	523,9	554,3	593,4	606,7
Engine Oil Temperature	C	80	83	88	84	85	90	94
Ambient Temperature	C	24,3	25	25,8	26,5	25,5	26,7	25,1
Ambient Pressure	mm-Hg	742	742	742	742	742	742	742
Relative Humidity	%	55	55	55	55	55	55	55
Load	%	100%	100%	100%	100%	100%	100%	100%
Density of Fuel	g/cc	0,875	0,875	0,875	0,875	0,875	0,875	0,875
Heating Value of Fuel	kj/kg	37000	37000	37000	37000	37000	37000	37000
Fuel Cost	YTL/kg	1,34	1,34	1,34	1,34	1,34	1,34	1,34
(A/F) stiometric		12,481	12,481	12,481	12,481	12,481	12,481	12,481
Fuel Type		Canola	Canola	Canola	Canola	Canola	Canola	Canola

Table A4: Full Load-Variable Speed Tests Calculated Data for Canola Oil

		1	2	3	4	5	6	7
Water Vapor Pressure	**mm-Hg**	22,78	23,76	24,91	25,96	24,47	26,27	23,90
Dry Air Pressure	**mm-Hg**	729,47	728,93	728,30	727,72	728,54	727,55	728,86
Break Pow. Cor. Factor		1,01	1,01	1,01	1,02	1,01	1,02	1,01
Corrected Break Torque	**Nm**	178,04	182,58	178,67	177,86	175,61	170,63	165,22
Corrected Break Power	**HP**	35,08	38,64	43,53	48,01	51,71	54,90	56,38
BSFC	**kg/HP-h**	0,262	0,245	0,237	0,235	0,242	0,245	0,268
BSEC	**kJ/HP-h**	9682,90	9066,03	8750,72	8712,47	8937,73	9050,52	9922,73
SEC	**YTL/HP-h**	0,351	0,328	0,317	0,316	0,324	0,328	0,359
Cp(For Air Con. Cor.)		0,96	0,96	0,96	0,96	0,96	0,96	0,96
Ct(For Air Con. Cor.)		0,98	0,98	0,97	0,97	0,97	0,97	0,97
w(For Air Con. Cor.)		0,02	0,02	0,02	0,02	0,02	0,02	0,02
Chr(For Air Con)		0,97	0,97	0,97	0,97	0,97	0,97	0,97
Air Con. Cor. Factor		0,92	0,91	0,91	0,91	0,91	0,91	0,91
Corrected Air Con.	**kg/h**	104,62	107,49	126,95	138,89	151,00	166,68	176,46
Air /Fuel Ratio		11,40	11,35	12,33	12,29	12,09	12,41	11,67
Excess Air Coefficient		0,91	0,91	0,99	0,98	0,97	0,99	0,94
Equivalence Ratio		1,10	1,10	1,01	1,02	1,03	1,01	1,07
Teorik Air Consumption	**kg/h**	198,21	212,90	245,11	271,53	296,25	323,66	343,30
Volumetric Efficiency	**%**	52,78	50,49	51,79	51,15	50,97	51,50	51,40
Thermal Efficiency	**%**	27,72	29,61	30,68	30,81	30,04	29,66	27,05

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Table A5: Full Load-Variable Speed Tests Measured Data for Canola-Ethanol Blend

		1	2	3	4	5	6	7
Speed	(rpm)	1380	1512	1708	1935	2112	2295	2424
Engine Torque	Nm	181,6	183,4	179,3	174,7	173,2	166,8	160,2
Fuel Flow Rate	g/s	2,71	2,85	3,08	3,36	3,78	3,99	4,31
Air Consumption	kg/h	110,6	118,7	133,7	149,6	168,4	178,3	186,8
Fuel Temperature	C	65,1	67,9	70,2	69,3	71,2	70,6	71,6
Exhaust Temperature	C	398,3	456,7	490,3	513,9	521,9	542,4	565,7
Engine Oil Tempeature	C	81	83	85	84	86	89	90
Ambient Temperature	C	27,2	27,5	28	28,2	28,4	28,6	28,4
Ambient Pressure	mm-Hg	741	741	741	741	741	741	741
Relatve Humidity	%	51	50	50	50	50	50	50
Load	%	100%	100%	100%	100%	100%	100%	100%
Density of Fuel	g/cc	0,862	0,862	0,862	0,862	0,862	0,862	0,862
Heating Value of Fuel	kj/kg	34300	34300	34300	34300	34300	34300	34300
Fuel Cost	YTL/kg	2,14	2,14	2,14	2,14	2,14	2,14	2,14
(A/F) stiometric		12,567	12,567	12,567	12,567	12,567	12,567	12,567
Fuel Type		70% Can. 30% Eth.	70% Can. 30% Eth.	70% Can. 30% Eth.	70% Can. 30% Eth.	70% Can. 30% Eth.	70% Can. 30% Eth.	70% Can. 30% Eth.

Table A6: Full Load-Variable Speed Tests Calculated Data for Canola –Ethanol Blend

		1	2	3	4	5	6	7
Water Vapor Pressure	mm-Hg	27,05282	27,5319	28,3467	28,6785	29,0136	29,3522	29,0136
Dry Air Pressure	mm-Hg	727,20	727,23	726,83	726,66	726,49	726,32	726,49
Break Pow. Cor. Factor		1,02	1,02	1,02	1,02	1,02	1,02	1,02
Corrected Break Torque	Nm	184,76	186,68	182,73	178,12	176,68	170,23	163,42
Corrected Break Power	HP	35,81	39,64	43,83	48,40	52,40	54,86	55,63
BSFC	kg/HP-h	0,272	0,259	0,253	0,250	0,260	0,262	0,279
BSEC	kJ/HP-h	9345,67	8878,20	8677,50	8571,74	8907,27	8980,05	9567,02
SEC	YTL/HP-h	0,583	0,554	0,541	0,535	0,556	0,560	0,597
Cp(For Air Con. Cor.)		0,96	0,96	0,96	0,96	0,96	0,96	0,96
Ct(For Air Con. Cor.)		0,97	0,97	0,97	0,97	0,97	0,97	0,97
w(For Air Con. Cor.)		0,02	0,02	0,02	0,02	0,02	0,03	0,02
Chr(For Air Con)		0,97	0,97	0,97	0,97	0,97	0,97	0,97
Air Con. Cor. Factor		0,90	0,90	0,90	0,90	0,90	0,90	0,90
Corrected Air Con.	kg/h	99,81	106,98	120,21	134,38	151,13	159,86	167,64
Air /Fuel Ratio		10,23	10,43	10,84	11,11	11,11	11,13	10,80
Excess Air Coefficient		0,81	0,83	0,86	0,88	0,88	0,89	0,86
Equivalence Ratio		1,23	1,21	1,16	1,13	1,13	1,13	1,16
Teorik Air Consumption	kg/h	194,96	213,61	241,30	273,37	298,37	324,22	342,45
Volumetric Efficiency	%	51,20	50,08	49,82	49,16	50,65	49,31	48,95
Thermal Efficiency	%	28,72	30,24	30,94	31,32	30,14	29,89	28,06

Table A7: Mod 13 Measured Data for Diesel Fuel (Mode 1-6)

		1	2	3	4	5	6
Speed	**(rpm)**	990	1520	1885	1895	1520	1510
Engine Torque	**Nm**	5,4	187,1	86,8	129,7	94,4	145,5
Fuel Flow Rate	**g/s**	0,275	2,29	1,7	2,29	1,31	1,88
Air Consumption	**kg/h**	104,3	120,7	158,7	160,06	123,9	125
Fuel Temperature	**C**	373	25,1	36,3	37,9	37,8	34,7
Exhaust Temperature	**C**	90,3	486,3	329,5	426,6	295	385,1
ISP Temperature	**C**	74,1	440	291,5	377,1	256,9	340,2
Sample Temperature	**C**	10,4	26,2	34	41,4	27,4	35,8
Engine Oil Temp.	**C**	68	73	89	95	75	85
Back Pressure	**mm-Hg**	4	12	22	20	10	12
Tunnel Pressure	**"WC**	1,12	1,8	1,8	1,8	1,8	1,74
Sampling Rate	**scfm**	0,6	0,9	0,9	0,9	0,9	0,85
AVL HC	**ppm**	8	11	7	7	9	10
AVL Opacity	**%**	0,5	72,3	9,7	19,3	3,9	18,5
CO2	**%**	0,1	0,9	0,9	1	0,8	1,1
CO	**%**	0,01	0,09	0,01	0,01	0,008	0,02
O2	**%**	20,5	19,46	19,52	19,33	19,77	19,2
Particulate Matter	**mg**	0,1	1,3	0,5	0,8	0,6	0,9
Ambient Temperature	**C**	21,5	23,4	24,3	24,5	23,2	23,7
Ambient Pressure	**mm-Hg**	743	743	743	743	742	742
Relative Humidity	**%**	60	53	53	53	60	60
Load	**%**	0%	100%	50%	75%	50%	75%
Sampling Duration	**min**	4	2	2	2	2	2
Weight Factor	**%**	0,15	0,08	0,1	0,1	0,05	0,05
Density of Fuel	**g/cc**	0,82	0,82	0,82	0,82	0,82	0,82
Heating Value of Fuel	**kj/kg**	42000	42000	42000	42000	42000	42000
(A/F) stiometric		14,389	14,389	14,389	14,389	14,39	14,39
Fuel Type		Diesel	Diesel	Diesel	Diesel	Diesel	Diesel

Table A8: Mod 13 Measured Data for Diesel Fuel (Mode 7-13)

	7	8	9	10	11	12	13
Speed	1530	1880	1915	2280	2320	2310	2290
Engine Torque	47,6	180,5	42,5	171,6	41,1	148,5	85,5
Fuel Flow Rate	1,002	2,74	1,195	3,47	1,44	2,646	2,12
Air Consumption	134,3	158,9	163,1	200,8	201,4	199,6	197,6
Fuel Temperature	39,1	21,2	42,7	29,3	29	34,6	39,3
Exhaust Temperature	272,3	583,2	273,2	555,5	236,3	430,6	301,6
ISP Temperature	238,2	503,9	220,6	481,6	184,5	394,6	247,6
Sample Temperature	32,3	51,7	27,1	50,2	22,7	44	36,1
Engine Oil Temp.	87	83	95	99	85	88	85
Back Pressure	13	25	20	35	25	32	24
Tunnel Pressure	1,74	2,2	2	2,3	1,62	3,2	3,2
Sampling Rate	0,85	1,1	0,9	1	0,7	1,3	1,3
AVL HC	8	9	6	8	7	9	7
AVL Opacity	1,2	56,1	1,9	43	3,4	25,2	10,5
CO2	0,6	1,3	0,8	1,6	0,7	1,2	0,4
CO	0,03	0,09	0,03	0,02	0,01	0,01	0,01
O2	20,02	18,45	19,75	18,,51	20,22	19,2	20,27
Particulate Matter	0,2	1,2	0,3	1,1	0,3	0,7	0,5
Ambient Temperature	24,1	23,2	24,2	24,1	23,5	23,5	26
Ambient Pressure	742	744	744	744	744	744	744
Relative Humidity	60	60	60	60	60	60	60
Load	25%	100%	25%	100%	25%	75%	50%
Sampling Duration	2	2	2	2	2	2	2
Weight Factor	0,05	0,09	0,1	0,08	0,05	0,05	0,05
Density of Fuel	0,82	0,82	0,82	0,82	0,82	0,82	0,82
Heating Value of Fuel	42000	42000	42000	42000	42000	42000	42000
(A/F) stiometric	14,389	14,39	14,389	14,389	14,39	14,389	14,389
Fuel Type	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel

Table A9: Mod 13 Calculated Data for Diesel Fuel (Mode 1-6)

		1	2	3	4	5	6
Water Vapor Pres.	**mm-Hg**	19,23	21,58	23,06	23,06	21,98	21,98
Dry Air Pressure	**mm-Hg**	731,46	731,56	730,78	730,78	728,81	728,81
Break Pow. Cor. Fac.		1,00	1,01	1,01	1,01	1,01	1,01
Cor. Break Torque	**Nm**	5,42	188,42	87,60	130,95	95,26	146,96
Cor. Break Power	**HP**	0,75	40,22	23,19	34,85	20,33	31,16
BSFC	**kg/HP-h**	1,31	0,20	0,26	0,24	0,23	0,22
BSEC	**kJ/HP-h**	55170	8609,16	11084	9936	9741	9122
Cp(For Air Con. Cor.		0,97	0,97	0,97	0,97	0,96	0,96
Ct(For Air Con. Cor.		0,98	0,98	0,98	0,98	0,98	0,98
w(For Air Con. Cor.		0,02	0,02	0,02	0,02	0,02	0,02
Chr(For Air Con)		0,98	0,97	0,97	0,97	0,97	0,97
Air Con. Cor. Factor		0,93	0,92	0,92	0,92	0,92	0,92
Corrected Air Con.	**kg/h**	96,87	111,23	145,64	146,81	113,94	114,80
Air /Fuel Ratio		97,85	13,49	23,80	17,81	24,16	16,96
Excess Air Coefficient		6,80	0,94	1,65	1,24	1,68	1,18
Equivalence Ratio		0,15	1,07	0,60	0,81	0,60	0,85
Th. Air Cons.	**kg/h**	139,86	214,74	266,30	267,71	214,74	213,32
Volumetric Efficiency	**%**	69,26	51,80	54,69	54,84	53,06	53,81
Thermal Efficiency	**%**	4,87	31,18	24,22	27,02	27,56	29,43
Dil. Exh. Flow Rate	**m3/h**	44,03	47,39	47,39	47,39	47,39	47,10
Density of Air	**kg/m3**	1,17	1,16	1,16	1,16	1,16	1,16
Air vol. flow rate	**m3/h**	82,66	95,52	125,45	126,54	97,91	98,82
Exhaust flow rate	**m3/h**	83,42	101,87	130,16	132,89	101,54	104,03
Exh. flow rate on Dry	**m3/h**	81,92	89,34	120,86	120,36	94,38	93,74
Dilution Ratio	**%**	11,24	9,91	7,76	7,60	9,94	9,65
Eq. Diluted Exh.	**m3/h**	938	1010	1010	1010	1010	1003
HC	**ppm**	89,95	109,03	54,30	53,19	89,49	96,45
CO	**%**	0,11	0,89	0,08	0,08	0,08	0,19
CO2	**%**	1,12	8,92	6,98	7,60	7,95	10,61
HC Mass Flow Rate	**g/h**	4,64	6,87	4,37	4,37	5,62	6,21
HC Emission	**g/HPh**	6,16	0,17	0,19	0,13	0,28	0,20
PM Mass Rate	**g/h**	1,38	25,75	9,90	15,85	11,89	18,76
PM Emission	**g/HPh**	1,83	0,64	0,43	0,45	0,58	0,60

Table A10: Mod 13 Calculated Data for Diesel Fuel (Mode 7-13)

	7	8	9	10	11	12	13
Water Vapor Pres.	21,33	21,33	22,51	22,51	21,71	21,71	4,58
Dry Air Pressure	729,20	731,20	730,49	730,5	730,97	730,97	741,25
Break Pow. Cor. Fac.	1,01	1,01	1,01	1,01	1,01	1,01	1,00
Cor. Break Torque	48,09	181,77	42,90	173,2	41,42	149,65	85,74
Cor. Break Power	10,33	47,99	11,54	55,45	13,49	48,55	27,57
BSFC	0,35	0,21	0,37	0,23	0,38	0,20	0,28
BSEC	14662	8633	15662	9462	16135	8241	11625
Cp(For Air Con. Cor.	0,96	0,97	0,97	0,97	0,97	0,97	0,97
Ct(For Air Con. Cor.	0,98	0,98	0,98	0,98	0,98	0,98	0,97
w(For Air Con. Cor.	0,02	0,02	0,02	0,02	0,02	0,02	0,00
Chr(For Air Con)	0,97	0,97	0,97	0,97	0,97	0,97	0,99
Air Con. Cor. Factor	0,92	0,92	0,92	0,92	0,92	0,92	0,94
Corrected Air Con.	123,31	146,85	150,12	184,9	185,90	184,24	184,89
Air /Fuel Ratio	34,18	14,89	34,90	14,80	35,86	19,34	24,23
Excess Air Coefficient	2,38	1,03	2,43	1,03	2,49	1,34	1,68
Equivalence Ratio	0,42	0,97	0,41	0,97	0,40	0,74	0,59
Th. Air Cons.	216,15	265,60	270,54	322,1	327,76	326,34	323,52
Volumetric Efficiency	57,05	55,29	55,49	57,39	56,72	56,45	57,15
Thermal Efficiency	18,31	31,10	17,14	28,37	16,64	32,57	23,09
Dil. Exh. Flow Rate	47,10	49,35	48,38	49,84	46,51	54,18	54,18
Density of Air	1,16	1,17	1,16	1,16	1,17	1,17	1,16
Air vol. flow rate	106,28	125,86	129,09	158,9	159,48	158,05	159,95
Exhaust flow rate	109,06	133,45	132,40	168,5	163,47	165,39	165,83
Exh. flow rate on Dry	103,58	118,46	125,86	149,5	155,59	150,91	154,23
Dilution Ratio	9,20	7,88	7,78	6,30	6,06	6,98	6,96
Eq. Diluted Exh.	1003	1051	1031	1062	991	1154	1154
HC	73,60	70,91	46,70	50,40	42,43	62,82	48,73
CO	0,28	0,71	0,23	0,13	0,06	0,07	0,07
CO2	5,52	10,24	6,23	10,08	4,24	8,38	2,78
HC Mass Flow Rate	4,97	5,86	3,83	5,26	4,29	6,43	5,00
HC Emission	0,48	0,12	0,33	0,09	0,32	0,13	0,18
PM Mass Rate	4,17	20,25	6,07	20,62	7,50	10,98	7,84
PM Emission	0,40	0,42	0,53	0,37	0,56	0,23	0,28

Table A11: Mod 13 Measured Data for Canola Oil (Mode 1-6)

		1	2	3	4	5	6
Speed	**(rpm)**	1010	1510	1915	1890	1485	1495
Engine Torque	**Nm**	3,8	177,4	81,3	135,7	85,44	130,3
Fuel Flow Rate	**g/s**	0,36	2,65	2,03	2,49	1,64	2,06
Air Consumption	**kg/h**	90,7	114,7	159,1	158,1	125,6	123,7
Fuel Temperature	**C**	56,6	62,3	76,1	64,7	64,1	66,3
Exhaust Temperature	**C**	113,7	516,4	340,4	459,1	317,7	402,5
ISP Temperature	**C**	78,4	465,4	276,1	390,9	257,4	337,2
Sample Temperature	**C**	13	36,2	36,4	41,4	27,8	31,5
Engine Oil Temp.	**C**	62	85	85	66	67	69
Back Pressure	**mm-Hg**	6	15	24	25	12	12
Tunnel Pressure	**"WC**	1,42	1,96	2,1	2,1	2	2
Sampling Rate	**scfm**	0,7	0,95	1,1	1,1	0,9	1
AVL HC	**ppm**	6	9	4	6	7	10
AVL Opacity	**%**	1,2	73,6	12,5	30,3	6,8	20
CO2	**%**	0,1	0,7	0,6	0,8	0,6	0,8
CO	**%**	0,01	0,12	0,02	0,01	0,008	0,02
O2	**%**	20,88	19,36	20,1	19,35	20,11	19,67
Particulate Matter	**mg**	0,1	1,4	0,6	1	0,5	1
Ambient Temperature	**C**	23,8	27	28,6	26,5	26,1	26,3
Ambient Pressure	**mm-Hg**	742	742	742	742	742	742
Relative Humidity	**%**	55	55	55	53	53	53
Load	**%**	0%	100%	50%	75%	50%	75%
Sampling Duration	**min**	4	2	2	2	2	2
Weight Factor	**%**	0,15	0,08	0,1	0,1	0,05	0,05
Density of Fuel	**g/cc**	0,875	0,875	0,875	0,875	0,875	0,875
Heating Value of Fuel	**kj/kg**	37000	37000	37000	37000	37000	37000
(A/F) stiometric			12,481	12,481	12,481	12,481	12,481	12,481
Fuel Type		Canola	Canola	Canola	Canola	Canola	Canola

Table A12: Mod 13 Measured Data for Canola Oil (Mode 7-13)

	7	8	9	10	11	12	13
Speed	1510	1905	1920	2270	2280	2300	2290
Engine Torque	41,4	173,5	45,7	164,9	43,8	128,5	86,3
Fuel Flow Rate	1,17	3,41	1,56	3,75	1,57	3,62	2,47
Air Consumption	127,5	153,1	160,5	185,9	195,8	196,1	194,1
Fuel Temperature	70,2	69,7	76,8	73,5	76,3	78,8	78,7
Exhaust Temperature	254,5	593,9	296,7	593,4	264,1	555,1	424,4
ISP Temperature	202,4	512,3	244,7	521,6	221,3	485,2	367,9
Sample Temperature	23	41,2	33,8	48,9	30,2	46,3	42,4
Engine Oil Temp.	67	70	68	83	74	78	76
Back Pressure	10	20	20	32	28	32	30
Tunnel Pressure	2	2,3	2,2	2,42	3,06	2,8	2,8
Sampling Rate	1,1	1,1	1	1,1	1,3	1,2	1,2
AVL HC	5	8	5	6	4	7	6
AVL Opacity	0,9	53,7	1	46,8	0,9	23,9	11,6
CO2	0,4	1,1	0,6	1,2	0,6	1,1	0,8
CO	0,03	0,1	0,01	0,04	0,02	0,01	0,01
O2	20,69	18,93	19,79	18,64	20,03	19,3	19,62
Particulate Matter	0,3	1,2	0,4	1,2	0,2	0,9	0,5
Ambient Temperature	26,4	26,5	26,6	26,7	26,7	26,6	26,6
Ambient Pressure	742	742	742	742	742	742	742
Relatıve Humidity	53	50	50	50	50	50	50
Load	25%	100%	25%	100%	25%	75%	50%
Sampling Duration	2	2	2	2	2	2	2
Weight Factor	0,05	0,09	0,1	0,08	0,05	0,05	0,05
Density of Fuel	0,875	0,875	0,875	0,875	0,875	0,875	0,875
Heating Value of Fuel	37000	37000	37000	37000	37000	37000	37000
(A/F) stiometric	12,481	12,481	12,481	12,481	12,481	12,481	12,481
Fuel Type	Canola	Canola	Canola	Canola	Canola	Canola	Canola

Table A13: Mod 13 Calculated Data for Canola Oil (Mode 1-6)

		1	2	3	4	5	6
Water Vapor Pres.	**mm-Hg**	22,11	26,74	25,96	25,96	25,66	25,66
Dry Air Pressure	**mm-Hg**	729,84	727,29	727,72	728,24	728,40	728,40
Break Pow. Cor. Fac.		1,01	1,02	1,02	1,02	1,01	1,01
Cor. Break Torque	**Nm**	3,84	180,41	82,87	137,77	86,68	132,23
Cor. Break Power	**HP**	0,54	38,26	22,29	36,57	18,08	27,76
BSFC	**kg/HP-h**	2,38	0,25	0,33	0,25	0,33	0,27
BSEC	**kJ/HP-h**	88153	9226,54	12133	9070	12085	9884
Cp(For Air Con. Cor.		0,96	0,96	0,96	0,96	0,96	0,96
Ct(For Air Con. Cor.		0,98	0,97	0,97	0,97	0,97	0,97
w(For Air Con. Cor.		0,02	0,02	0,02	0,02	0,02	0,02
Chr(For Air Con)		0,97	0,97	0,97	0,97	0,97	0,97
Air Con. Cor. Factor		0,92	0,91	0,90	0,91	0,91	0,91
Corrected Air Con.	**kg/h**	83,27	103,82	143,54	143,43	114,11	112,33
Air /Fuel Ratio		64,25	10,88	19,64	16,00	19,33	15,15
Excess Air Coefficient		5,15	0,87	1,57	1,28	1,55	1,21
Equivalence Ratio		0,19	1,15	0,64	0,78	0,65	0,82
Th. Air Cons.	**kg/h**	142,69	213,32	270,54	267,01	209,79	211,20
Volumetric Efficiency	**%**	58,36	48,67	53,06	53,72	54,39	53,18
Thermal Efficiency	**%**	3,05	29,10	22,13	29,60	22,21	27,16
Dil. Exh. Flow Rate	**m3/h**	45,52	48,18	48,87	48,87	48,38	48,38
Density of Air	**kg/m3**	1,16	1,15	1,14	1,15	1,15	1,15
Air vol. flow rate	**m3/h**	71,70	90,36	125,59	124,63	99,02	97,53
Exhaust flow rate	**m3/h**	72,70	97,71	131,22	131,53	103,57	103,25
Exh. flow rate on Dry	**m3/h**	70,73	83,21	120,11	117,91	94,59	91,97
Dilution Ratio	**%**	13,34	10,51	7,93	7,91	9,95	9,98
Eq. Diluted Exh.	**m3/h**	970	1026	1041	1041	1031	1031
HC	**ppm**	80,04	94,55	31,73	47,49	69,66	99,82
CO	**%**	0,13	1,26	0,16	0,08	0,08	0,20
CO2	**%**	1,33	7,35	4,76	6,33	5,97	7,99
HC Mass Flow Rate	**g/h**	3,60	5,72	2,58	3,87	4,47	6,38
HC Emission	**g/HPh**	6,62	0,15	0,12	0,11	0,25	0,23
PM Mass Rate	**g/h**	1,22	26,71	10,03	16,71	10,11	18,20
PM Emission	**g/HPh**	2,25	0,70	0,45	0,46	0,56	0,66

Table A14: Mod 13 Calculated Data for Canola Oil (Mode 7-13)

	7	8	9	10	11	12	13
Water Vapor Pres.	25,96	25,96	26,27	26,27	26,12	26,12	4,58
Dry Air Pressure	728,24	729,02	728,86	728,9	728,94	728,94	739,71
Break Pow. Cor. Fac.	1,02	1,01	1,01	1,02	1,01	1,01	1,01
Cor. Break Torque	42,03	176,03	46,38	167,4	44,46	130,40	86,75
Cor. Break Power	8,91	47,09	12,51	53,36	14,23	42,12	27,90
BSFC	0,47	0,26	0,45	0,25	0,40	0,31	0,32
BSEC	17488	9645	16616	9361	14692	11448	11793
Cp(For Air Con. Cor.	0,96	0,96	0,96	0,96	0,96	0,96	0,96
Ct(For Air Con. Cor.	0,97	0,97	0,97	0,97	0,97	0,97	0,97
w(For Air Con. Cor.	0,02	0,02	0,02	0,02	0,02	0,02	0,00
Chr(For Air Con)	0,97	0,97	0,97	0,97	0,97	0,97	0,99
Air Con. Cor. Factor	0,91	0,91	0,91	0,91	0,91	0,91	0,93
Corrected Air Con.	115,70	138,90	145,52	168,5	177,51	177,83	180,58
Air /Fuel Ratio	27,47	11,31	25,91	12,48	31,41	13,65	20,31
Excess Air Coefficient	2,20	0,91	2,08	1,00	2,52	1,09	1,63
Equivalence Ratio	0,45	1,10	0,48	1,00	0,40	0,91	0,61
Th. Air Cons.	213,32	269,13	271,25	320,7	322,11	324,93	323,52
Volumetric Efficiency	54,24	51,61	53,65	52,54	55,11	54,73	55,82
Thermal Efficiency	15,35	27,83	16,16	28,68	18,27	23,45	22,76
Dil. Exh. Flow Rate	48,38	49,84	49,35	50,42	53,51	52,26	52,26
Density of Air	1,15	1,15	1,15	1,15	1,15	1,15	1,15
Air vol. flow rate	100,50	120,69	126,49	146,5	154,35	154,57	156,96
Exhaust flow rate	103,74	130,14	130,81	156,9	158,70	164,61	163,81
Exh. flow rate on Dry	97,34	111,48	122,27	136,4	150,11	144,80	150,29
Dilution Ratio	9,93	8,16	8,04	6,85	7,18	6,76	6,80
Eq. Diluted Exh.	1031	1062	1051	1074	1140	1113	1113
HC	49,67	65,27	40,19	41,08	28,74	47,35	40,78
CO	0,30	0,82	0,08	0,27	0,14	0,07	0,07
CO2	3,97	8,97	4,82	8,22	4,31	7,44	5,44
HC Mass Flow Rate	3,19	5,26	3,25	3,99	2,82	4,82	4,14
HC Emission	0,36	0,11	0,26	0,07	0,20	0,11	0,15
PM Mass Rate	4,96	20,45	7,43	20,69	3,10	14,74	8,19
PM Emission	0,56	0,43	0,59	0,39	0,22	0,35	0,29

Table A15: Mod 13 Measured Data for 30% Canola+ 70% Ethanol Oil (Mode 1-6)

		1	2	3	4	5	6
Speed	(rpm)	1000	1520	1890	1910	1490	1520
Engine Torque	Nm	4	181,6	82,4	132,3	91,7	133
Fuel Flow Rate	g/s	0,41	2,82	2,15	2,74	1,65	2,14
Air Consumption	kg/h	90,4	119,4	147,9	156,1	116,2	115,1
Fuel Temperature	C	53,5	64	68,7	66,5	61,4	65,1
Exhaust Temperature	C	125	519,7	340,9	457,6	317,8	388,8
ISP Temperature	C	117	519,7	340,9	457,6	317,8	388,8
Sample Temperature	C	117	482,3	317,6	393,3	297,6	374,2
Engine Oil Temp.	C	63	75	85	93	78	81
Back Pressure	mm-Hg	5	15	20	24	10	12
Tunnel Pressure	"WC	1,48	2	2	2,1	3,8	1,9
Sampling Rate	scfm	0,7	1	1	1	0,9	0,9
AVL HC	ppm	5	10	6	8	7	10
AVL Opacity	%	1,00	68,8	5,5	28,3	6,8	11,8
CO2	%	0,1	0,8	0,7	0,8	0,5	0,8
CO	%	0,01	0,11	0,01	0,01	0,008	0,02
O2	%	20,66	19,4	19,8	19,66	19,76	19,48
Particulate Matter	mg	0,1	1,2	0,5	0,9	0,5	0,8
Ambient Temperature	C	27,3	27,6	28,2	28,4	27,8	29,2
Ambient Pressure	mm-Hg	741	741	741	741	741	741
Relative Humidity	%	51	51	51	51	50	50
Load	%	0%	100%	50%	75%	50%	75%
Sampling Duration	min	4	2	2	2	2	2
Weight Factor	%	0,15	0,08	0,1	0,1	0,05	0,05
Density of Fuel	g/cc	0,862	0,862	0,862	0,862	0,862	0,862
Heating Value of Fuel	kj/kg	34300	34300	34300	34300	34300	34300
(A/F) stiometric		12,567	12,567	12,567	12,567	12,567	12,567
Fuel Type		Can.+Et	Can.+Et	Can.+Et	Can.+Et	Can.+Et	Can.+Et

Table A16: Mod 13 Measured Data for 30% Canola+ 70% Ethanol Oil (Mode 7-13)

	7	8	9	10	11	12	13
Speed	1510	1900	1930	2290	2310	2305	2320
Engine Torque	42,5	173,7	46,8	160,6	41,4	125,4	78,7
Fuel Flow Rate	1,18	3,65	1,72	3,89	2,19	3,68	2,75
Air Consumption	116,7	146,6	147,5	171,4	179,8	177	175
Fuel Temperature	68,3	70,7	73,1	67,2	69,6	66,2	70,3
Exhaust Temperature	290,2	523,8	279	509,9	294,4	424,7	376,5
ISP Temperature	290,2	502,4	262,7	497,6	274,6	397,2	367,9
Sample Temperature	264,7	44,1	34,5	45,1	28,5	41,5	36,9
Engine Oil Temp.	85	89	95	98	87	93	94
Back Pressure	12	24	20	38	24	30	28
Tunnel Pressure	1,7	2,2	2	2,3	2,1	2,3	2,2
Sampling Rate	0,85	1,1	1	1,2	1	1,1	1
AVL HC	6	8	7	7	5	8	7
AVL Opacity	1,2	50,7	2	40,5	1,6	20,6	8
CO2	0,4	1,1	0,6	1,2	0,5	1,1	0,9
CO	0,03	0,08	0,01	0,03	0,01	0,01	0,01
O2	19,95	19,01	19,81	18,76	19,62	18,93	19,43
Particulate Matter	0,2	1,1	0,3	1,1	0,3	0,9	0,6
Ambient Temperature	30,1	29,6	31,5	31,6	29,2	30,1	30,1
Ambient Pressure	741	741	741	741	741	741	741
Relatıve Humidity	50	50	50	50	50	50	50
Load	25%	100%	25%	100%	25%	75%	50%
Sampling Duration	2	2	2	2	2	2	2
Weight Factor	0,05	0,09	0,1	0,08	0,05	0,05	0,05
Density of Fuel	0,862	0,862	0,862	0,862	0,862	0,862	0,862
Heating Value of Fuel	34300	34300	34300	34300	34300	34300	34300
(A/F) stiometric	12,567	12,567	12,567	12,567	12,567	12,567	12,567
Fuel Type	Can.+Et	Can.+Et	Can.+Et	Can.+Et	Can.+Et	Can.+Et	Can.+Et

Table A17: Mod 13 Calculated Data for 30%Canola+ 70%Ethanol Oil (Mode 1-6)

		1	2	3	4	5	6
Water Vapor Pres.	**mm-Hg**	27,21	27,69	29,01	29,01	30,39	30,39
Dry Air Pressure	**mm-Hg**	727,12	726,88	726,20	726,20	725,81	725,81
Break Pow. Cor. Fac.		1,02	1,02	1,02	1,02	1,02	1,02
Cor. Break Torque	**Nm**	4,07	184,94	84,05	134,99	93,51	135,94
Cor. Break Power	**HP**	0,57	39,48	22,31	36,21	19,57	29,02
BSFC	**kg/HP-h**	2,58	0,26	0,35	0,27	0,30	0,27
BSEC	**kJ/HP-h**	88564	8820,84	11901	9344	10413	9107
Cp(For Air Con. Cor.		0,96	0,96	0,96	0,96	0,96	0,96
Ct(For Air Con. Cor.		0,97	0,97	0,97	0,97	0,97	0,96
w(For Air Con. Cor.		0,02	0,02	0,02	0,02	0,03	0,03
Chr(For Air Con)		0,97	0,97	0,97	0,97	0,96	0,96
Air Con. Cor. Factor		0,90	0,90	0,90	0,90	0,90	0,89
Corrected Air Con.	**kg/h**	81,55	107,56	132,80	140,09	104,27	102,90
Air /Fuel Ratio		55,25	10,59	17,16	14,20	17,55	13,36
Excess Air Coefficient		4,40	0,84	1,37	1,13	1,40	1,06
Equivalence Ratio		0,23	1,19	0,73	0,88	0,72	0,94
Th. Air Cons.	**kg/h**	141,27	214,74	267,01	269,83	210,50	214,74
Volumetric Efficiency	**%**	57,72	50,09	49,74	51,92	49,54	47,92
Thermal Efficiency	**%**	3,03	30,43	22,56	28,73	25,78	29,48
Dil. Exh. Flow Rate	**m3/h**	45,82	48,38	48,38	48,87	57,04	47,89
Density of Air	**kg/m3**	1,15	1,15	1,14	1,14	1,14	1,14
Air vol. flow rate	**m3/h**	71,14	93,93	116,20	122,66	91,12	90,34
Exhaust flow rate	**m3/h**	72,28	101,74	122,16	130,26	95,69	96,27
Exh. flow rate on Dry	**m3/h**	70,03	86,31	110,40	115,26	86,66	84,56
Dilution Ratio	**%**	13,50	10,13	8,44	7,99	12,70	10,60
Eq. Diluted Exh.	**m3/h**	976	1031	1031	1041	1215	1020
HC	**ppm**	67,52	101,29	50,62	63,94	88,89	105,96
CO	**%**	0,14	1,11	0,08	0,08	0,10	0,21
CO2	**%**	1,35	8,10	5,91	6,39	6,35	8,48
HC Mass Flow Rate	**g/h**	3,02	6,38	3,83	5,16	5,26	6,31
HC Emission	**g/HPh**	5,28	0,16	0,17	0,14	0,27	0,22
PM Mass Rate	**g/h**	1,23	21,84	9,10	16,54	11,92	16,01
PM Emission	**g/HPh**	2,15	0,55	0,41	0,46	0,61	0,55

Table A18: Mod 13 Calculated Data for 30%Canola+ 70%Ethanol Oil (Mode 7-13)

	7	8	9	10	11	12	13
Water Vapor Pres.	31,10	31,10	34,86	34,86	32,00	32,00	4,58
Dry Air Pressure	725,45	725,45	723,57	723,6	725,00	725,00	738,71
Break Pow. Cor. Fac.	1,02	1,02	1,03	1,03	1,02	1,02	1,01
Cor. Break Torque	43,52	177,71	48,11	165,1	42,34	128,45	79,64
Cor. Break Power	9,23	47,42	13,04	53,10	13,74	41,58	25,95
BSFC	0,46	0,28	0,47	0,26	0,57	0,32	0,38
BSEC	15790	9505	16288	9046	19687	10929	13087
Cp(For Air Con. Cor.	0,96	0,96	0,96	0,96	0,96	0,96	0,96
Ct(For Air Con. Cor.	0,96	0,96	0,96	0,96	0,96	0,96	0,96
w(For Air Con. Cor.	0,03	0,03	0,03	0,03	0,03	0,03	0,00
Chr(For Air Con)	0,96	0,96	0,96	0,96	0,96	0,96	0,99
Air Con. Cor. Factor	0,89	0,89	0,88	0,88	0,89	0,89	0,92
Corrected Air Con.	103,99	130,81	130,34	151,4	160,43	157,55	160,98
Air /Fuel Ratio	24,48	9,96	21,05	10,81	20,35	11,89	16,26
Excess Air Coefficient	1,95	0,79	1,68	0,86	1,62	0,95	1,29
Equivalence Ratio	0,51	1,26	0,60	1,16	0,62	1,06	0,77
Th. Air Cons.	213,32	268,42	272,66	323,5	326,34	325,64	327,76
Volumetric Efficiency	48,75	48,73	47,80	46,81	49,16	48,38	49,12
Thermal Efficiency	17,00	28,24	16,48	29,68	13,64	24,56	20,51
Dil. Exh. Flow Rate	46,90	49,35	48,38	49,84	48,87	49,84	49,35
Density of Air	1,14	1,14	1,13	1,13	1,14	1,14	1,14
Air vol. flow rate	91,57	114,99	115,30	134,0	140,84	138,73	141,75
Exhaust flow rate	94,84	125,11	120,07	144,8	146,91	148,93	149,37
Exh. flow rate on Dry	88,38	105,14	110,66	123,5	134,93	128,79	134,32
Dilution Ratio	10,54	8,40	8,58	7,33	7,09	7,13	7,04
Eq. Diluted Exh.	999	1051	1031	1062	1041	1062	1051
HC	63,21	67,23	60,08	51,34	35,43	57,04	49,27
CO	0,32	0,67	0,09	0,22	0,07	0,07	0,07
CO2	4,21	9,24	5,15	8,80	3,54	7,84	6,34
HC Mass Flow Rate	3,71	5,21	4,47	4,60	3,22	5,26	4,56
HC Emission	0,40	0,11	0,34	0,09	0,23	0,13	0,18
PM Mass Rate	4,15	18,57	5,46	17,19	5,51	15,34	11,14
PM Emission	0,45	0,39	0,42	0,32	0,40	0,37	0,43

APPENDİX B

FIBERGLASS FILTER PHOTOS

1000 rpm -0%	1500 rpm-100%
1900 rpm-50%	1900 rpm-75%
1500 rpm-50%	1500 rpm-75%
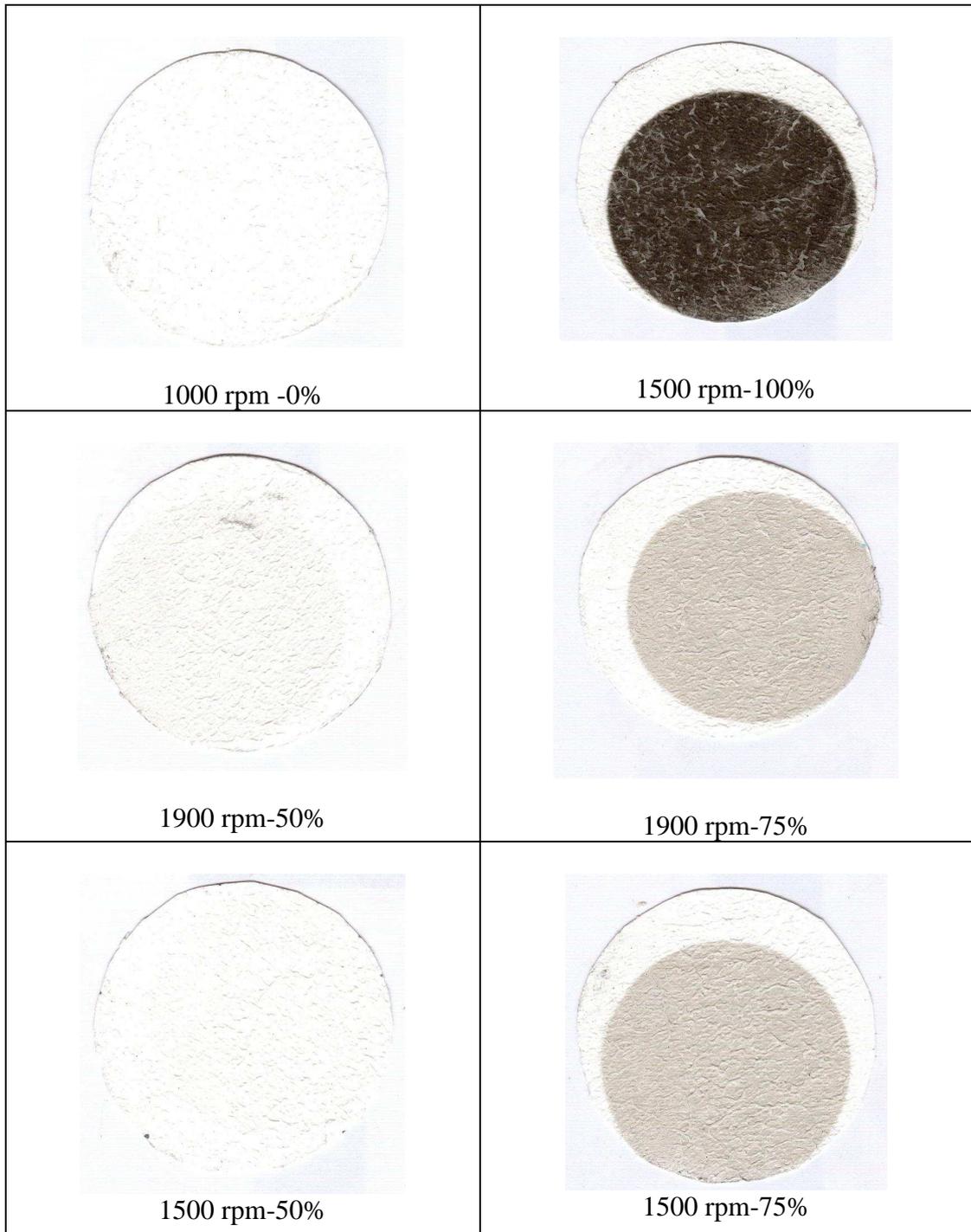
Figure B.1: Particulate Filters for Diesel Fuel (Mode 1-6)

1500 rpm -25%	1900 rpm-100%
1900 rpm–25%	2300 rpm–100%
2300 rpm-25%	2300 rpm-75%
2300 rpm-50%	
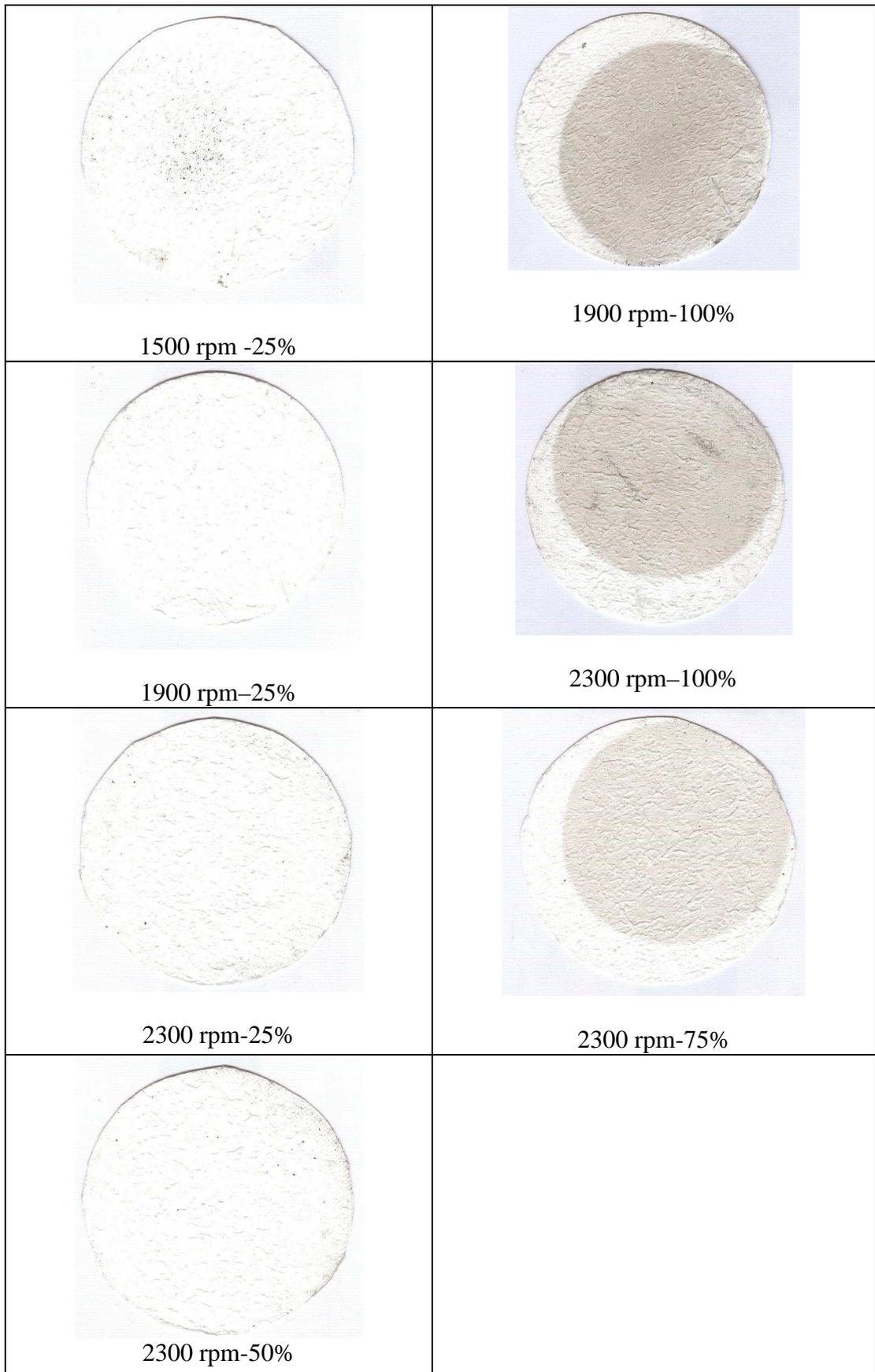
Figure B.2: Particulate Filters for Diesel Fuel (Mode 7-13)

1000 rpm -0%	1500 rpm-100%
1900 rpm-50%	1900 rpm-75%
1500 rpm-50%	1500 rpm-75%
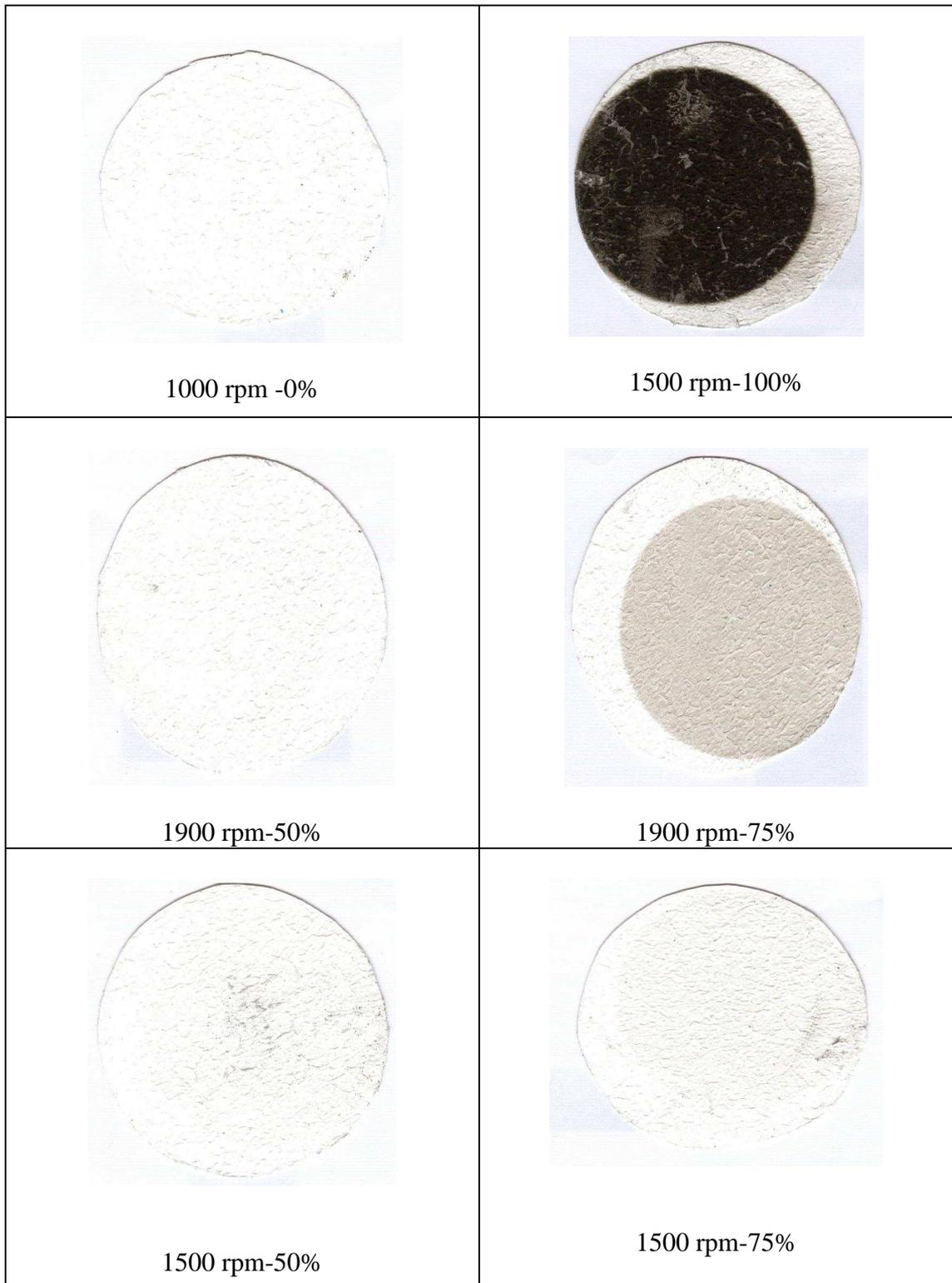
Figure B.3: Particulate Filters for Canola Oil (Mode 1-6)

1500 rpm -25%	1900 rpm-100%
1900 rpm–25%	2300 rpm–100%
2300 rpm-25%	2300 rpm-75%
2300 rpm-50%	
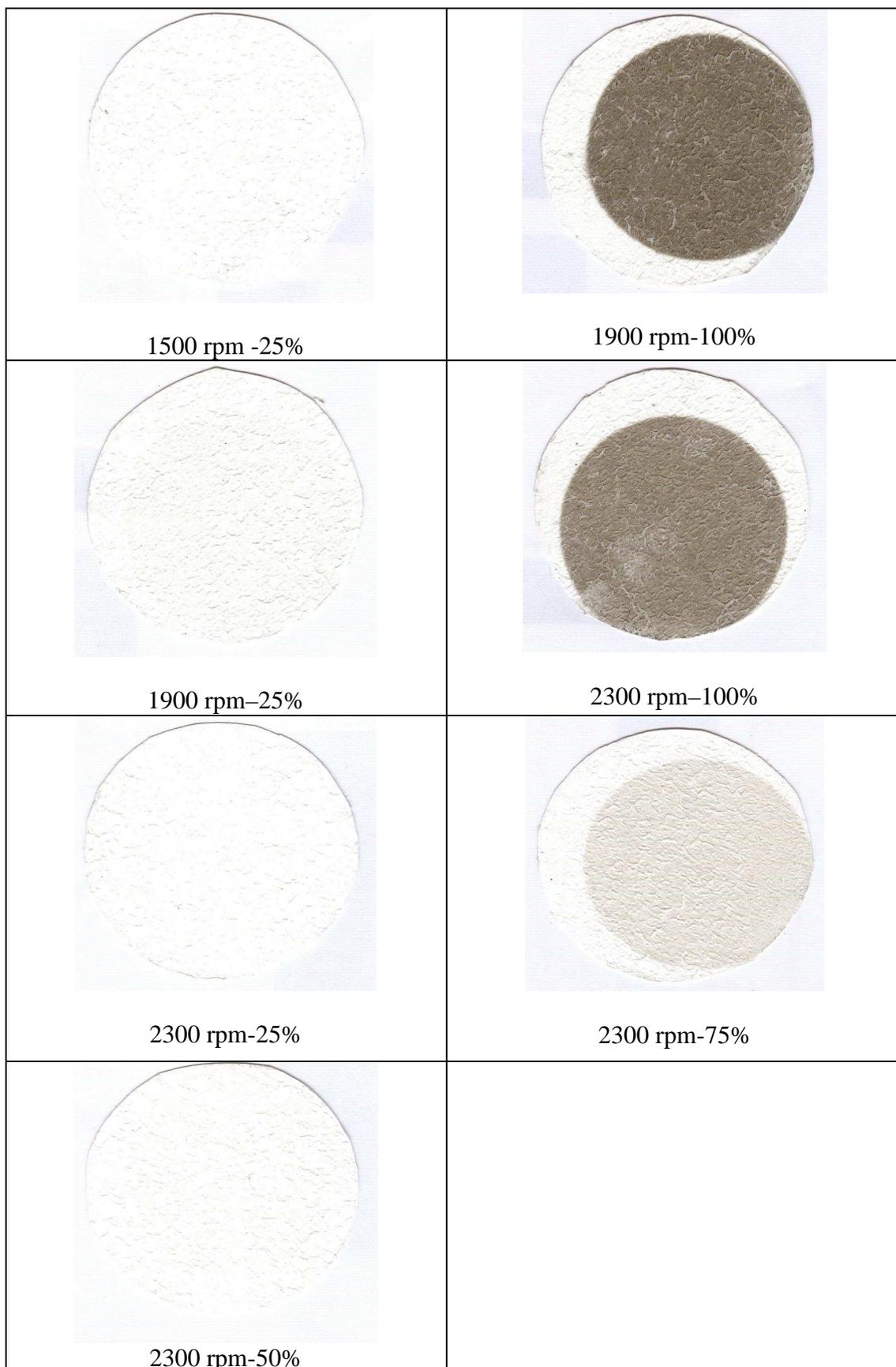
Figure B.4: Particulate Filters for Canola Oil (Mode 7-13)

1000 rpm -0%	1500 rpm-100%
1900 rpm-50%	1900 rpm-75%
1500 rpm-50%	1500 rpm-75%
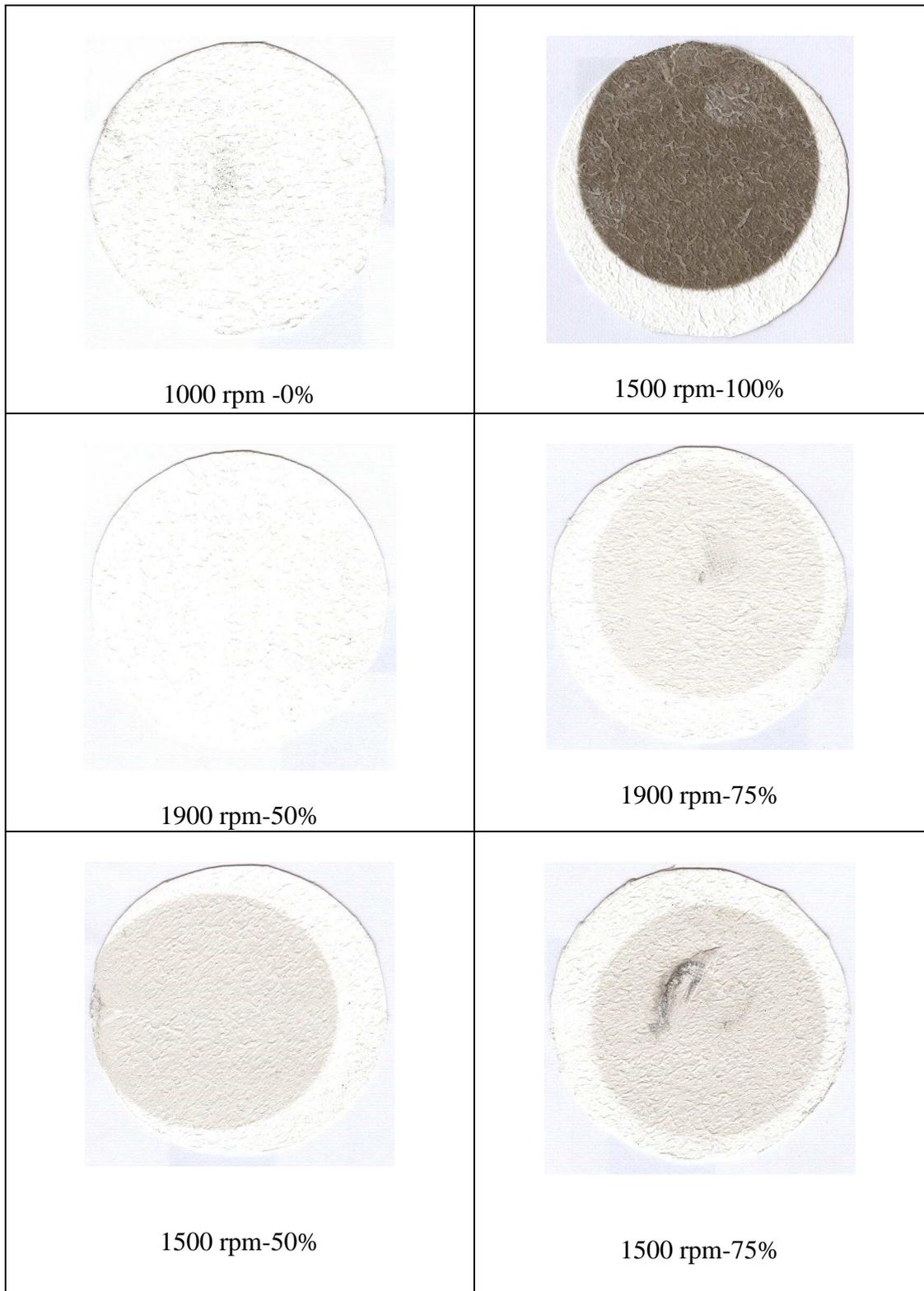
Figure B.5: Particulate Filters 70% Canola-30%Ethanol (Mode 1-6)

    1500 rpm -25%	 1900 rpm-100%
    1900 rpm–25%	 2300 rpm–100%
    2300 rpm-25%	 2300 rpm-75%
    2300 rpm-50%	
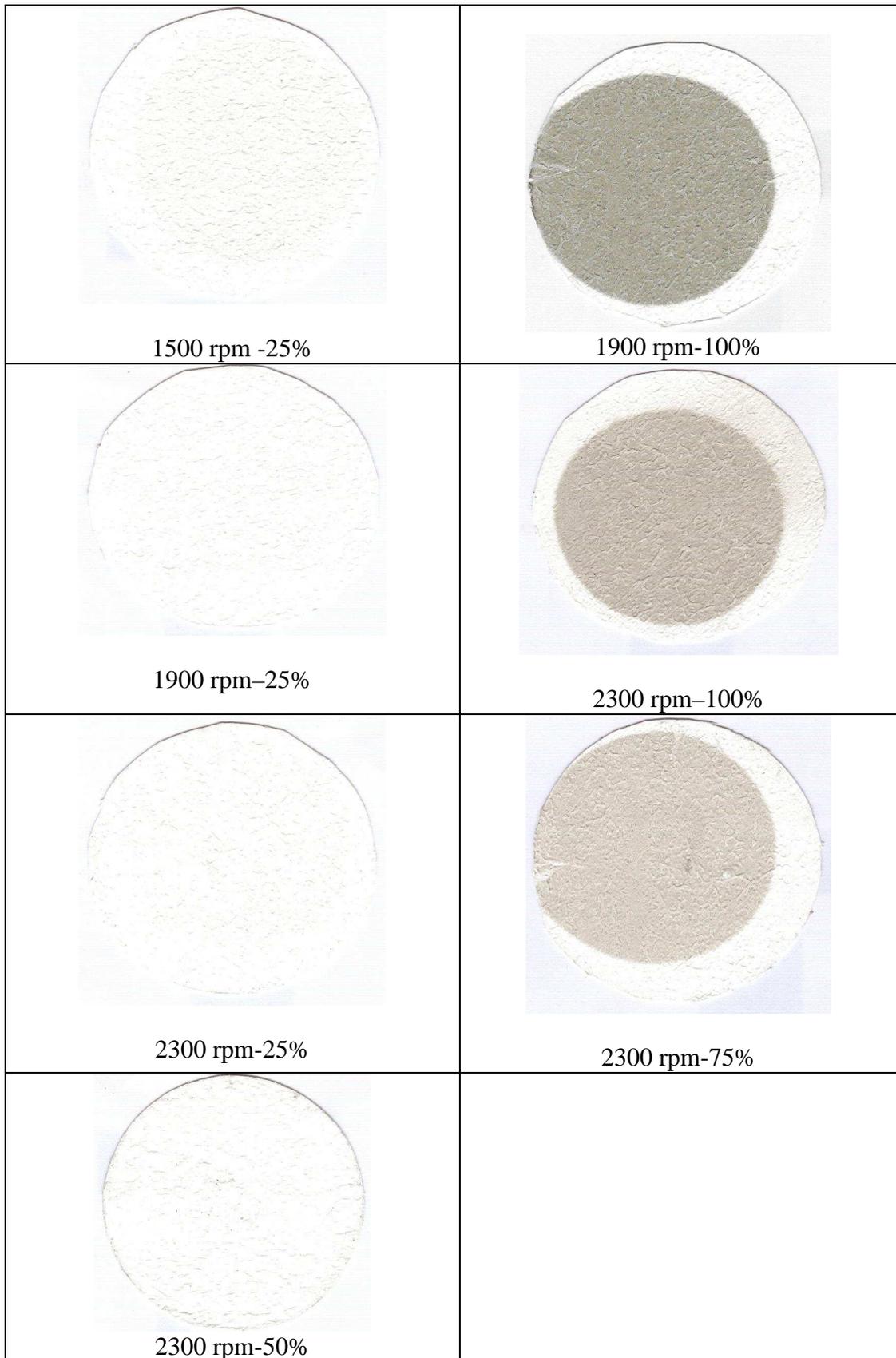
Figure B.6: Particulate Filters for 70% Canola-30%Ethanol (Mode 7-13)

CALIBRATION CURVES

$y = -16,567x^2 + 646,54x - 127,15$
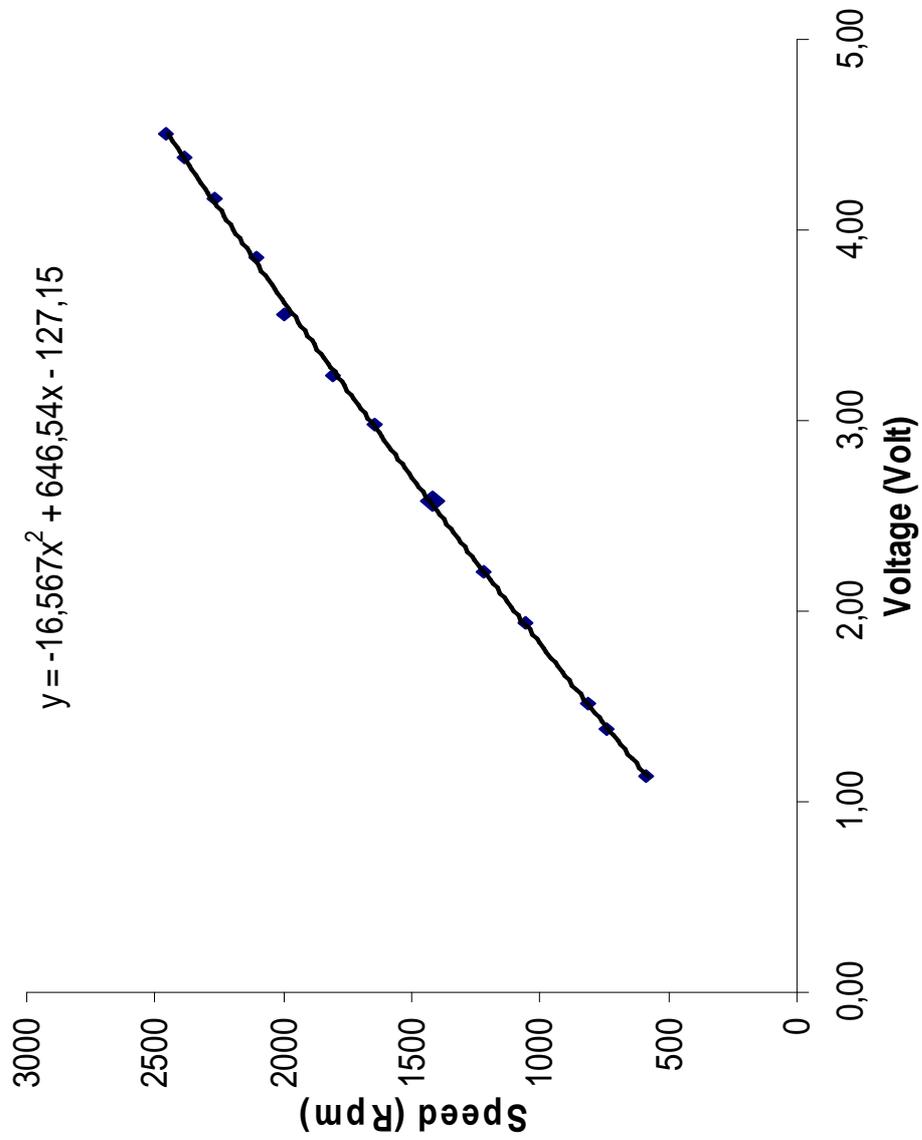
Figure C.1: Speed Sensor Calibration Curve
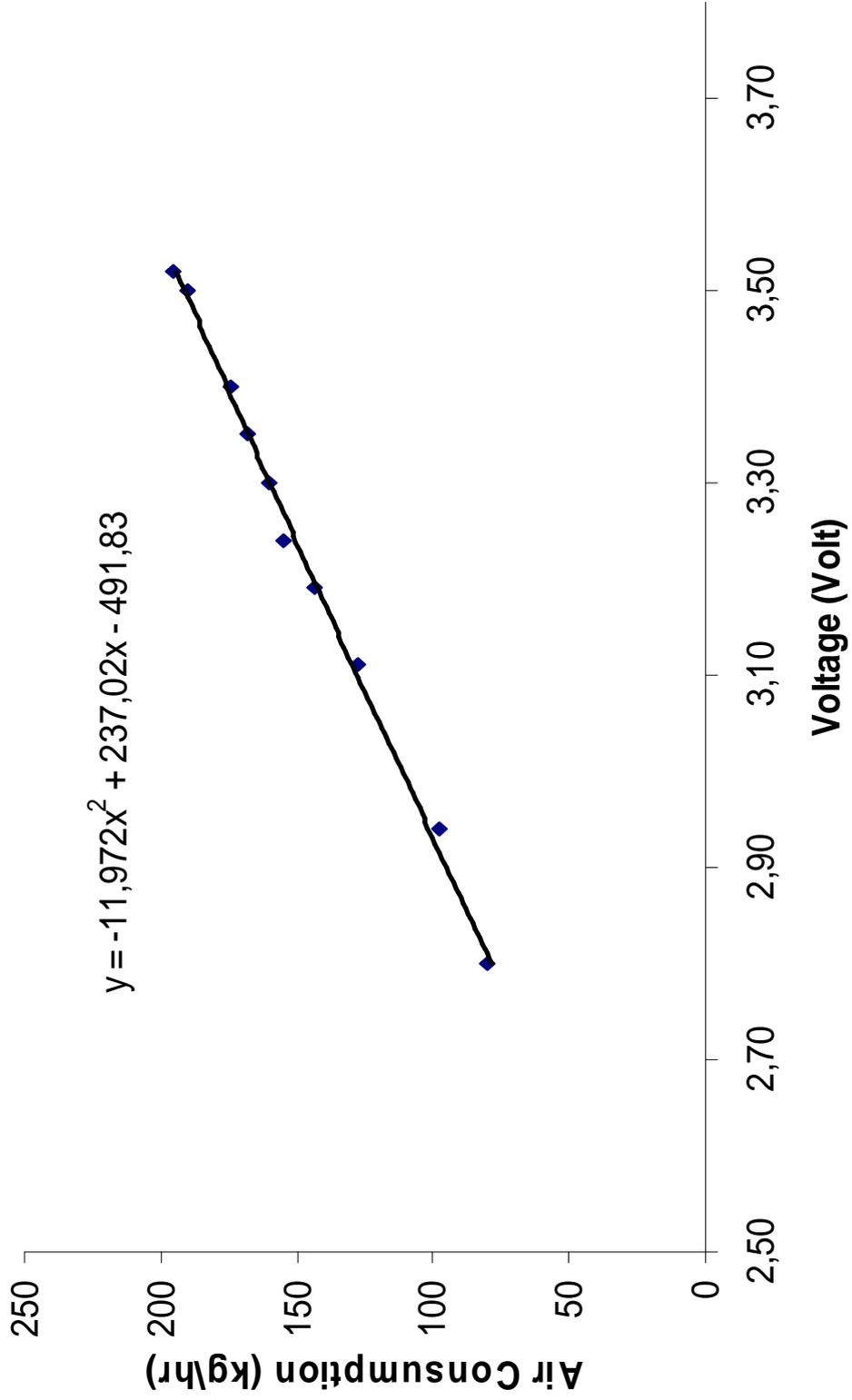
Figure C.2: Air Mass Meter Calibration Curve

The figure shows the Air Consumption (kg/hr) versus Voltage (Volt) with the equation $y = -11,972x^2 + 237,02x - 491,83$
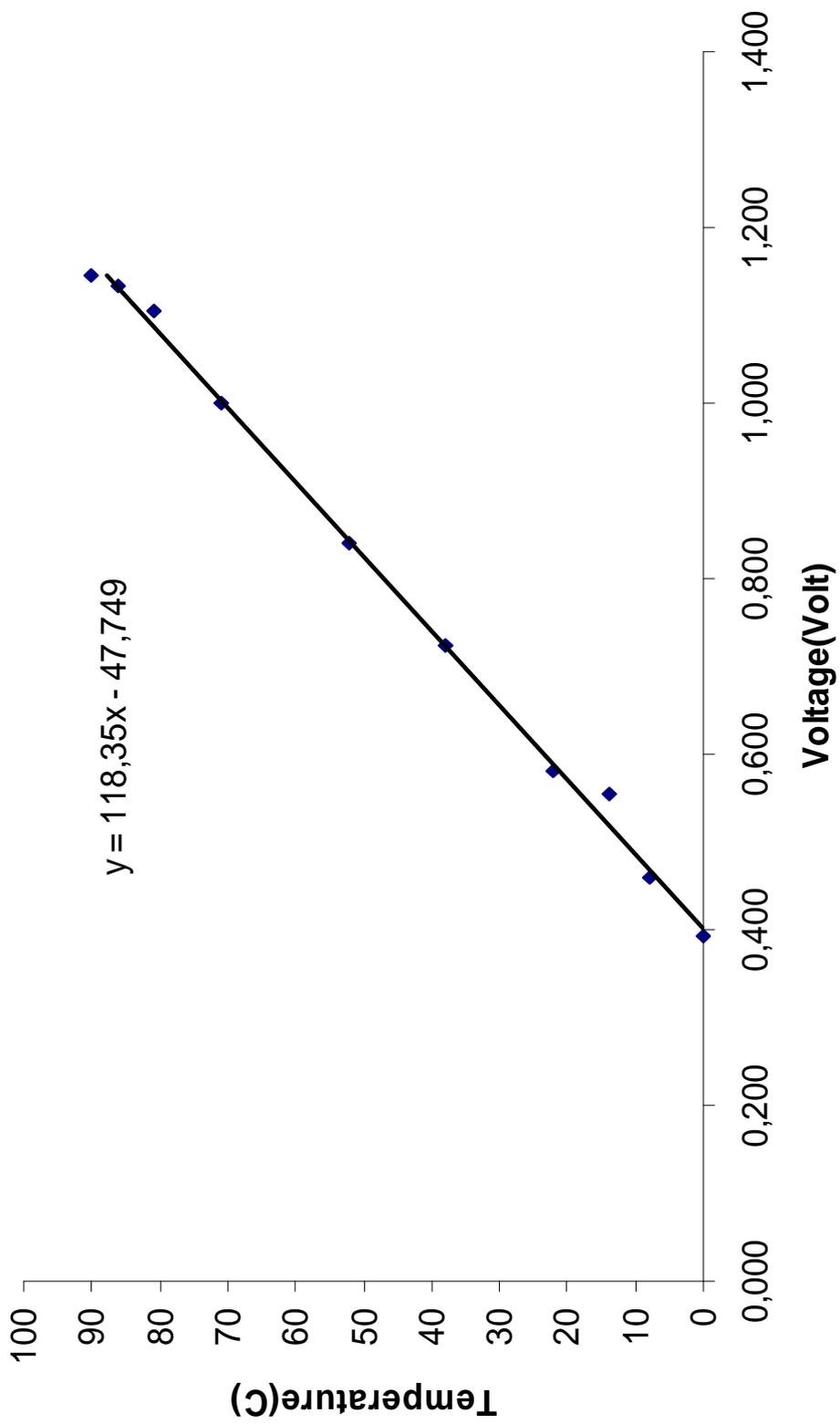
Figure C.3: Calibration Curve of the Amplifier 1.

y = 118,35x - 47,749
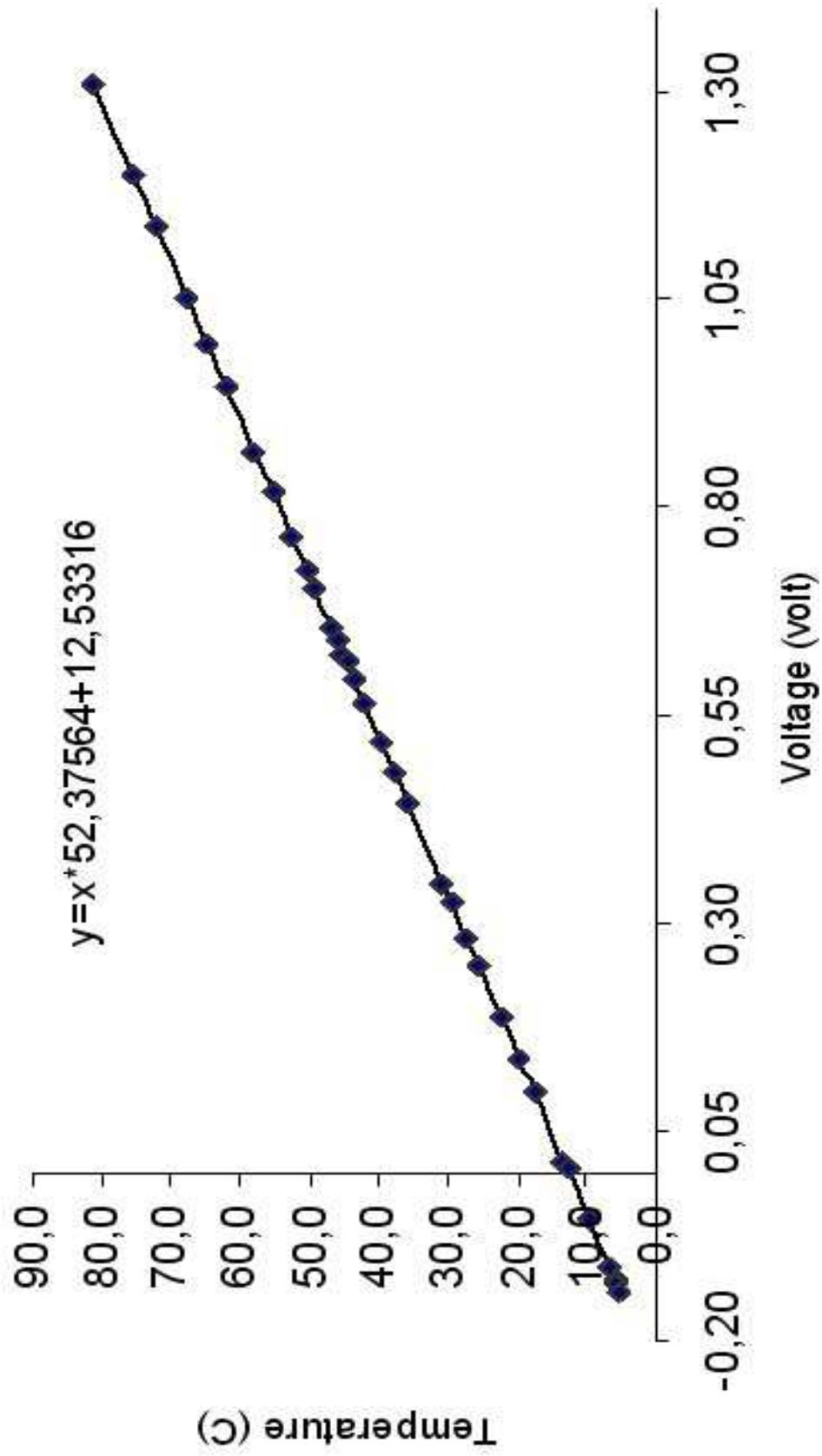
Figure C.4: Calibration Curve of the Amplifier 2.

y=x*52,37564+12,53316

123
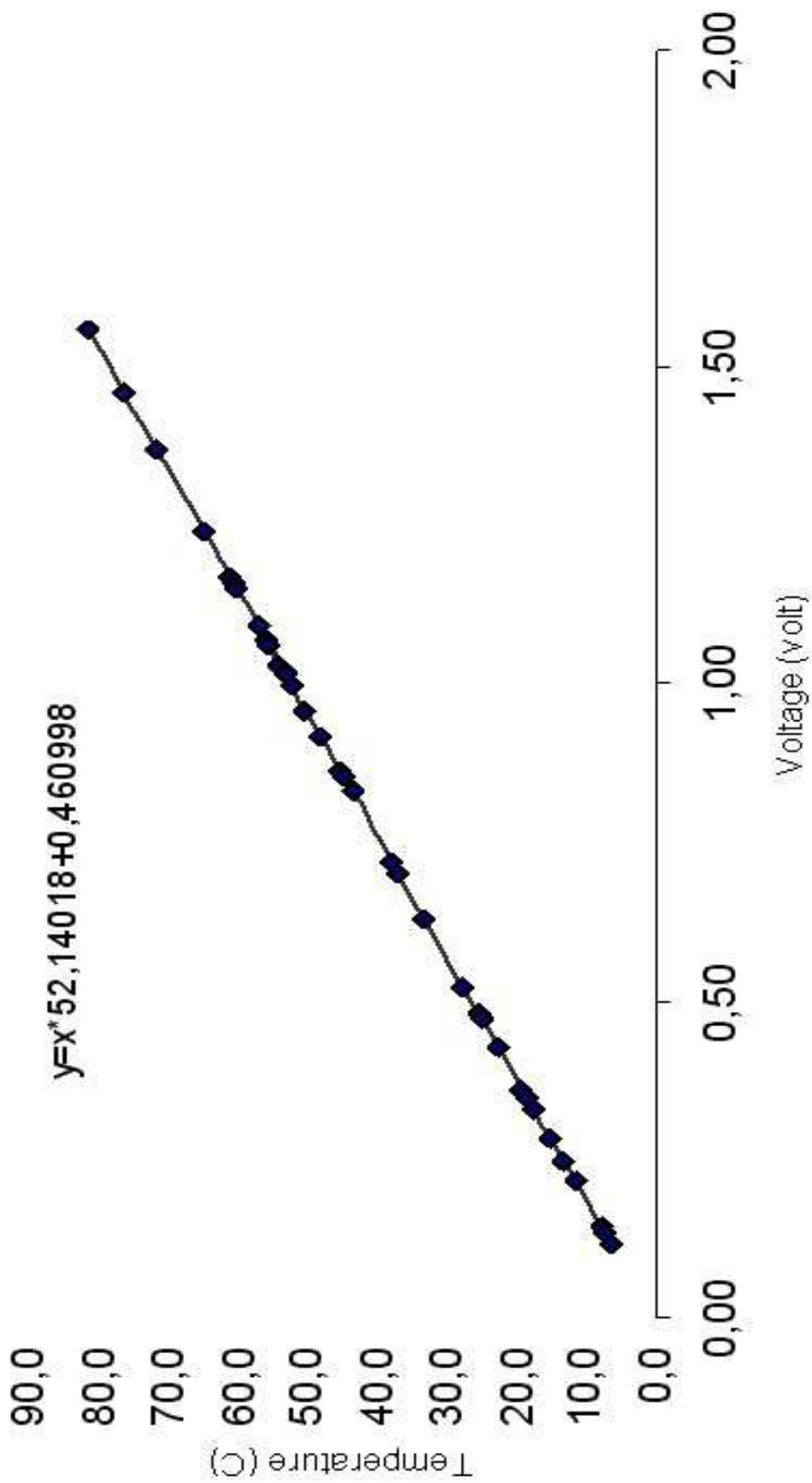
Figure C.5: Calibration Curve of the Amplifier 3.
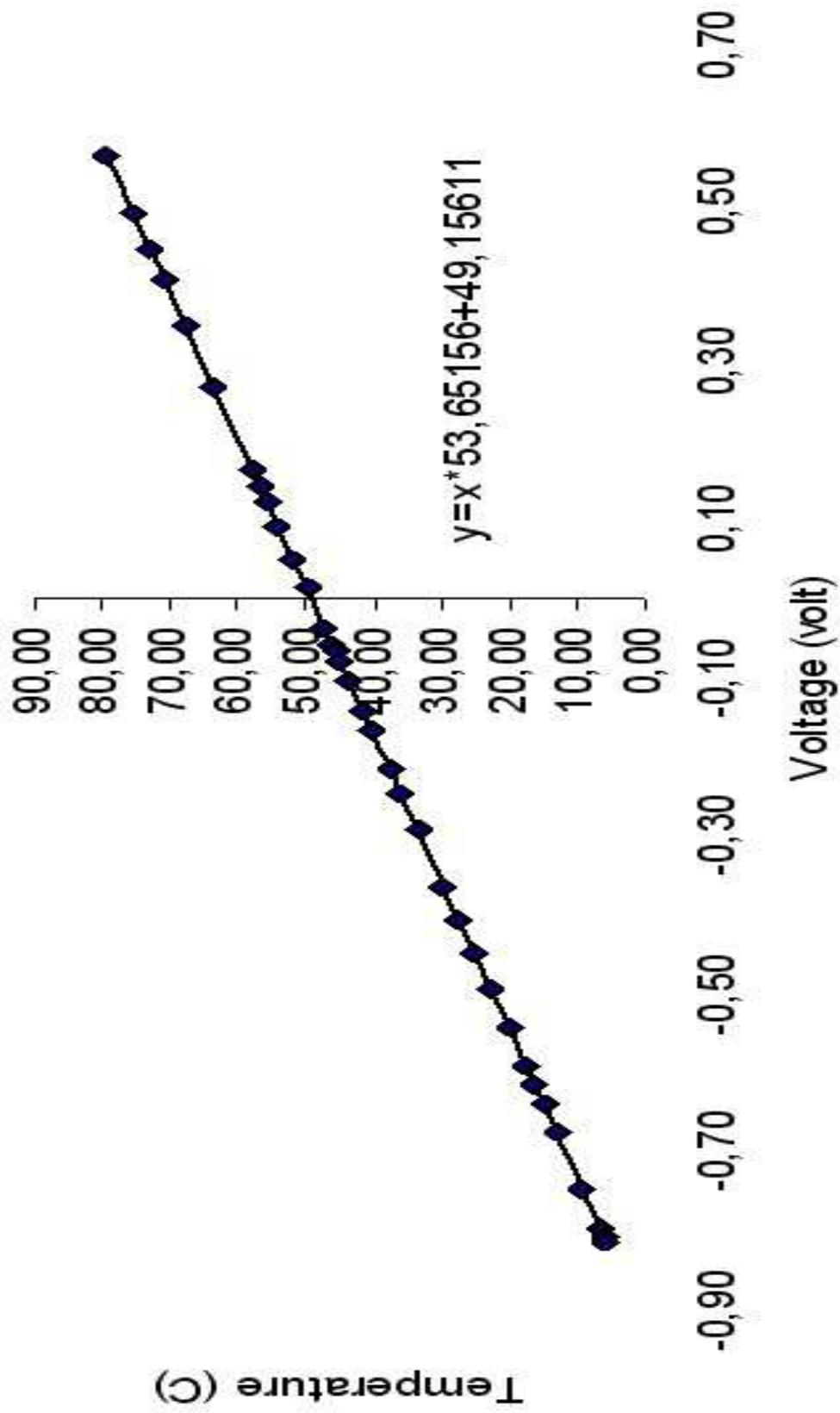
Figure C.6: Calibration Curve of the Amplifier 4.

The plot shows Temperature (C) on the vertical axis versus Voltage (volt) on the horizontal axis, with the fit equation y=x*53,65156+49,15611
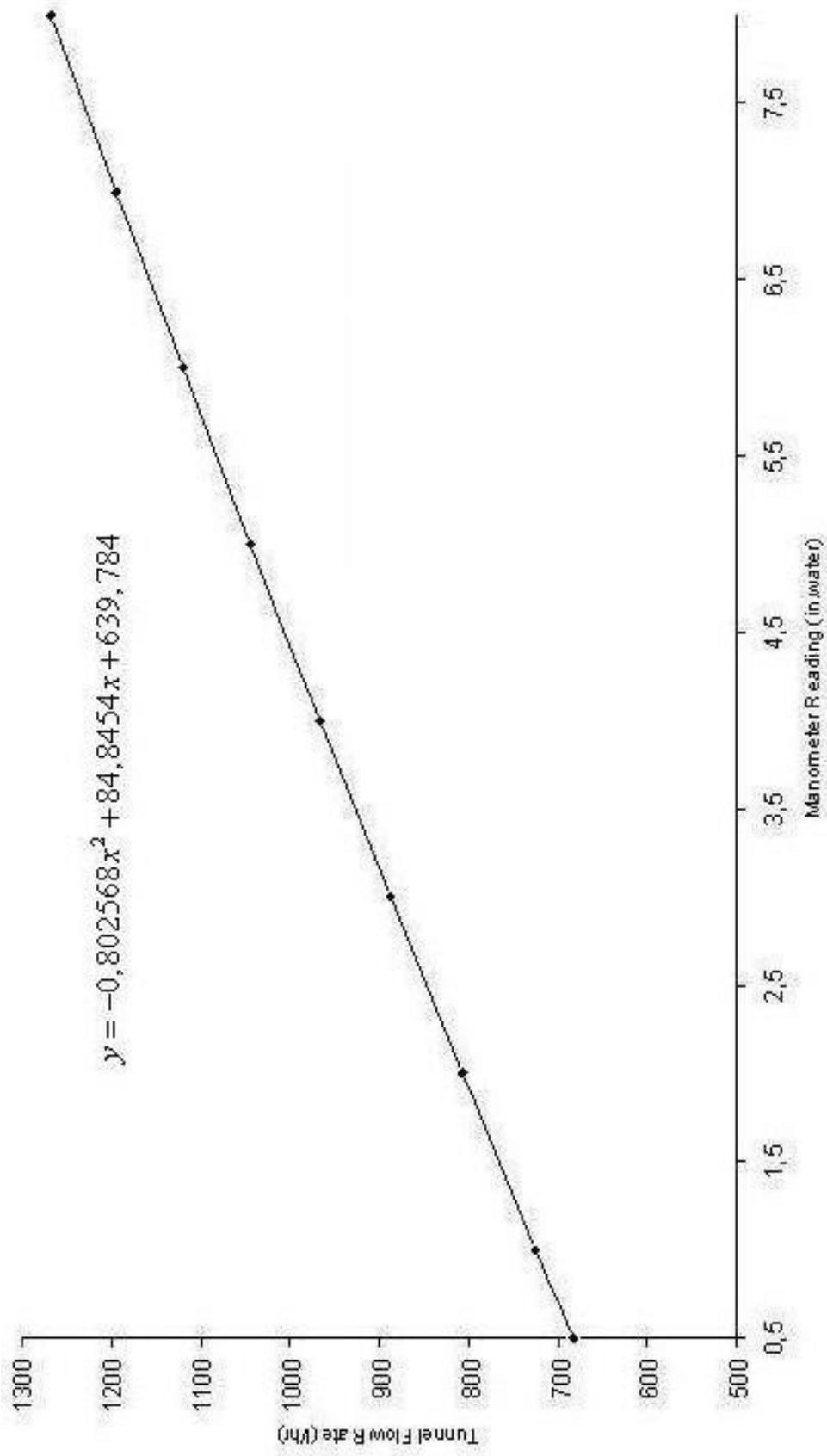
Figure C.7: Calibration Curve of Dilution Tunnel Flow Rate [37]

$$y = -0.802568x^2 + 84.8454x + 639.784$$

APPENDİX D

SAMPLE CALCULATION

Sample calculation is being performed for Diesel fuel feeding for following data.

Ambient Temperature $\quad$: 23.2°C

Ambient Pressure $\qquad$: 744 mmHg

Relative Humidity $\qquad$: 60 %

Engine Speed $\qquad$: 1900 rpm

Load-cell Voltage $\qquad$: 6.57 Volt

Fuel Consumption Time $\quad$: 26 s

Air-Mass Meter Voltage $\quad$: 3.3 Volt

Dilution Tunnel Pressure $\;$: 2.2"WC

Sampling Rate $\qquad$: 1 scfm

AVL HC $\qquad$: 8 ppm

AVL Opacity $\qquad$: 40%

Particulate Matter $\qquad$: 1.1 mg

Duration $\qquad$: 120 sn

Load $\qquad$: 100%

Fuel Density $\qquad$: 820 kg/m^3

Fuel Cost $\qquad$: 3.41 YTL/kg

Fuel Type $\qquad$: Diesel

Weight Factor $\qquad$: 0.09

D.1 Engine Torque (Nm)

$$\text{Load(kg)}=(5\frac{\text{kg}}{\text{volt}})\text{xV}_{\text{load-cell}}\,(\text{Volt})$$

$$\text{Load(kg)}=5\text{x}6.57=32.85 \text{ kg}$$

$$\text{T=Loadxlxg}$$

$$\text{T}=32.85\text{x}0.56\text{x}9.81=180.5 \text{ Nm}$$

Then, the correction factor for torque

$$P_v=\left(6.10708\text{x}10^{\frac{7.5\text{x}T_{\text{amb}}}{237.3+T_{\text{amb}}}}\right)0.75$$

$$P_V=\left(6.10708\text{x}10^{\frac{7.5\text{x}23.2}{237.3+23.2}}\right)0.75=21.3 \text{ mm-Hg}$$

$$P_d=P_{\text{atm}}\text{-RHxP}_v$$

$$P_d=744\text{-}21.3\text{x}0.6=731.2 \text{ mm-Hg}$$

$$C_f=\left(\frac{742.56107}{P_d}\right)^{0.65}\left(\frac{T_{\text{amb}}+273.15}{298.15}\right)^{0.5}$$

$$C_f=\left(\frac{742.56107}{731.2}\right)^{0.65}\left(\frac{23.2+273.15}{298.15}\right)^{0.5}=1.007$$

$$T_c=\text{TxC}_f$$

$$T_c=180.5\text{x}1.007=181.76 \text{ Nm}$$

D.2 Brake Power (HP)

$$P_b=T_c\text{xN}_{\text{speed}}\text{x}\frac{\pi}{30000}\text{x}1.36$$

$$P_b = 181.76 \times 1900 \times \frac{\pi}{30000} \times 1.36 = 48.49 \text{ HP}$$

D.3 Fuel Consumption (kg/h)

$$\dot{m}_{fuel} = \frac{V_{container} \times \rho_{fuel} \times 3.6}{t_f \times 1000}$$

$$\dot{m}_{fuel} = \frac{86 \times 820 \times 3.6}{26 \times 1000} = 9.76 \text{ kg/h}$$

D.4 Brake Specific Fuel Consumption (kg/HP-h)

$$BSCF = \frac{\dot{m}_{fuel}}{P_b}$$

$$BSCF = \frac{9.76}{48.49} = 0.201 \text{ kg/HP-h}$$

D.5 Brake Specific Energy Consumption (kJ/HP-h)

$$BSEC = BSFC \times Q_L$$

$$BSEC = 0.201 \times 42000 = 8442 \text{ kJ/HP-h}$$

D.6 Specific Energy Cost (YTL/HP-h)

$$SEC = BSFC \times C_{fuel}$$

$$SEC = 0.201 * 3.41 = 0.685 \text{ YTL/HP-h}$$

D.7 Air Flow Rate (kg/h)

$$C_p = 0.066428571 + 0.011238095 \left(\frac{P_{atm}}{25.4} \right) + 0.00066666667 \left(\frac{P_{atm}}{25.4} \right)^2$$

$$C_p = 0.066428571 + 0.011238095\left(\frac{744}{25.4}\right) + 0.00066666667\left(\frac{744}{25.4}\right)^2 = 0.967$$

$$C_T = 1.0954518 - 0.0016846296(1.8T_{amb} + 32) + 1.5872009\text{E-}06(1.8T_{amb} + 32)^2$$

$$C_T = 1.0954518 - 0.0016846296(1.8\text{x}23.2 + 32) + 1.5872009\text{E-}06(1.8\text{x}23.2 + 32)^2$$

$$C_T = = 0.979$$

$$C_h = \left(\frac{0.733826288((0.62198P_v)/P_d)}{0.733726456}\right)$$

$$C_h = \left(\frac{0.733826288 - ((0.62198\text{x}21.32)/731.2)}{0.733726456}\right) = 0.975$$

$$C_{air} = C_p \text{x} C_t \text{x} C_h$$

$$C_{air} = 0.967\text{x}0.979\text{x}0.975 = 0.923$$

$$\dot{m}_{air} = (-11.971831V_a^2 + 237.02446V_a - 491.8309)C_{air}$$

$$\dot{m}_{air} = (-11.971831\text{x}3.3^2 + 237.02446\text{x}3.3 - 491.8309)\text{x}0.923 = 147.65 \ \text{kg/h}$$

D.8 Air/ Fuel Ratio

$$\left(\frac{A}{F}\right)_{actual} = \frac{\dot{m}_{air}}{\dot{m}_{fuel}} = \frac{147.65}{9.76} = 15.12$$

D.9 Excess Air Coefficient

$$\lambda = \frac{\left(\dfrac{A}{F}\right)_{actual}}{\left(\dfrac{A}{F}\right)_{stioc}} = \frac{15.12}{14.389} = 1.05$$

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$$\phi = \frac{1}{\lambda} = \frac{1}{1.05} = 0.95$$

D.10 Volumetric Efficiency (%)

$$V_s = \frac{\pi.D^2.S}{4} = \frac{\pi \times 0.104^2 \times 0.115}{4} = 9.76 \times 10^{-4} \text{ m}^3$$

$$\rho_{std} = \frac{P_{std}}{R_{air}.T_{std}} = \frac{101.325}{0.287 \times 293} = 1.205 \text{ kg/m}^3$$

$$\dot{m}_{ath} = \frac{\rho_{std}.V_s.N_{speed}.i.2.60}{j} = \frac{1.205 \times 9.76 \times 10^{-4} \times 1900 \times 4 \times 2 \times 60}{4} = 268.39 \text{ kg/h}$$

$$\eta_v = \frac{\dot{m}_{air}}{\dot{m}_{ath}} = \frac{147.65}{268.39} = 0.55 = 55\%$$

D.11 Thermal Efficiency (%)

$$\eta_{th} = \frac{P_b \times 3600}{Q_L \times \dot{m}_{fuel} \times 1.341} = \frac{48.49 \times 3600}{42000 \times 9.76 \times 1.341} = 0.31 = 31\%$$

D.12 Dilution Tunnel Flow Rate (m³/h)

$$\dot{V}_{dt} = (639.784 + 84.8454 P_{dt} - 0.802568 P_{dt}^2)0.06$$

$$\dot{V}_{dt} = (639.784 + 84.8454 \times 2.2 - 0.802568 \times 2.2^2)0.06 = 49.34 \text{ m}^3/\text{h}$$

D.13 Exhaust Gas Flow Rate (m³/h)

$$\rho_{air} = \frac{P_{atm} \times 0.1333224}{R_{air} \times (T_{abm} + 273.15)} = \frac{744 \times 0.1333224}{0.277 \times (23.2 + 273.15)} = 1.166 \text{ kg/m}^3$$

$$\dot{V}_{air} = \frac{\dot{m}_{air}}{\rho_{air}} = \frac{147.65}{1.166} = 126.6 \text{ m}^3/\text{h}$$

$$\dot{V}_{exh} = \dot{V}_{air} + 0.77\,\dot{m}_{fuel}$$

$$\dot{V}_{exh} = 126.6 + 0.77 \times 9.76 = 134.11\,m^3/h$$

$$\dot{V}_{exd} = \dot{V}_{air} - 0.75\,\dot{m}_{fuel}$$

$$\dot{V}_{exd} = 126.6 - 0.75 \times 9.76 = 119.28\,m^3/h$$

D.14 Dilution Ratio

$$A_p = \frac{\pi \times (0.013)^2}{4} = 1.3273229 \times 10^{-4}\,m^2 \;,\; A_s = \frac{\pi \times (0.06)^2}{4} = 2.82743339 \times 10^{-4}\,m^2$$

$$r = \frac{A_p}{A_t} = \frac{1.3273229 \times 10^{-4}}{2.82743339 \times 10^{-4}} = 0.04694$$

$$q = \frac{\dot{V}_{dt}}{\dot{V}_{exh}.r} = \frac{49.34}{134.11 \times o.o4694} = 7.837$$

D.15 Equivalent Diluted Exhaust Gas Flow Rate (m³/h)

$$\dot{V}_{EDF} = \dot{V}_{exh} \times q = 134.11 \times 7.837 = 1051.02\,m^3/h$$

D.16 Particulate Mass Flow Rate (g/h)

$$V_{SAM} = \frac{V_{vp} \times t_s \times 1.69906}{3600} = \frac{1 \times 120 \times 1.69906}{3600} = 0.056\,m^3$$

$$PT_{mass} = \frac{P_f \times \dot{V}_{EDF}}{V_{SAM} \times 1000} = \frac{1.1 \times 1051.02}{0.056} = 20.41\,g/h$$

D.17 Particulate Emission (g/HP-h

$$PT_e = \frac{PT_{mass}}{P_b} = \frac{20.41}{48.49} = 0.42\,g/HP\text{-}h$$

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D.18 HC Emissions Mass Flow Rate (g/h)

$$HC_{mass} = \frac{\rho_{HC} \, x \, HC_{conc} \, x \, \overset{.}{V}_{EDF}}{1000} = \frac{0.619 x 8 x 1051.02}{1000} = 5.204 \text{ g/h}$$

D.19 HC Emissions (g/HP-h)

$$HC_e = \frac{HC_{mass}}{P_b} = \frac{5.204}{48.49} = 0.107 \text{ g/HP-h}$$

After all mode 13 calculation, the mean emissions is found using weight factor (see 4.36 formula)

APPENDIX E

TECHNICAL DRAWINGS

In this Appendix, technical drawings of parts manufactured in the Work Shop of Mechanical Engineering Department of the Middle East Technical University. If the part composed of many manufactured parts, an assembly drawing is supplied together with each part manufactured.
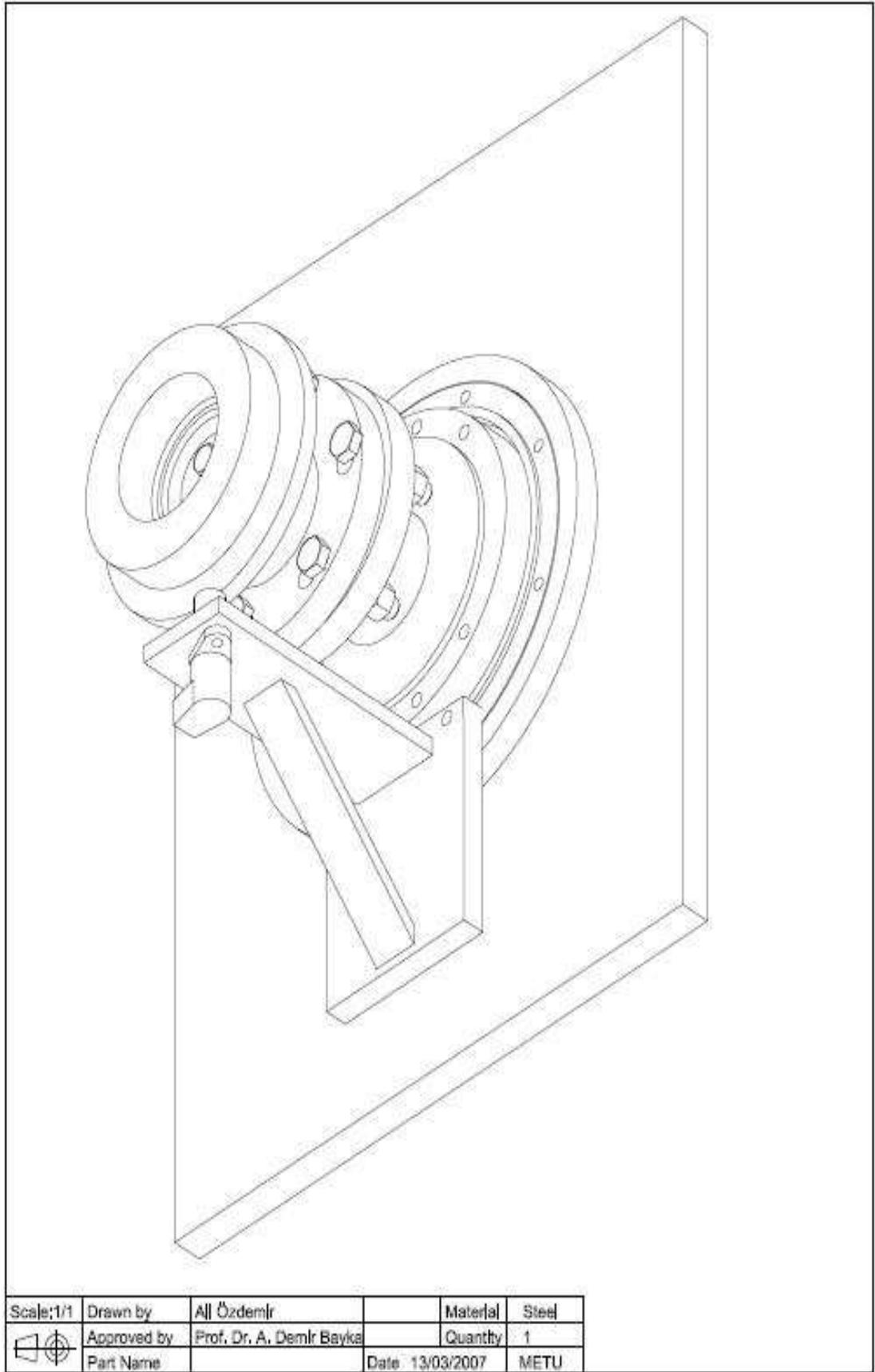
Figure E.1: Assembly Drawing of the Engine Speed Sensor
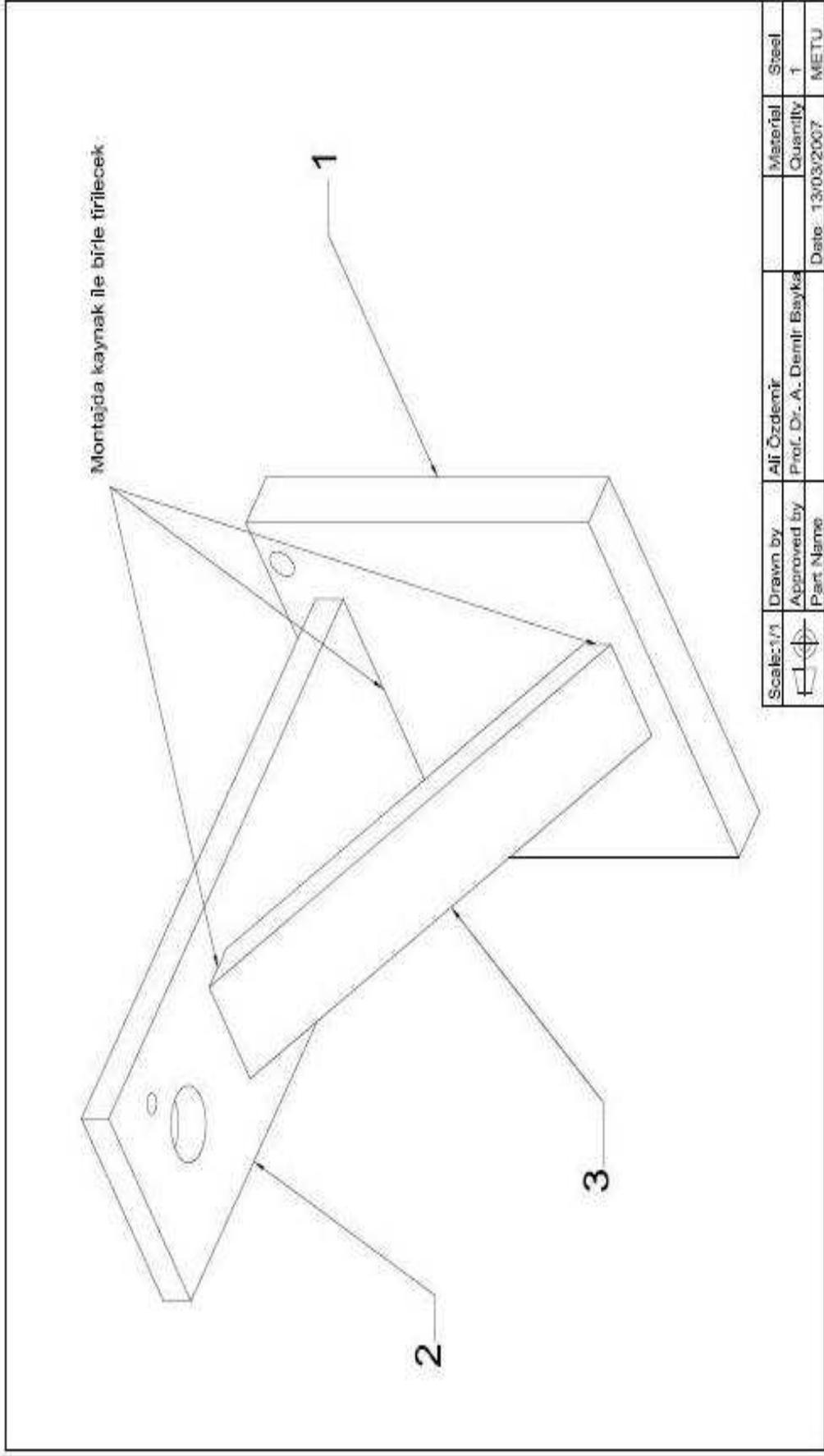
Figure E.2: Assembly Drawing of the Engine Speed Sensor Holder
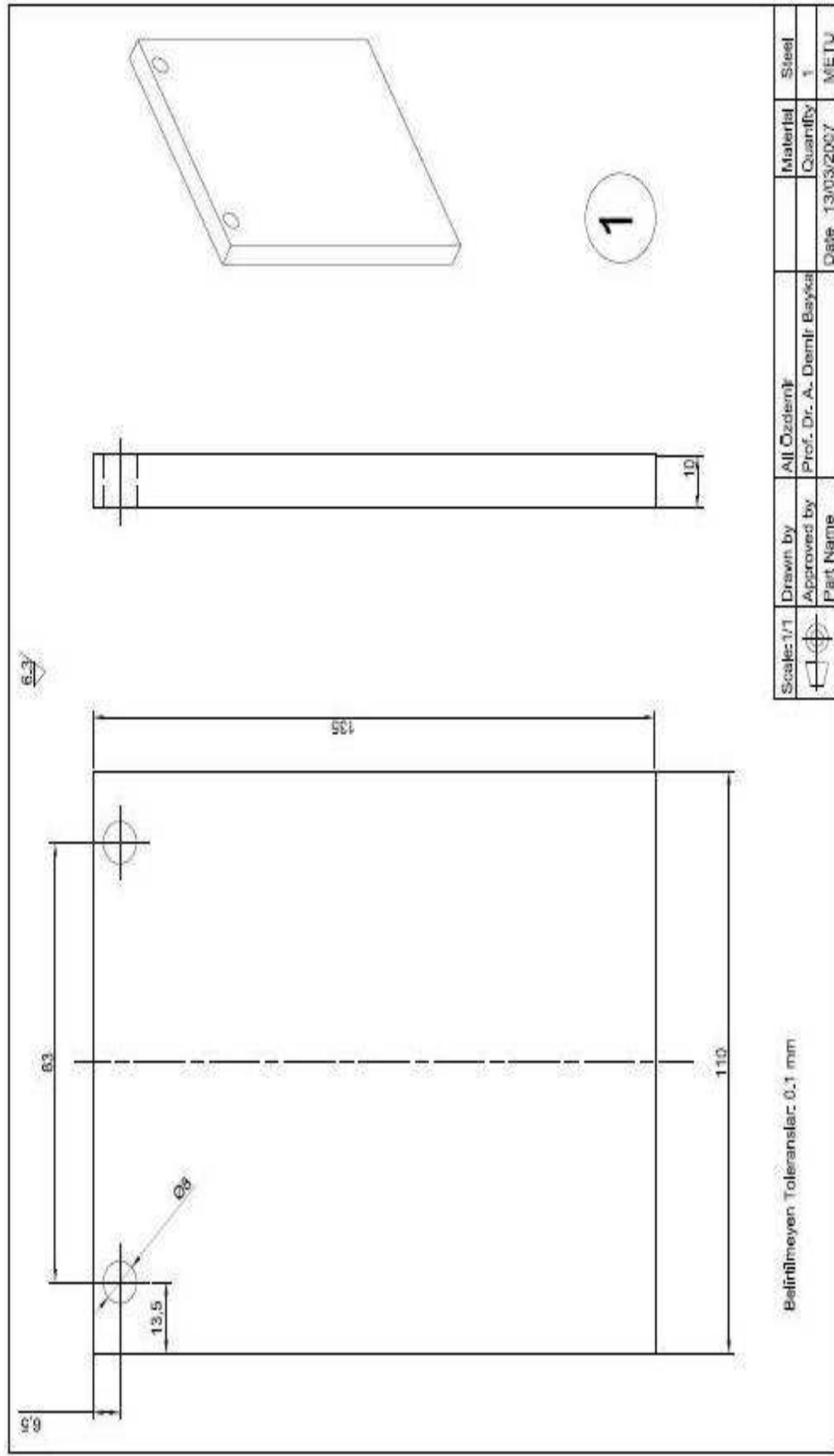
Figure E.3: Technical Drawing of the Back Board
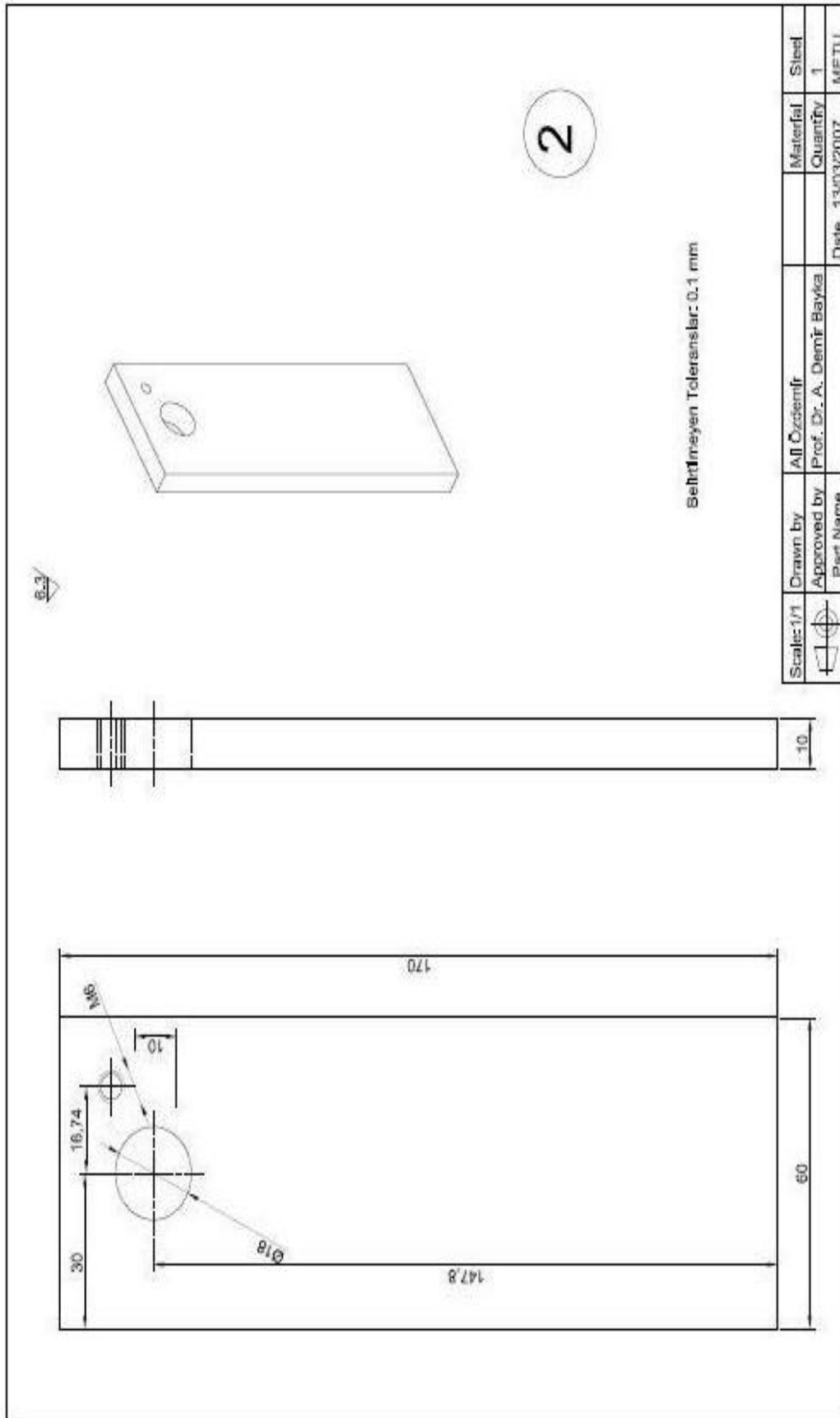
Figure E.4: Technical Drawing of the Base Plate
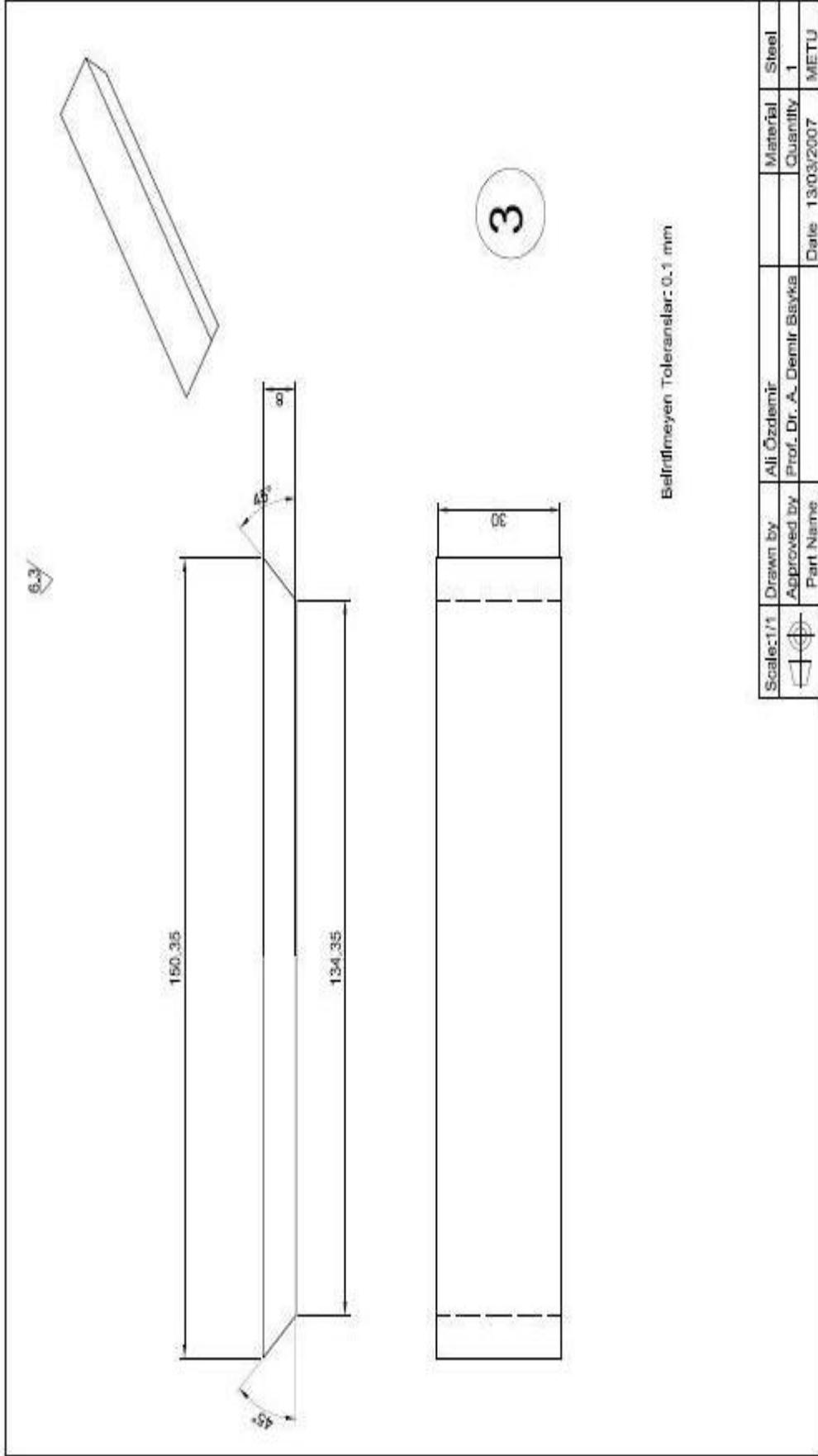
Figure E.5: Technical Drawing of the Angle Tie
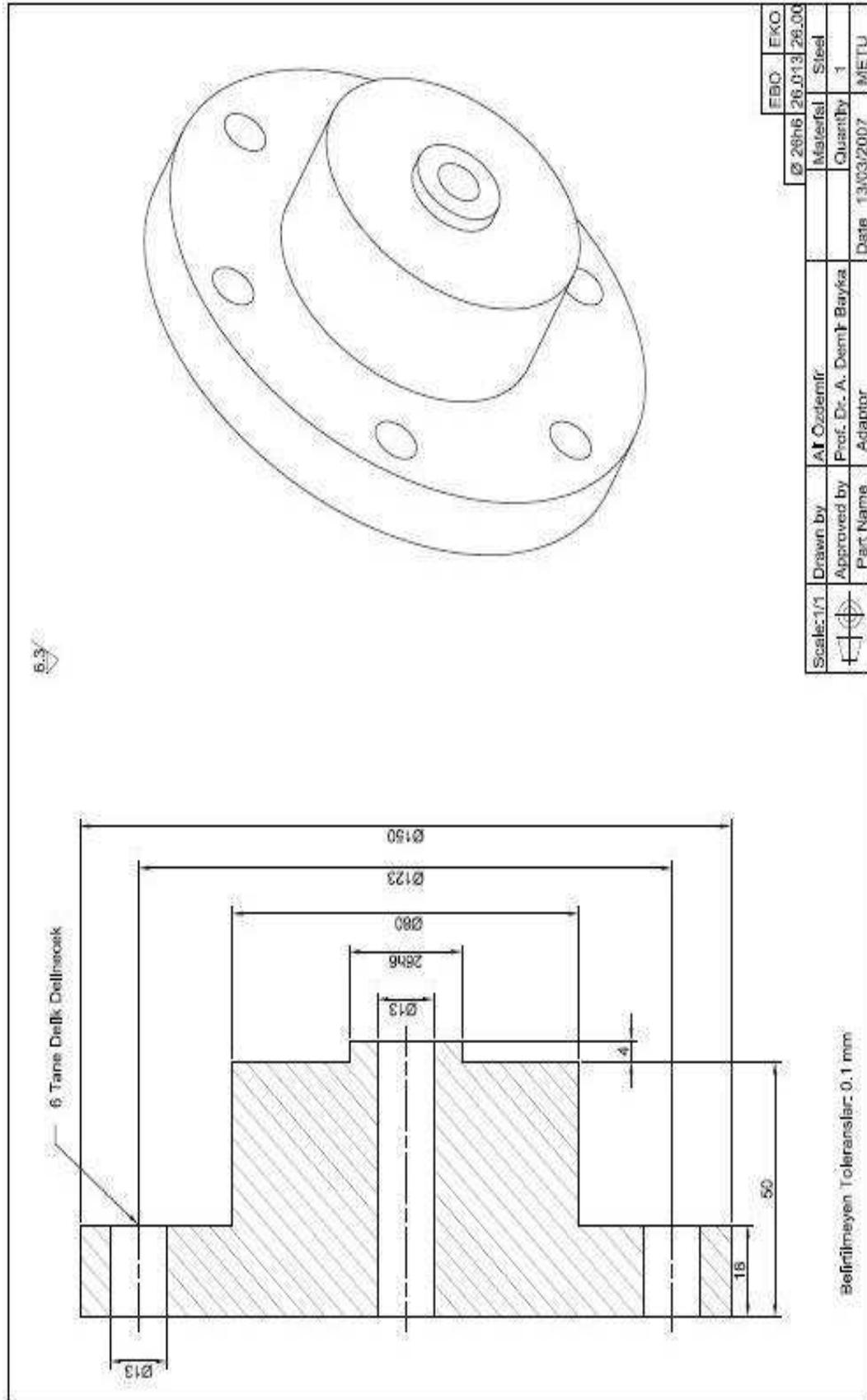
Figure E.6: Technical Drawing of Flange of Speed Sensor

SCALE 0.400

Drawn By	Ali Á–zdemir			Material	
Approved By	Prof. Dr. A. Demir Bayka		Quantity	Date	
Part Name					METU
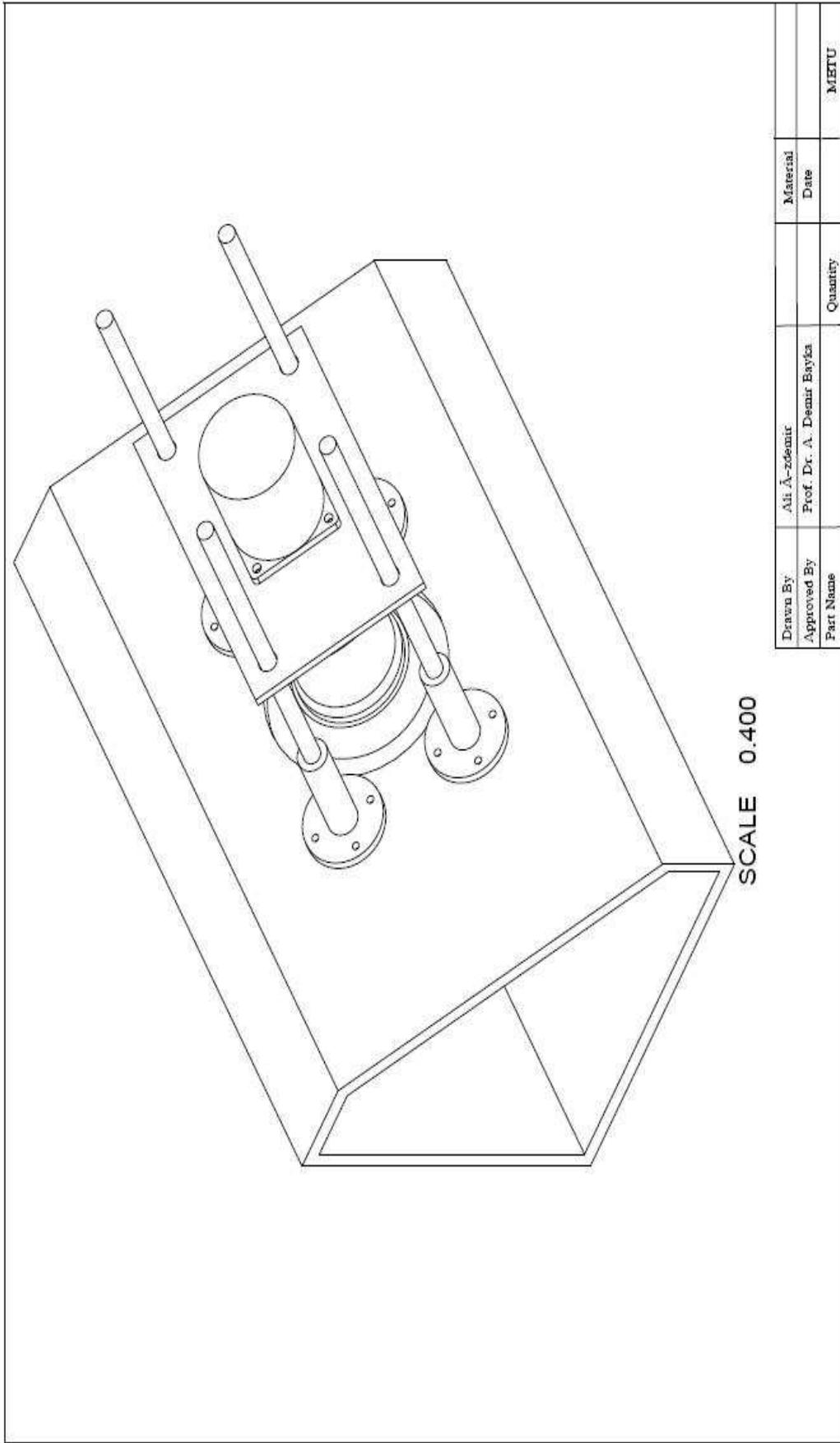
Figure E.7: Assembly Drawing of the Loading Mechanism

SCALE 1.000

SCALE 1.000

SECTION A-A

M4

∅6.5

∅14

∅6

∅4

∅9

∅75

6

18

28

12

25

Drawn By	Ali Å-zdemir		Material	Aluminum
Approved By	Prof. Dr. A. Demir Bayka		Date	27/6/2007
Part Name	Adoptor	Quantity	1	METU
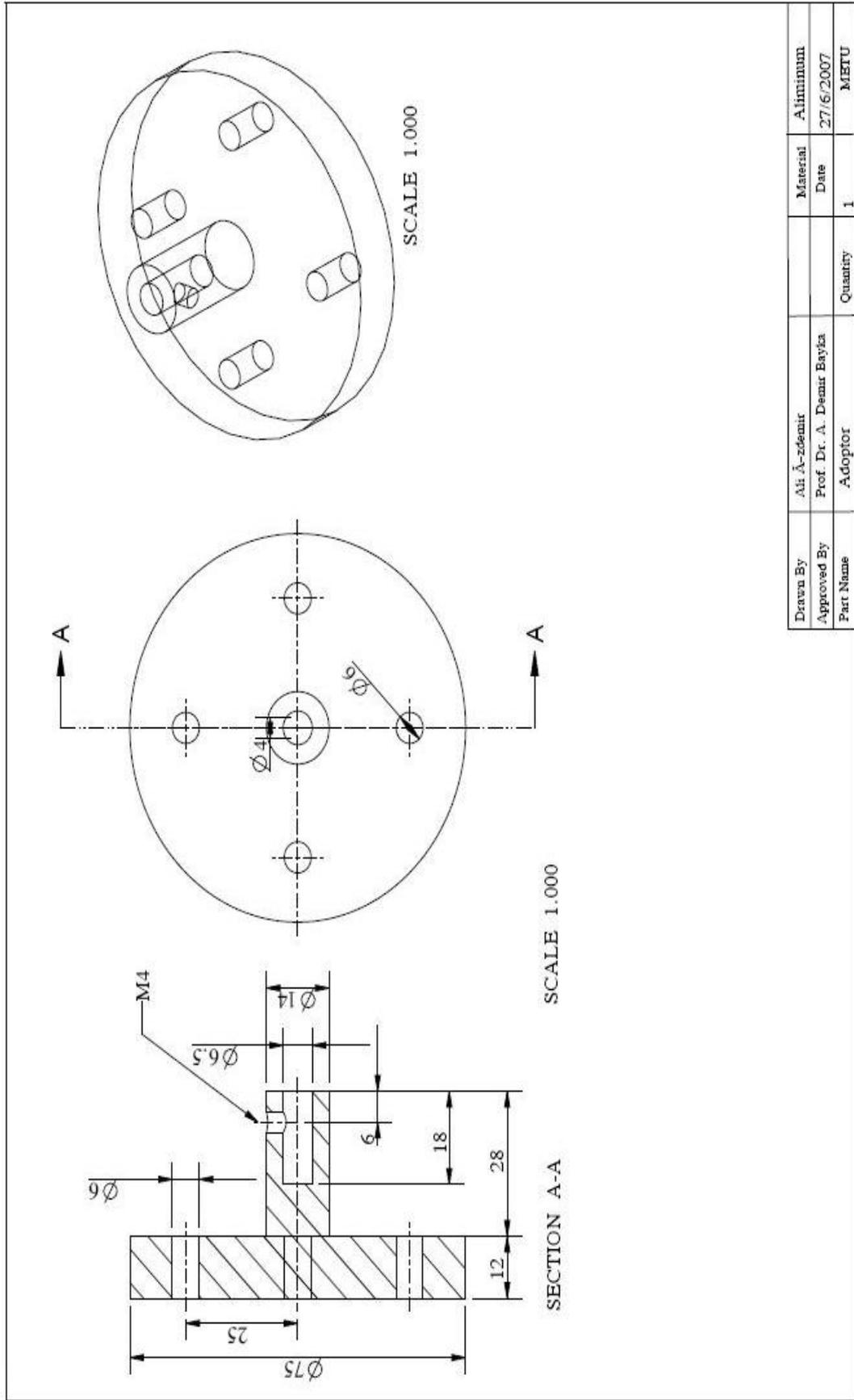
Figure E.8: Technical Drawing of Flange of Loading Mechanism
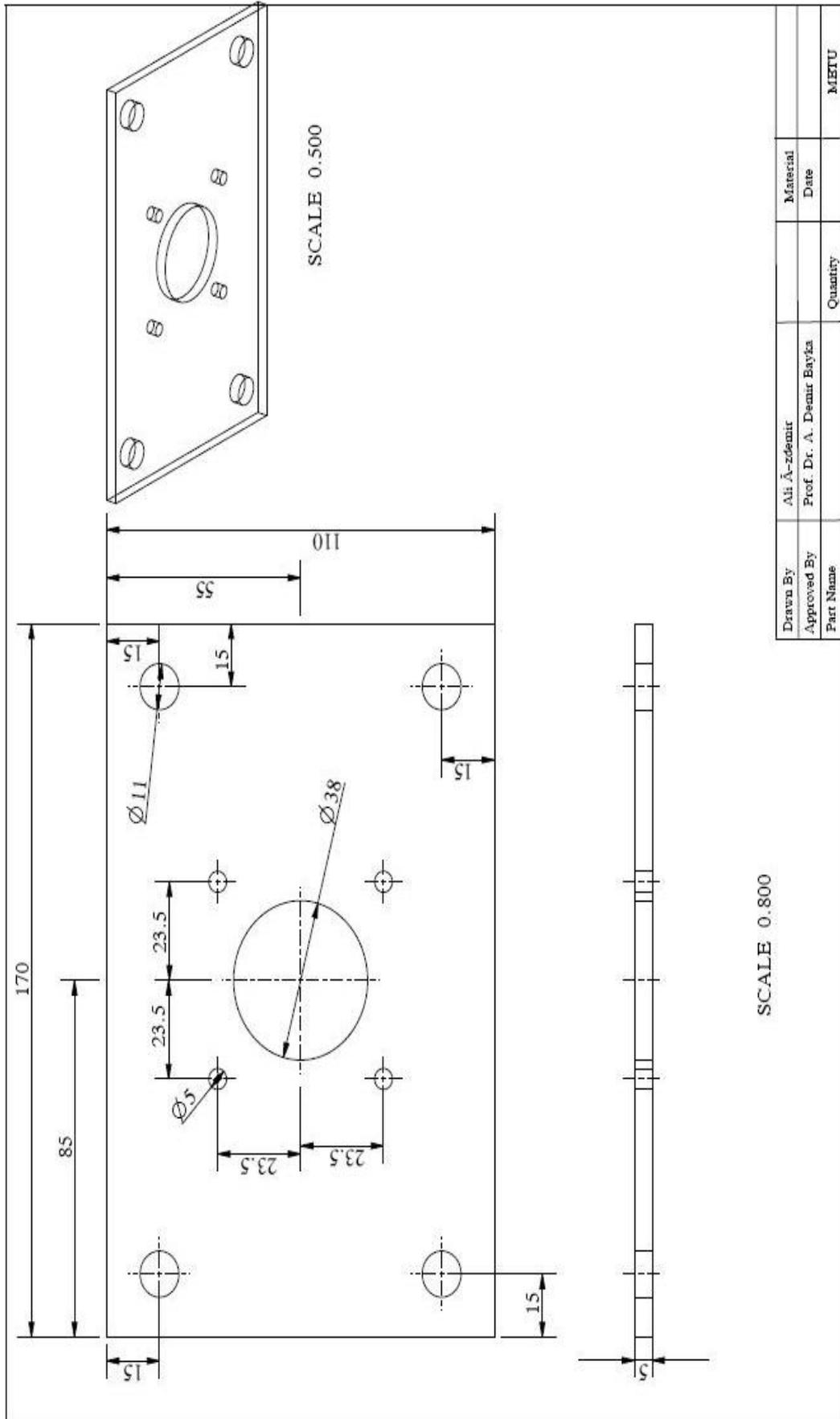
Figure E.9: Technical Drawing of Stepper Engine Support

SCALE 0.500

SCALE 0.800

SCALE 1.500

SECTION A-A
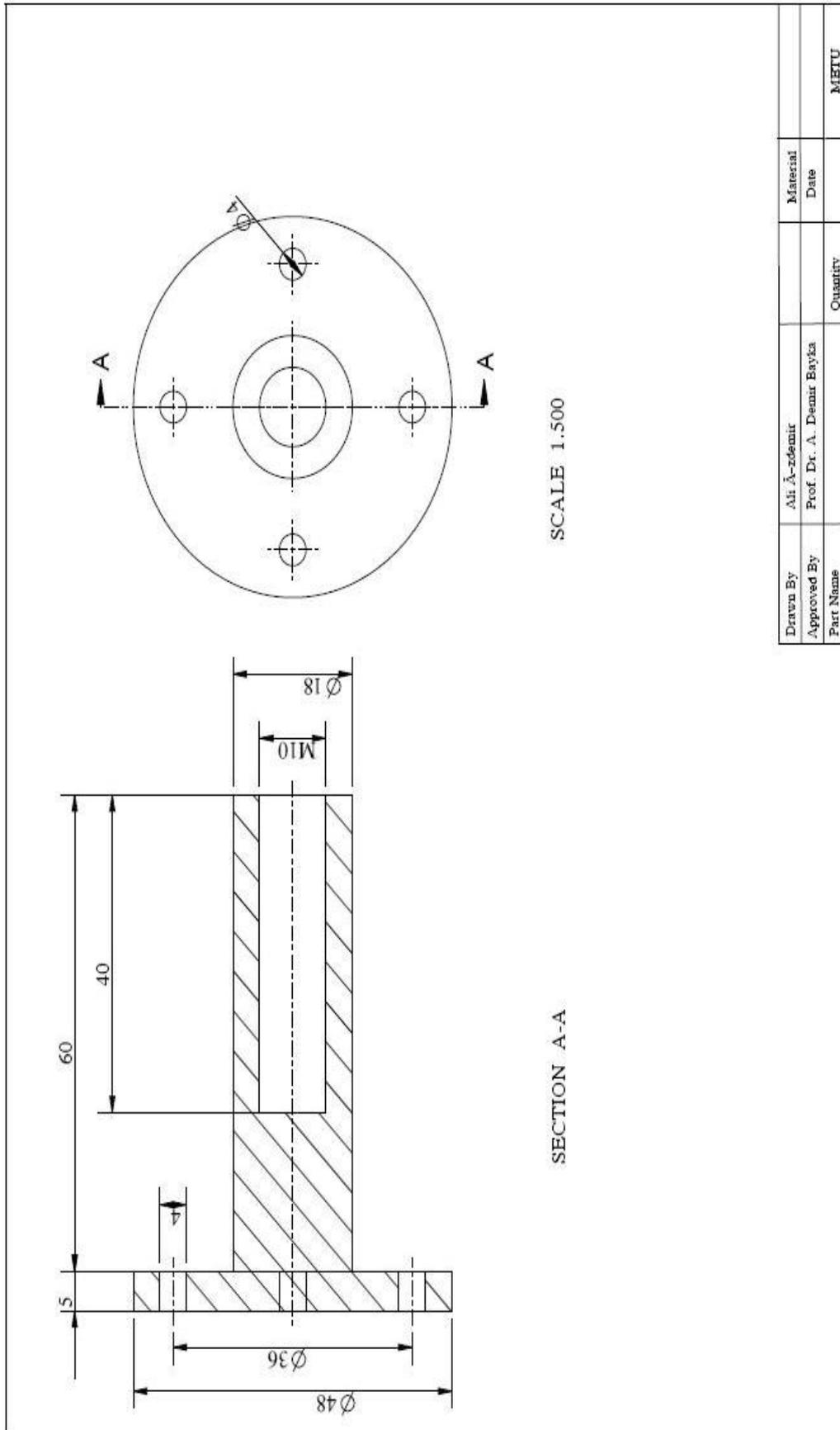
Figure E.10: Technical Drawing of Holder of Stud Bolt

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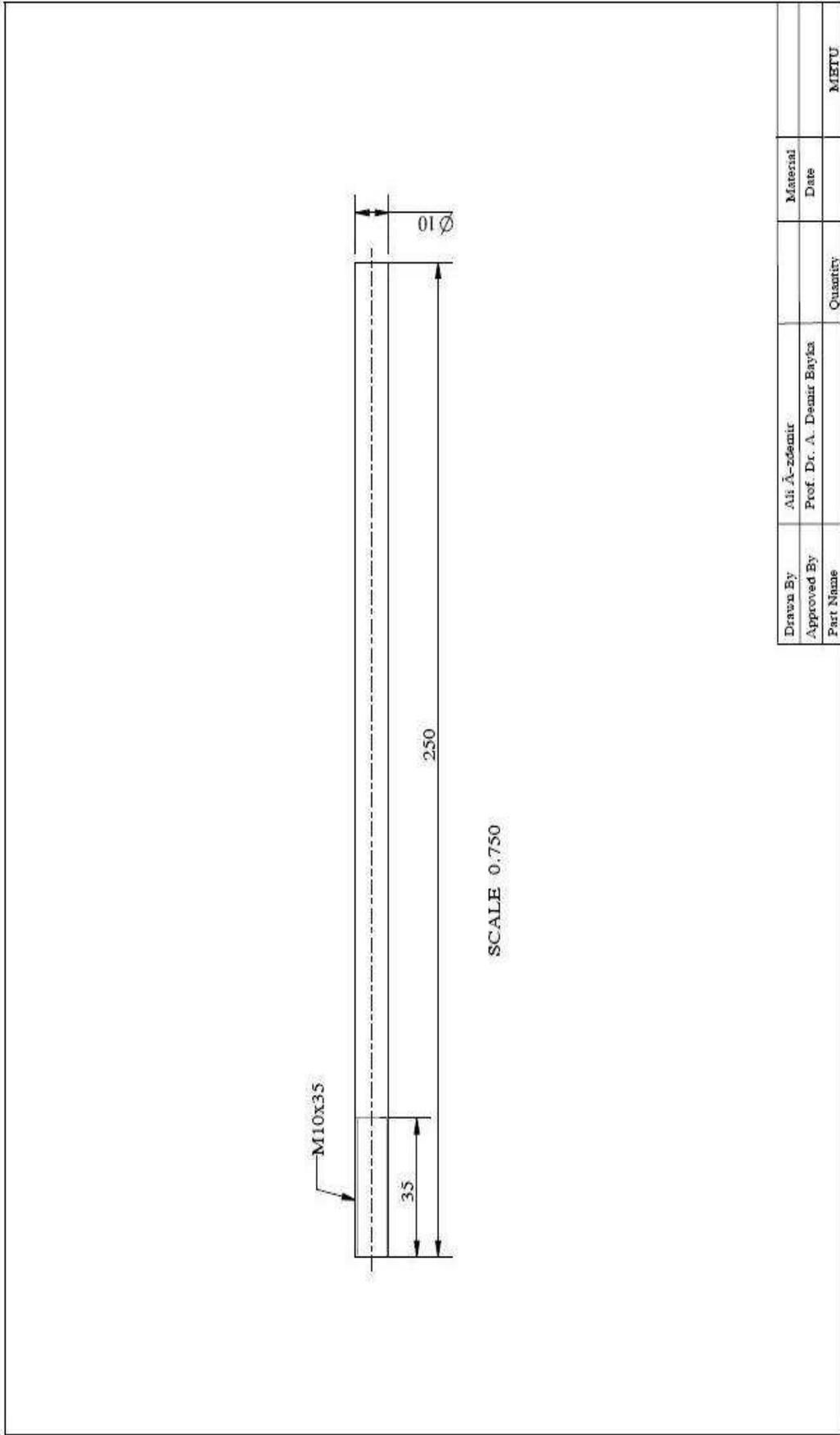
Figure E.11: Technical Drawing of Stud Bolt
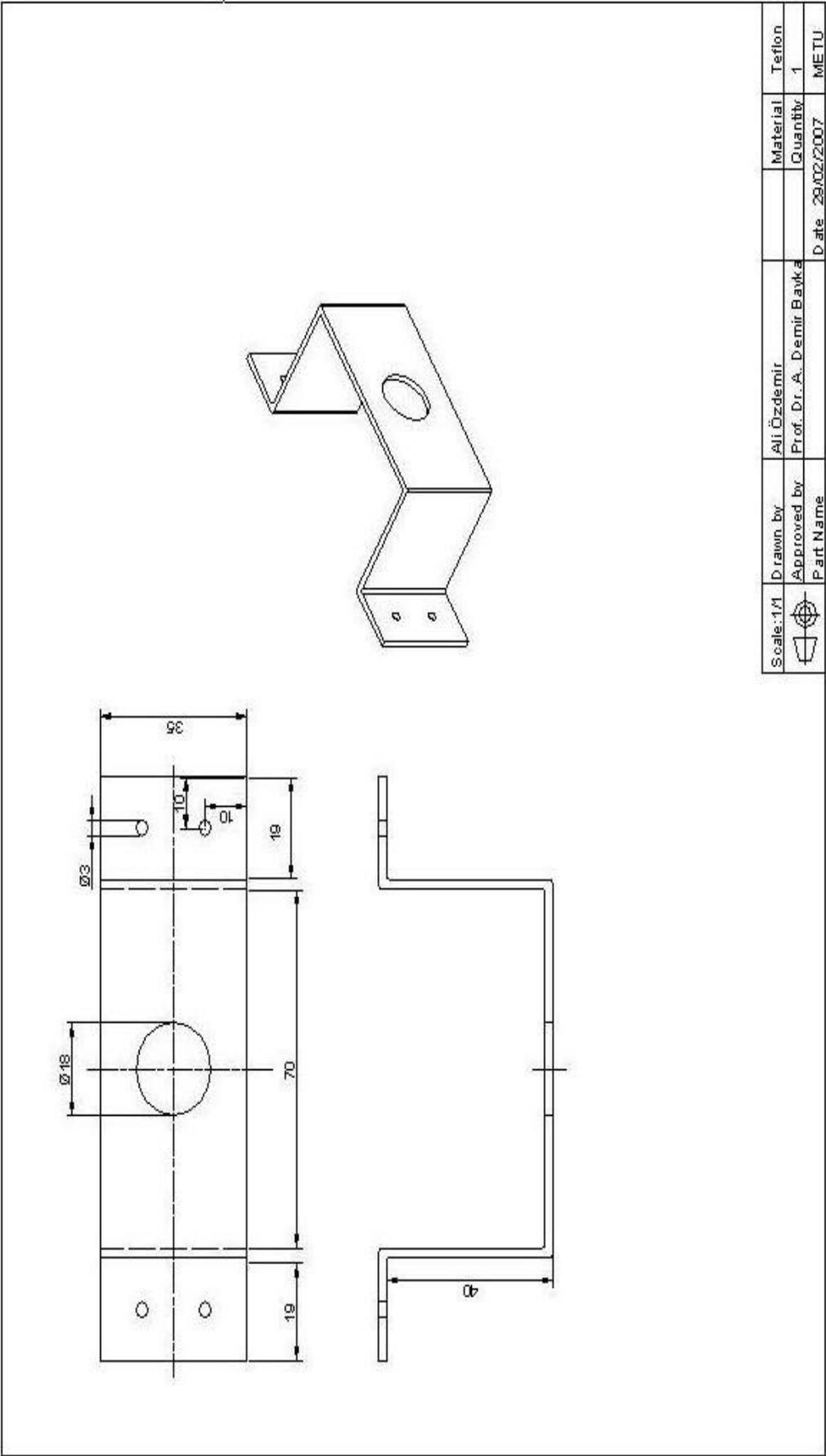
Figure E.12: Technical Drawing of Capacitive Sensor Holder

146
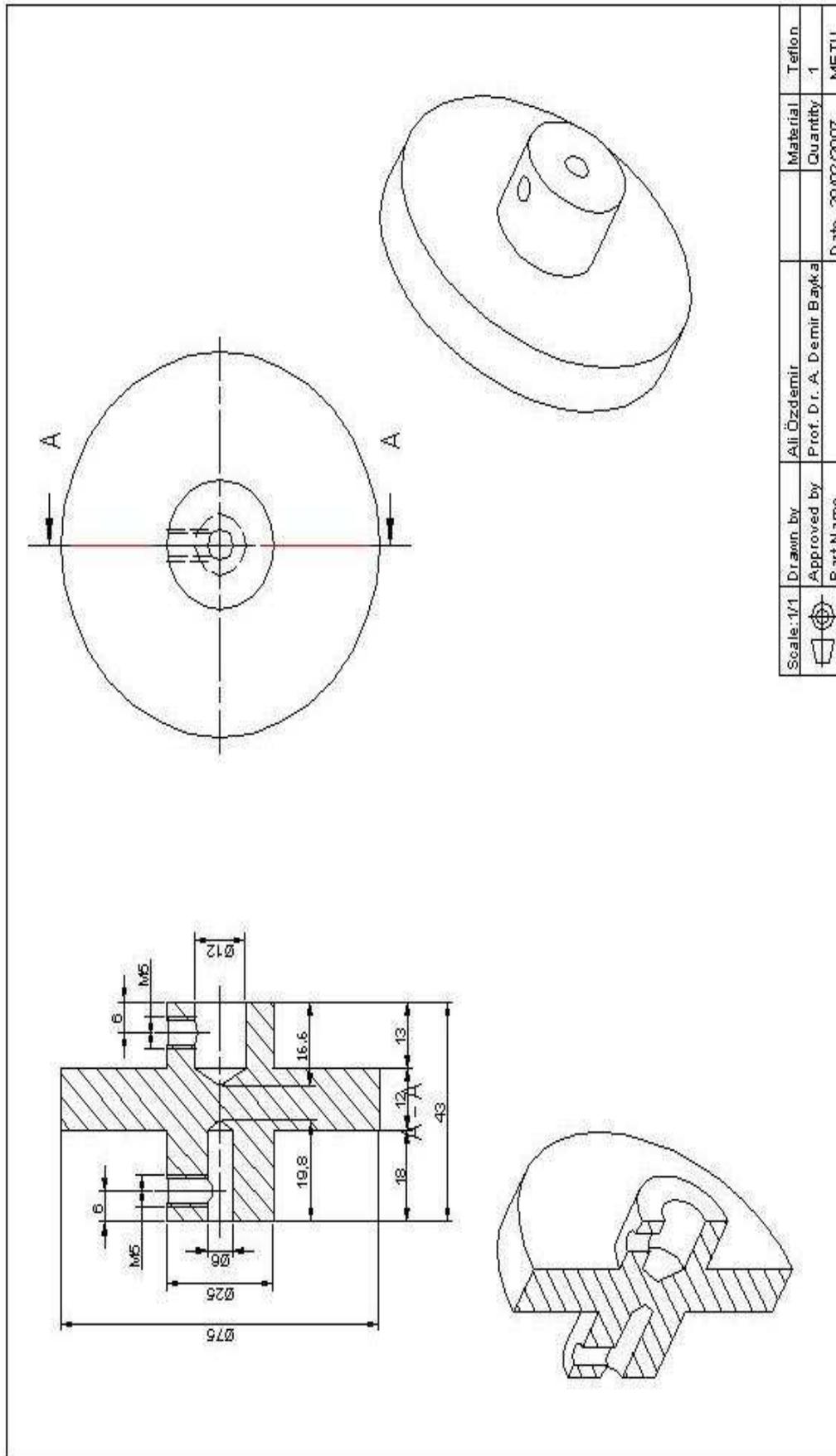
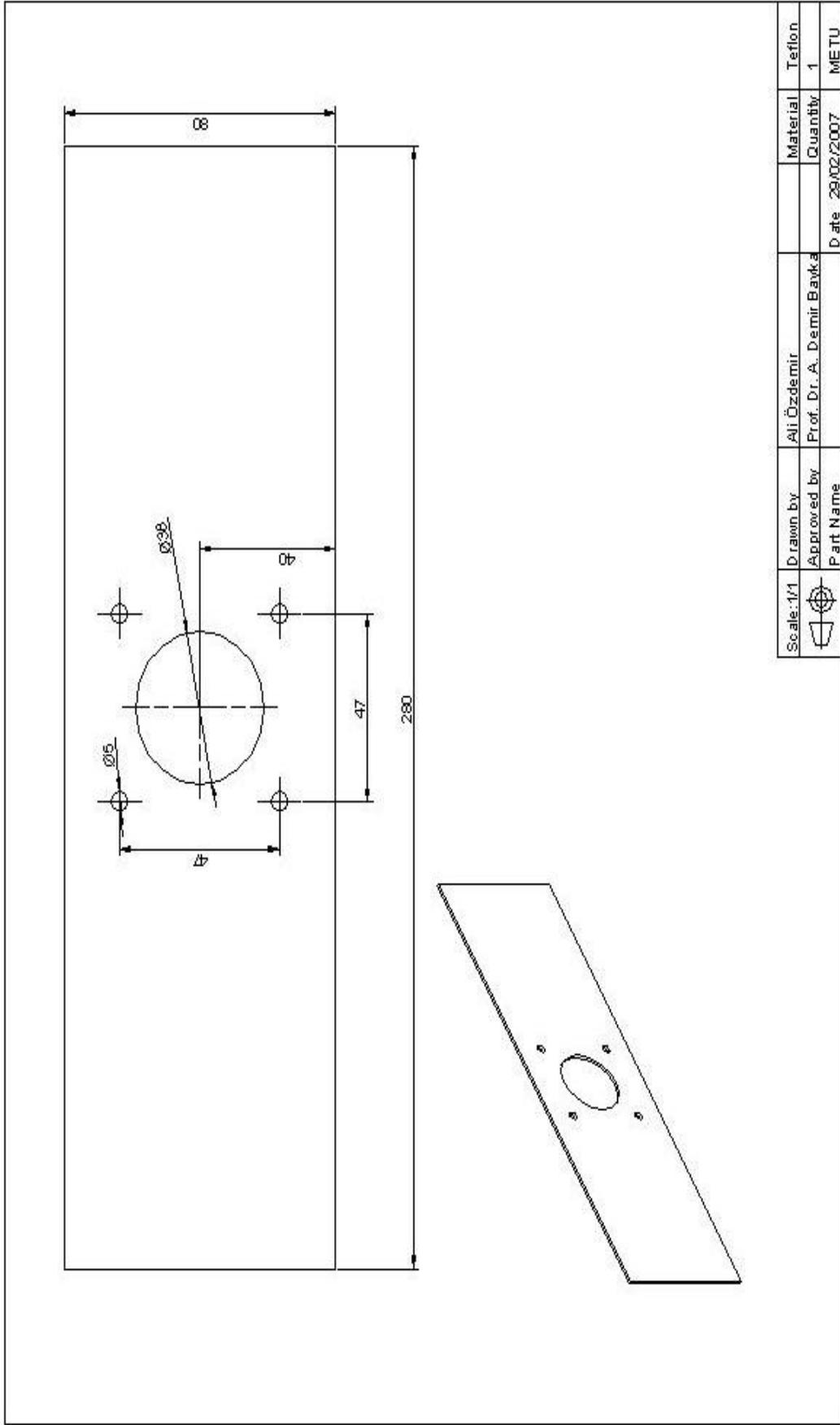**Figure E.13:** Technical Drawing of the Adaptor of Dilution Tunnel Stepper Motor

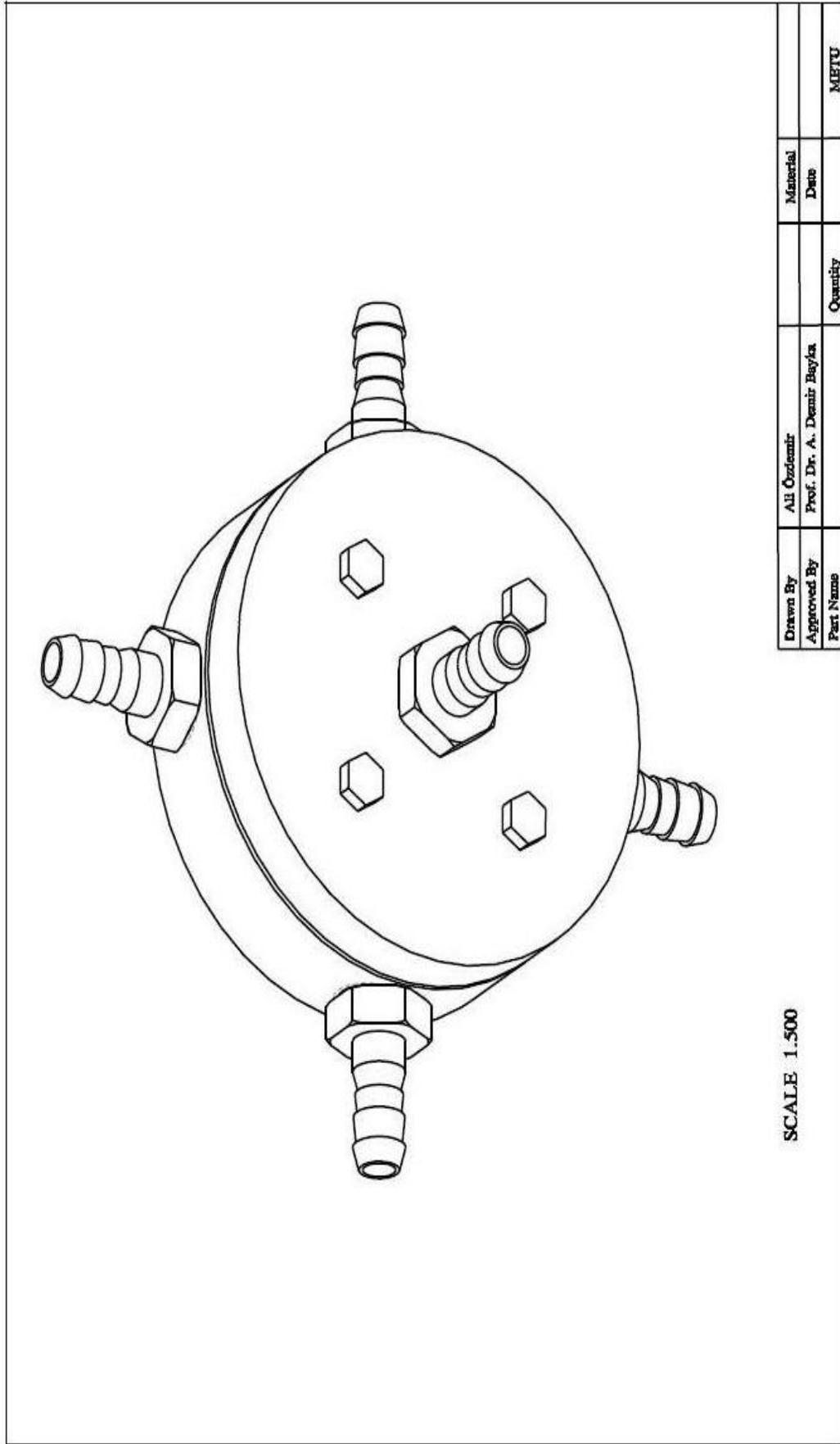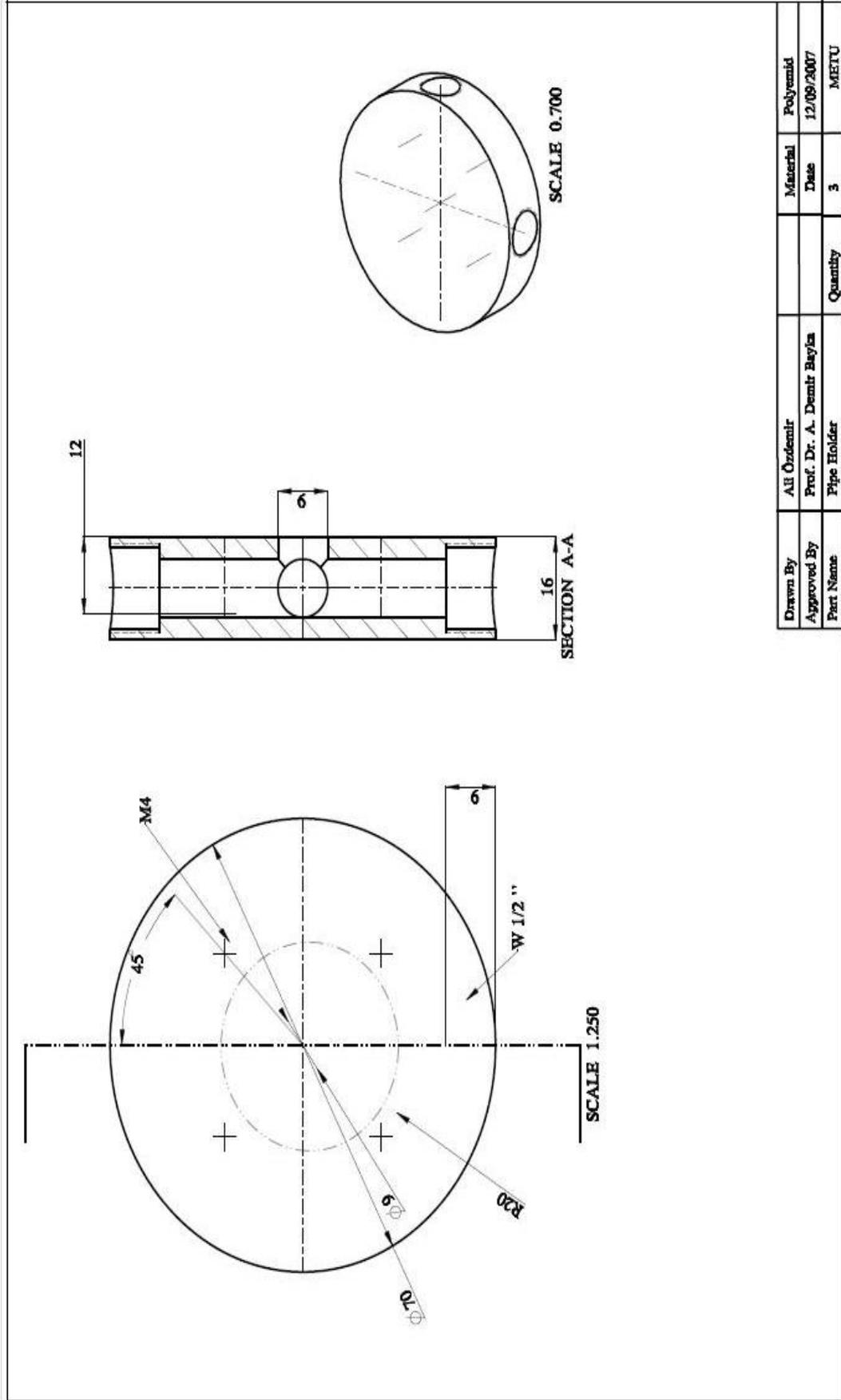**Figure E.14:** Technical Drawing of the Support of ;Dilution Tunnel Stepper Motor

The table in the drawing (rotated):

Drawn By	Ali Özdemir		Material		
Approved By	Prof. Dr. A. Demir Bayka	Quantity	Date		MBTU
Part Name					

SCALE 1.500

Figure E.15: Assembly drawing of the Support of Input/Output Port

Figure E.16: Technical Drawing of the Support of Pipe Holder
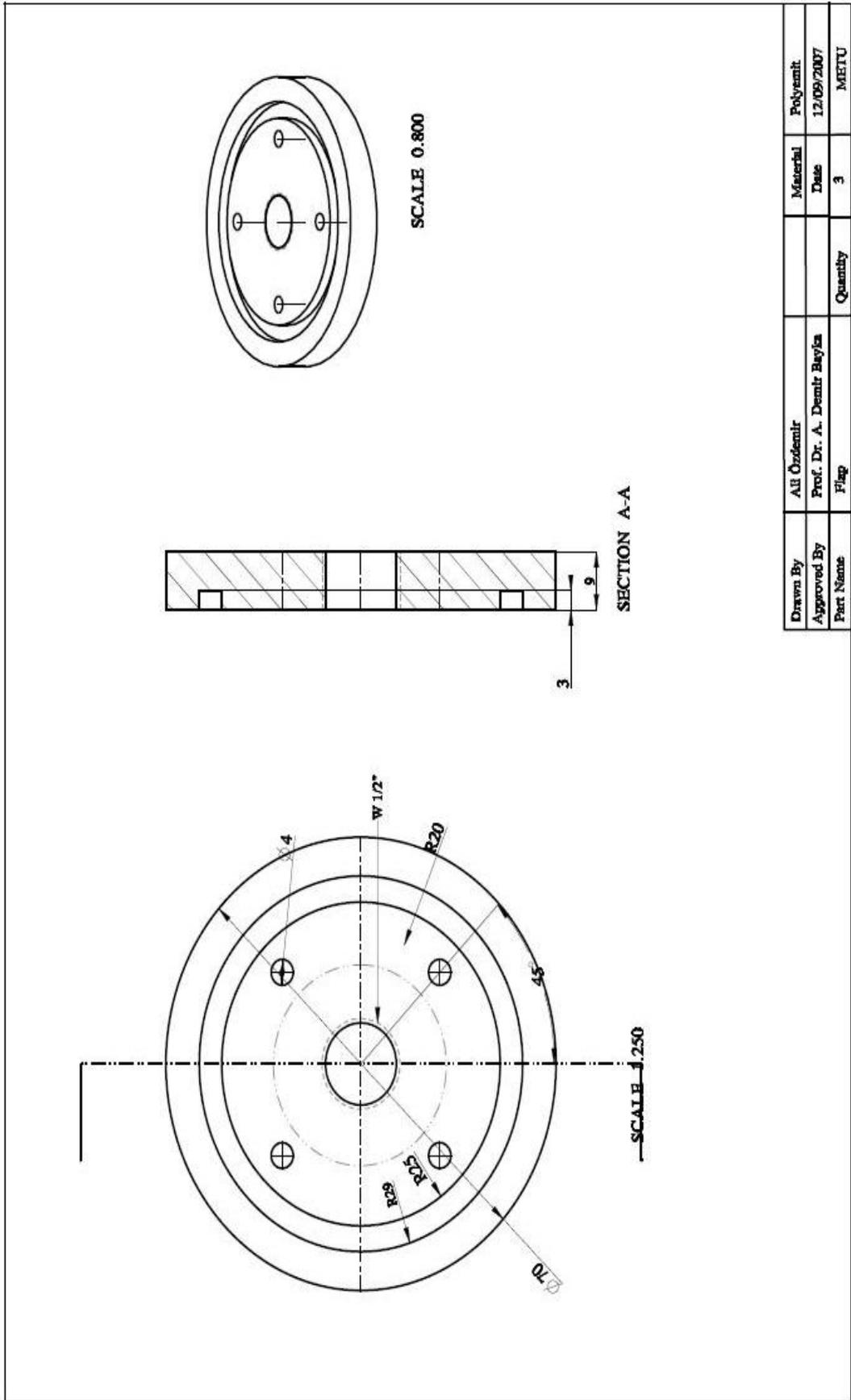
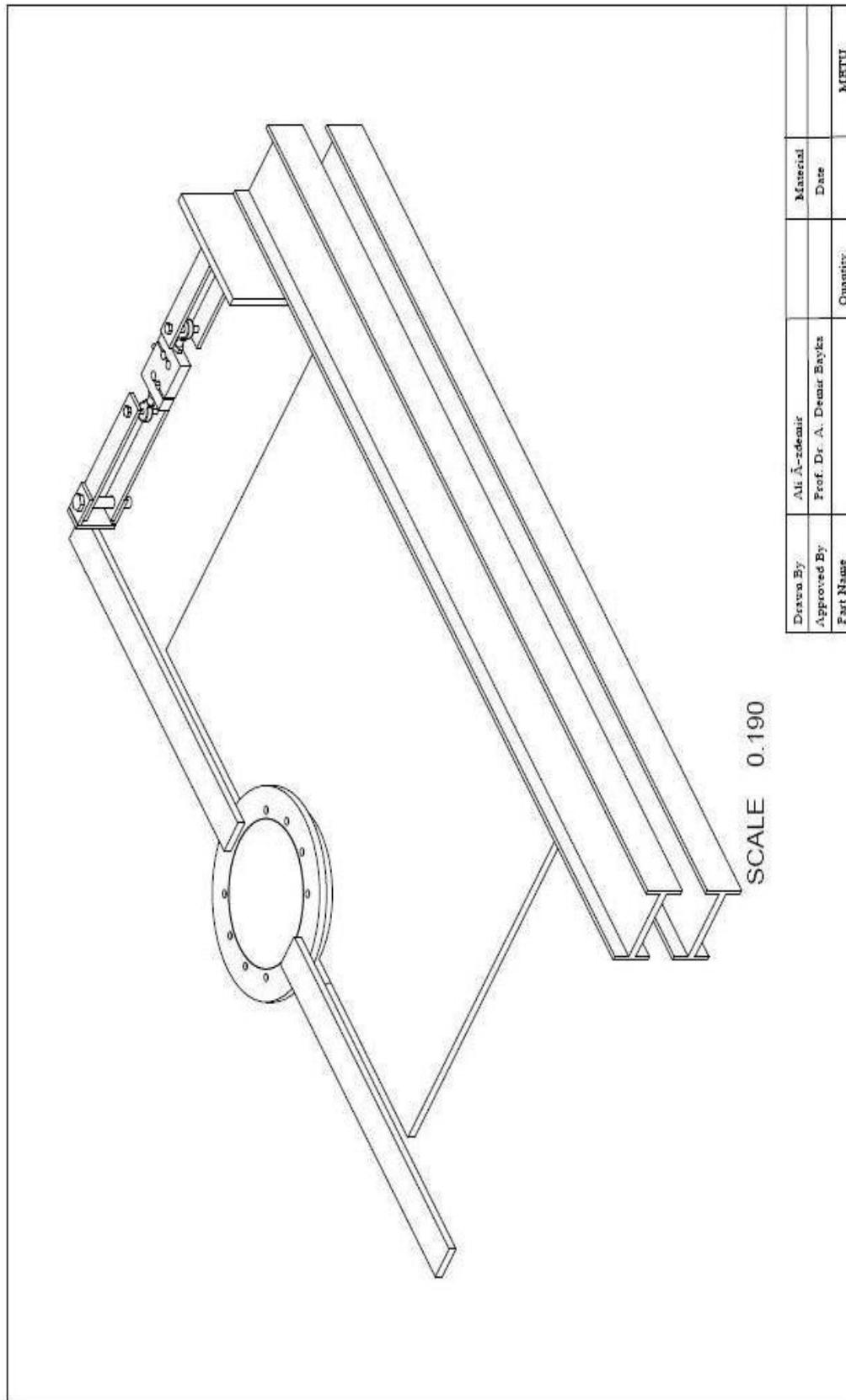**Figure E.17:** Technical Drawing of the Support of Flap

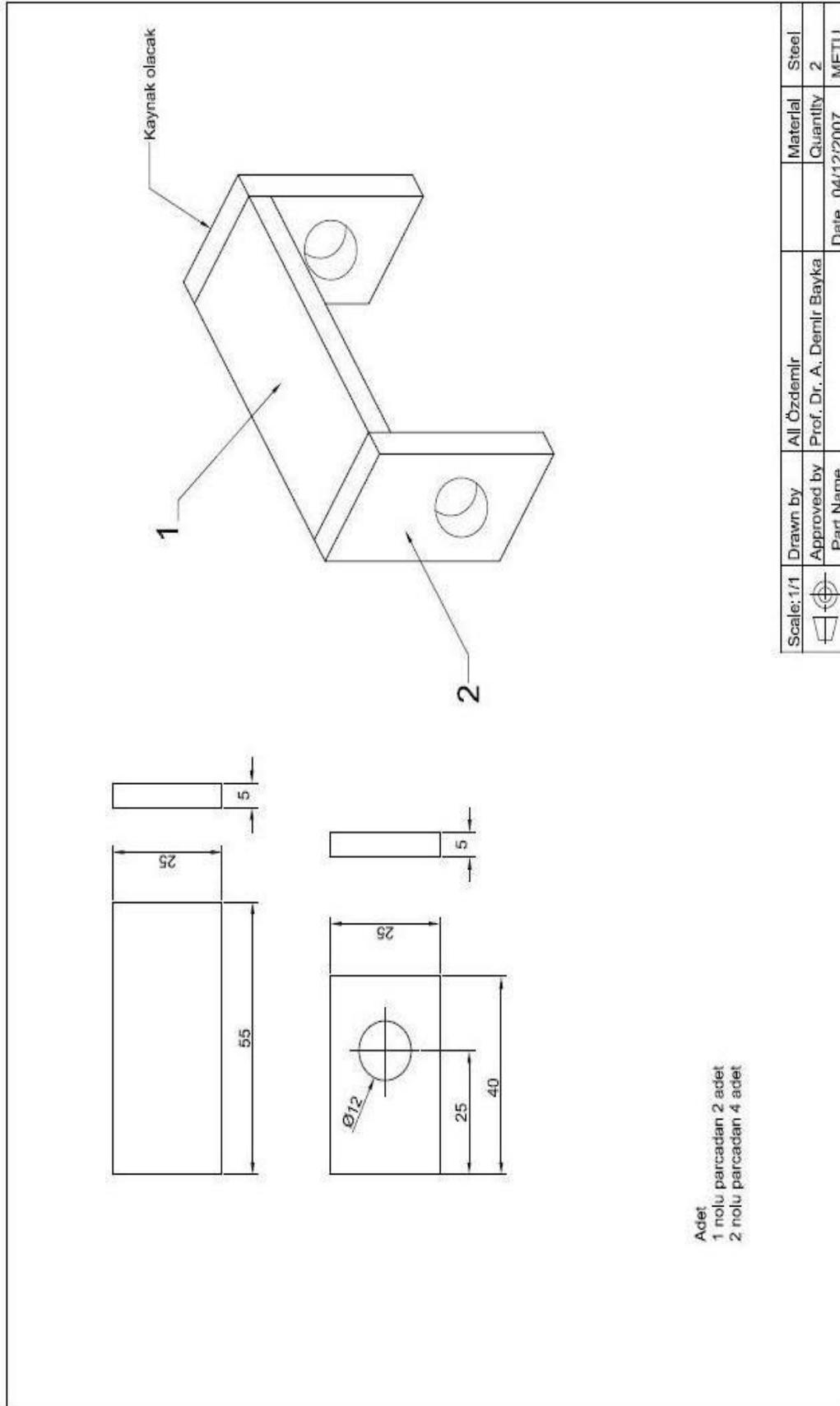**Figure E.18:** Assembly Drawing of the Load-Cell

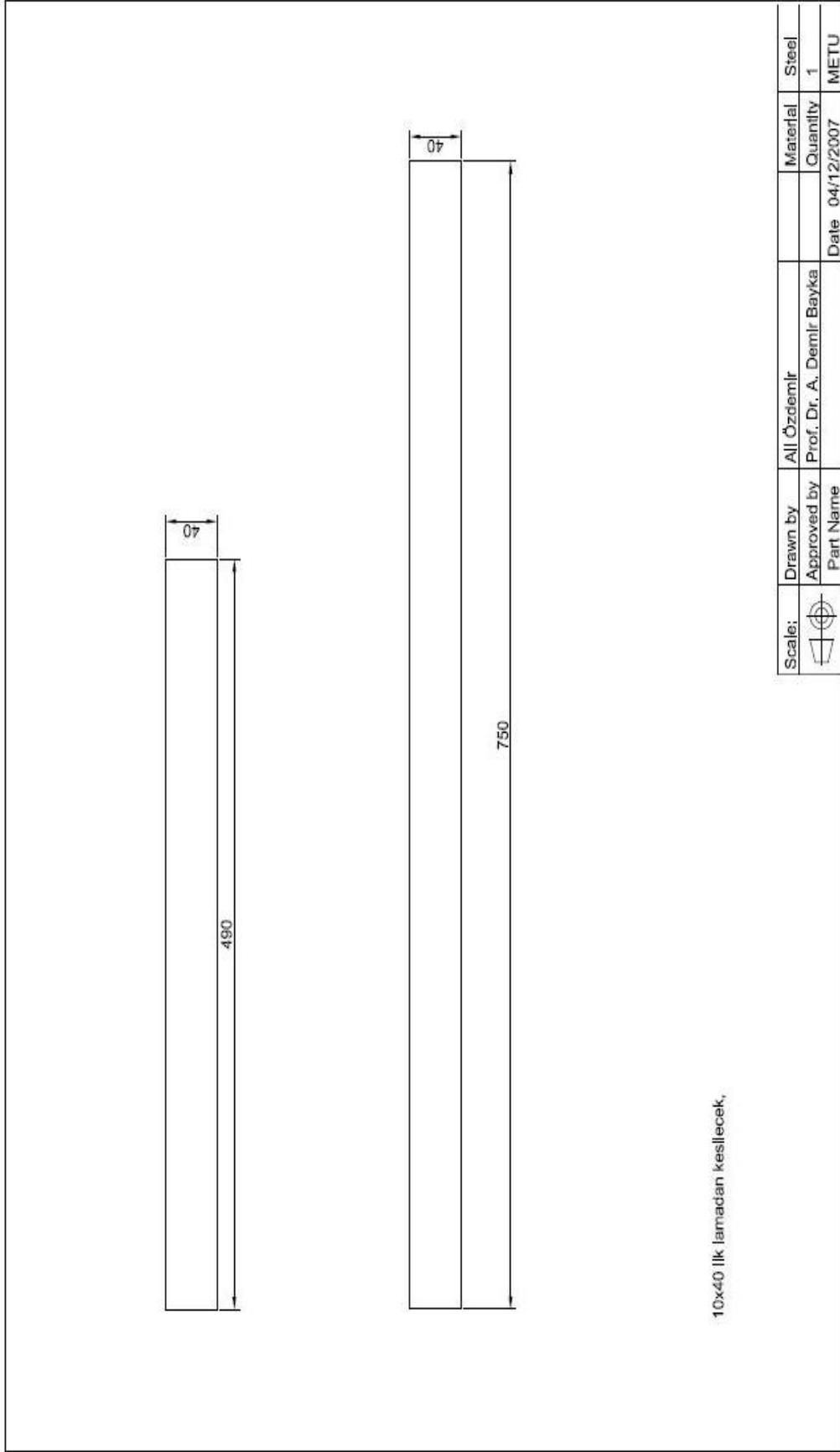**Figure E.19:** Technical Drawing of Load-Cell Collection
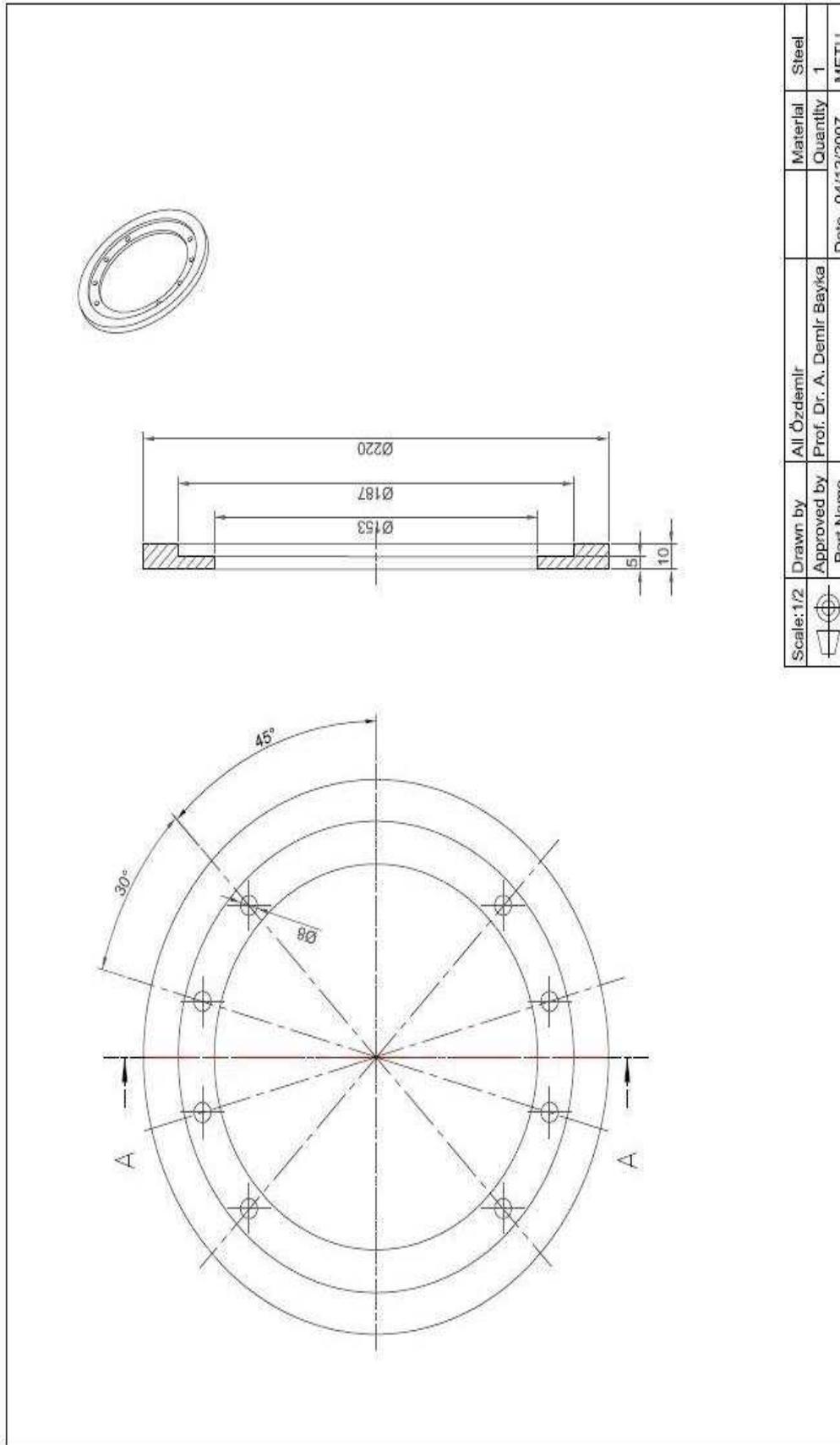
Figure E.20: Technical Drawing of Load-Cell Arm

Figure E.21: Technical Drawing of Load-Cell Flange

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APPENDİX F

EXPERIMENTAL MEASURING DEVICES' SPECIFICATION

HBM LOAD CELL

Dimensions (in mm; 1 mm= 0.03937 inches)

Cable 7.6 m, $\varnothing \sim 5$ mm
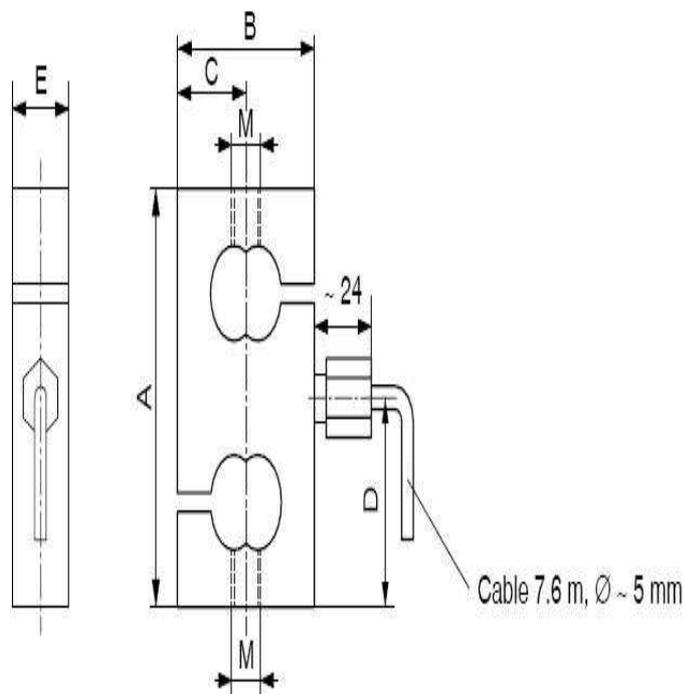
E_{max} RSCA...	A	B	C	D	E	M
50 kg; 100 kg	62	50.8	25.4	31	15	M8x1.25
200 kg; 500 kg; 1 t	87.3	57.2	28.6	43.7	24	M12x1.75
2 t	100	69.8	34.9	50	30.2	M24x2
5 t	100	76.2	38.1	50	36.6	M24x2

Figure F.1: Dimensions of the Load-Cell

Table F.1: Specifications of the Load-Cell

Technical Data

Type		RSCA C1						
Accuracy class according to OIML R 60 Max. numbers of load cell intervals (n_{LC})		C1 1000						
Nominal (rated) capacity (E_{max})		50 kg	100 kg	200 kg	500 kg	1 t	2 t	5 t
Minimum LC verification interval (v_{min})	% of E_{max}	0.0286						
Sensitivity (C_n)	mV/V	2						
Sensitivity tolerance	%	± 0.2500						
Temperature effect on sensitivity (TK_C) [1]	% of C_n / 10 K	± 0.0230 [1]						
Temperature effect on zero signal (TK_0)		± 0.0400						
Hysteresis error (d_{hy}) [1]	% of C_n	± 0.0500 [1]						
Non-Linearity (d_{lin}) [1]		± 0.1000 [1]						
Creep (d_{cr}) 30 min.		± 0.0490						
Input resistance (R_{LC}) (nominal)	Ω	350						
Output resistance (R_0)		350 ± 1.5						
Reference excitation voltage(U_{ref})	V	5						
Nominal range of excitation voltage (B_U)		0.5 ... 12						
Insulation resistance (R_{is})	GΩ	> 5						
Nominal range of ambient temperature (B_T)	°C [°F]	–10 ... +40 [+14 ... +104]						
Service temperature range (B_{tu})		–30 ... +70 [–22 ... +158]						
Storage temperature range (B_{tl})		–50 ... +85 [–58 ... +185]						
Limit load (E_L)	% of E_{max}	150						
Breaking load (E_d)		250						
Permissible dynamic load (F_{srel}) (vibration amplitude according to DIN 50100)		70						
Deflection at E_{max} (s_{nom}), approx.	mm	0.15				0.25	0.38	0.46
Weight (G) with cable, approx.	kg	0.4		0.77			1.6	1.8
Protection class accord. to EN60529 (IEC529)		IP65 (tightened test conditions 1 m water column / 30 min.)						
Material: Measuring body / Application sealing Cable fitting / Cable sheath		stainless steel / Polyurethane stainless steel, gasket from Perbunan / Polyurethane						

[1] The data for Non–Linearity (d_{lin}), Hysteresis error (d_{hy}) and Temperature effect on sensitivity (TK_C) are typical values. The sum of these data meets the requirements according to OIML R60.

ELIMKO AMPLIFIER SPECIFICATIONS
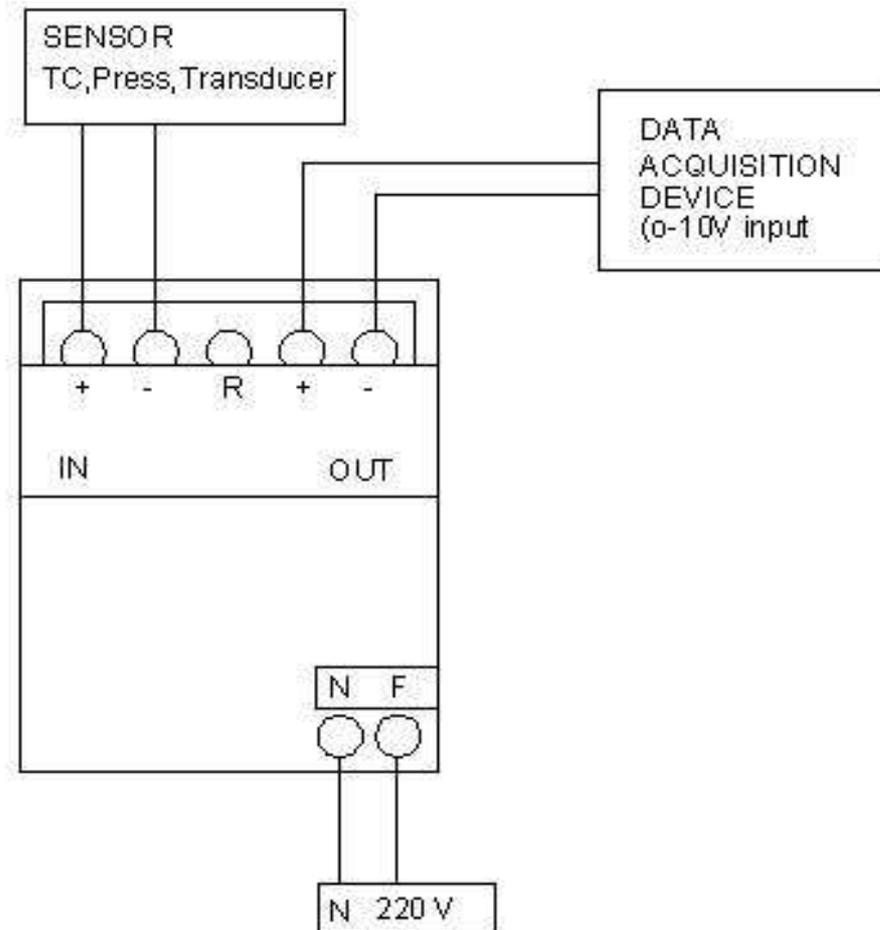

Figure F.2: ELIMKO Amplifier Connections

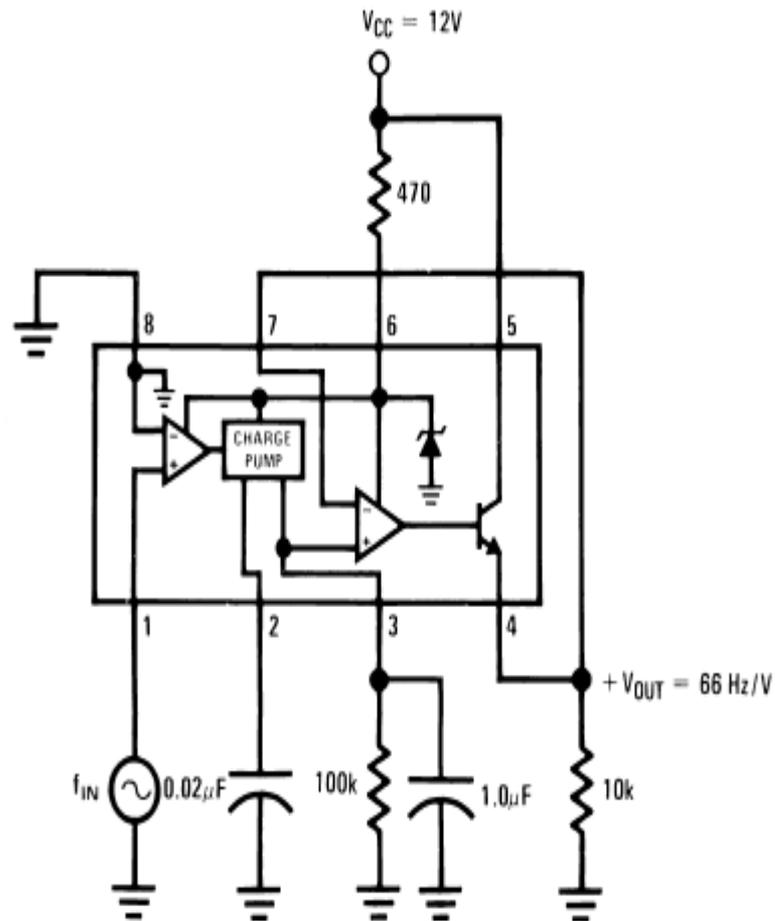SPECIFICATIONS of E-75v

Input Impedance :> 1 Mohm
Output Voltage   : 0-10 V
Hysteresis   : %0.1
Nonlinearly   : %0.1
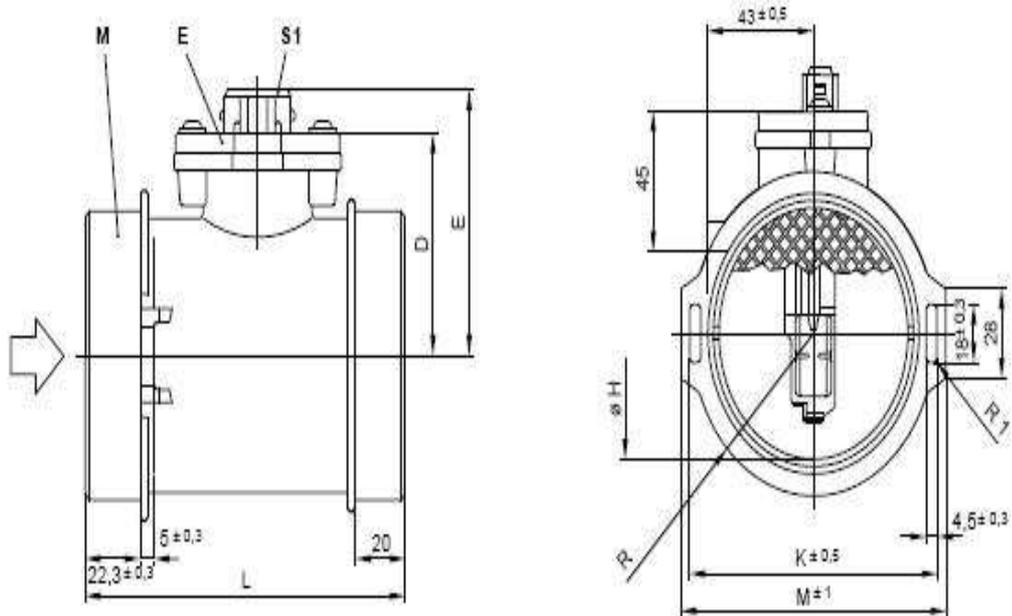Operation Temp   : Between -10^oC and -40^oC

Figure F.3: Speed Sensor Circuit Scheme

AIR MASS METER

Dimension drawings.
E Plug-in sensor, M Measurement venturi, S1/S2 Plug connection

Ø A	Ø B	C	D	E	H	K	L	M	R	Measurement venturi	Plug-in connection	Part number
60	66	70	73	86	33	75	130	82	37	KS	S1	0 280 217 102
70	76	50	69	82	34.8	–	96	–	42	KS	S1	0 280 217 107
70	76	70	69	82	33.5	85	130	92	42	KS	S2	0 280 217 120
80	86	70	73	86	39	–	130	–	–	KS	S2	0 280 217 519
95.6	102	70	76.2	91.2	45	110	130	117	54	Alu	S1	0 280 217 801
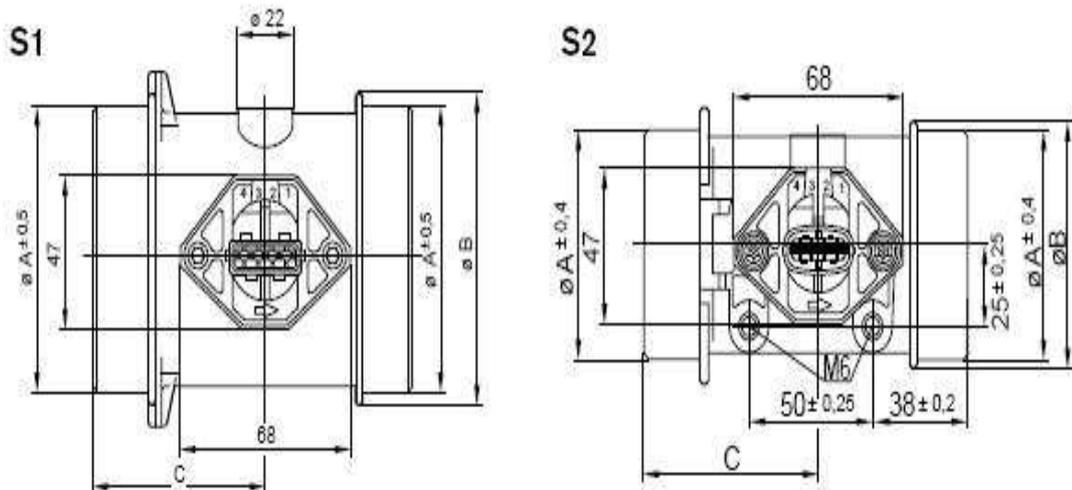
Figure F.4: Dimension of the Air Mass Meter

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Table F.2: Specifications of the Air Mass Meter

Technical data / range

Nominal supply voltage U_N	14 V
Supply-voltage range U_V	8...17 V
Output voltage U_A	0...5 V
Input current I_V	< 0.1 A
Permissible vibration acceleration	≤ 150 ms^{-2}
Time constant τ_{63} [1]	≤ 15 ms
Time constant τ_Δ [2]	≤ 30 ms
Temperature range	–40...+120 °C [3]

Part number	0 280 217 123	0 280 218 019	0 280 217 531	0 280 218 008	0 281 002 421
Measuring range Q_m	8...370 kg/h	10...480 kg/h	12...640 kg/h	12...850 kg/h	15...1000 kg/h
Accuracy [4]	≤ 3%	≤ 3%	≤ 3%	≤ 3%	≤ 3%
Fitting length L_E	22 mm	22 mm	22 mm	16 mm	22 mm
Fitting length L_A	20 mm	20 mm	20 mm	16 mm	20 mm
Installation length L	96 mm	96 mm	130 mm	100 mm	130 mm
Connection diam. D	60 mm	70 mm	80 mm	86/84 mm [6]	92 mm
Venturi ID	50 mm	62 mm	71 mm	78 mm	82 mm
Pressure drop at nominal air mass [5]	< 20 hPa	< 15 hPa	< 15 hPa	< 15 hPa	< 15 hPa
Temperature sensor	Yes	Yes	Yes	No	Yes
Version	1	2	3	4	5

[1] In case of sudden increase of the air-mass flow from 10 kg · h^{-1} auf 0,7 $Q_{m\,nominal}$, time required to reach 63% of the final value of the air-mass signal.

[2] Period of time in case of a throughflow jump of the air mass | $\Delta\,m/m$ | ≤ 5%.

[3] For a short period up to +130 °C.

[4] |$\Delta Q_m/Q_m$|: The measurement deviation ΔQ_m from the exact value, referred to the measured value Q_m.

[5] Measured between input and output

[6] Inflow/outflow end

Function diagram with connector-pin assignment.
1 Additional temperature sensor ϑ_u (not on version 4, Part number 0 280 218 008),
2 Supply voltage U_V, 3 Signal ground, 4 Reference voltage 5 V, 5 Measurement signal U_A.
ϑ Temperature-dependence of the resistor, R_H Heater resistor, U_K Constant voltage
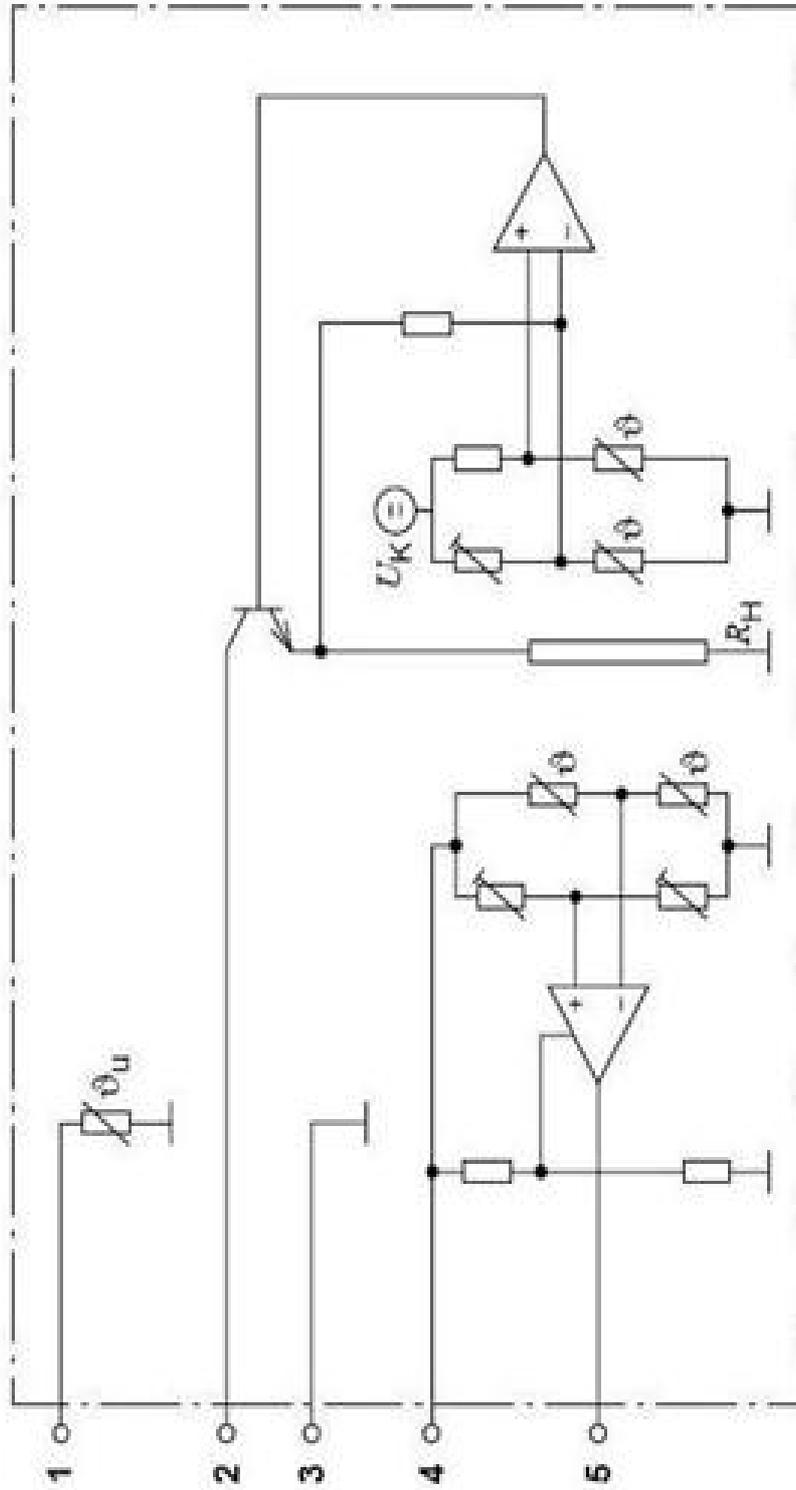

Figure F.4: Air Mass Meter Connections

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Electrical data:

Connection	cable
Load current capacity (Ie)	200 mA
Electrical type	DC
Utilization category	DC 13
Hysteresis max (H)	15 %
No-load supply current damped	= 8 mA
Off-state current max (Ir)	10 µA
Ripple max. of Ue	= 15 %
Switching output	PNP
Switching element function	NO
Operating frequency (f)	1500 Hz
Voltage drop max. static	1,5 V
Supply voltage max. (Ub)	30 V
Supply voltage min. (Ub)	10 V

Mechanical data:

Number of wires	3-wire
Rated operating distance (sn)	4 mm
Diameter	M12x1 mm
Assured operating distance	0...3,2 mm
Cable code designation	LiYY-O
Mounting	non flush mountable
Ambient temperature max	+70 °C
Ambient temperature min	-25 °C
Degree of polution	3
Sensing face material	PA 12
Housing material	corrosion resistance Steel
Repeat accuracy max. (R)	= 5 %

General data:

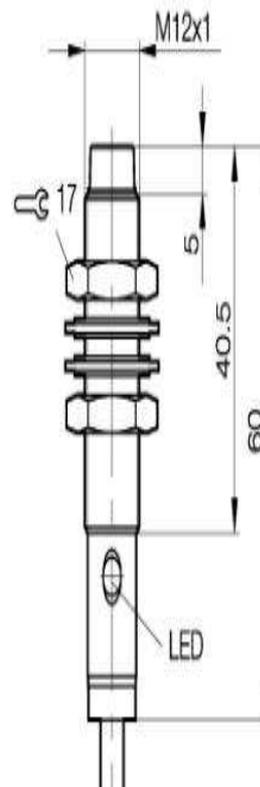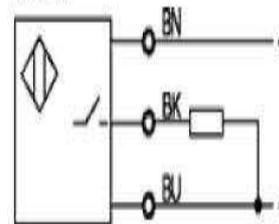|	
Output indication	yes
Short circuit protected	yes
Degree of protection IP	IP68 per BWN Pr 20
Insulation class	2
Protected against polarity reversal	yes
Approval	CE,c_ul_us

wiring

Figure F.5: Technical Specifications of Capacitive Sensors

Table F.3: Voltage range of Analog Inputs

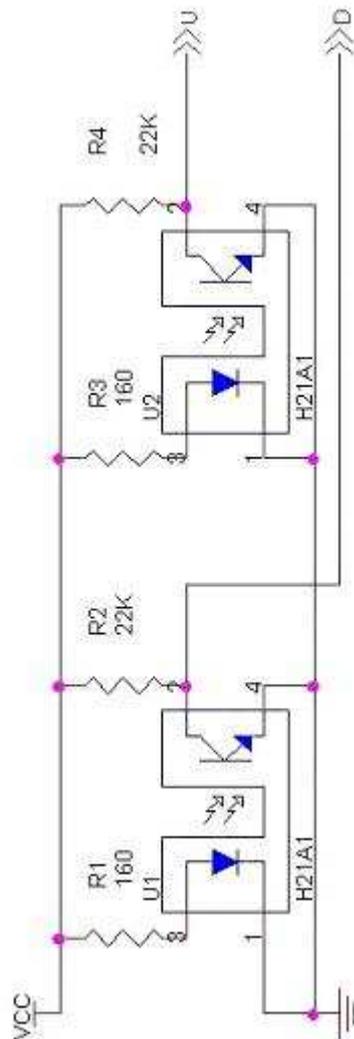| Channel No	Measurement	Voltage Range
0	Room Temperature	0 - 5 V
1	Exhaust Temperature	-10/10 V
2	ISP Temperature	-10/10 V
3	Particulate Sampling Temp.	-10/10 V
4	Load-cell	0 - 10 V
5	Speed sensor	0 - 10 V
6	Throttle Position	0 - 10 V
7	Left Capacitive Sensor	0 - 10 V
8	Right Capacitive Sensor	0 - 10 V
9	Air Mass Meter	0 - 5 V
10	Fuel Temperature	0 - 5 V

Figure F.6: Optic Sensor Connection

APPENDIX G

ERROR ANALYSIS

In this appendix, error analysis of the each formulae used in calculations data read will be supplied. The analysis is being performed for following data.

Ambient Temperature	: $23.2^{o}C$
Ambient Pressure	: 744 mmHg
Ambient Humidity	: 60 %
Engine Speed	: 1900 rpm
Load-cell Voltage	: 6.57 Volt
Fuel Consumption Time	: 26 s
Air-Mass Meter Voltage	: 3.3 Volt
Dilution Tunnel Pressure	: 2.2"WC
Sampling Rate	: 1 scfm
AVL HC	: 8 ppm
AVL Opacity	: % 40
Particulate Matter	: 1.1 mg
Duration	: 120 sn
Load	: 100%
Fuel Density	: 820 kg/m^{3}
Fuel Type	: Diesel
Weight Factor	: 0.09

Assuming that:

Error in Ambient Temperature	: 0.1ºC then 0.43% for $23.2^{o}C$
Error in Ambient Pressure	: 0.1 mmHg then 0.013% for 744mmHg
Error in Humidity	: 0.5% for %60

Error in Engine Speed : ±10 rpm then 0.52% for 1900 rpm

Error in Load Reading : 0.1% (see load-cell specifications in Appendix F)

Error in Fuel Cons. Time : 0.01 s then 0.03% for 26 s

Error in Air-Mass Meter : 1% (see air-mass meter specifications in App. F)

Error in Dil. Tun. Pressure : 0.005"WC then 0.22 % 2.2 "WC

Error in Sampling Rate : 0.02 scfm then 2% for 1 scfm

Error in Opacity : 0.2 % (Ref. [41])

Error in HC : 0.5 % (Ref. [41])

Error in PM : 0.01%

Error in Duration : 0.01s then 0.0083% for 120s

Using:

$$z = f(x_1, x_2, x_3 \ldots x_n)$$

Then,

$$\delta_z = \sqrt{\left(\frac{\P z}{\P x_1}\delta x_1\right)^2 + \left(\frac{\P z}{\P x_2}\delta x_2\right)^2 + \left(\frac{\P z}{\P x_3}\delta x_3\right)^2 + \ldots + \left(\frac{\P z}{\P x_n}\delta x_n\right)^2}$$

Error in Engine Torque

$$\delta_{\text{load-cell}} = V_{\text{load-cell}} \times 0.001 = 0{,}00657 \text{ V}$$

$$\delta_{\text{load}} = 5 \times \delta_{\text{load-cell}}$$

$$\delta_{\text{load}} = 5 \times 0.00657 = 0.032 \text{ kg} \text{ then } 0.1 \text{ \% for } 32.85 \text{ kg}$$

$$\delta_T = \delta_{\text{Load}} \times l \times g$$

$$\delta_T = 0.032 \times 0.56 \times 9.81 = 0.17 \text{ Nm} \text{ then } 0.09 \text{ \% for } 180.5 \text{ Nm}$$

$$\delta_{P_d} = \sqrt{(\delta_{P_{\text{atm}}})^2 + (-P_v \times \delta_{RH})^2}$$

$$\delta_{P_d} = \sqrt{(0.1)^2 + (-21.3 \times 0.6)^2} = 12.78 \text{ mmHg then } 1.74 \text{ \% for } 731.2 \text{ mmHg}$$

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$$\delta_{C_f} = \sqrt{\left[\frac{0.5}{298.15} \times \left(\frac{T_{amb}+273.15}{298.15}\right)^{-0.5} \times \left(\frac{742.56107}{P_d}\right)^{0.65} \times \delta_{T_{amb}}\right]^2 \left[-\frac{742.65 \times 13}{20} \times \left(\frac{742.56107}{P_d}\right)^{-0.35} \times \left(\frac{T_{amb}+273.15}{298.15}\right)^{0.5} \times (P_d)^{-2} \times \delta_{P_{dry}}\right]^2}$$

$$\delta_{C_f} = \sqrt{\left[\frac{0.5}{298.15} \times \left(\frac{23.2+273.15}{298.15}\right)^{-0.5} \times \left(\frac{742.56107}{731.2}\right)^{0.65} \times 0.1\right]^2 + \left[-\frac{742.65 \times 13}{20} \times \left(\frac{742.56107}{731.2}\right)^{-0.35} \times \left(\frac{23.2+273.15}{298.15}\right)^{0.5} \times 731.2^{-2} \times 12.78\right]^2}$$

$\delta_{C_f} = 0.0022$ then 0.22 % for 1.007

$$\delta_{T_c} = \sqrt{(C_f \times \delta_T)^2 + (T \times \delta_{C_f})^2}$$

$$\delta_{T_c} = \sqrt{(1.007 \times 0.09)^2 + (180.5 \times 0.0022)^2} = 0.39 Nm \quad \text{then } 0.21 \text{ % for } 181.76 \text{ Nm}$$

Error in Brake Power

$$\delta_{P_b} = \frac{\pi}{30000} \times 1.36 \times \sqrt{(N_{speed} \times \delta_{T_c})^2 + (T_c \times \delta_{N_{speed}})^2}$$

$$\delta_{P_b} = \frac{\pi}{30000} \times 1.36 \times \sqrt{(1900 \times 0.39)^2 + (181.7 \times 10)^2} = 0.279 HP \quad \text{then } 0.57\% \text{ for } 48.48 \text{ HP}$$

Error in Fuel Consumption

$$\delta_{m_{fuel}} = \frac{V_{container} \times \rho_{fuel} \times 3.6}{t_f^2 \times 1000} \times \delta_{t_f}$$

$$\delta_{m_{fuel}} = \frac{86 \times 820 \times 3.6}{26^2 \times 1000} \times 0.1 = 0.0375 \text{ kg/h then } 0.3 \text{ for } 9.76 \text{ kg/h}$$

Error in Brake Specific Fuel Consumption

$$\delta_{BSFC}=\sqrt{\left[\dfrac{\delta_{m_{fuel}}}{P_b}\right]^2+\left[\dfrac{-m_{fuel}x\delta_{P_b}}{(P_b)^2}\right]^2}$$

$$\delta_{BSFC}=\sqrt{\left[\dfrac{0.0375}{48.49}\right]^2+\left[\dfrac{-9.76x0.57}{48.49^2}\right]^2}=0.00248 \text{ kg/HPh} \text{ then 1.23 \% for 0.201 kg/HPh}$$

Error in Brake Specific Energy Consumption

$$\delta_{BSEC}=Q_L x \delta_{BSFC}$$

$$\delta_{BSEC}=42000x0.00276=115.94 \text{ kJ/HPh} \text{ then 1.37\% for 8442 kJ/HPh}$$

Error in Air Flow Rate

$$\delta_{C_p}=\left(\dfrac{0.011238095}{25.4}+\dfrac{2x0.006666667xP_{atm}}{25.4}\right)x\delta_{P_{amb}}$$

$$\delta_{C_p}=\left(\dfrac{0.011238095}{25.4}+\dfrac{2x0.006666667x744}{25.4}\right)x0.1=0.039 \text{ then 0.4\% for 0.967}$$

$$\delta_{C_T}=(-0.00303+1.028E\text{-}04xT_{amb}+1.82E\text{-}03)x\delta_{T_{amb}}$$

$$\delta_{C_T}=(-0.00303+1.028E\text{-}04x23.2+1.82E\text{-}03)x0.1=0.016 \text{ then 0.16\% for 0.979}$$

$$\delta_{C_h}=1.001x\left(\dfrac{0.62198xP_v}{(P_d)^2}\right)x\delta_{P_d}$$

$$\delta_{C_h}=1.001x\left(\dfrac{0.62198x21.3}{(731.2)^2}\right)x12.78=0.045 \text{ then 0.46\% for 0.975}$$

$$\delta_{C_{air}}=\sqrt{(C_t x C_h x\delta_{C_P})^2+(C_p x C_h x\delta_{C_t})^2+(C_p x C_h x\delta_{C_t})^2}$$

$$\delta_{C_{air}}=\sqrt{(0.979x0.975x0.039)^2+(0.967x0.975x0.016)^2+(0.967x0.979x0.045)^2}$$

$$\delta_{C_{air}}=0.05 \text{ then 0.63\% for 0.923}$$

$$\delta_{m_{air}} = \sqrt{\begin{array}{l} ((-11.97183 \times 2 \times V_a) + 237.02446) \times \delta_{C_{air}})^2 + \\ ((-11.971831 V_a^2 + 237.02446 V_a - 491.8309) \times \delta_{V_a})^2 \end{array}}$$

$$\delta_{m_{air}} = \sqrt{\begin{array}{l} ((-11.97183 \times 2 \times 3.3) + 237.02446) \times 0.05)^2 + \\ ((-11.971831 \times 3.3^2 + 237.02446 \times 3.3 - 491.8309) \times 0.03)^2 \end{array}}$$

$\delta_{m_{air}} = 3.6$ kg/h then 2.4% for 147.65kg/h

Error in Air/ Fuel Ratio

$$\delta_{\left(\frac{A}{F}\right)_{actual}} = \sqrt{\left[\frac{\delta_{m_{air}}}{m_{fuel}}\right]^2 + \left[\frac{-m_{air} \times \delta_{m_{fuel}}}{(m_{fuel})^2}\right]^2}$$

$$\delta_{\left(\frac{A}{F}\right)_{actual}} = \sqrt{\left[\frac{3.6}{9.76}\right]^2 + \left[\frac{-147.65 \times 0.003}{9.76^2}\right]^2} = 0.36 \text{ then 2.4 \% for 15.12}$$

Error in Excess Air Coefficient

$$\delta_\lambda = \frac{\delta_{\left(\frac{A}{F}\right)_{actual}}}{\left(\frac{A}{F}\right)_{stic}} = \frac{0.36}{14.389} = 0.025 \text{ then 2.6\% for 0.95}$$

Error in Volumetric Efficiency

$$\delta_{m_{ath}} = \frac{\rho_{std} . V_s . i . 2.60}{j} \delta_{N_{speed}} = \frac{1.205 \times 9.76E\text{-}04 \times 2 \times 60}{4} \times 10 = 0.342 \text{ kg/h}$$

Then the error is 0.4% for 268.39 kg/h

$$\delta_{\eta_v} = \sqrt{\left[\frac{\delta_{m_{air}}}{m_{th}}\right]^2 + \left[\frac{-m_{air} \times \delta_{m_{th}}}{(m_{th})^2}\right]^2}$$

$$\delta_{\eta_v} = \sqrt{\left[\frac{3.6}{266.39}\right]^2 + \left[\frac{-147.65 \times 0.342}{(266.39)^2}\right]^2} = 0.013 \text{ Then error is 2.45 \% for 55.\%}$$

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Error in Thermal Efficiency

$$\delta_{\eta_{th}} = 0.0631 \sqrt{\left[\frac{\delta_{P_b}}{m_{fuel}}\right]^2 + \left[\frac{-P_b x \delta_{m_{fuel}}}{(m_{fuel})^2}\right]^2}$$

$$\delta_{\eta_{th}} = 0.0631 \sqrt{\left[\frac{0.57}{9.76}\right]^2 + \left[\frac{-48.49 x 0.003}{(9.76)^2}\right]^2} = 0.06$$

Then error is 0.18 % for 31 %

Error in Dilution Tunnel Flow Rate

$$\delta_{V_{dt}} = (84.8454 - 1.605136 x P_{dt}) x 0.06 x \delta_{P_{dt}}$$

$$\delta_{V_{dt}} = (84.8454 - 1.605136 x 2.2) x 0.06 x 0.005 = 0.024 \, m^3/h \text{ then } 0.049 \text{ % for } 49.34$$

Error in Exhaust Gas Flow Rate

$$\delta_{V_{exh}} = \sqrt{(\delta_{V_{air}})^2 + (0.77 \, x \, \delta_{\dot{m}_{fuel}})^2}$$

$$\delta_{V_{exh}} = \sqrt{(3.1)^2 + (0.77 \, x \, 0.00375)^2} = 3.1 \, m^3/h \text{ then } 1.73 \text{ % for } 134.11 \, m^3/h$$

Error in Dilution Ratio

$$\delta_q = \frac{1}{r} \sqrt{\left[\frac{\delta_{V_{dt}}}{V_{exh}}\right]^2 + \left[\frac{-V_{dt} x \delta_{V_{exh}}}{(V_{exh})^2}\right]^2}$$

$$\delta_q = \frac{1}{0.046} \sqrt{\left[\frac{2.3}{49.34}\right]^2 + \left[\frac{-134.11 x 0.024}{(49.34)^2}\right]^2} = 0.0214 \text{ then } 0.2 \text{ % for } 7.87$$

Error in Equivalent Diluted Exhaust Gas Flow Rate

$$\delta_{V_{EDF}} = \sqrt{(q x \delta_{V_{exh}})^2 + (V_{exh} x \delta_q)^2}$$

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$$\delta_{V_{EDF}} = \sqrt{(7.87 \times 3.1)^2 + (134.11 \times 0.00214)^2} = 18.10 \ m^3/h \quad \text{then } 1.72\% \text{ for } 1051.2$$

Error in Particulate Mass Flow Rate

$$\delta_{V_{SAM}} = \frac{1.69906}{3600} \sqrt{(t_s \times \delta_{V_{vp}})^2 + (V_{Vp} \times \delta_{t_s})^2}$$

$$\delta_{V_{SAM}} = \frac{1.69906}{3600} \sqrt{(120 \times 0.02)^2 + (1 \times 0.01)^2} = 0.0011 m^3 \quad \text{then } 2.02\% \text{ for } 0.05 \ m^3$$

$$\delta_{PT_{mass}} = \sqrt{\left[\frac{\dot{V}_{EDF} \times \delta_{P_f}}{V_{SAM} \times 1000}\right]^2 + \left[\frac{P_f \times \dot{\delta}_{V_{EDF}}}{V_{SAM} \times 1000}\right]^2 + \left[\frac{-P_f \times \dot{V}_{EDF} \times \delta_{V_{SAM}}}{1000 \times (V_{SAM})^2}\right]^2}$$

$$\delta_{PT_{mass}} = \sqrt{\left[\frac{1051.2 \times 0.01}{0.05 \times 1000}\right]^2 + \left[\frac{1.1 \times 18.1}{0.05 \times 1000}\right]^2 + \left[\frac{1.1 \times 1051 \times 0.001}{1000 \times 0.056^2}\right]^2}$$

$$\delta_{PT_{mass}} = 0.39 \ g/h \quad \text{then } 1.9 \ \% \quad \text{for } 20.41 \ g/h$$

Error in Particulate Emission

$$\delta_{PT} = \sqrt{\left[\frac{\delta_{PT_{mass}}}{P_b}\right]^2 + \left[\frac{-PT_{mass} \times \delta_{P_b}}{(P_b)^2}\right]^2}$$

$$\delta_{PT} = \sqrt{\left[\frac{0.39}{48.49}\right]^2 + \left[\frac{-20.41 \times 0.57}{(48.49)^2}\right]^2} = 0.008 \ g/HPh \quad \text{then } 1.9\% \text{ for } 0.42 \ g/HP$$

Error in HC Emissions Mass Flow Rate

$$\delta_{HC_{mass}} = \frac{\rho_{HC}}{1000} \sqrt{(V_{EDF} \times \delta_{HC})^2 + (HC_{conc} \times \delta_{V_{EDF}})^2}$$

$$\delta_{HC_{mass}} = \frac{0.619}{1000} \sqrt{(1051.2 \times 0.04)^2 + (8 \times 18.10)^2} = 0.092 \ g/h \quad \text{then } 1.78 \ \% \text{ for } \%5.204 \ g/h$$

Error in HC Emissions

$$\delta_{HC} = \sqrt{\left[\frac{\delta_{HC}}{P_b}\right]^2 + \left[\frac{-HCx\delta_{P_b}}{(P_b)^2}\right]^2}$$

$$\delta_{HC} = \sqrt{\left[\frac{0.092}{48.49}\right]^2 + \left[\frac{-5.204 \times 0.57}{(48.49)^2}\right]^2} = 0.0019 \text{ g/HPh then } 1.79\% \text{ for } 0.107 \text{ g/HPh}$$

APPENDIX H

COST ANALYSIS

In this appendix, cost analysis of the each test fuel used will be supplied.

Cost analysis of Canola Oil

The production cost of canola oil for farmer is calculated as follows.

Table H.1: Canola Production Cost (YTL/DA)

Seed	YTL	13,6
Fertilizer	YTL	43,1
Spray	YTL	15,6
Workmanship	YTL	13,5
Harvest	YTL	17
Fuel	YTL	30,4
Machine Repair	YTL	2,9
Insurance	YTL	2,76
Land Cost	YTL	70
Extraction	YTL	5,86
Cost (seed)	YTL/DA	214,72

1 Dakar land gives 400 kg canola seeds.

160 kg canola oil is obtained from 400 kg canola seeds (%40).

Therefore the cost of canola oil in per unit kilogram is $C_{fuel} = 1.34 \ YTL / kg$

Cost analysis of Canola-Ethanol Blend

The selling price of ethanol is 3.2 YTL/l. To found the cost of ethanol per unit kilogram, it is divided by density of ethanol. Hence, the cost of ethanol in per unit kilogram is $4.01 \ YTL / kg$. The cost of canola ethanol blend used is calculated as follows

$$C_{fuel} = 1.34x0.7 + 4.01x0.3 = 2.14 \ YTL / kg$$

Cost analysis of Diesel Fuel

The selling price of diesel fuel at market is 2.8 YTL/l. To found the cost of diesel fuel per unit kilogram, it is divided by density of diesel. Hence, the cost of diesel in per unit kilogram is $C_{fuel} = 3.41 \, YTL \, / \, kg$